ENGINEERING DYNAMICS COMPANY

EDVTS

HVE Human Vehicle Environment

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

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EDVTS — Vehicle-Trailer Simulator

Engineering Dynamics Company Vehicle-Trailer Simulator, Version 7

Updated Markdown edition, converted from the Sixth Edition (January 2006) printed manual and brought into line with the current HVE software (July 2026).

How to Use This Manual

This manual is the user's manual for the EDVTS 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-2D or HVE User's Manual. The User's Manual provides in-depth coverage of the human, vehicle and environment models, as well as the Event Editor and Playback Editor. For specific model definitions, the user is referred to the User's Manual.

EDVTS is compatible with both HVE-2D and HVE. If you are using EDVTS within the HVE environment, the Human, Vehicle, and Environment Editors will have additional features that are not available in HVE-2D. These features are described in great detail in the HVE User's Manual. While some dialogs do look different, the required input for EDVTS is found in both. Where there are differences related to the use of EDVTS, these differences are noted in this manual. Information specific to HVE is designated with a **[HVE]** marker throughout this manual (grey background in the original printed edition).

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

- Your user ID number
- Your System Hardware Profile report (available from EDC)
- HVE-2D or HVE Version Information (available from the HVE Help System)
- EDVTS Version Information (available from the EDVTS Program Data report)

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The printed manual's Chapter 8 (Index) is omitted; use text search in this Markdown edition.

See also: EDVTS Calculation Options.

Chapter 1 — EDVTS Program Description

Overview

EDVTS (Engineering Dynamics Company Vehicle Trailer Simulator) is a simulation analysis of an articulated vehicle (either a passenger car pulling a standard trailer, or a commercial tractor-trailer vehicle) to driver inputs (accelerating, braking and steering). It is based on a program called TBSTT developed at the University of Michigan Transportation Research Institute [14]. EDVTS determines how the vehicle responds to the inputs by generating the path, velocity, acceleration, tire force, and other data as a function of time.

Accident investigators can use EDVTS to determine how a driver may have lost vehicular control. By repeated adjustments of the throttle, braking and steering input tables, the user will converge on those driver inputs which match accident site evidence. EDVTS can also be used to study the handling effects due to changes in vehicle weight distribution, wheelbase, track width, CG height, tire friction, cornering stiffness, hitch or kingpin location and other parameters.

An extremely useful feature of EDVTS is the ability to quickly and accurately review the results generated from different input scenarios. Termed

what if

analysis, changes can be made to an isolated variable or set of variables and the effects are displayed immediately. For example, the sensitivity of the trajectory to various front/rear tire combinations can be studied simply by changing the tire data; the sensitivity to CG location can be studied by moving its position. However, the major purpose of EDVTS can be realized by changing the driver input tables (throttle, braking and steering) until the resulting trajectory matches the actual trajectory produced by the vehicle during a particular maneuver. Thus, the user learns how a driver's inputs may have affected the outcome of an accident.

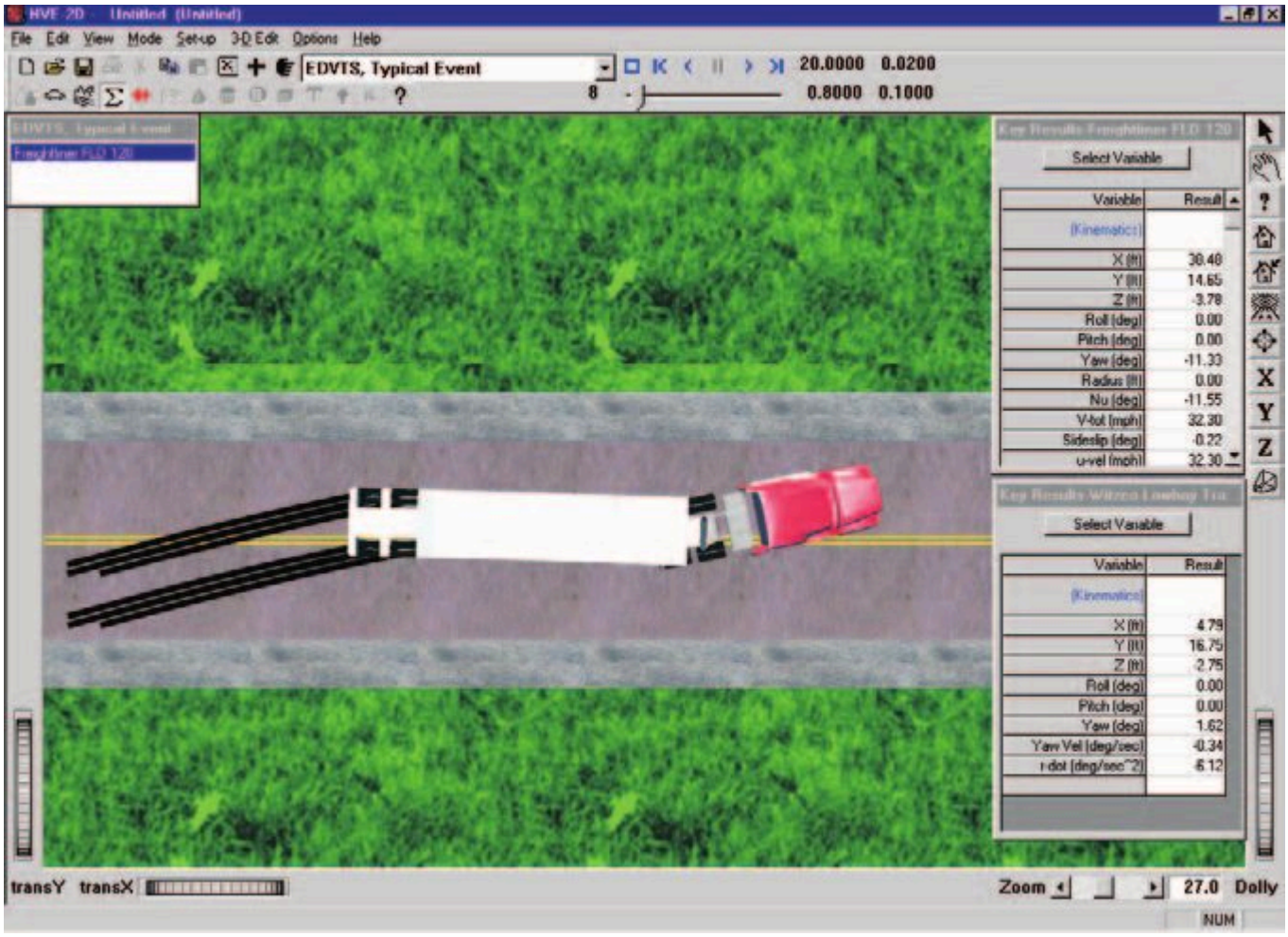


Figure 1-1: EDVTS Event.

Model Inputs

EDVTS inputs include two vehicles (one tow vehicle and one trailer) and an optional environment. Event set-up parameters include vehicle initial positions and velocities, and various driver control options (steering, braking and throttle).

Model Outputs

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

Validation

The EDVTS simulation model was first validated by direct comparison with results using TBSTT. These in-house validations included a validation study in the original TBSTT research document [14].

The in-use accuracy of the program is dependent upon several factors. Because EDVTS is a 4-degree of freedom analysis (three degrees of freedom for the tow vehicle and one for the trailer), jounce and rebound suspension effects are ignored. Therefore, the program is well suited for the study of vehicle trajectories on low-friction surfaces, such as ice

and snow. It also serves as an excellent first-order approximation for normally encountered road surfaces, such as dry asphalt and concrete. Good geometrical, inertial, and tire data are essential for accurate results.

[HVE] EDVTS has been extended and revalidated for use in the HVE environment to account for 3-D terrain. Vehicle roll and pitch angles are allowed and accounted for within the limits of the small angle assumption (normally 15 degrees). See reference 25 for further details regarding the validation of EDVTS.

HVE-2D and HVE

EDVTS is compatible with both HVE-2D and HVE. While EDVTS has been extended and revalidated for use in the HVE environment to account for 3-D terrain (described above), EDVTS is essentially a 2-dimensional physics simulation program.

[HVE] If you are using EDVTS within the HVE environment, the Human, Vehicle, and Environment Editors will have additional features that are not available in HVE-2D. These features are described in great detail in the HVE User's Manual. While some dialogs do look different between HVE-2D and HVE, the required input for EDVTS is found in both. Where there are differences related to the use of EDVTS, these differences are noted in this manual. Information specific to HVE is designated with a **[HVE]** marker throughout this manual.

Basic Procedure

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

- Use the Vehicle Editor to add a tow vehicle and a trailer 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 EDVTS simulation model by performing the following steps:
- Choose the tow vehicle and trailer *in that order* from the list of vehicles created earlier.
- Choose the EDVTS 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.
- 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.

Contents | Next: Chapter 2 — Program Input

Chapter 2 — EDVTS Program Input

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

- **Objects** — The number of vehicles and the specific vehicle parameters actually used by EDVTS.
- **Events** — The various HVE-2D options available for setting up and executing an EDVTS event.

Objects Overview

The objects used by the EDVTS model are:

- **Vehicles** — Two vehicles (a tow vehicle and a trailer) may be studied by EDVTS.
- **Environment** — Like the *real* world, EDVTS 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 EDVTS calculation model.

Vehicles

EDVTS uses two vehicles created using the Vehicle Editor (see Figures 2-1 and 2-2). Vehicles are selected from the Vehicle Database by choosing the following attributes:

- **Type** — EDVTS supports the following vehicle types: *Passenger Car, Pickup, Van, Sport-Utility, Truck, Trailer* and *Movable Barrier*.
- **Make** — EDVTS supports all available vehicle makes.
- **Model** — EDVTS supports all available vehicle models, within the limits defined by number of axles and drive axles; see below.
- **Year** — EDVTS supports all available vehicle years.
- **Body Style** — EDVTS 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 EDVTS. However, *Driver Location* must not be *None*; otherwise, the Driver Controls (Steering, Throttle, Brakes) will not be available during Event mode.
- **Engine Location** — The Engine Location is not used by EDVTS. However, Engine Location must not be *None*; otherwise, the Throttle Table will not be available during Event mode.
- **Number of Axles** — EDVTS supports 2- and 3-axled tow vehicles and 1- and 2-axled trailers.
- **Drive Axle(s)** — EDVTS supports all drive axles.

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

- Choose Vehicle Mode. The Vehicle Editor is displayed.
- Choose *Add New Object*. The Vehicle Information dialog is displayed.

- Click on the *Type, Make, Model, Year* and *Body Style* option buttons to select a vehicle from the database.
- If desired, modify the *Driver Location, Engine Location, Number of Axles* and *Drive Axle(s)* for the current vehicle.
- 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.

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

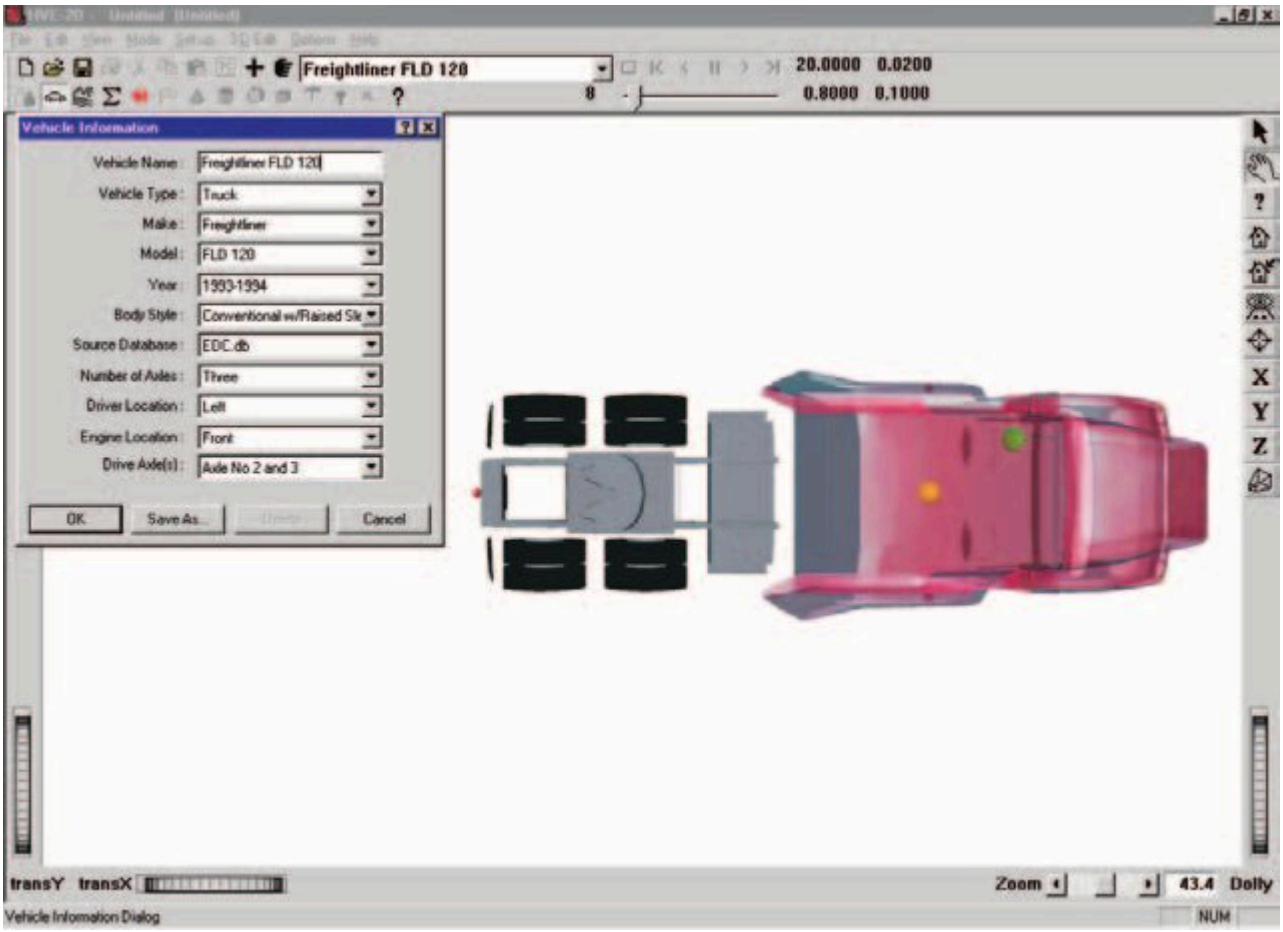


Figure 2-1: HVE-2D Vehicle Editor, adding a tow vehicle to the current case.

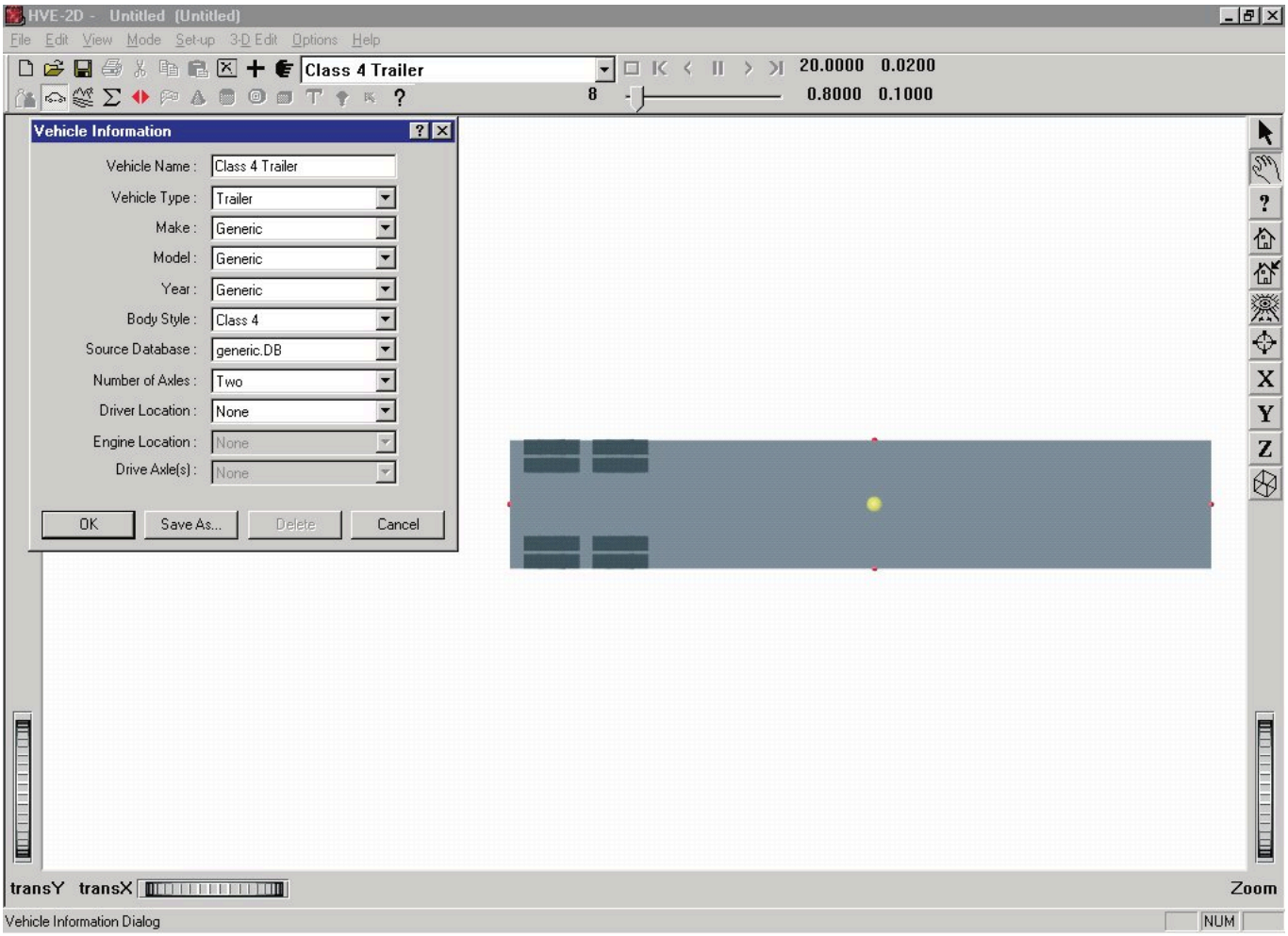


Figure 2-2: HVE-2D Vehicle Editor, adding a trailer to the current case.

The following Vehicle Parameter groups are used by EDVTS:

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

> NOTE: The Exterior Data Group (Overall Dimensions, Structural Stiffness Coefficients), Brake System and Drivetrain are not used by EDVTS.

The specific data used in each of the above parameter groups are defined in Tables 2-1 through 2-3.

Sprung Mass

The Sprung Mass parameters are shown in Table 2-1. Information on each group is provided below.

Table 2-1: Vehicle Sprung Mass Parameters Used By EDVTS

Parameter	Description
Weight	Total vehicle weight
Total Yaw Inertia	Total rotational inertia about the vehicle-fixed z axis
Move CG (x, y, z)	Relocates the CG in the vehicle-fixed x, y and z directions. This entry causes an automatic adjustment of all vehicle coordinate-related parameters (e.g., contact surface, belt anchor points).
Connection x,z	Vehicle-fixed location of the connection
Connection Friction, Radius and Maximum Articulation Angle	Connection properties

Inertias

EDVTS uses the total vehicle weight (converted to mass according to the current gravitational constant; see Environment), and the total yaw rotational inertia.

The total weight is used because it is the value traditionally obtained from data sources. Because EDVTS does not have separate degrees of freedom for the unsprung masses, the Total Yaw Moment of inertia used by EDVTS is the sum of the sprung mass yaw inertia plus the additional yaw inertia created by the individual wheels. See also EDVTS Output, Vehicle Data report.

Move CG

Move CG is not directly used by EDVTS. 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 and z coordinates for the wheels are updated to reflect the new CG location.

[HVE] If using HVE, the CG may also be relocated in the vehicle-fixed y direction.

Geometry File

The Geometry File is not used by EDVTS.

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.

The Connection Friction, Radius and Maximum Articulation Angle are 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, EDVTS cannot be executed; a message will be displayed during Event Set-up.
>
> NOTE: Be sure both vehicles have the proper connections (Hitch/Ball or King Pin/Fifth Wheel). If the connections are not compatible, or if connections are not supplied, a message will be issued during Event Set-up.
>
> NOTE: The connection elevation above ground must also be the same for the tow vehicle and the trailer. Otherwise, the vehicle will accelerate or decelerate on level ground (the 2-D equations of motion have no way of knowing how to handle non-normal tire forces).

Unsprung Mass

The Unsprung Mass parameters used by EDVTS are shown in Table 2-2. Information on each group is provided below.

Table 2-2: Vehicle Unsprung Mass, Brake and Tire Parameters Used By EDVTS

Parameter	Description
Wheel Location	Vehicle-fixed x,y,z coordinates for each wheel
Anti-lock Effectiveness	The percentage of gain in longitudinal braking force due to anti-lock
Tire Unloaded Radius	Tire radius in unloaded condition (editable in HVE)
Tire Friction Table, Test Load/Speed	The load and speed for a given set of friction results (EDVTS uses the middle load and middle speed)
Peak Longitudinal Friction, Slide Friction, Slip at Peak Friction and Longitudinal Stiffness	Tire frictional properties
Friction In-use Factor	Multiplier for Longitudinal and Slide Friction
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

Wheel Location

Although HVE-2D provides values for the vehicle-fixed x,y,z coordinates of each wheel, EDVTS uses only the following parameters:

- **Tow Vehicle** — a, the distance from the CG to the front axle; b, the distance from the CG to the rear axle; tw_f, the front track width; tw_r, the rear track width, and z_w, the vertical distance from the CG to the wheel (for each wheel).
- **Trailer** — d, the distance from the CG to the rear axle; tw_r, the rear track width, and z_w, the vertical distance from the CG to the wheel (for each wheel).

> NOTE: For Tandem rear suspensions, the average track width of the two axles is used.
>
> NOTE: EDVTS uses the average x_{wheel} for the front wheels to calculate a and the average x_{wheel} for the rear wheels to calculate b. Similarly, EDVTS uses the total distance between right-side and left-side tires to calculate track width. Bilateral symmetry is initially assumed. Finally, EDVTS uses z_{wheel} and the tire radius (see Tire Parameters) to calculate CG elevation above ground.

[HVE] NOTE: In HVE, tire radius is user-editable.

Brake

EDVTS uses the wheel brake system Antilock Effectiveness. The specific parameters used by EDVTS are shown in Table 2-2.

Tire

The HVE tire parameters provide the following data groups:

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

EDVTS's use of these parameters is described below.

Physical Data

The Tire Physical Data used by EDVTS are shown in Table 2-2. The tire's unloaded radius is used to establish the vehicle's CG elevation. Other physical data parameters are not used.

[HVE] In HVE, tire unloaded radius is user-editable.

Friction Data

The Friction Data used by EDVTS are shown in Table 2-2. EDVTS uses both Peak and Slide Friction values.

[HVE] The EDVTS tire model does not incorporate load- or speed-dependence. If friction data for more than one load or speed are supplied, EDVTS uses the friction parameters for the middle load and/or speed.

> NOTE: If any doubt exists about which value is actually used by the EDVTS tire model, you can check the Vehicle Data output report.

[HVE] 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.

Cornering Stiffness Data

The Cornering Stiffness data used by EDVTS are shown in Table 2-2.

[HVE] EDVTS does not use the F_y vs Slip Angle table, but instead uses the cornering stiffness parameter directly. If cornering stiffness data for more than one load or speed are supplied, EDVTS uses the parameters for the middle load and/or speed.

> NOTE: If any doubt exists about which value is actually used by the EDVTS tire model, you can check the Vehicle Data output report.

[HVE] Cornering Stiffness *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'll probably want to reduce the In-use Factor to about 0.1.

Slip vs Rolloff Table

EDVTS uses the longitudinal Slip vs Rolloff Table. Lateral rolloff is not used.

Suspension

The HVE-2D Suspension Model provides the following data groups:

- Inter-tandem Load Transfer

EDVTS supports all suspension types, including those with tandem axles. However, the suspension at each wheel is not modeled, per se. Rather,

roll couple distribution

(see Event Editor, Calculation Options) is used.

Table 2-3: Vehicle Suspension and Steering Parameters Used By EDVTS

Parameter	Description
Inter-tandem Axle Load Transfer	Rear-to-front inter-axle load transfer due to braking of tandem axles
Steering Gear Ratio	Ratio of the angle at the steering wheel to the angle at the wheel

Inter-tandem Axle Load Transfer

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

Studies have shown the value of -0.38 to be representative of typical four spring suspension systems [4]. The negative sign indicates load transfer from the front to the rear axle.

The value for walking beam suspensions with 100% torque rod effectiveness is 0.0 [14]. For non-perfect torque rods with effectiveness less than 100%, the load transfer is:

$$(\frac{AAA}{R})(\frac{100 - T_e}{100})$$

where:

Symbol	Meaning
AAA	inter-tandem dimension
R	tire radius
T_e	torque rod efficiency

Exterior

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

Steering System Data

EDVTS uses the steering gear ratio if the

At Steering Wheel

Steering Table option is used during Event set-up (see Table 2-3). Otherwise, the steering system data are not used by EDVTS.

Brake System Data

The Brake System data are not used by EDVTS.

Environment

EDVTS uses the environment created by the Environment Editor (see Figure 2-3). The environment is created by defining the following groups of attributes:

- Visual Data
- Physical Data



Figure 2-3: Environment Editor.

Creating an Environment

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

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

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
- Surface Geometry

The specific physical environment data used by EDVTS are described below; see also Table 2-4.

Table 2-4: Environment Model Parameters Used By EDVTS

Parameter	Description
Gravitational Constant	Local gravitational constant
3-D Surface Geometry (Friction Factor, Elevation, Slope)	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 EDVTS event because it affects the location of the sun.

Wind Speed and Direction

Wind Speed and Direction are not used by EDVTS.

Atmospheric Temperature and Pressure

Atmospheric temperature and pressure are not used by EDVTS.

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.

Surface Geometry

The Surface Geometry is used by the tire model in EDVTS to calculate the friction multiplier for the current X,Y position of the tire.

[HVE] In HVE, it is also used to calculate the elevation and slope.

[HVE] If the elevation changes result in a vehicle roll or pitch that exceeds the allowable angle, EDVTS will terminate and report an error condition (Excessive Roll or Pitch Angle). See Chapter 6 — Messages for more information.

Event

EDVTS uses the Event Editor (see Figure 2-4) to create, set up and execute an event. Each of these topics is described below.

Creating an Event

An EDVTS event is created using the Event Information dialog.

To create an EDVTS event:

- Choose Event Mode. The Event Editor is displayed.
- Choose *Add New Object*. The Event Information dialog is displayed.
- Select the tow vehicle from the Active Vehicles list.
- Select the trailer 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.

- Select the calculation model, *EDVTS*, from the Calculation Model options list.
- 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.

- Click *OK* to create the EDVTS event.

> NOTE: If you choose a vehicle that is not compatible with EDVTS, 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 EDVTS-compatible objects are selected.

Setting Up an Event

EDVTS uses the following

event set-up

options:

- Position/Velocity
- Driver Controls
- Payload Data

The specific Event Set-up data used by EDVTS are defined in Table 2-5.

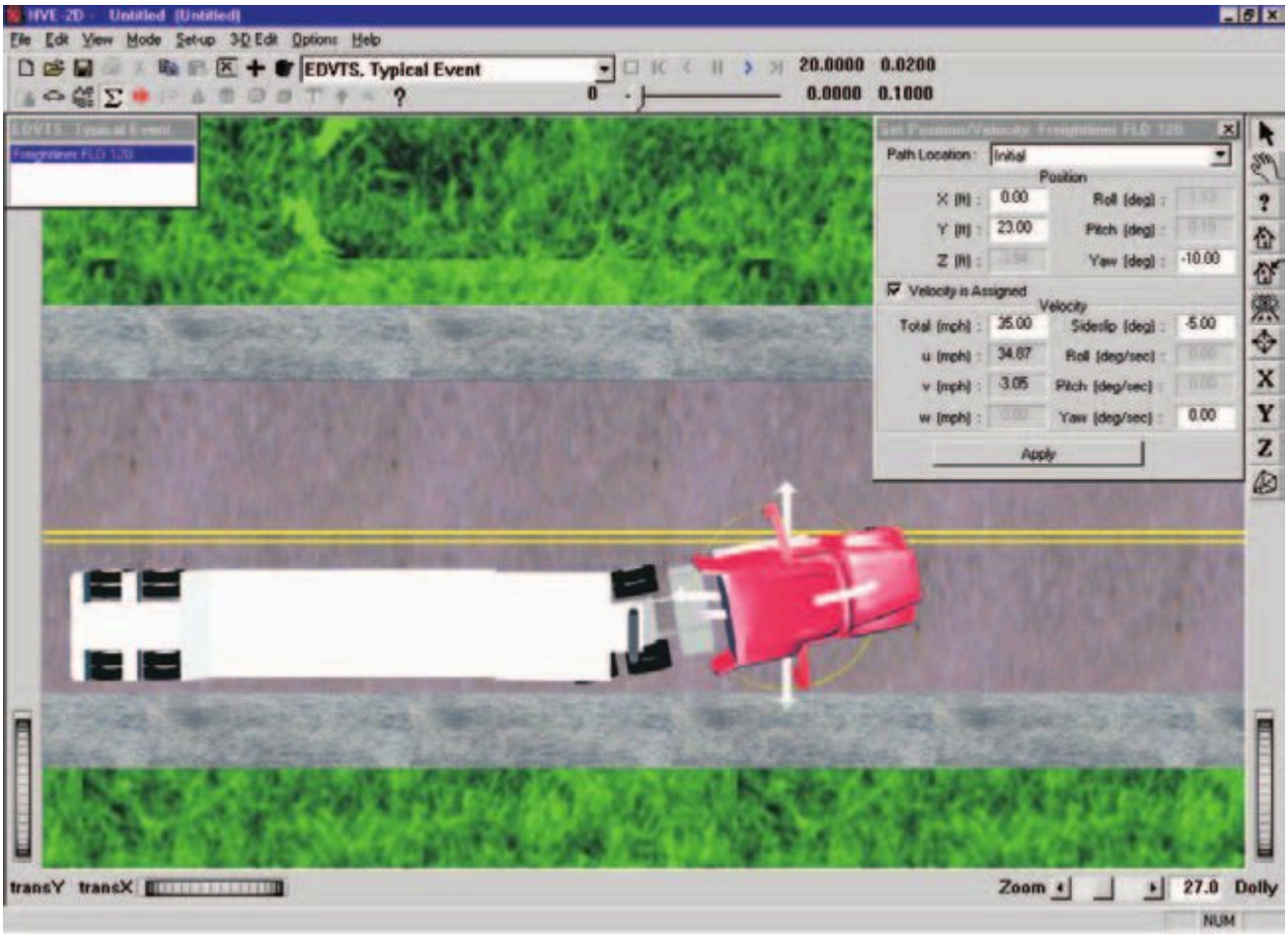


Figure 2-4: HVE-2D Event Editor, setting up and executing an EDVTS event.

Table 2-5: Event Set-up Parameters Used by EDVTS

Parameter	Description
Vehicle Initial Position	The earth-fixed X,Y coordinates and heading angle of the tow vehicle, and the articulation angle of the trailer, at the start of the simulation
Vehicle Initial Velocity	The forward and lateral linear velocities, and the yaw and articulation 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: Wheel Force vs Time or Percent Available Friction vs Time
Driver Controls, Throttle Table	Throttle Table Option: Wheel Force vs Time or Percent Available Friction vs Time
Payload Data	Payload Exists option; Payload vehicle-fixed x,y,z coordinates; Payload Weight, Yaw Inertia

Position/Velocity

Like all simulations, EDVTS 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 (Φ), pitch (Θ) and yaw (Ψ) angles about vehicle x, y and z axes, respectively.

> NOTE: In HVE-2D, Z is equal to the CG height above ground, and roll and pitch are equal to 0.0.

[HVE] NOTE: In HVE, Z, roll and pitch are supplied automatically by AutoPosition.

The trailer is positioned relative to the tow vehicle by supplying the initial articulation angle, γ. The default articulation angle is 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. Vertical velocity is set to zero.

The trailer articulation angular velocity is assigned relative to the tow vehicle.

Driver Controls

EDVTS uses the following Driver Controls:

- **Steering** — A table of steering inputs as a function of time. The *At Steering Wheel* 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.

The Driver Controls Data used by EDVTS are shown in Table 2-5.

Brake

Typical values for non-braking rolling resistance for passenger car tires are provided below for reference in Table 2-7 [11]. These values should be entered in the Driver Controls - Brakes dialog using the Percent Available Friction option.

Representative values for locked-wheel (slide) friction coefficients for passenger car tires on a variety of surfaces are also provided, in Table 2-8 [10]. While the table is very complete, EDC makes no claim as to the accuracy of the data. The user is urged to perform thorough research in order to supply EDVTS with the best possible data.

Table 2-7: Rolling Resistance Braking Inputs for Pavement [11]

Tire/Wheel Condition	% Available Friction
Normal Inflation	0.010 / μ
Partial Inflation	0.013 / μ
Damaged	0.0 to 1.0
Engine Braking — High Gear	0.150 / μ to 0.200 / μ
Engine Braking — Low Gear	0.200 / μ to 0.400 / μ

Table 2-8: Tire-Ground Friction Coefficients on Various Surfaces [10]

Surface	Dry <30 mph	Dry >30 mph	Wet <30 mph	Wet >30 mph
Portland Cement — New, Sharp	0.80 - 1.20	0.70 - 1.00	0.50 - 0.80	0.40 - 0.75
Portland Cement — Traveled	0.60 - 0.80	0.60 - 0.75	0.45 - 0.70	0.45 - 0.65
Portland Cement — Polished	0.55 - 0.75	0.50 - 0.65	0.45 - 0.65	0.45 - 0.60
Asphalt or Tar — New, Sharp	0.80 - 1.20	0.65 - 1.00	0.50 - 0.80	0.45 - 0.75
Asphalt or Tar — Traveled	0.60 - 0.80	0.55 - 0.70	0.50 - 0.80	0.45 - 0.75
Asphalt or Tar — Polished	0.55 - 0.75	0.45 - 0.65	0.45 - 0.65	0.40 - 0.60
Asphalt or Tar — Excess Tar	0.50 - 0.60	0.35 - 0.60	0.30 - 0.60	0.25 - 0.55
Gravel — Packed, Oiled	0.55 - 0.85	0.50 - 0.80	0.40 - 0.80	0.40 - 0.60
Gravel — Loose	0.40 - 0.70	0.40 - 0.70	0.45 - 0.75	0.45 - 0.75
Cinders — Packed	0.50 - 0.70	0.50 - 0.70	0.65 - 0.75	0.65 - 0.75
Rock — Crushed	0.55 - 0.75	0.55 - 0.75	0.55 - 0.75	0.55 - 0.75
Ice — Smooth	0.10 - 0.25	0.07 - 0.20	0.05 - 0.10	0.05 - 0.10
Snow — Packed	0.30 - 0.55	0.35 - 0.55	0.30 - 0.60	0.30 - 0.60
Snow — Loose	0.10 - 0.25	0.10 - 0.20	0.30 - 0.60	0.30 - 0.60

Damage Profile

The Damage Profile Data are not used by EDVTS.

Payload

The Payload Data used by EDVTS include the payload coordinates relative to the vehicle's CG, the payload mass and yaw inertia.

> NOTE: Payload positioning is relative to the vehicle CG, not the rear suspension.
>
> NOTE: You must select the trailer before adding a payload. Placing the payload on the tow vehicle has no effect.

Simulation Controls

EDVTS uses the current simulation control parameters in the Simulation Controls dialog (see Options Menu, Simulation Controls). The Simulation parameters used by EDVTS are shown in Table 2-6.

> NOTE: The output time interval should be an even multiple of the vehicle trajectory integration timestep. For example, if the integration timestep is 0.02, the output interval might be 5 x 0.02, or 0.10.

Table 2-6: Simulation Control Parameters Used by EDVTS

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
Min 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)

Calculation Options

EDVTS does not have a Calculation Options dialog. The Roll Couple Distribution is taken directly from the tow vehicle's **Roll Couple Distribution** suspension value (Vehicle Editor → Suspension Parameters; default 0.55). The terrain surface-search method is selected in the separate **Get Surface Information Options** dialog on the Options menu.

Roll Couple Distribution describes the ratio of lateral load transferred between the front and rear suspensions during cornering. This distribution depends directly on the characteristics of the front and rear suspension systems and chassis stiffness. As EDVTS is a limited-degree-of-freedom analysis, the effects of the suspension system and chassis are included in this one parameter. A good approximation for the fraction of the total load transfer borne by the front axle can be obtained by dividing the roll moment produced at the front suspension by the total roll moment (i.e., the total produced by both front and rear suspensions together) during a steady turn. Note that a neutral vehicle will tend to have a lateral load transfer coefficient equal to the percentage of load on the front axle; an understeering vehicle will tend to have a greater value and an oversteering vehicle will have a lesser value. The default value is 0.55 (55 percent of the roll couple carried by the front axle).

For full details of the current dialog and how the value is applied by the simulation, see EDVTS Calculation Options.

Get Surface Information

Both HVE-2D and HVE use a surface information lookup to determine on which environment polygon each tire is riding. The lookup searches below the X,Y coordinates of each tire contact patch, and uses a user-selectable algorithm to determine the friction and other characteristics of the surface beneath.

The default surface-search method is

From Previous Polygon

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

(updated: The surface-search method is now selected in the separate Get Surface Information Options dialog (Options menu), not in the EDVTS Calculation Options dialog. The available methods are From First Polygon, From Previous Polygon and From Previous Polygon (Sorted); the By Elevation method is not supported.)

Executing An Event

To execute an EDVTS event, use the Event Controller, shown in Figure 2-5. 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 2-5: 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 the Options Menu to choose useful options, such as Key Results, Axes, Velocity Vectors and Skidmarks.

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Chapter 3 — EDVTS Program Output

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

Overview

EDVTS 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, 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 the Files menu or click on the Print icon in the toolbar. Refer to the User's Manual for further details.

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

- Choose Playback Mode. The Playback Editor is displayed.
- Choose *Add New Object*. The Report Window Information dialog is displayed, showing a list of all the current events in the case.
- Select an EDVTS event from the list. Once an event is selected, the Report Type list is displayed, containing all the available reports for the selected event.
- 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:
- Messages
- Accident History
- Program Data
- Vehicle Data
- Trajectory Simulation
- Variable Output
- 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-2D and HVE truncate the name to 30 characters, you should ensure that two truncated names are not the same.

- Click *OK* to display the report.

Alpha-Numeric Reports

EDVTS produces the following alpha-numeric reports:

- **Accident History** — A table of initial and final positions and velocities
- **Messages** — A list of messages produced by the current run
- **Program Data** — A table containing program control information for the current run
- **Vehicle Data** — A series of tables containing the vehicle data used by EDVTS

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

Accident History

The Accident History Report displays a table of initial and final positions and velocities for the vehicle. A typical Accident History Report is shown in Figure 3-1.

The report includes the Total Distance Travelled and Time, followed by Position (X, Y, PSI — and, for the trailer, GAMMA) and Velocity (V-tot, u-vel, v-vel, Yaw Vel — and, for the trailer, Gam Vel) at the Initial and Final positions.

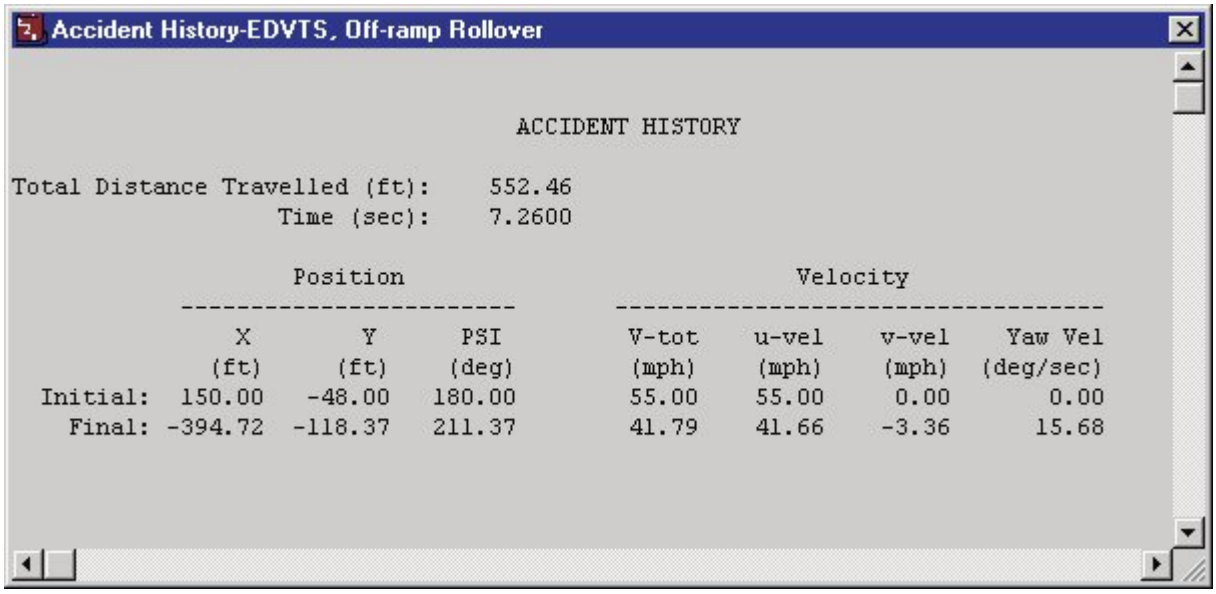


Figure 3-1: Typical Accident History Output Report issued by EDVTS.

Messages

A typical Messages Report is shown in Figure 3-2. For a complete listing of messages issued by EDVTS, see Chapter 6 — Messages.



Figure 3-2: Typical Messages Output Report issued by EDVTS.

Program Data

The Program Data Report includes the following information:

- **Simulation Controls** — Integration parameters used for the current event (Max Simulation Time, Trajectory Phase dt, Output Interval, Linear Termination Velocity)

(updated: In the current version the Program Data report also includes a General Program Information section — HVE Version, EDVTS Version, Date and Time of Execution, Dimension Basis — and General Environment Data / 3-D Environment Terrain Data sections reporting the environment name, gravity constant, 3-D geometry filename, number of polygons, the Get Surface Information method in use, and terrain elevation limits.)

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

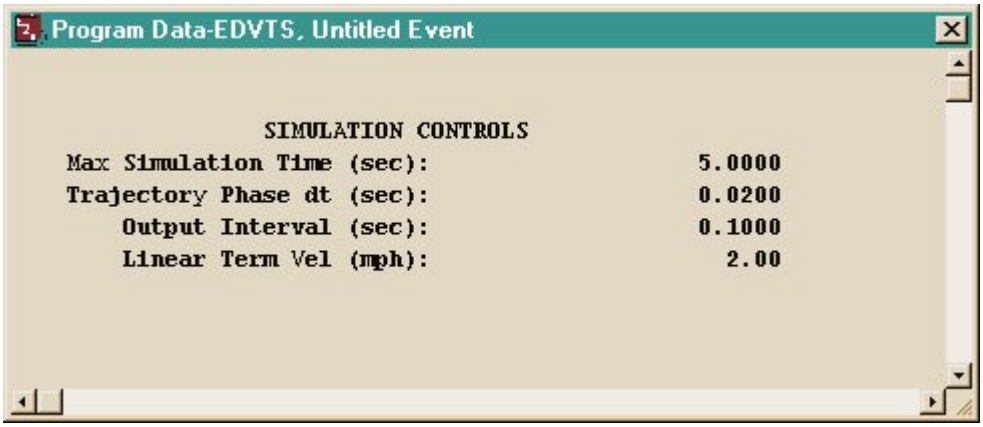


Figure 3-3: Typical Program Data Output Report issued by EDVTS.

Vehicle Data

The Vehicle Data Report includes the following information:

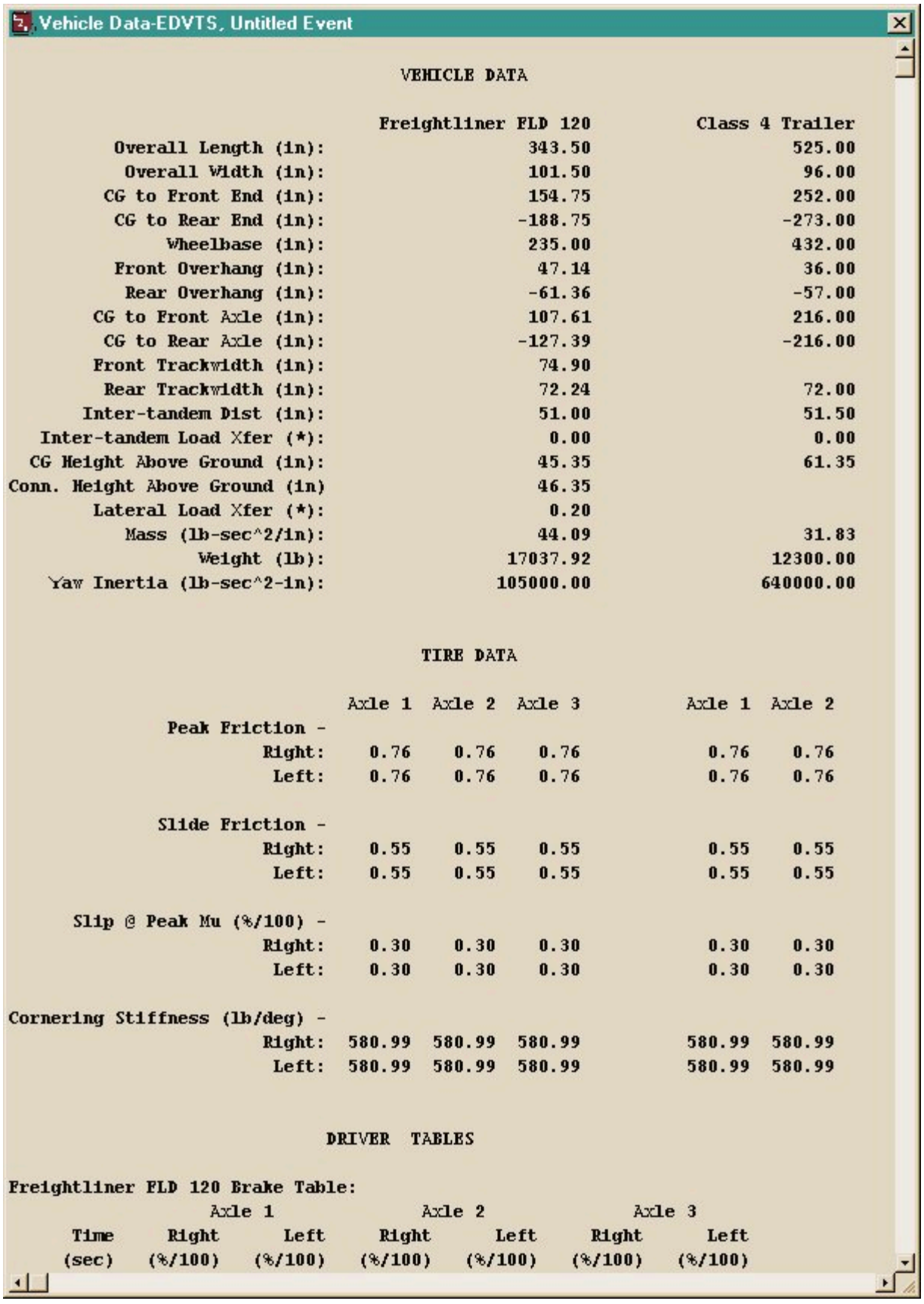
- **Vehicle Dimensional and Inertial Properties** — The dimensional and inertial parameters used by EDVTS in the current event.

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

- **Tire Properties** — The tire parameters used by EDVTS in the current event (peak friction, slide friction, slip at peak mu, cornering stiffness and antilock efficiency, per axle, right and left).

- **Driver Tables** — Individual Driver Control tables for steering, braking, throttle and gear selection used by EDVTS in the current event.

A portion of a typical Vehicle Data Report is shown in Figure 3-4. Dimensional entries include Overall Length and Width, CG to Front/Rear End, Wheelbase, Front/Rear Overhang, CG to Front/Rear Axle, Front/Rear Trackwidth, Inter-tandem Distance and Load Transfer, CG Height Above Ground, Connection Height Above Ground, Lateral Load Transfer, Mass, Weight and Yaw Inertia.



Vehicle Data-EDVTS, Untitled Event

VEHICLE DATA

	Freightliner FLD 120	Class 4 Trailer
Overall Length (in):	343.50	525.00
Overall Width (in):	101.50	96.00
CG to Front End (in):	154.75	252.00
CG to Rear End (in):	-188.75	-273.00
Wheelbase (in):	235.00	432.00
Front Overhang (in):	47.14	36.00
Rear Overhang (in):	-61.36	-57.00
CG to Front Axle (in):	107.61	216.00
CG to Rear Axle (in):	-127.39	-216.00
Front Trackwidth (in):	74.90	
Rear Trackwidth (in):	72.24	72.00
Inter-tandem Dist (in):	51.00	51.50
Inter-tandem Load Xfer (*):	0.00	0.00
CG Height Above Ground (in):	45.35	61.35
Conn. Height Above Ground (in)	46.35	
Lateral Load Xfer (*):	0.20	
Mass (lb-sec^2/in):	44.09	31.83
Weight (lb):	17037.92	12300.00
Yaw Inertia (lb-sec^2-in):	105000.00	640000.00

TIRE DATA

	Axle 1	Axle 2	Axle 3	Axle 1	Axle 2
Peak Friction -					
Right:	0.76	0.76	0.76	0.76	0.76
Left:	0.76	0.76	0.76	0.76	0.76
Slide Friction -					
Right:	0.55	0.55	0.55	0.55	0.55
Left:	0.55	0.55	0.55	0.55	0.55
Slip @ Peak Mu (%/100) -					
Right:	0.30	0.30	0.30	0.30	0.30
Left:	0.30	0.30	0.30	0.30	0.30
Cornering Stiffness (lb/deg) -					
Right:	580.99	580.99	580.99	580.99	580.99
Left:	580.99	580.99	580.99	580.99	580.99

DRIVER TABLES

Freightliner FLD 120 Brake Table:

	Axle 1		Axle 2		Axle 3	
Time (sec)	Right (%/100)	Left (%/100)	Right (%/100)	Left (%/100)	Right (%/100)	Left (%/100)

Figure 3-4: Typical Vehicle Data Output Report issued by EDVTS (only a portion of the total report is shown).

Graphic Reports

EDVTS 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

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

Vehicle Output Groups

- **Kinematics** — Position, velocity and acceleration for the vehicle
- **Kinetics** — Forces and moments at the vehicle CG due to inter-vehicle connections
- **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 3-5. A detailed listing of each Variable Output parameter produced by EDVTS is found in Table 3-1. For more information about Variable Output parameters, refer to the 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; Φ, Θ, Ψ orientation; Path Radius of CG; ν (Course Angle); Total linear velocity, u,v,w components; Sideslip angle; r angular velocity; Total linear accel, fwd, side components; u-dot, v-dot linear components; r-dot angular components
Vehicle Kinetic Data	F_x, F_y, F_z from Connections about CG; M_z from Connections about CG
Tire Data	X,Y,Z position of tire contact patch; Slip Angle; F'_x, F'_y, F'_z; Skid Flag
Wheel Data	x,y,z location of each wheel; F_x, F_y, F_z; Steer Angle (δ) at each steerable wheel
Connection Data	γ Articulation Angle; F_x, F_y, F_z at Connection
Driver Data (*)	Steering wheel angle

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

Variable Output-EDVTS, Untitled Event

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

Time (sec)	Freightliner F w-vel (mph)	Freightliner F Yaw Vel (deg/sec)	Freightliner F Acc-tot (g)	Freightliner F Fwd Acc (g)	Freightliner F Lat Acc (g)	Freightliner F r-dot (deg/sec^2)	Freightliner F Axle 1, Righ Fz' (tire) (lb)	Freightliner F Axle 1, Left Fz' (tire) (lb)
3.8000	0.0	-4.2	0.3	-0.3	-0.1	4.3	6096.0	5291.9
3.8500	0.0	-4.2	0.3	-0.3	-0.1	0.8	6000.0	5387.0
3.9000	0.0	-4.2	0.3	-0.3	-0.1	-2.7	5904.0	5482.1
3.9500	0.0	-4.2	0.3	-0.3	-0.1	-0.0	5979.5	5407.3
4.0000	0.0	-4.2	0.3	-0.3	-0.1	2.6	6055.0	5332.5
4.0500	0.0	-4.2	0.3	-0.3	-0.1	0.6	5999.6	5387.2
4.1000	0.0	-4.2	0.3	-0.3	-0.1	-1.5	5944.2	5442.0
4.1500	0.0	-4.2	0.3	-0.3	-0.1	-0.2	5980.9	5405.6
4.2000	0.0	-4.1	0.3	-0.3	-0.1	1.2	6017.7	5369.1
4.2500	0.0	-4.1	0.3	-0.3	-0.1	0.3	5992.2	5394.2
4.3000	0.0	-4.1	0.3	-0.3	-0.1	-0.6	5966.7	5419.4
4.3500	0.0	-4.2	0.3	-0.3	-0.1	-0.2	5979.6	5406.5
4.4000	0.0	-4.2	0.3	-0.3	-0.1	0.3	5992.5	5393.6
4.4500	0.0	-4.2	0.3	-0.3	-0.1	0.0	5982.7	5403.2
4.5000	0.0	-4.2	0.3	-0.3	-0.1	-0.2	5972.8	5412.9
4.5500	0.0	-4.2	0.3	-0.3	-0.1	-0.1	5975.0	5410.6
4.6000	0.0	-4.2	0.3	-0.3	-0.1	-0.0	5977.2	5408.3
4.6500	0.0	-4.2	0.3	-0.3	-0.1	-0.0	5972.7	5412.6
4.7000	0.0	-4.2	0.3	-0.3	-0.1	-0.0	5968.2	5416.9
4.7500	0.0	-4.2	0.3	-0.3	-0.1	-0.0	5966.9	5418.1
4.8000	0.0	-4.2	0.3	-0.3	-0.1	-0.1	5965.6	5419.2
4.8500	0.0	-4.2	0.3	-0.3	-0.1	-0.0	5962.3	5422.4
4.9000	0.0	-4.2	0.3	-0.3	-0.1	0.0	5958.9	5425.5

Figure 3-5: Typical Variable Output Table from EDVTS.

Trajectory Simulations

EDVTS produces a trajectory simulation of the current event. The trajectory simulation is a visualization of the data displayed in the Variable Output table (see previous section). An example of a trajectory simulation is shown in Figure 3-6.

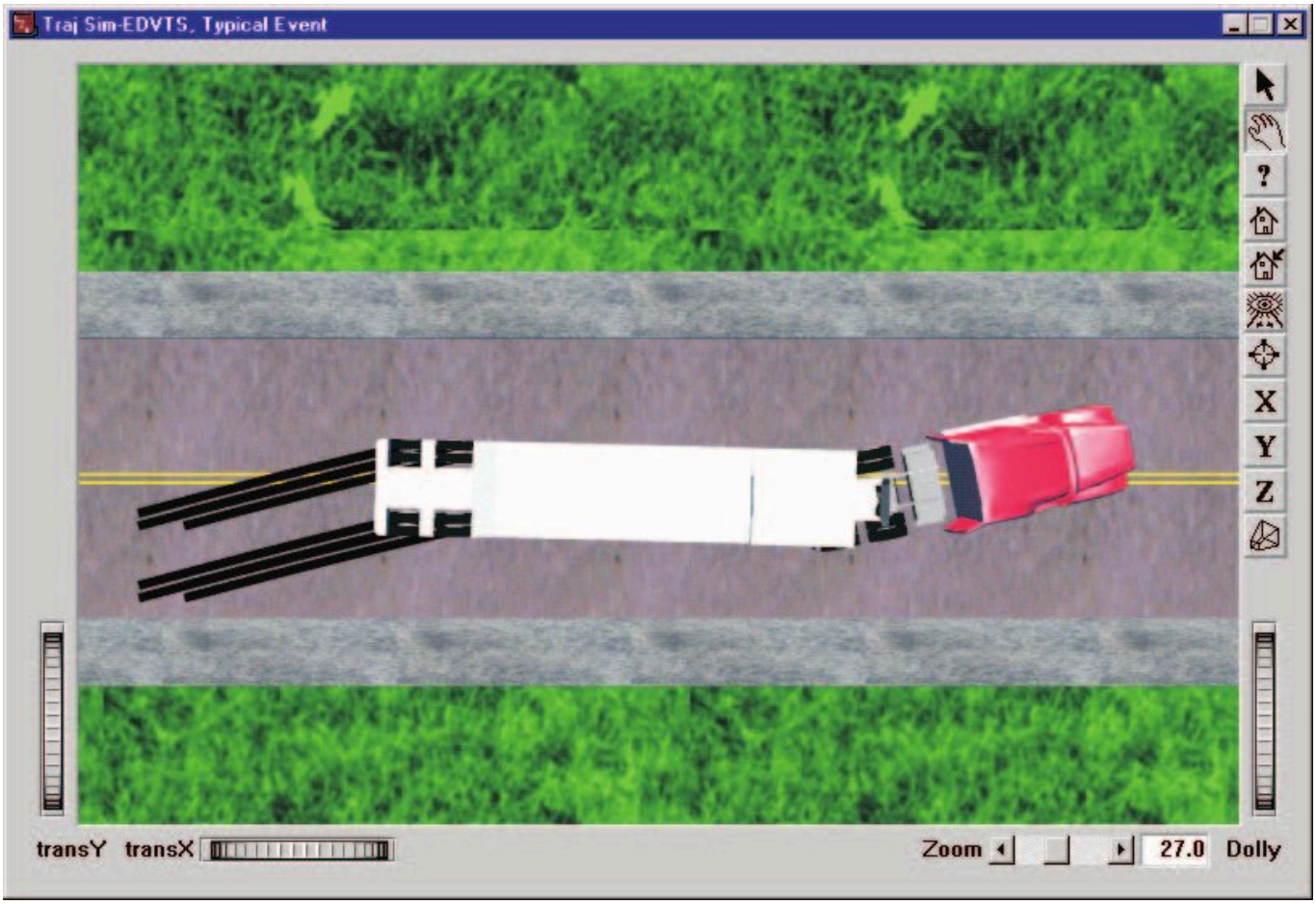


Figure 3-6: Typical EDVTS Trajectory Simulation.

Displaying a Trajectory Simulation

The Trajectory Simulation is controlled using the Playback Controller (see Figure 3-7).

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 3-7: Playback Controller.

> NOTE: The Playback Controller is also used for controlling the Playback Window. This window is used for combining events and for making movie files. Refer to the User's Manual for more information on the Playback Window and making movie files.

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Chapter 4 — Calculation Method

Basis for Analysis

EDVTS is a dynamic analysis of vehicle motion in the horizontal (yaw) plane. Using the standard engineering approach, the equations of motion are written using Newtonian mechanics. The mathematical model for EDVTS was developed and validated at the University of Michigan Transportation Research Institute [1-3,14], and extended by EDC [25].

For successful use of EDVTS, a good understanding of vehicle 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 Physics Manual as well as those listed in User's Manual Appendix VI, References.

Equations of Motion

The 4-degree of freedom analysis solves the equations of motion in the horizontal (yaw) plane. In this plane, the tow vehicle x- and y- linear motion and yaw angle (rotation about the z-axis) and the articulation angle of the trailer about its connection are calculated. Vehicle motion is defined relative to the vehicle-fixed coordinate system (see User's Manual Appendix III, Coordinate Systems; for more information, refer to SAE J670e — Vehicle Dynamics Terminology [6.2], portions of which are found in the Help Index).

The required equations of motion are written below:

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

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

$$I_{zz}\dot{r} = \Sigma M_z$$

$$I_{z,2}\ddot{\gamma} = \Sigma M_{z,conn}$$

where:

Symbol	Meaning
m	total mass of tow vehicle
$I_{zz1,2}$	total yaw moment of inertia of tow vehicle and trailer
u	forward velocity (vehicle-fixed component) of tow vehicle
v	lateral velocity (vehicle-fixed component) of tow vehicle
r	angular yaw velocity of tow vehicle
γ	articulation angle
ΣF_x	summation of external forces in the x-direction
ΣF_y	summation of external forces in the y-direction
ΣM_z	summation of external moments about the z-axis
$\Sigma M_{z,conn}$	summation of external moments about the connection z-axis

EDVTS solves these equations of motion at discrete time intervals (specified by the vehicle trajectory integration timestep, see 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. EDVTS uses **Hamming's modified predictor-corrector** method, which helps to ensure stable results. Where the predicted and corrected values disagree by more than the Velocity Convergence Criterion, the integration timestep is halved and the step retried; exceeding the Maximum Bisections terminates the run (see Simulation Controls). 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.

There are no degrees of freedom (and hence no equations of motion) for vertical motion, or pitch or roll rotation. Therefore, suspension dynamics cannot be studied directly. However, EDVTS considers the suspension as it affects tire forces by calculating the

roll couple distribution

(the ratio of lateral load transferred at the front and rear suspensions during cornering). The CG elevation above ground is used in conjunction with longitudinal and lateral accelerations to compute quasi-static load transfers due to pitch and roll, respectively.

Load transfer

EDVTS has no vertical, pitch or roll degree of freedom, so load transfer is computed quasi-statically from the current accelerations and applied as a change in vertical force at each wheel. The transfers sum to zero — load is moved between wheels, never added.

Lateral transfer is apportioned between the axles by the roll couple distribution:

$$\Delta F_{z,Lat} = \frac{\gamma\, h\, m}{T}(a_y - g\sin\phi_{Road})$$

where γ is the fraction of the roll couple carried by that axle, h the CG height, T the track width at that axle, and $a_y = \dot{v} + ur$ the vehicle-fixed lateral acceleration. The road roll angle term removes the component of gravity acting across a superelevated surface, so a vehicle standing on a banked road carries the correct static crossfall load without any lateral acceleration.

Longitudinal transfer is taken about the wheelbase:

$$\Delta F_{z,Long} = \frac{-m(a_x + g\sin\theta_{Road})h + \gamma_T\, \ell_T \sum F_{x,Rear}}{2(a+b)}$$

where $a_x = \dot{u} - vr$, a and b are the CG distances to the front and rear axles, and the final term is the inter-tandem transfer: γ_T is the inter-tandem load transfer coefficient entered with the suspension, ℓ_T the spacing between the tandem axles, and the sum is the longitudinal force at the rear wheels. For a vehicle without tandem axles the coefficient is zero and the term vanishes.

Where tandem axles are present, the rear-axle share of both transfers is split equally between the two tandem axles before the inter-tandem term is applied.

> **NOTE:** The accelerations used are those from the **previous** timestep, not the current one. This is inherent to a quasi-static treatment computed alongside the tire forces that produce it — the load transfer at any instant reflects the acceleration that has just occurred. At normal timesteps the difference is immaterial, but it is one reason a very coarse timestep degrades results in hard transient manoeuvres.

Because EDVTS simulates a tow vehicle and trailer, both transfers additionally carry the forces at the hitch. The lateral transfer on each tow-vehicle axle includes a term in the lateral connection force acting at the hitch height, and the longitudinal transfer includes both the longitudinal connection force and a **vertical** load transfer through the hitch, which moves load between the tow vehicle and the trailer as the combination accelerates, brakes or rolls. The trailer axle transfers are formed the same way from the connection forces resolved into the trailer's own frame.

Tire Forces

All of the external forces applied to the vehicle which direct its motion are applied at the tires. Therefore, accurate computation of these forces is essential. 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.

Historically, two methods have been used to compute 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*). EDVTS uses the Fiala tire model [5] to compute the lateral forces on a free rolling tire. This model has been used in many popular simulations developed at Calspan [8]. Using this model, the tire forces are computed for the current integration timestep as follows:

Symbol	Meaning
C_α	tire cornering stiffness (lb/radian)
α	tire slip angle (radians)
F_z	tire vertical force (lb)
F_{sx}	attempted brake or acceleration force (lb)
μ_p	peak coefficient of friction
μ_s	slide coefficient of friction
μ_{slip}	% slip at μ_p
δ_{dual}	dual-tire factor (1 for dual tires, 0 for a single tire)
s_{fx}	determines direction of wheel force relative to vehicle

At the current simulation time, the force is computed for each tire, one tire at a time. If the percent wheel lock-up method was used to supply wheel forces when entering the Brake and/or Throttle Table, the percent lock-up must be converted into the actual wheel force,

$$F_{sx} = F_{sx}\ \mu_p F_z (1 + \delta_{dual})$$

(updated: earlier editions applied this conversion whenever the tabulated value was less than 1.0. It is applied according to the table method selected, not the magnitude of the entry. The Brake table offers three methods and the Throttle table two:

Table method	Attempted wheel force
Wheel Force	*Used directly as entered*
Percent Available Friction	*Converted as shown above*
Pedal Force (brake only)	*Converted through the vehicle's brake pressure ratio and the wheel's brake torque ratio, divided by the tire radius*

The Pedal Force brake method was not described in earlier editions.)

The attempted wheel force is assigned as the longitudinal wheel force (lb),

$$F_x = F_{sx} \cdot s_{fx}$$

where s_{fx} determines the direction of the wheel force relative to the vehicle-fixed coordinate system.

If the vehicle's forward and lateral velocities are both below the minimum linear velocity, the lateral force is set to zero for this tire and the Fiala calculation below is skipped, so that a stopped vehicle develops no side force.

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

Next, the non-dimensional sideslip parameter, $\bar{\alpha}$, is determined as

$$\bar{\alpha} = C_\alpha \sin(\alpha) / (\mu_p F_z)$$

If $|\bar{\alpha}|$ is equal to or greater than 3, the tire's ability to produce a cornering force, F_y (lb), is saturated. In this case,

$$F_y = -\mu_p F_z (1 + \delta_{dual}) \operatorname{sign}(\bar{\alpha})$$

Since the tire is saturated, it is assumed to be generating a scuff mark due to the excessive lateral forces, and the skid flag is turned on.

Otherwise, $|\bar{\alpha}|$ is less than 3, and the Fiala tire model computes the lateral force, F_y, using a 3rd-order polynomial in $\bar{\alpha}$:

$$F_y = -\mu_p F_z (\bar{\alpha} - \frac{\bar{\alpha} \mid \bar{\alpha}|}{3} + \frac{\bar{\alpha}^3}{27})(1 + \delta_{dual})$$

In this case, the tire is operating within its traction limits, and the skid flag is turned off.

In either case, the direction of the lateral force, F_y, is determined by the sign of $\bar{\alpha}$.

Next, a potential reduction in tire forces, F_x and F_y, due to the amount of lateral tire slip is determined. μ_p is modified by the tire slip angle, α:

$$\mu_{mod} = \mu_p (1 - 1.72 \mid \alpha \mid)$$

If $\mu_{mod} < |\mu_s \cos(\alpha)|$ then

$$\mu_{mod} = |\mu_s \cos(\alpha)|$$

The attempted longitudinal wheel force, F_x (see above), is compared to available force at the current slip angle, α. This available force, F_{max} (lb), is

$$F_{max} = \mu_{mod} F_z (1 + \delta_{dual})$$

If the attempted force, F_x, is less than F_{max}, the amount of longitudinal tire slip, S, is computed:

$$\mu_x = |F_x / (F_z (1 + \delta_{dual}))|$$

$$S = (\mu_x / \mu_p) \mu_{slip}$$

The longitudinal tire slip, S, is used in the slip vs. rolloff table to determine the reduction in lateral tire force, F_y. The following table illustrates this effect for typical tires [14]:

Slip, S	Rolloff
0.00	1.00
0.05	0.88
0.10	0.64
0.15	0.46
0.20	0.33

Linear interpolation is used to determine the amount of rolloff for values of slip between the table values of S. The computed lateral force, F_y, is then adjusted by the rolloff,

$$F_y = F_y \cdot Rolloff$$

The skid flag is set for this tire if the longitudinal slip has reached the slip at peak friction, $S \geq \mu_{slip}$, which is wheel lock-up.

(updated: earlier editions stated that the tire is reported as not skidding in this case. It is reported as skidding if either the lock-up test above or the saturation test applies.)

If the attempted longitudinal wheel force, F_x, is greater than F_{max}, the longitudinal slip exceeds the slip at μ_p and the tire is either locked (braking) or spinning (accelerating). The skid flag is turned on and the forward and lateral tire forces are:

$$F_x = \mu_s |\cos(\alpha)| F_z (1 + \delta_{dual}) s_{fx}$$

(updated: the magnitude of $\cos\alpha$ *is used here, so that the longitudinal force keeps the direction given by* s_{fx} *at slip angles beyond 90 degrees.)*

$$F_y = -\mu_s \sin(\alpha) F_z (1 + \delta_{dual})$$

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

Antilock Model

EDVTS allows the use of a simple antilock model to study the effects of improvements due to

perfect braking

. Perfect braking is defined as "braking which maintains the longitudinal braking force at the level associated with the peak friction coefficient". Under normal conditions (without antilock), it is nearly impossible to hold this level of braking. The tire locks up, thus causing a reduction in brake force from that associated with the peak friction coefficient to that associated with the slide friction coefficient.

The Vehicle Brake Model includes an antilock effectiveness coefficient, η_a, which defines the effectiveness of the antilock system; an antilock coefficient equal to 0.0 is the same as no antilock, while a coefficient equal to 1.0 defines the perfect system. The same antilock coefficient applies to both longitudinal and lateral tire forces. The antilock parameters are assigned using the Vehicle Editor's Wheel Brake dialog (see User's Manual, Section 4 (Vehicle Editor) for more information).

The antilock model is only applicable if the attempted brake force, F_x, is greater than F_{max} (see above). Under this condition, an additional amount of force, ΔF, is generated because of the difference between μ_p and μ_s. For longitudinal tire force:

$$\Delta F_x = (\mu_p - \mu_s)\cos(\alpha)\, F_z\, s_{fx}\,(1 + \delta_{dual})\,\eta_a$$

$$F_x = (\mu_s F_z (1 + \delta_{dual})\cos(\alpha)\, s_{fx}) + \Delta F_x$$

For lateral tire force:

$$\Delta F_y = (F_y + \mu_s F_z (1 + \delta_{dual})\sin(\alpha))\,\eta_a$$

$$F_y = -\mu_s F_z (1 + \delta_{dual})\sin(\alpha) + \Delta F_y$$

(updated: with antilock active, the longitudinal force takes the sign of the attempted wheel force directly, rather than the vehicle-fixed direction s_{fx} used without antilock. The two differ only when the tire is travelling rearward.)

Assumptions

In order to provide a useful analysis without becoming burdensome and overly complex, EDVTS makes several simplifying assumptions. If EDVTS 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. EDVTS will issue results which may not be valid for the given circumstances.

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

No Rollover Allowed

EDVTS is a yaw plane analysis and does not consider roll or pitch degrees of freedom. The analysis is only valid while all wheels are generating a positive (downward) force on the road surface. As soon as a wheel load becomes negative, wheel lift-off is assumed and computations are halted. A warning message will be displayed indicating the time at which wheel lift-off occurred and the wheel that lifted.

No Suspension Effects

EDVTS assumes the wheels remain vertical at all times. Therefore, camber stiffness does not contribute to lateral force generation. There is no roll degree of freedom, so bump steer and roll steer are also ignored. (See Roll Couple Distribution for information about how the suspension affects the front/rear distribution of lateral forces.)

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.

Small Angle Assumption for Roll and Pitch

[HVE] EDVTS has been extended for use in the HVE 3-D environment to include a gravity vector. Thus, vehicle motion on sloped surfaces may be accommodated. However, the model is valid only for small roll and pitch angles. If this angle is exceeded, a message is issued (*Excessive Roll or Pitch*) and the run is terminated.

Roll/Pitch Not Greater Than 15 Degrees

[HVE] EDVTS uses the small angle assumption; if the roll and/or pitch exceed about 15 degrees, errors may become significant. To prevent this problem, EDVTS returns a fatal message under this condition.

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Chapter 5 — EDVTS Tutorial

This tutorial examines a common use for EDVTS: the simulation analysis of a tractor-trailer off-ramp rollover accident. The purpose of the analysis is to determine if the rollover was the result of excessive speed or an abnormal loading condition (in this case, the payload CG was rather high).

We approach the analysis by first determining the CG location of the payload, then estimating the CG elevation of the combined vehicle and payload. This information is critical, because CG elevation is the primary independent variable we wish to hold constant while trying various speeds to estimate the *maximum* speed at which the offramp can be successfully negotiated. Once this speed is found, we can compare it to the posted off-ramp speed. If the speed is *less* than the posted speed, we conclude the vehicle was improperly loaded or the posted speed was too high (the latter conclusion would require further supporting analysis); otherwise, we can conclude the driver was speeding.

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

- Create the vehicles
- Create the environment
- Execute the EDVTS event(s)
- Review the EDVTS output reports

This basic procedure is described in detail in this tutorial.

> NOTE: It is assumed that HVE-2D is up and running, and that the user is familiar with HVE-2D's basic features. The purpose of this tutorial is to illustrate those features while setting up and executing an EDVTS 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: In HVE-2D, all options simply affect the appearance in a viewer during Event or Playback mode.

[HVE] However, in HVE, AutoPosition affects 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
- **[HVE]** ON: *Show* Contacts
- OFF: *Show* Velocity Vectors

- ON: *Show* Skidmarks
- OFF: *Show* Targets
- **[HVE]** ON: *AutoPosition*
- Units equals *U.S.*
- Render Options:
- Show Humans as *Actual*
- Show Vehicles as *Actual*
- *Phong* Render Method
- **[HVE]** Complexity equals *Object*
- Render Quality equals *5*
- **[HVE]** Texture Quality equals *1*
- 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 chrome-yellow Mack truck tractor; the trailer is a 44 foot-long van trailer:

- 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: Our Vehicle Database does not include a Mack tractor, so we'll build one from a Generic Class 3 (short wheelbase, tandem axle) truck.
>
> 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 = *Generic*
- Model = *Generic*
- Year = *Generic*
- Body Style = *Class 3*

The default vehicle name is

Class 3 Truck

. Let's add something a little more descriptive:

- Replace the default name; enter `Mack Truck Tractor`.
- Click *OK* to add *Mack Truck Tractor* to the Active Vehicles list.

The Mack tractor is displayed in the viewer, as shown in Figure 5-1.

Next, let's add the 44 foot semi-trailer. Again, we don't have the exact vehicle in our database, so we'll create it, starting with a generic, tandem axle (Class 4) trailer. To create the trailer, perform the following steps:

- 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 `44 Ft Semi-trailer`.
- Click *OK* to add *44 Ft Semi-trailer* to the Active Vehicles list.
- The 44 foot semi-trailer is displayed in the viewer, as shown in Figure 5-2.

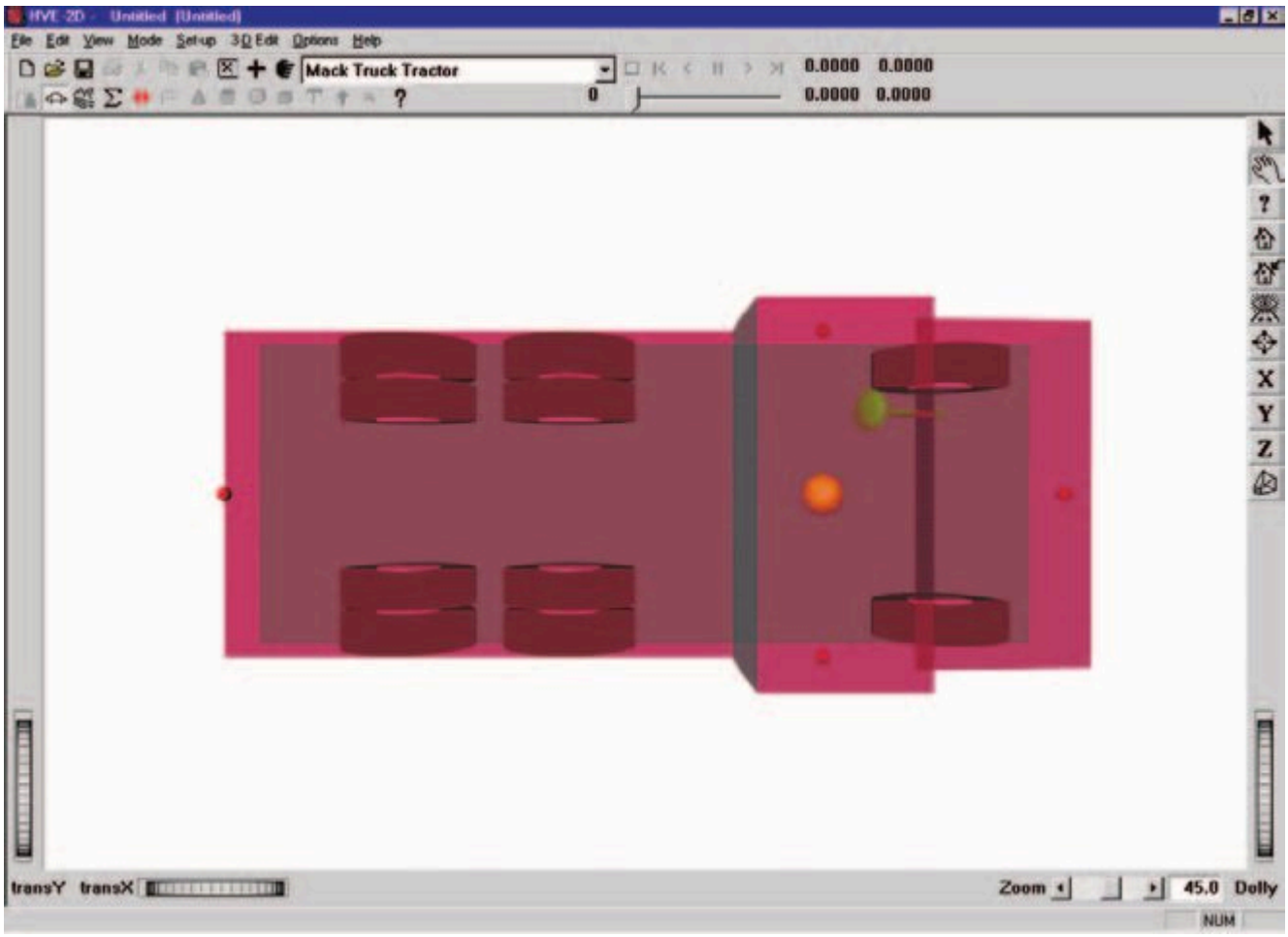


Figure 5-1: Mack Truck Tractor, created from a generic Class 3 short wheelbase truck.

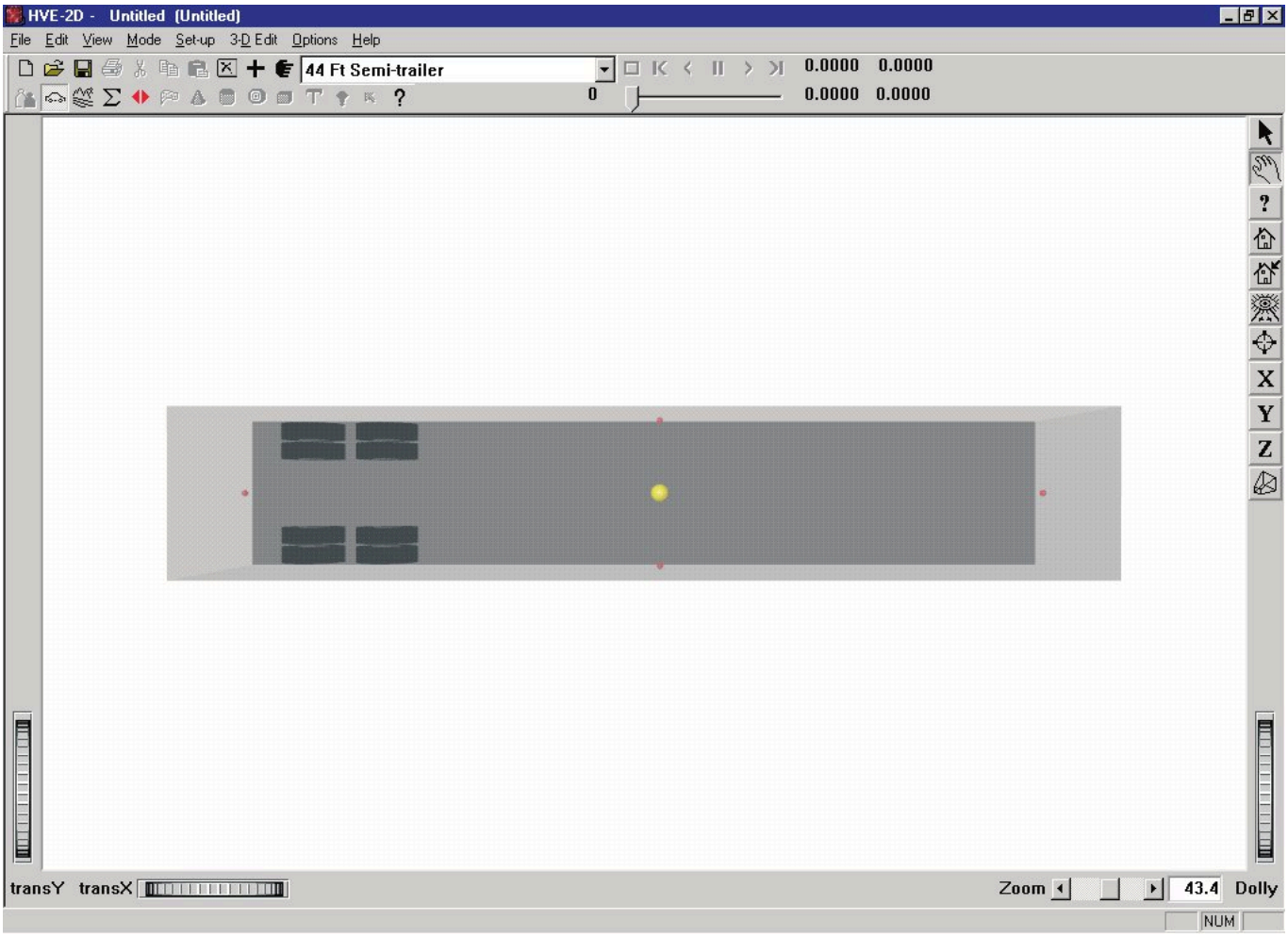


Figure 5-2: 44 Ft Semi-trailer, created from a generic Class 4 Trailer.

Editing the Vehicles

This tutorial includes more vehicle editing than other tutorials, mainly because nearly every on-highway truck is custom built to some degree, and there are so many sizes of trailers. This gives us an opportunity to exercise more features of the Vehicle Editor. Let's begin by editing the color of the Mack tractor:

- Select *Mack Tractor* from the Active Vehicles list in the drop-down menu, making it the current vehicle. The Mack Tractor is now displayed in the Vehicle Editor Viewer.
- Click on the CG and choose *Color*. The Vehicle Color dialog is displayed (see Figure 5-3), 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 outside of the yellow area. To brighten the color, click on the intensity slider and drag it to the far right end of the slider.

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

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



Figure 5-3: Vehicle Color dialog, used for assigning the vehicle color.

> 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.

Now, let's position the rear axles to match those of the Mack Tractor.

- Click on the right tire of the third axle and then choose *Wheel Location* from the pop-up menu. The Wheel Location dialog is displayed.
- Edit the x value of -127.75 in. to be `-161.50` in.
- Click the checkbox for *Copy To Other Side*.
- Click *OK* to move the third axle towards the rear of the vehicle.
- Now click on the right tire of the second axle and then choose *Wheel Location* from the pop-up menu. The Wheel Location dialog is displayed.
- Edit the x value of -76.25 in. to be `-110.00` in.
- Click the checkbox for *Copy To Other Side*.
- Click *OK* to move the second axle towards the rear of the vehicle.

Now, let's move the fifth wheel connection to the proper position:

- Click on the CG and choose *Connections*. The Connections dialog is displayed.
- Position the Rear Connection (Fifth Wheel) between the rear axles by changing the x coordinate from -92.0 in. to be `-135.75` in.
- Raise the height of the Rear Connection above the CG of the vehicle by changing the z coordinate from -3 in to be `-4` in.
- Click *OK* to move the connection to the proper position.

Next, let's add the 3-D geometry file for the Mack truck. The geometry file was previously digitized by EDC, named *TKMackTractor.h3d* and placed in the `supportFiles/images/vehicles` subdirectory. To attach the geometry file to our generic vehicle, perform the following steps:

- Click on the CG, choose *Exterior Geometry* and select *Open*. The Geometry File Selection dialog is displayed (see Figure 5-4), and we're ready to select a geometry file from the listbox.

- Click on the *Files of Type* option list and choose *HVE Geometry Files (*.h3d)*.
- Scroll down the list and double-click on *TKMackTractor.h3d*.

The new geometry file is applied to the Mack Truck Tractor (see Figure 5-5).

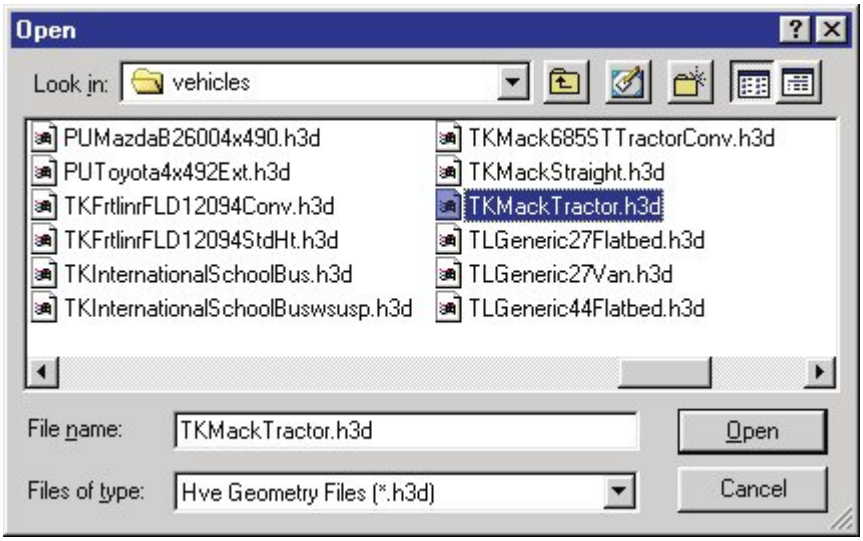


Figure 5-4: Vehicle Geometry File Selection dialog, used for adding a 3-D geometry file to the Mack tractor.

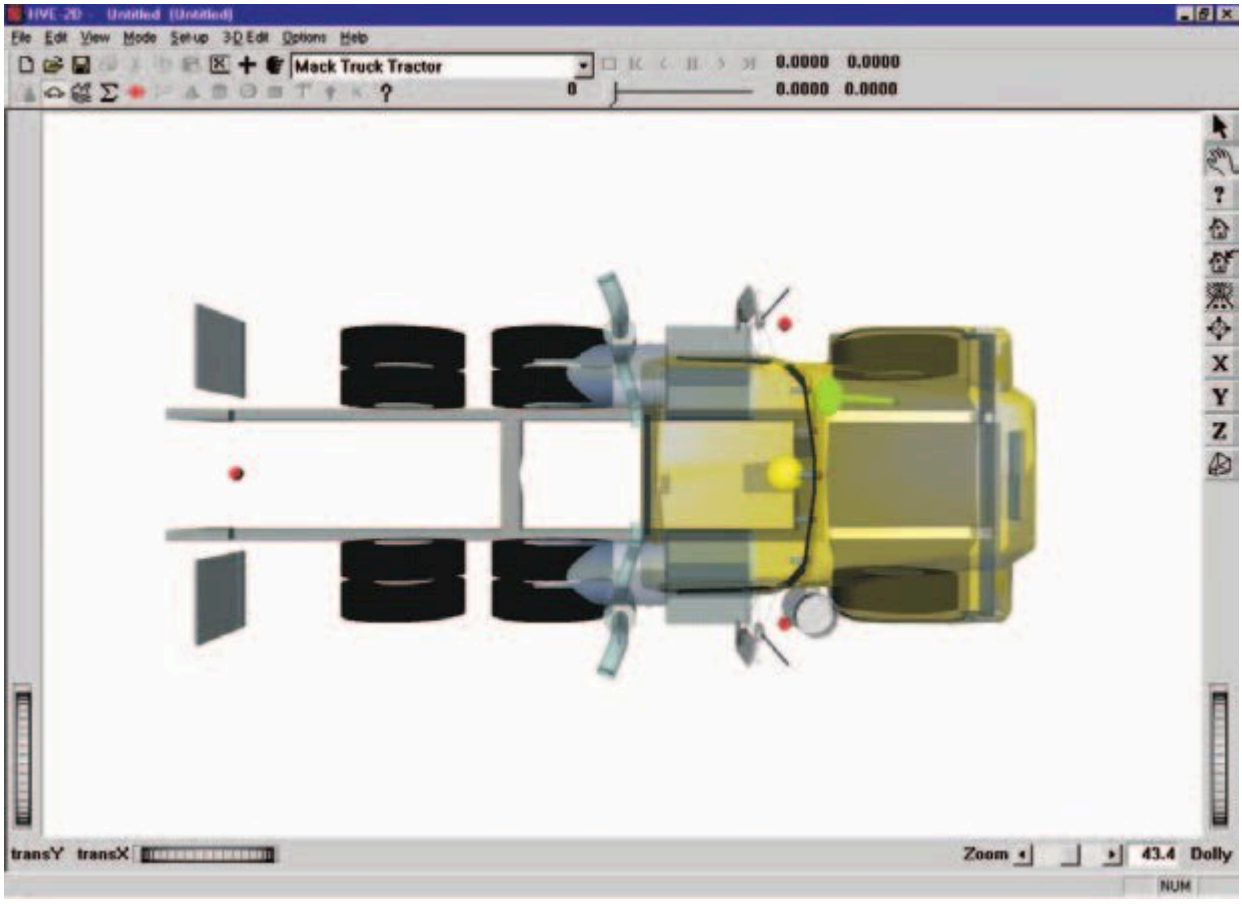


Figure 5-5: Mack Tractor after adding its geometry file.

Next, let's edit the trailer by changing its color and adding a geometry file.

Let's begin by editing the color of the 44 foot semi-trailer:

- Select the *44 Ft Semi-trailer* from the Active Vehicles drop-down list, making it the current vehicle. The trailer is now displayed in the Vehicle Editor Viewer.
- Click on the CG and choose *Color*. The Vehicle Color dialog is displayed, showing the vehicle's current color and intensity. Click on the hot spot and drag it to the yellow area near the outside of the color circle. To brighten the color, click on the intensity slider and drag it to the far right end of the slider.
- When the color is darkened to your liking, close the dialog by clicking the close button on the upper right corner of the dialog.

Next, let's add the 3-D geometry file. A generic 44 foot van trailer geometry file, appropriately named *TLGeneric44Van.h3d*, was prepared by EDC and placed in the `supportFiles/images/vehicles` subdirectory. To attach the geometry file to the trailer, perform the following steps:

- Click on the CG, choose *Exterior Geometry* and select *Open*. The Geometry dialog is displayed (see Figure 5-6), and we're ready to select a geometry file from the listbox.
- Scroll down the list and double-click on *TLGeneric44Van.h3d*.

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

The tractor and trailer are now ready for our EDVTS simulation analysis.

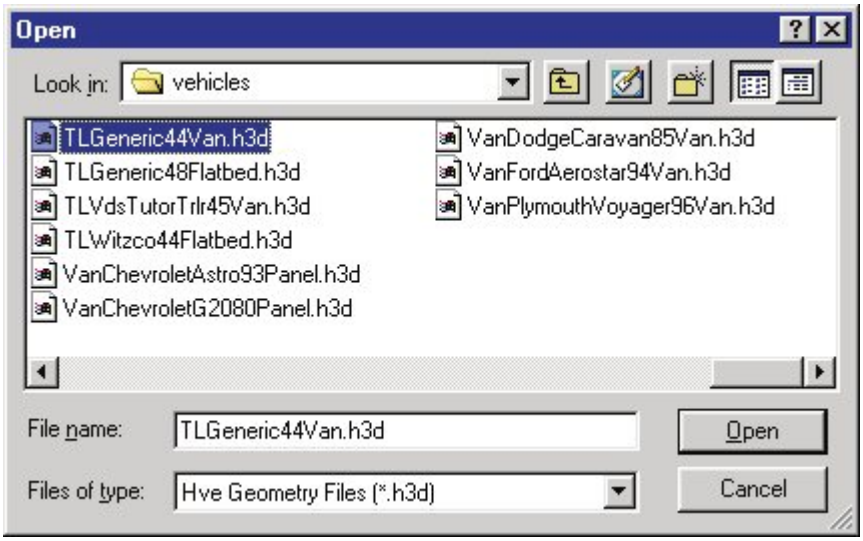


Figure 5-6: Vehicle Geometry File Selection dialog, used for adding a 3-D geometry file to the 44 foot van trailer.

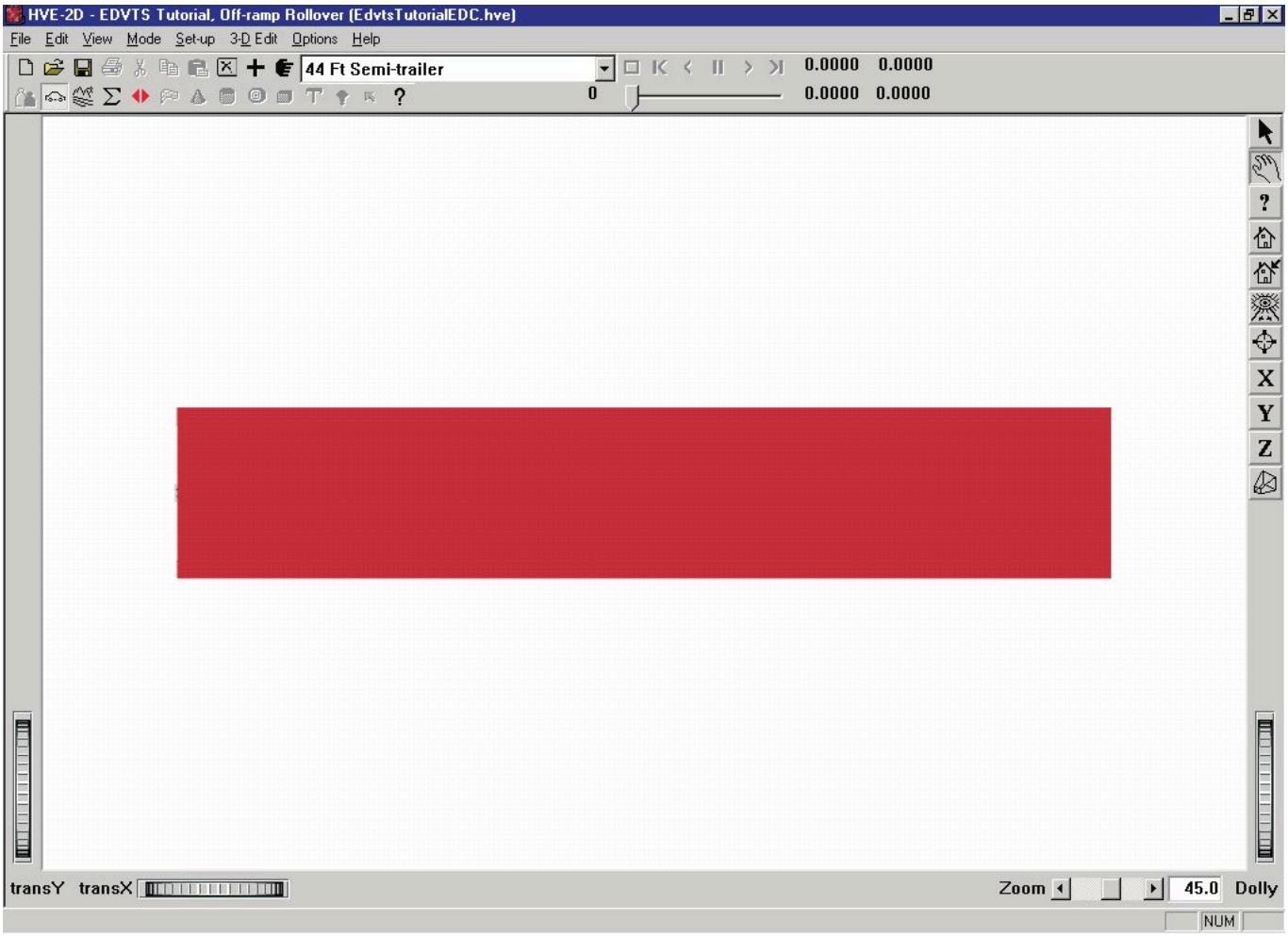


Figure 5-7: 44 Ft Semi-trailer after adding its geometry file.

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 *Denver, Colorado, USA*. The latitude (39.45.00N), longitude (105.00.00W) and GMT, hours from the prime meridian (-7.0) are displayed for the selected location.
- Enter a name for the environment, `Freeway Offramp, Exit 342`.
- Enter the date and time of the incident we are studying, `10/22/00` and `1045`, respectively.
- Enter the angle from *true north* to the earth-fixed X axis in our environment, `0.0` 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.

- Click on the *Files of Type* option list and choose *HVE Geometry Files (*.h3d)*. A list of environment geometry files using the .h3d file format is displayed in a list box.
- Double-click on *EdvtsTutorial_2D.h3d* to choose the environment file and remove the dialog.

[HVE] HVE users should double-click on *FreewayOfframp.h3d*.

- Press *OK*.

The selected environment is added to our case and displayed in the Environment Viewer (see Figures 5-8 and 5-9). Use the viewer thumb wheels to view the scene.

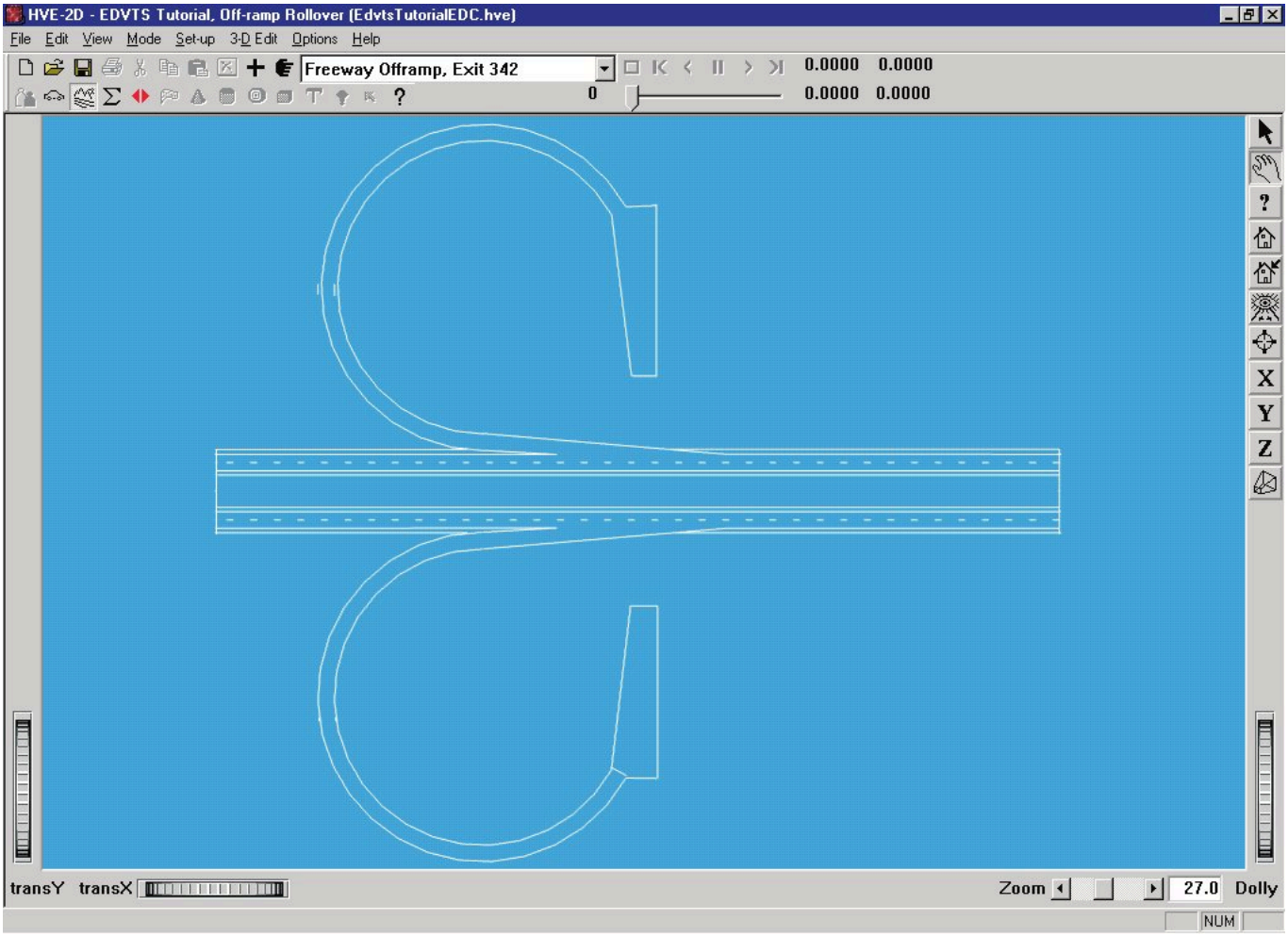


Figure 5-8: HVE-2D environment used for the EDVTS tutorial.

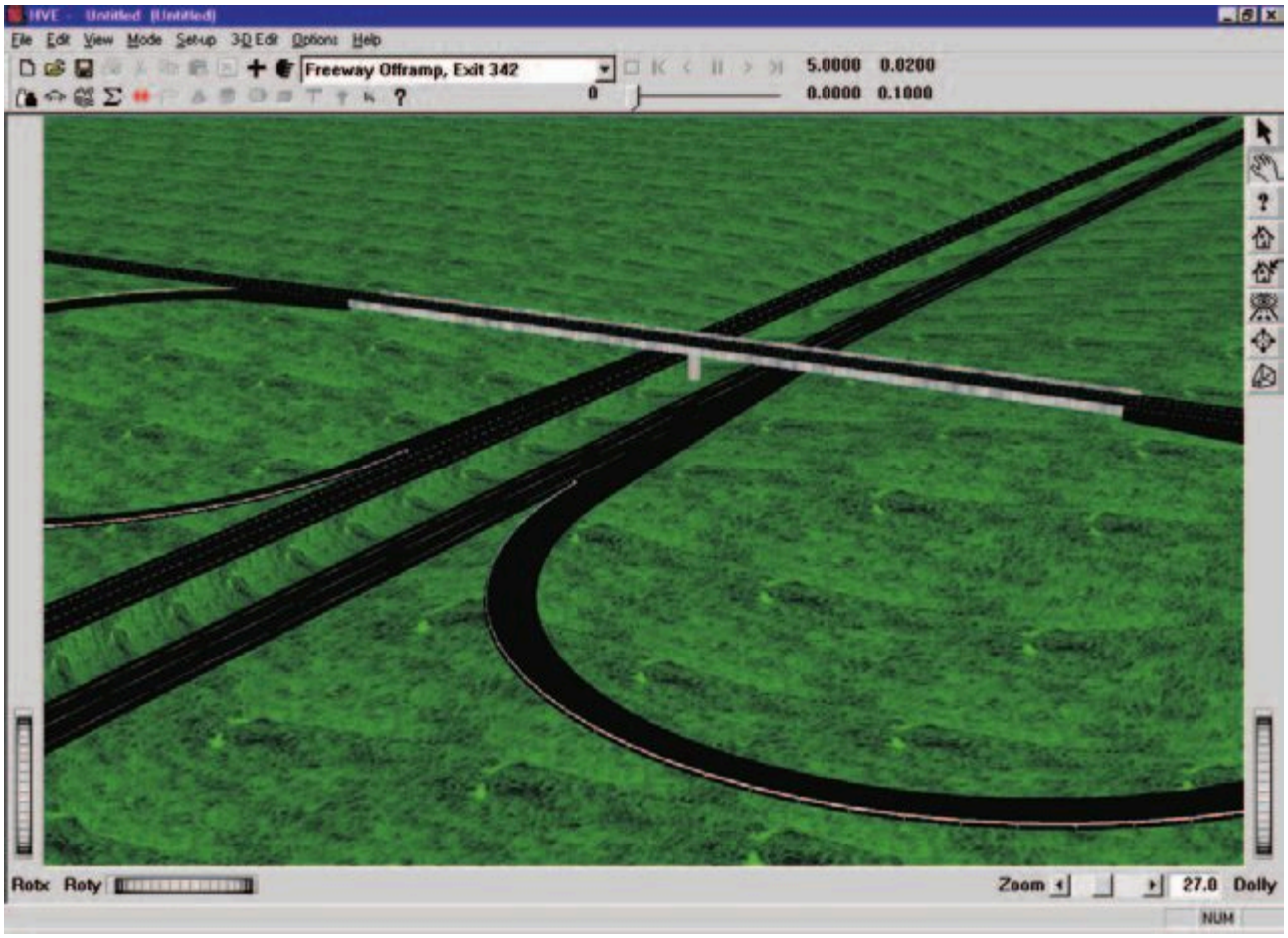


Figure 5-9: HVE environment used for the EDVTS tutorial.

Saving the Case

Now that we've created all the objects (*vehicle* 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.

- In the Case Title text field, enter `EDVTS Tutorial, Off-ramp Rollover`.

> 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 `EdvtsTutorial`.
- Click *SAVE*. The current case data are saved in the `/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 a tractor-trailer offramp accident to determine if the offramp is negotiable at the posted speed. 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 *Mack Truck Tractor* and *44 Ft Semi-trailer* from the Active Vehicles list.
- Select *EDVTS* from the *Calculation Method* options list.
- Enter a name for the event, `Offramp Rollover`.

> NOTE: The name of the calculation method will be appended to the event name, thus the complete event name will become "EDVTS, Offramp Rollover."

- Press *OK* to display the event editor.

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

- *Mack Truck Tractor* is the only object listed in the Event Humans & Vehicles list box. Choose *Set-up* from the main menu bar and select *Position/Velocity*. The Mack tractor and 44 foot semi-trailer are displayed in the environment. The Position/Velocity dialog for the tractor is also displayed. The tractor CG is located above the earth-fixed origin, and the trailer is connected to the tractor with a zero articulation angle.

> NOTE: Even though you didn't select the trailer from the Event Humans and Vehicles list (in fact, it's not even in the list), the trailer is automatically attached to the tractor and displayed in the Event viewer because the trailer is a "child" vehicle, that is, HVE-2D knows that the trailer's position is not independent from the tractor; it is attached to it.

- Click on the Mack truck's X-Y manipulator (see Figure 5-10), wait for it to turn bright yellow (indicating it has been selected), and drag it to its initial position, X=`250.0` ft, Y=`-48.0` ft (for HVE, X=`150.0` ft, Y=`-48.0` ft). In the Position/Velocity dialog, enter a heading (yaw) angle of `180.0` degrees.

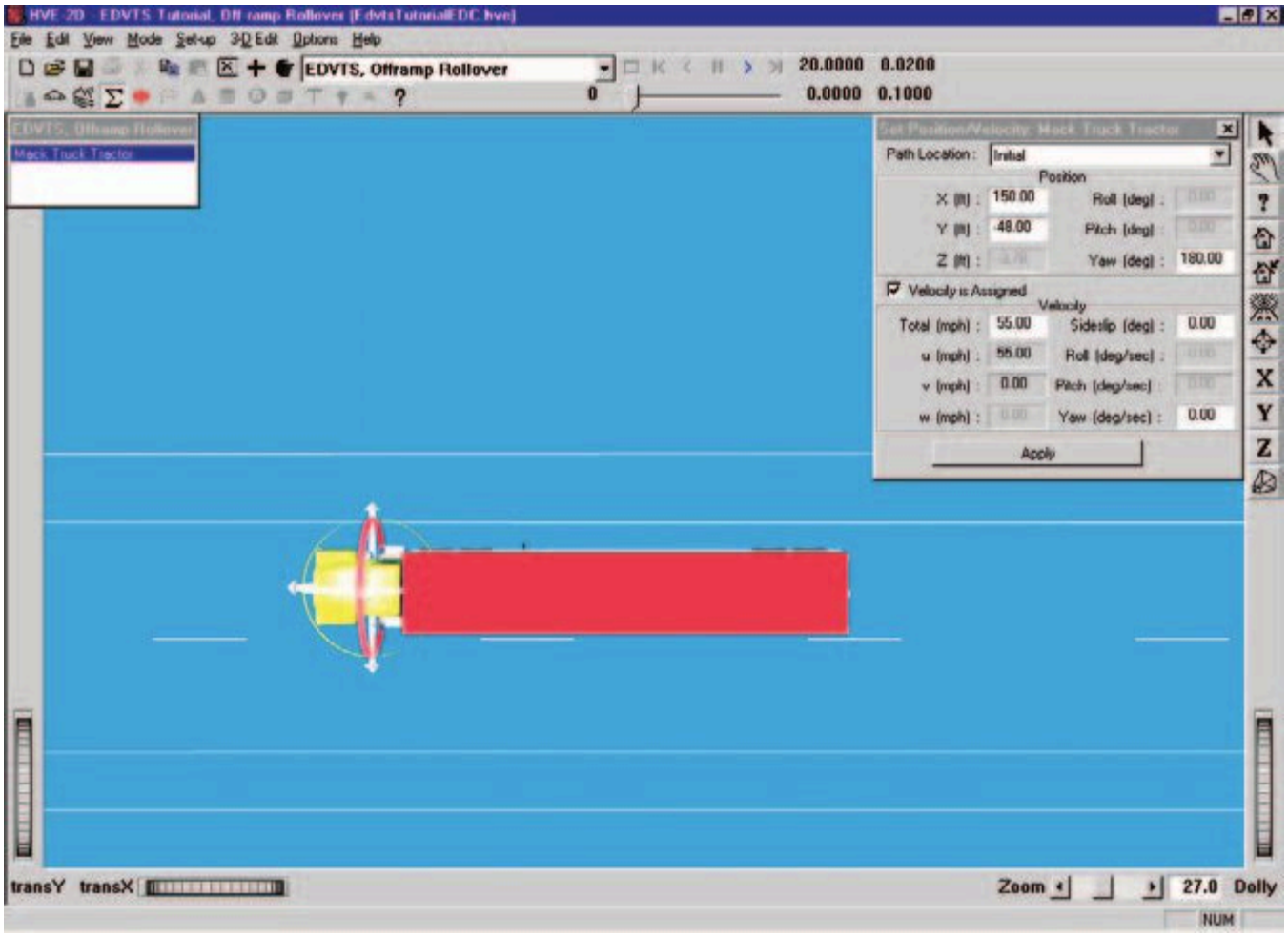


Figure 5-10: Vehicle positioning using the Event Editor. The manipulators can be used to drag and drop the vehicle into position.

> 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 5-10).
>
> NOTE: Be sure to keep the mouse button depressed while you drag the manipulators.
>
> NOTE: Adjust the viewer by dollying back (using the Dolly thumb wheel) until you can see the entire intersection.
>
> NOTE: If you can't position the vehicle at the exact coordinates, simply enter them in the Position/Velocity dialog (in fact, it's often easier to directly enter the coordinates using the dialog).
>
> NOTE: When entering coordinates using the Position/Velocity dialog, remember to press \<Enter> or Apply; otherwise, the values will not be assigned.

- Click the *Velocity Is Assigned* checkbox. Enter the initial total velocity, `55` mph.

The vehicles' initial conditions are now established. Let's enter the driver controls. We'll start with the Mack tractor's steering table. After a little trial and error, we have arrived at a steer table that causes the vehicle to exit from the freeway onto the offramp and begin steering around the curve.

To enter the steer angles, perform the following steps:

- Click on the Set-up Menu, select *Driver Controls*. The Driver Controls dialog appears and the Steering Table is displayed.

- Click on the *Table Is* option list and choose the *At Steering Wheel* option.
- Enter the steer angles for the Mack Truck Tractor, as shown in Table 5-1, below:

Table 5-1: Steer table entries for the Mack Truck Tractor

Time (sec)	Steer Angle at Steering Wheel (degrees)
0.00	10.0
2.00	10.0
4.00	9.0
5.50	0.0
6.00	180.0
8.00	270.0

> NOTE: Note the simplicity of the steer table. The steering angle changes gradually, just like it does when you are really driving! Complex driver tables containing several rows of slightly-changing steer angles are usually a bad sign.

Next we enter the braking table:

- Since the Driver Controls dialog is still displayed, simply click on the *Brake* tab. The Brake Table dialog is displayed.
- Click on the *Table Is* option list and choose the *Available Friction* option.
- Enter the values shown in Table 5-2, below.
- Press *OK* to accept the brake table.

Table 5-2: Brake table for Mack Truck Tractor

Time (sec)	Axle 1 Right	Axle 1 Left	Axle 2 Right	Axle 2 Left	Axle 3 Right	Axle 3 Left
2.00	0.00	0.00	0.00	0.00	0.00	0.00
2.10	0.01	0.01	0.15	0.15	0.15	0.15
5.00	0.01	0.01	0.15	0.15	0.15	0.15
5.10	0.25	0.25	0.25	0.25	0.25	0.25

(Values are Percent Available Friction, %/100.)

This table causes the vehicle to begin coasting when the vehicle leaves the freeway at 2 seconds. Moderate braking begins at 5 seconds, just as the vehicle enters the turn.

Next, we need to enter the driver controls for the trailer. To perform this operation, we first need to select the trailer:

- If necessary, use the Event Viewer thumb wheels or manipulators to adjust the view so the trailer is visible.
- Click on the trailer in the Event Viewer. A set of manipulators is displayed at its connection to the tow vehicle, and the Position/Velocity dialog is displayed, as shown in Figure 5-11.

> NOTE: To select the vehicle, the viewer must be in Pick mode, as indicated by the highlighted arrow in the upper right corner of the viewer (see Figure 5-11).
>
> NOTE: We can't select the trailer from the Event Humans & Vehicle list because the trailer is not an independent vehicle; it is a "child" of the Mack Tractor. Therefore, the trailer is not displayed in this list.

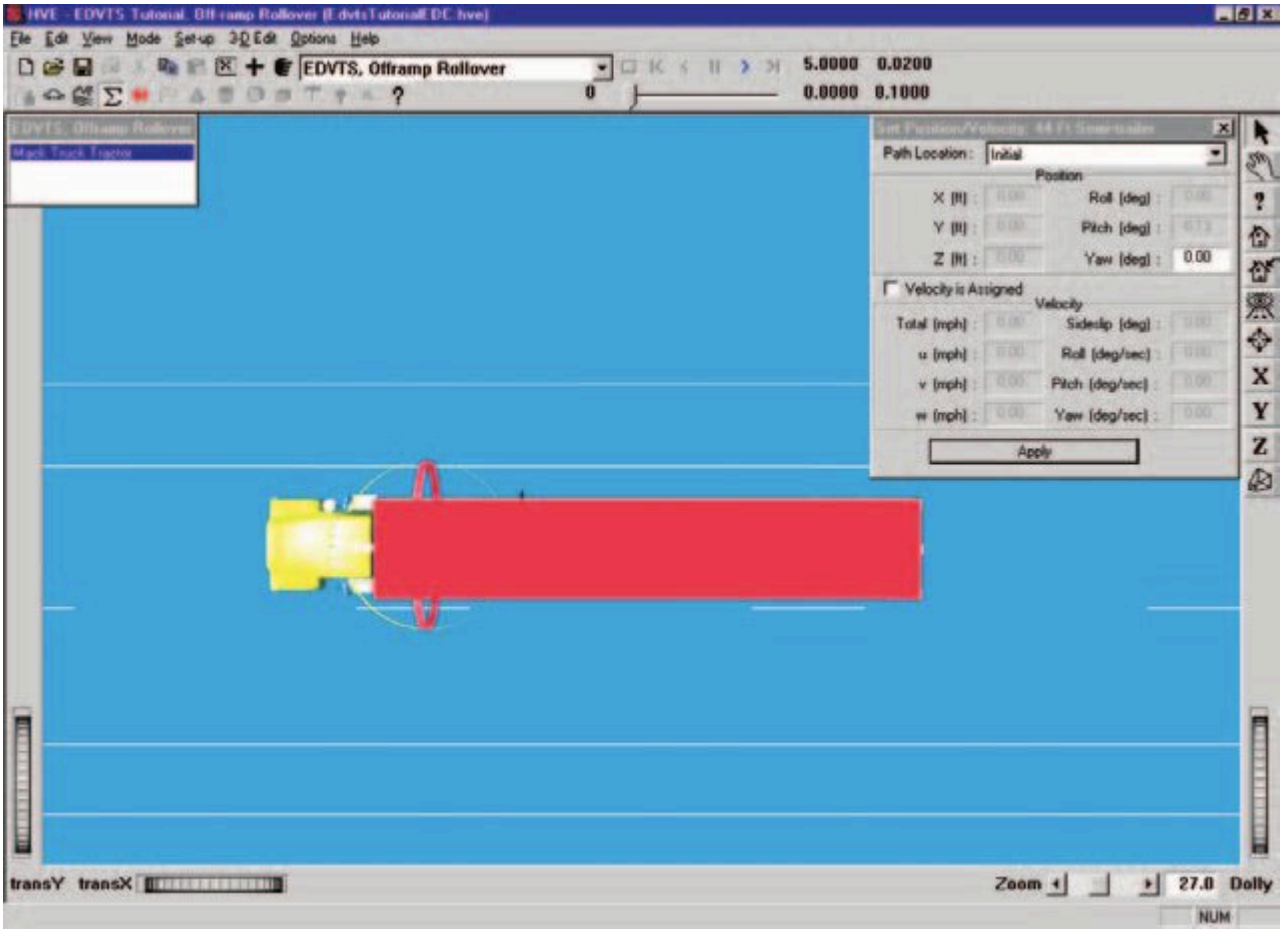


Figure 5-11: Trailer positioning using the Event Editor. The manipulators are displayed at the connection between the tractor and trailer. The manipulators can be used to drag and drop the vehicle into position.

Now, we're ready to enter the driver controls for the trailer. To enter the brake table, perform the following steps:

- Click on the Set-up Menu and select *Driver Controls*. The Driver Controls dialog appears.
- The *Brake* tab is the only available tab. The Brake Table is displayed.

> NOTE: The Steering, Throttle and Gear Selection options are not available in the Driver Controls cascade menu because the default Driver Location option for trailers is 'None' (see Vehicle Editor, Vehicle Information dialog).

- Click on the *Table Is* option list and choose the *Available Friction* option.
- Enter the brake table values for the 44 foot semi-trailer, as shown in Table 5-3:

Table 5-3: Brake Table for the 44 Ft Semi-trailer

Time (sec)	Axle 1 Right	Axle 1 Left	Axle 2 Right	Axle 2 Left
2.00	0.00	0.00	0.00	0.00
2.10	0.01	0.01	0.01	0.01
5.00	0.01	0.01	0.01	0.01
5.10	0.25	0.25	0.25	0.25

(Values are Percent Available Friction, %/100.)

> NOTE: The time and brake entries are identical to those used for the tow vehicle's rear tandem axles. We're assuming a pretty good brake system here; if desired, we could delay the time entries for the trailer and modify any specific entries to account for brake-to-brake variability.

- Press *OK* to accept the brake table for the trailer.

Now, let's add the payload to the trailer.

- Click on the Set-up menu and choose *Payload*. The trailer payload dialog is displayed.
- Click in the *Payload Exists* check box.
- Highlight the value in the *CG Coordinates*, z field and enter `-30.0` in.

> NOTE: Entering -30.0 locates the payload 30 inches above the unloaded trailer CG height.

- Highlight the value in the *Weight* field and enter `40000.0` lb.
- Highlight the value in the Rotational Inertia, Yaw field and enter `3360000.0` lb-sec²-in.
- Press *OK* to update the trailer's payload.

Finally, we must adjust the Roll Couple Distribution to reflect the fact that this is a heavy truck.

- In the **Vehicle Editor**, select the tow vehicle and open its **Suspension Parameters**.
- In the *Roll Couple Distribution* field, replace the default value, `0.55`, with a more representative value, `0.2`.
- Apply the change.

*(updated: The printed tutorial set this value through the Options menu's Calculation Options dialog. The current version does not present an EDVTS Calculation Options dialog; the roll-couple value is taken from the tow vehicle's **Roll Couple Distribution** suspension value. See EDVTS Calculation Options.)*

This event lasts more than 5 seconds. To prevent premature termination, let's increase the default maximum simulation time.

- Click on the Options menu and choose *Simulation Controls*. The Simulation Controls dialog is displayed.
- Edit the *Maximum Time*, changing it from `5` to `20` seconds.
- Press *OK* to update the simulation controls.

Since our goal for this event is to see if the vehicle rolls 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 *Mack Truck Tractor* Key Results window. The Variable Selection dialog for *Mack Truck Tractor* is displayed.

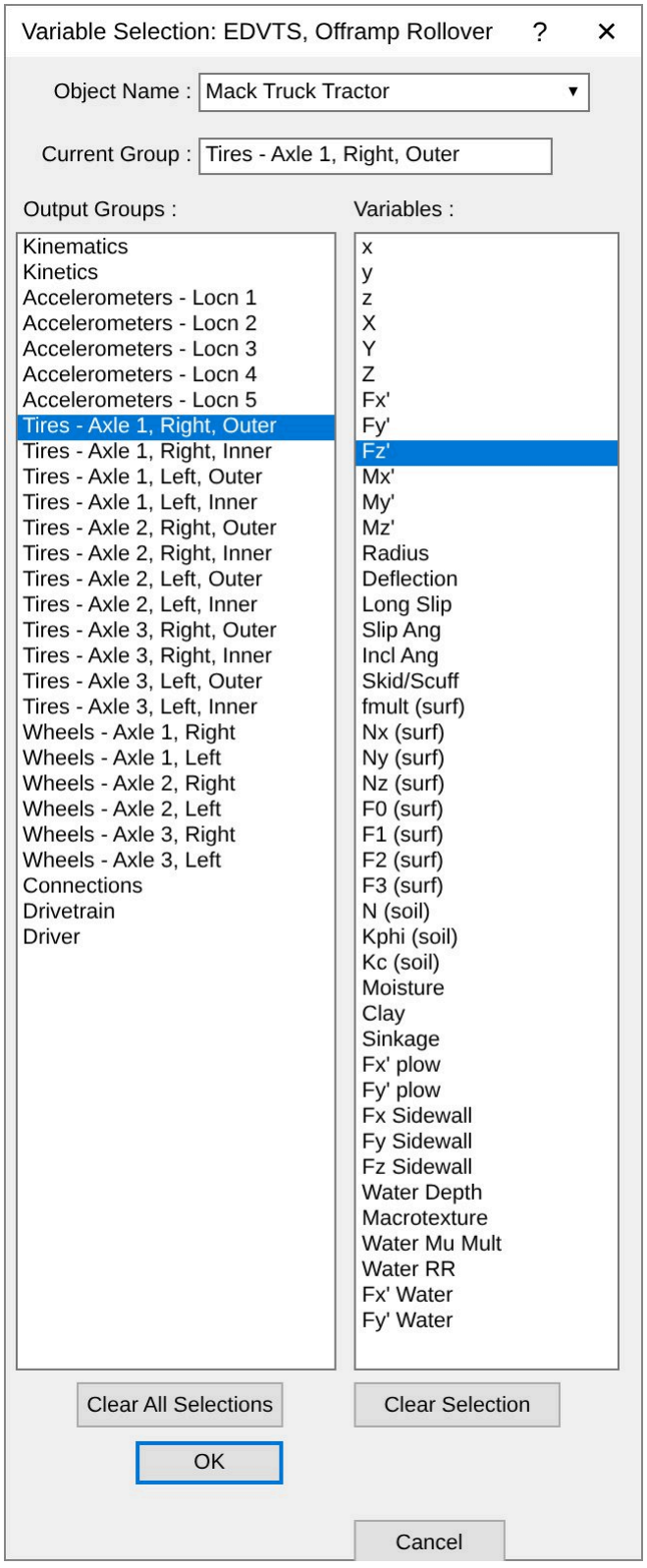


Figure 5-12: Key Results Variable Selection dialog, used for selecting variables to be displayed in the Key Results window.

Let's add

Tire Fz'

to the Mack's Key Results window:

- Choose *Tires, Axle 1, Right, Outer* from the variable group list. The Variable Selection list for the right front tire is displayed.
- Select *Fz'* from the list.
- Choose *Tires, Axle 1, Left, Outer* from the variable group list. The Variable Selection list for the left front tire is displayed; select *Fz'* from the list.
- Repeat the above steps for Mack's rear tandem axles, choosing *Fz'* for *Axle 2* and *Axle 3*.
- Press *OK* to include the new variables in the Key Results dialog.

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

- Click on *Select Variables* in the *44 Ft Semi-trailer* Key Results window. The Variable Selection dialog for *44 Ft Semi-trailer* is displayed.

Add

Tire Fz'

to the trailer's Key Results window:

- Choose *Tires, 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.

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.

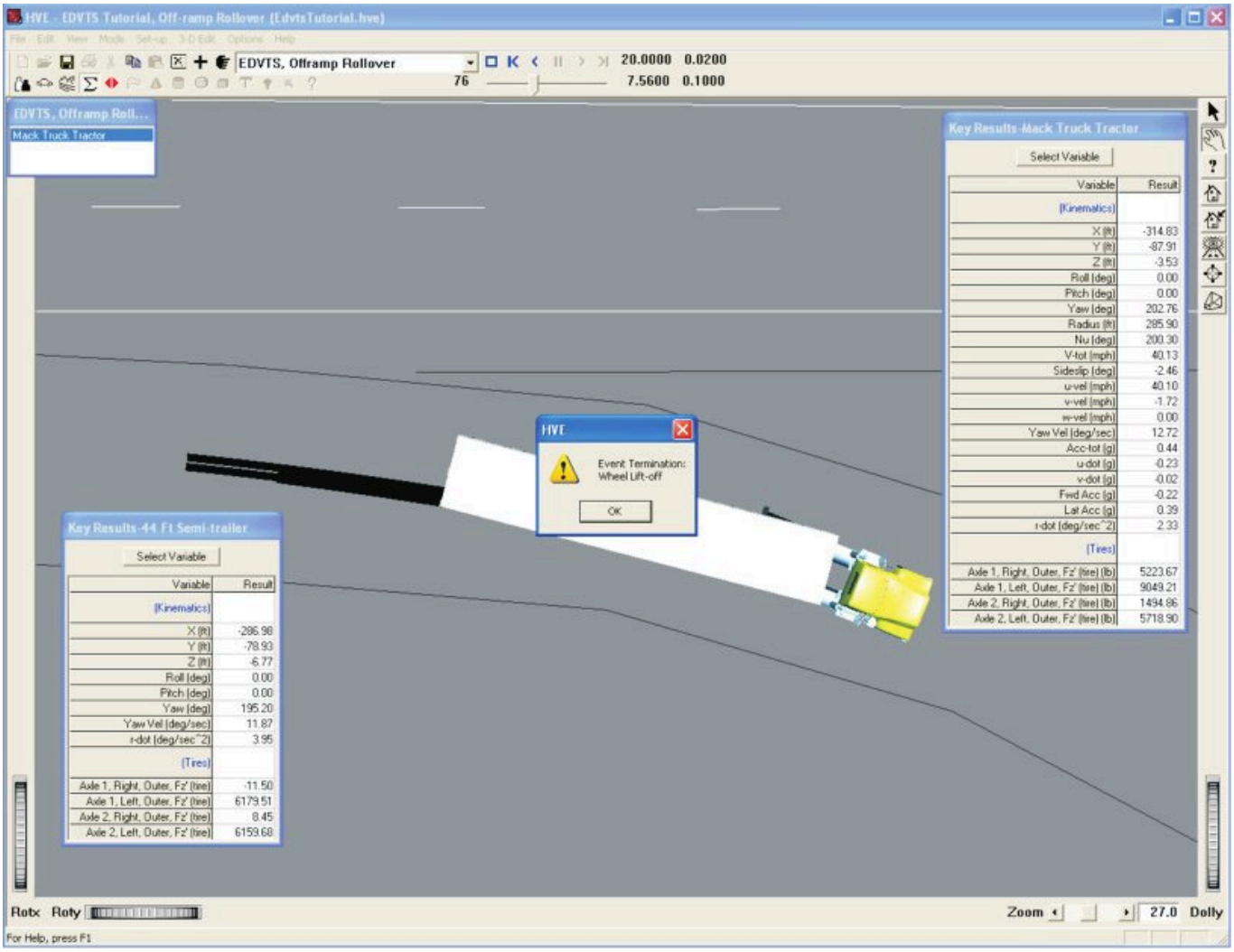


Figure 5-13: Event Editor executing the EDVTS event.

The EDVTS event terminates at time t = 7.56 seconds, when the event terminates due to the trailer's right front wheel lifting.

> 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.
>
> NOTE: EDVTS terminated and told HVE-2D to display a message alerting us to the reason for termination (note the message displayed in Figure 5-13).

We have now completed the event.

Viewing Results

Now that we have produced our EDVTS simulation, 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.

EDVTS produces the following reports:

- **Accident History** — A table of initial and final positions and velocities

- **Messages** — A list of messages produced by the current run
- **Program Data** — A table containing program control information
- **Trajectory Simulation** — A visualization of the event, displayed at a user-selectable time interval
- **Variable Output** — A table containing time-dependent simulation results
- **Vehicle Data** — A series of tables containing the vehicle data used by EDVTS

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.

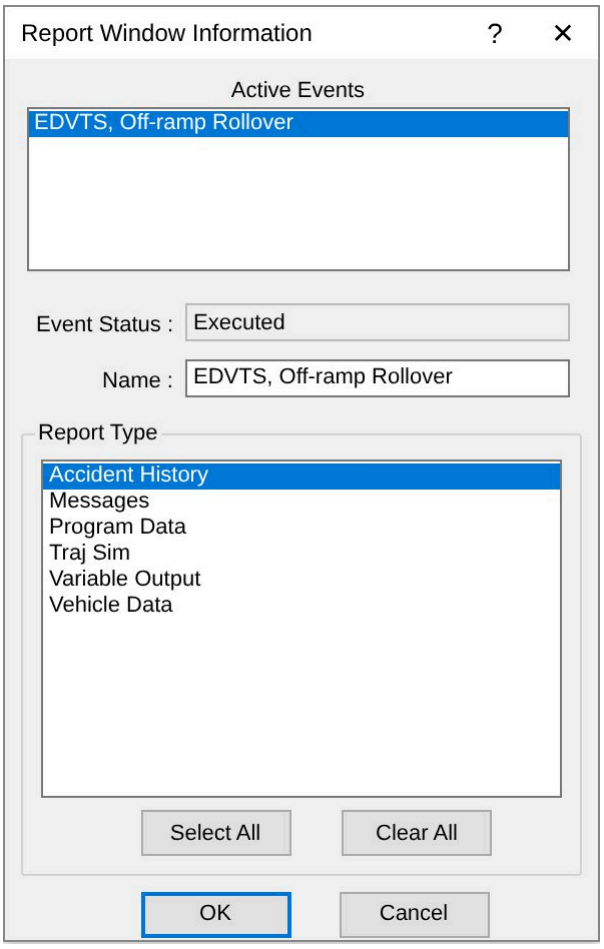


Figure 5-14: Report Window Information dialog, showing the name of the event(s) in the current case.

To view the reports produced by the

EDVTS, Offramp Rollover

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed, as shown in Figure 5-14, and includes a list of the active events (*EDVTS, Offramp Rollover* is the only event in this file). The Report Window Information dialog also includes the user-editable *Report Window Name* text field and the *Report Type* list.

- Select *EDVTS, Offramp Rollover* 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

EDVTS, Offramp Rollover

event.

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.

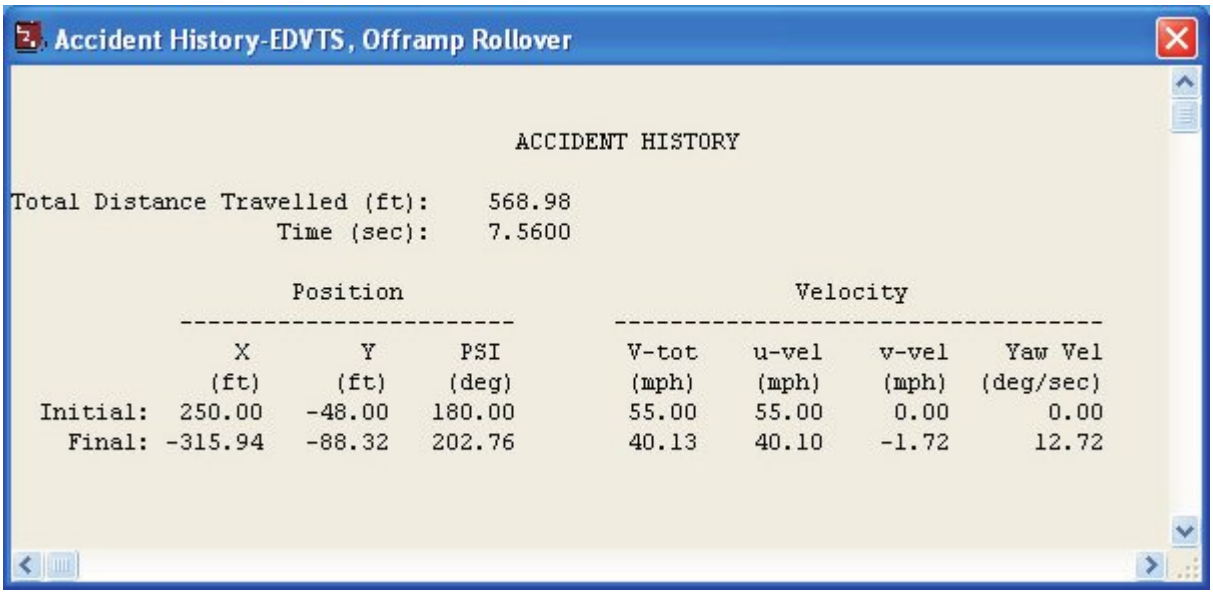


Figure 5-15: Accident History Report for EDVTS, Offramp Rollover.

To view the Accident History report for the

EDVTS, Offramp Rollover

event, perform the following steps:

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

The Accident History report is displayed for the

EDVTS, Offramp Rollover

event, as shown in Figure 5-15.

Messages

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

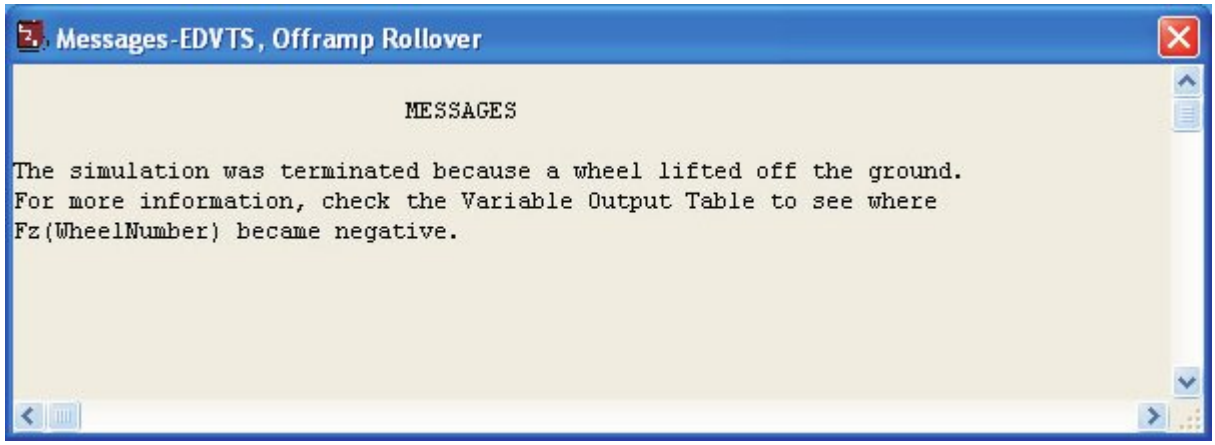


Figure 5-16: Messages Report for EDVTS, Offramp Rollover.

To view the Messages report produced by the

EDVTS, Offramp Rollover

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed.
- Select *EDVTS, Offramp Rollover* from the Active Events list.
- In the *Report Type* list, select *Messages*.
- Press *OK*.

The Messages report is displayed for the

EDVTS, Offramp Rollover

event, as shown in Figure 5-16. (In this tutorial the report shows: "The simulation was terminated because a wheel lifted off the ground. For more information, check the Variable Output Table to see where Fz(WheelNumber) became negative.")

Program Data

The Program Data report contains the EDVTS version number and the simulation controls used by the EDVTS event.

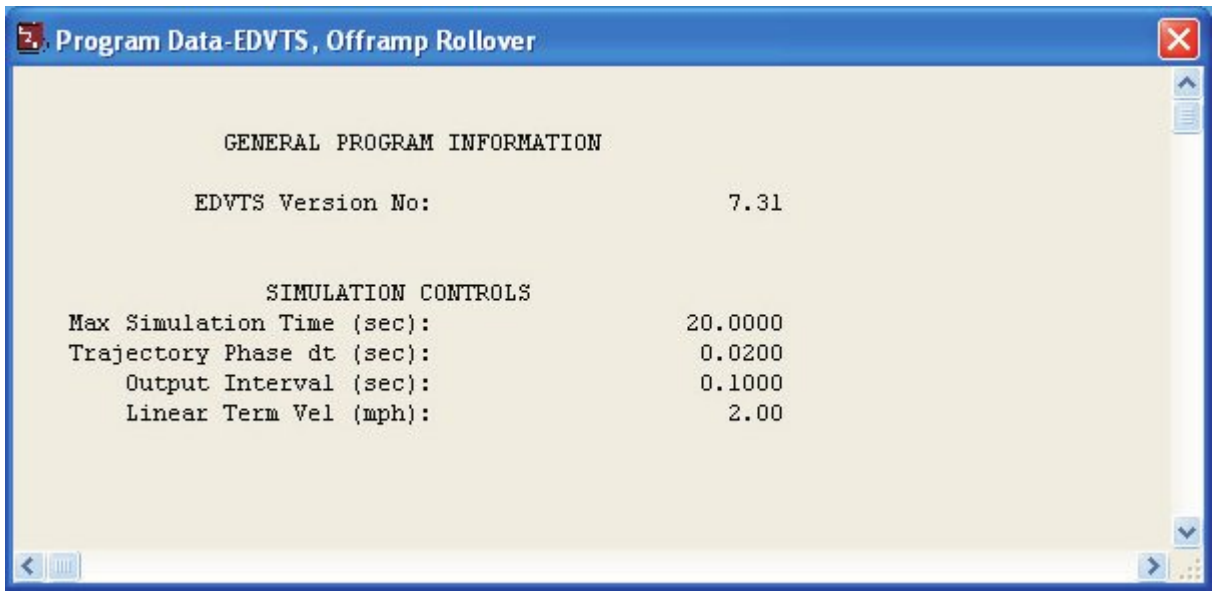


Figure 5-17: Program Data Report for EDVTS, Offramp Rollover.

To view the Program Data report for the

EDVTS, Offramp Rollover

event, perform the following steps:

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

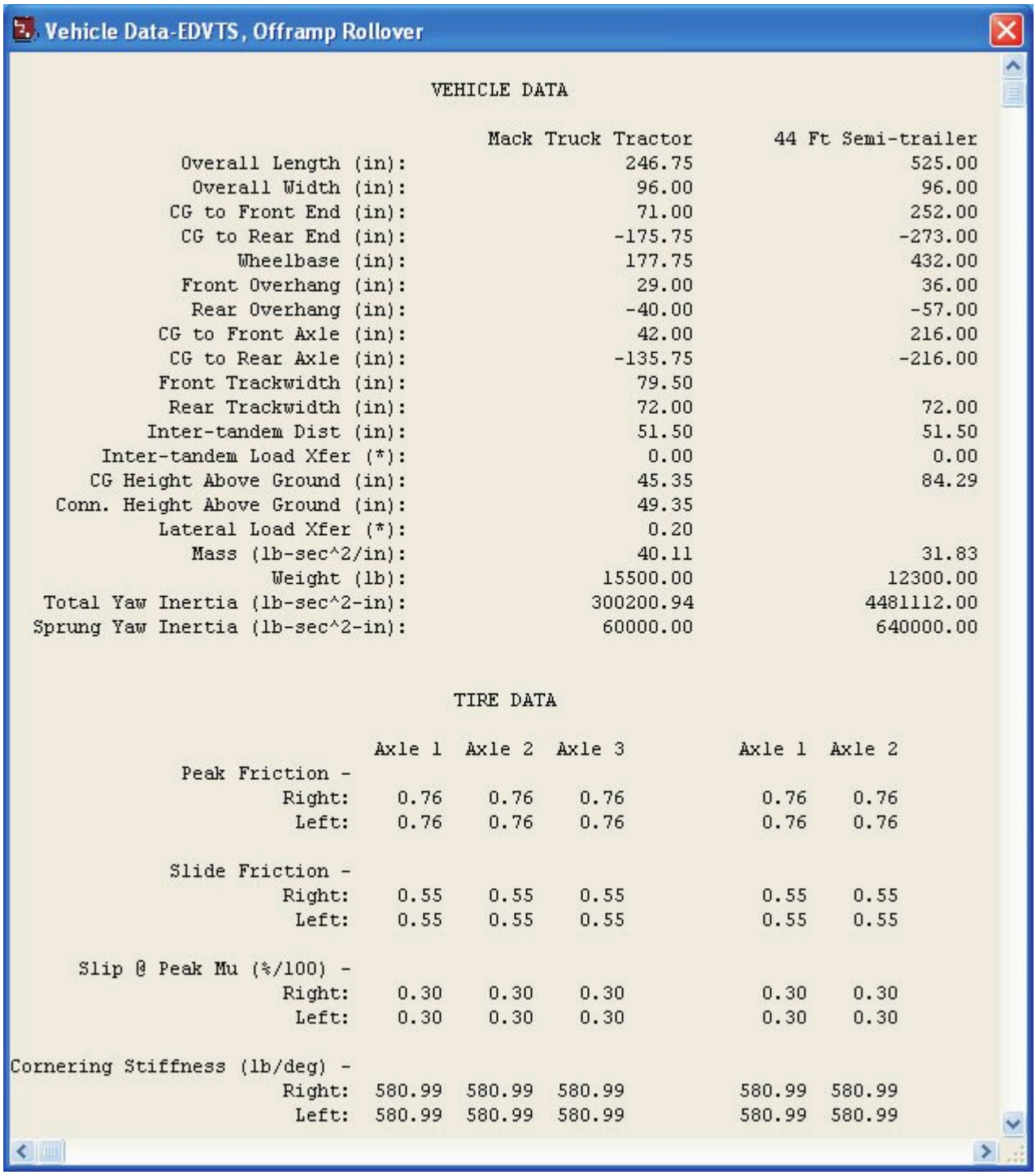
The Program Data report is displayed for the

EDVTS, Offramp Rollover

event, as shown in Figure 5-17.

Vehicle Data

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



VEHICLE DATA

	Mack Truck Tractor	44 Ft Semi-trailer
Overall Length (in):	246.75	525.00
Overall Width (in):	96.00	96.00
CG to Front End (in):	71.00	252.00
CG to Rear End (in):	-175.75	-273.00
Wheelbase (in):	177.75	432.00
Front Overhang (in):	29.00	36.00
Rear Overhang (in):	-40.00	-57.00
CG to Front Axle (in):	42.00	216.00
CG to Rear Axle (in):	-135.75	-216.00
Front Trackwidth (in):	79.50	
Rear Trackwidth (in):	72.00	72.00
Inter-tandem Dist (in):	51.50	51.50
Inter-tandem Load Xfer (*):	0.00	0.00
CG Height Above Ground (in):	45.35	84.29
Conn. Height Above Ground (in):	49.35	
Lateral Load Xfer (*):	0.20	
Mass (lb-sec^2/in):	40.11	31.83
Weight (lb):	15500.00	12300.00
Total Yaw Inertia (lb-sec^2-in):	300200.94	4481112.00
Sprung Yaw Inertia (lb-sec^2-in):	60000.00	640000.00

TIRE DATA

	Axle 1	Axle 2	Axle 3	Axle 1	Axle 2
Peak Friction -					
Right:	0.76	0.76	0.76	0.76	0.76
Left:	0.76	0.76	0.76	0.76	0.76
Slide Friction -					
Right:	0.55	0.55	0.55	0.55	0.55
Left:	0.55	0.55	0.55	0.55	0.55
Slip @ Peak Mu (%/100) -					
Right:	0.30	0.30	0.30	0.30	0.30
Left:	0.30	0.30	0.30	0.30	0.30
Cornering Stiffness (lb/deg) -					
Right:	580.99	580.99	580.99	580.99	580.99
Left:	580.99	580.99	580.99	580.99	580.99

Figure 5-18: Vehicle Data Report for EDVTS, Offramp Rollover.

To view the Vehicle Data report for the

EDVTS, Offramp Rollover

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed.
- Select *EDVTS, Offramp Rollover* from the Active Events list.
- In the *Report Type* list, select *Vehicle Data*.

- Press *OK*.

A portion of the Vehicle Data report displayed for

EDVTS, Offramp Rollover

is shown in Figure 5-18.

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

Variable Output

The Variable Output report provides variable values at each timestep in tabular form. It is possible to print these values versus time and export this table as a text file.

To view the Variable Output report for the

EDVTS, Offramp Rollover

event, perform the following steps:

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

The Variable Output report is displayed for the

EDVTS, Offramp Rollover

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 Mack Tractor is already displayed.

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

Next, let's add the vertical wheel loads:

- Choose *Tires, Axle 1, Right, Outer* from the variable groups list. The Variable Selection list for the right front tire is displayed (see Figure 5-19).
- Select *Fz'* from the list.
- Choose *Tires, Axle 1, Left, Outer* from the variable groups list. The Variable Selection list for the left front tire is displayed; select *Fz'* from the list.
- Repeat the above steps for Mack's rear tandem axles, choosing *Fz'* for *Axle 2* and *Axle 3*.

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

- Click on the *Object Name* option list and choose *44 Ft Semi-trailer*. The Kinematics Variables list for the semi-trailer is displayed.
- Choose *Tires, Axle 1, Right, Outer* from the variable group list. 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

EDVTS, Offramp Rollover

event now includes tow vehicle velocity and acceleration and vertical tire loads for each wheel location, as shown in Figure 5-20.

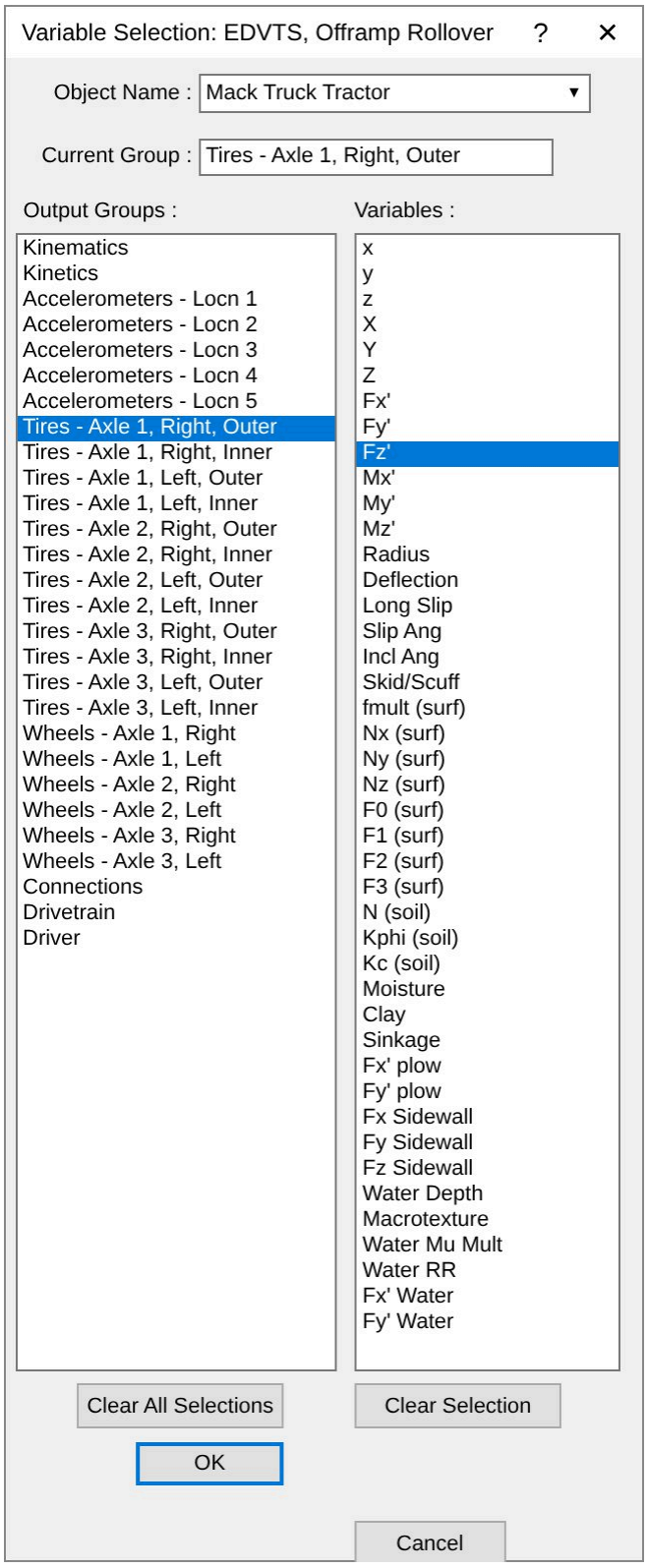
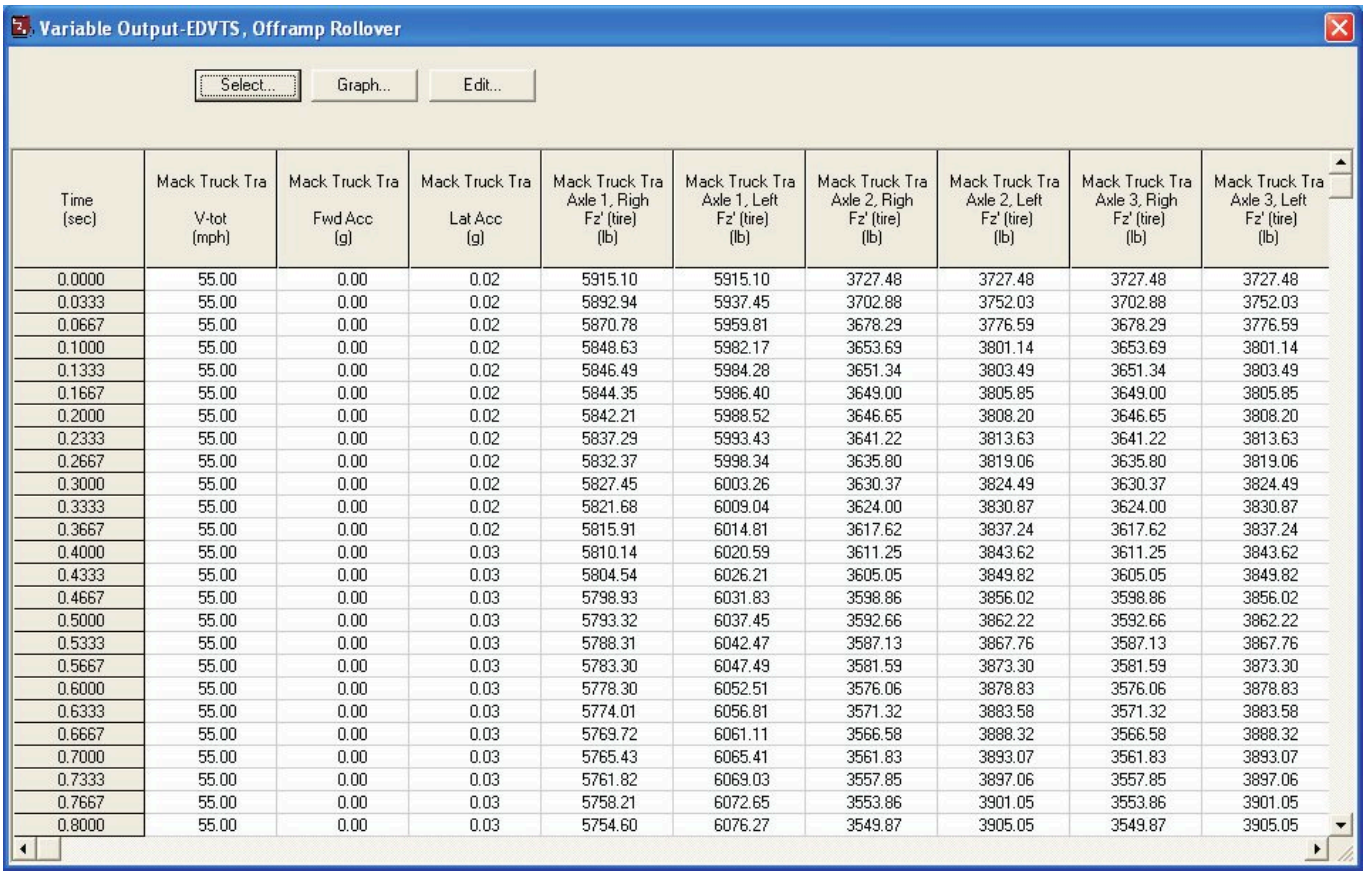


Figure 5-19: Variable Selection dialog, used for selecting the results displayed in the Output Report.



Time (sec)	Mack Truck Tra V-tot (mph)	Mack Truck Tra Fwd Acc (g)	Mack Truck Tra Lat Acc (g)	Mack Truck Tra Axle 1, Righ Fz' (tire) (lb)	Mack Truck Tra Axle 1, Left Fz' (tire) (lb)	Mack Truck Tra Axle 2, Righ Fz' (tire) (lb)	Mack Truck Tra Axle 2, Left Fz' (tire) (lb)	Mack Truck Tra Axle 3, Righ Fz' (tire) (lb)	Mack Truck Tra Axle 3, Left Fz' (tire) (lb)
0.0000	55.00	0.00	0.02	5915.10	5915.10	3727.48	3727.48	3727.48	3727.48
0.0333	55.00	0.00	0.02	5892.94	5937.45	3702.88	3752.03	3702.88	3752.03
0.0667	55.00	0.00	0.02	5870.78	5959.81	3678.29	3776.59	3678.29	3776.59
0.1000	55.00	0.00	0.02	5848.63	5982.17	3653.69	3801.14	3653.69	3801.14
0.1333	55.00	0.00	0.02	5846.49	5984.28	3651.34	3803.49	3651.34	3803.49
0.1667	55.00	0.00	0.02	5844.35	5986.40	3649.00	3805.85	3649.00	3805.85
0.2000	55.00	0.00	0.02	5842.21	5988.52	3646.65	3808.20	3646.65	3808.20
0.2333	55.00	0.00	0.02	5837.29	5993.43	3641.22	3813.63	3641.22	3813.63
0.2667	55.00	0.00	0.02	5832.37	5998.34	3635.80	3819.06	3635.80	3819.06
0.3000	55.00	0.00	0.02	5827.45	6003.26	3630.37	3824.49	3630.37	3824.49
0.3333	55.00	0.00	0.02	5821.68	6009.04	3624.00	3830.87	3624.00	3830.87
0.3667	55.00	0.00	0.02	5815.91	6014.81	3617.62	3837.24	3617.62	3837.24
0.4000	55.00	0.00	0.03	5810.14	6020.59	3611.25	3843.62	3611.25	3843.62
0.4333	55.00	0.00	0.03	5804.54	6026.21	3605.05	3849.82	3605.05	3849.82
0.4667	55.00	0.00	0.03	5798.93	6031.83	3598.86	3856.02	3598.86	3856.02
0.5000	55.00	0.00	0.03	5793.32	6037.45	3592.66	3862.22	3592.66	3862.22
0.5333	55.00	0.00	0.03	5788.31	6042.47	3587.13	3867.76	3587.13	3867.76
0.5667	55.00	0.00	0.03	5783.30	6047.49	3581.59	3873.30	3581.59	3873.30
0.6000	55.00	0.00	0.03	5778.30	6052.51	3576.06	3878.83	3576.06	3878.83
0.6333	55.00	0.00	0.03	5774.01	6056.81	3571.32	3883.58	3571.32	3883.58
0.6667	55.00	0.00	0.03	5769.72	6061.11	3566.58	3888.32	3566.58	3888.32
0.7000	55.00	0.00	0.03	5765.43	6065.41	3561.83	3893.07	3561.83	3893.07
0.7333	55.00	0.00	0.03	5761.82	6069.03	3557.85	3897.06	3557.85	3897.06
0.7667	55.00	0.00	0.03	5758.21	6072.65	3553.86	3901.05	3553.86	3901.05
0.8000	55.00	0.00	0.03	5754.60	6076.27	3549.87	3905.05	3549.87	3905.05

Figure 5-20: Variable Output Report for EDVTS, Offramp Rollover, displaying the selected results.

Trajectory Simulation

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

EDVTS, Offramp Rollover

event, perform the following steps:

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

The Trajectory Simulation viewer is displayed for the

EDVTS, Offramp Rollover

event (see Figure 5-21). The tractor and trailer are shown at their initial positions.

To visualize the motion as the tractor-trailer attempts to negotiate the off-ramp, perform the following steps using the Playback Controller:

- 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.

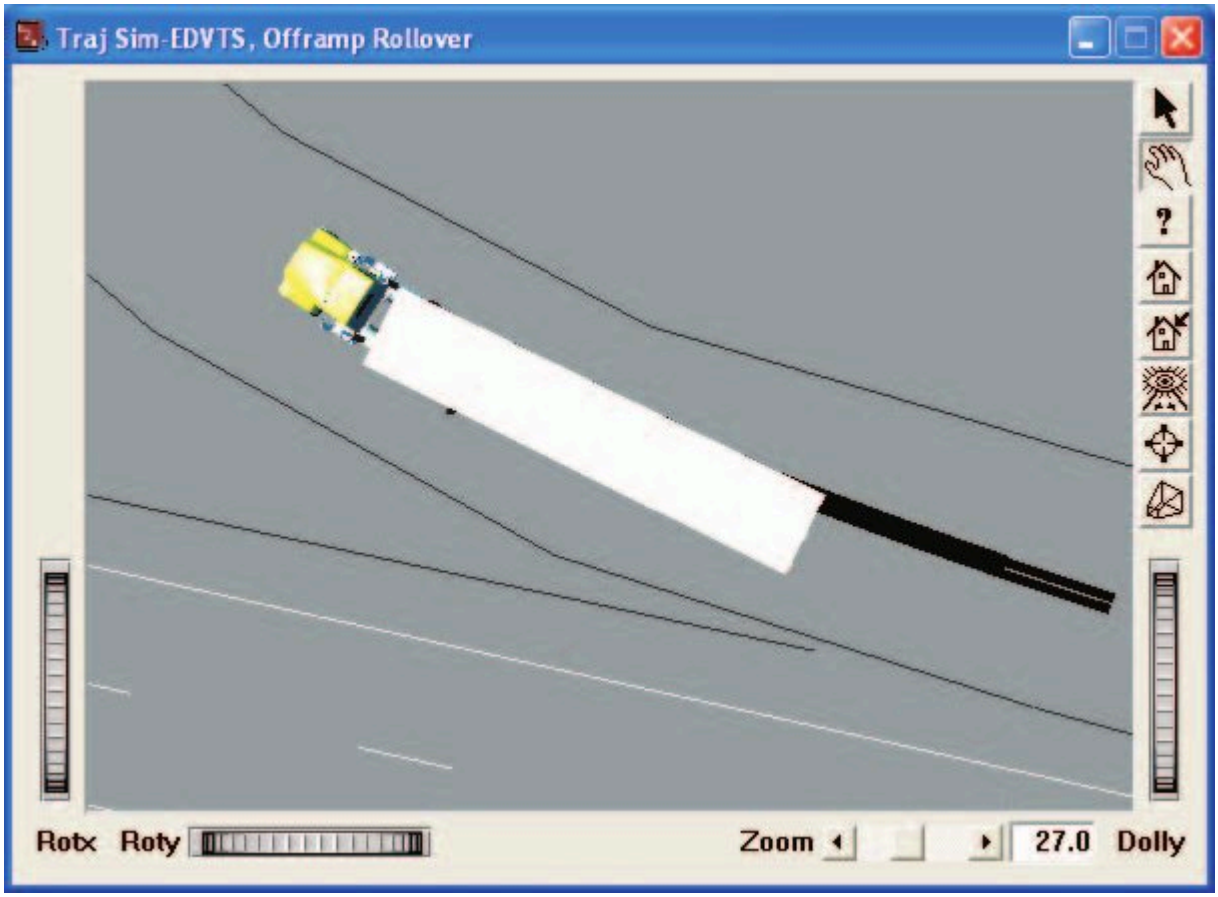


Figure 5-21: Trajectory Simulation for EDVTS, Offramp Rollover, showing the tractor-trailer near the end of the run, before the inside trailer wheels lift off the ground.

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 *Variable Output - EDVTS, Offramp Rollover* report. The dialog header is highlighted and the Variable Output 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 main menu bar.

- Press *OK*. The Variable Output report is printed on the system printer.

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

> NOTE: The Print dialog provides several options. Refer to your printer's User 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.

Previous: Chapter 4 — Calculation Method | Contents | Next: Chapter 6 — Messages

Chapter 6 — Messages

Messages can be issued by either the operating system, HVE-2D or HVE, or by EDVTS. 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-2D or HVE are described in the User's Manual, Appendix II.

Errors issued by EDVTS appear in the EDVTS 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 EDVTS 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-2D or operating system message by referring to the User's Manual 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: the six messages from the printed manual are unchanged in the current version. One additional message has been added since the printed edition; it is documented at the end of this chapter.)

The simulation was terminated because a wheel lifted off the ground. For more information, check the Variable Output Table to see where Fz (Wheel Number) became negative.

(Level 1 - Fatal)

This message occurs when EDVTS calculates a negative vertical tire load, Fz. EDVTS is a quasi-2D analysis and cannot handle the condition where a wheel leaves the ground. This condition occurs during hard cornering maneuvers or extremely hard braking, normally coupled with a relatively high center of gravity. This condition might also occur at the start of the simulation if the event begins under extremely dynamic conditions, such as high sideslip or angular velocity.

The simulation was terminated because the current roll or pitch angle exceeded 15 degrees. EDVTS is a quasi-3-D analysis. The small angle assumption is used.

(Level 1 - Fatal)

This message occurs when the vehicle travels over a surface with a significant slope. At each timestep, EDVTS uses the Get Surface Information search to determine the current roll and pitch angles. If either of these angles exceeds the allowable value, the run terminates. The termination reflects the fact that the small angle assumption is used, and the error may become significant.

The simulation was terminated because GetSurfaceInfo() failed

(Level 1 - Fatal)

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

The simulation was terminated due to 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: Velocity Convergence should be about 0.1 and Max Bisections should be about 10.

(Level 1 - Fatal)

This condition indicates dynamic instability. Experience suggests if reasonable integration timesteps 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 current articulation angle exceeded the allowable limit defined for the tow vehicle.

(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 EDVTS, so the run is terminated.

The simulation terminated because of a failure in the simultaneous solutions routine. The matrix is singular. Send your offending case to EDC for evaluation.

(Level 1 - Fatal)

The equations of motion are expressed in matrix form and solved by inverting the matrix. A singular matrix cannot be inverted, so the equations of motion could not be solved. This condition has never occurred for EDVTS; if it occurs in your case, please send your case file to EDC for evaluation.

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.

(Level 3 - Informative)

(updated: This message was added after the printed edition; it does not appear in the Sixth Edition manual.) This message is issued during input processing when EDVTS automatically adjusts the vehicle-fixed connection z-coordinate so that the earth-fixed heights of the hitch connection on the tow vehicle and the trailer coincide. No action is required; the adjusted value can be reviewed in the Vehicle Data output report. *(Note: the current message resource text attributes the calculation to "EDSMAC4"; this is a leftover from a shared resource template — in an EDVTS event the adjustment is performed by EDVTS itself.)*

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Chapter 7 — Technical References

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