ENGINEERING DYNAMICS COMPANY

EDVSM

HVE Human Vehicle Environment

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

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EDVSM — Engineering Dynamics Company Vehicle Simulation Model

Vehicle Simulator — User's Manual, Version 3

Fifth Edition (January 2006) —

converted to Markdown and updated to match the current version of HVE

How to Use This Manual

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

If You Have Questions

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

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

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

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See also: EDVSM Calculation Options reference (code-verified description of the Tire Model Method, GetSurfaceInfo Method, Steer Degree of Freedom, and Vehicle Body vs. Environment Contact options).

Notes on this Edition

This Markdown edition preserves the substance of the Fifth Edition (January 2006) printed manual and updates it where the current release differs. Notable updates:

- **Calculation Options:** the Tire Model Method options *Radial Spring* and *Sidewall Impact* are disabled in the current dialog and rejected by the physics (only *Normal* is available); the Steer Degree of Freedom *Append* option is likewise disabled and rejected (Off and Normal remain); *Vehicle Body vs. Environment Contact* (rollover model) is off by default.
- **Messages:** one message was added after the Fifth Edition (a second Integration Error concerning the Velocity Convergence Criterion and Maximum Bisections), and the GetSurfaceInfo() Error text was shortened. See Chapter 6.
- Figures from the printed manual are indicated by italic placeholders.

Chapter 1 — EDVSM Program Description

Overview

EDVSM (**E**ngineering **D**ynamics Company **V**ehicle **S**imulation **M**odel) is a 3-dimensional analysis of the response of a unit vehicle to a driver's inputs (steering, throttle, brakes, gear selection). EDVSM is based on the HVOSM model developed at Calspan [1,2,3]. The original HVOSM model was developed in two versions: The Roadside Design version (RD2) was developed for studying vehicle interactions with the roadside environment, while the Vehicle Dynamics version (VD2) was developed for studying vehicle response to driver inputs. EDVSM was derived from the VD2 version of HVOSM, and includes several extensions and refinements provided by Engineering Dynamics Company, LLC [4].

EDVSM computes vehicle kinematics (position, velocity and acceleration vs time), from forces defined at the tire-road interface, as well as from aerodynamics. EDVSM is useful for predicting and visualizing a vehicle's response to driver's inputs, as well as to study the effects of various design parameters on vehicle behavior.

The EDVSM vehicle model is *fully* three-dimensional. It includes six degrees of freedom for the sprung mass. It also includes degrees of freedom for both independent and solid axle suspension types. A wheel spin degree of freedom is also included for each wheel, and a steer degree of freedom exists for the steering system. Refer to the Calculation Method chapter of this manual for a detailed description of the simulation model.

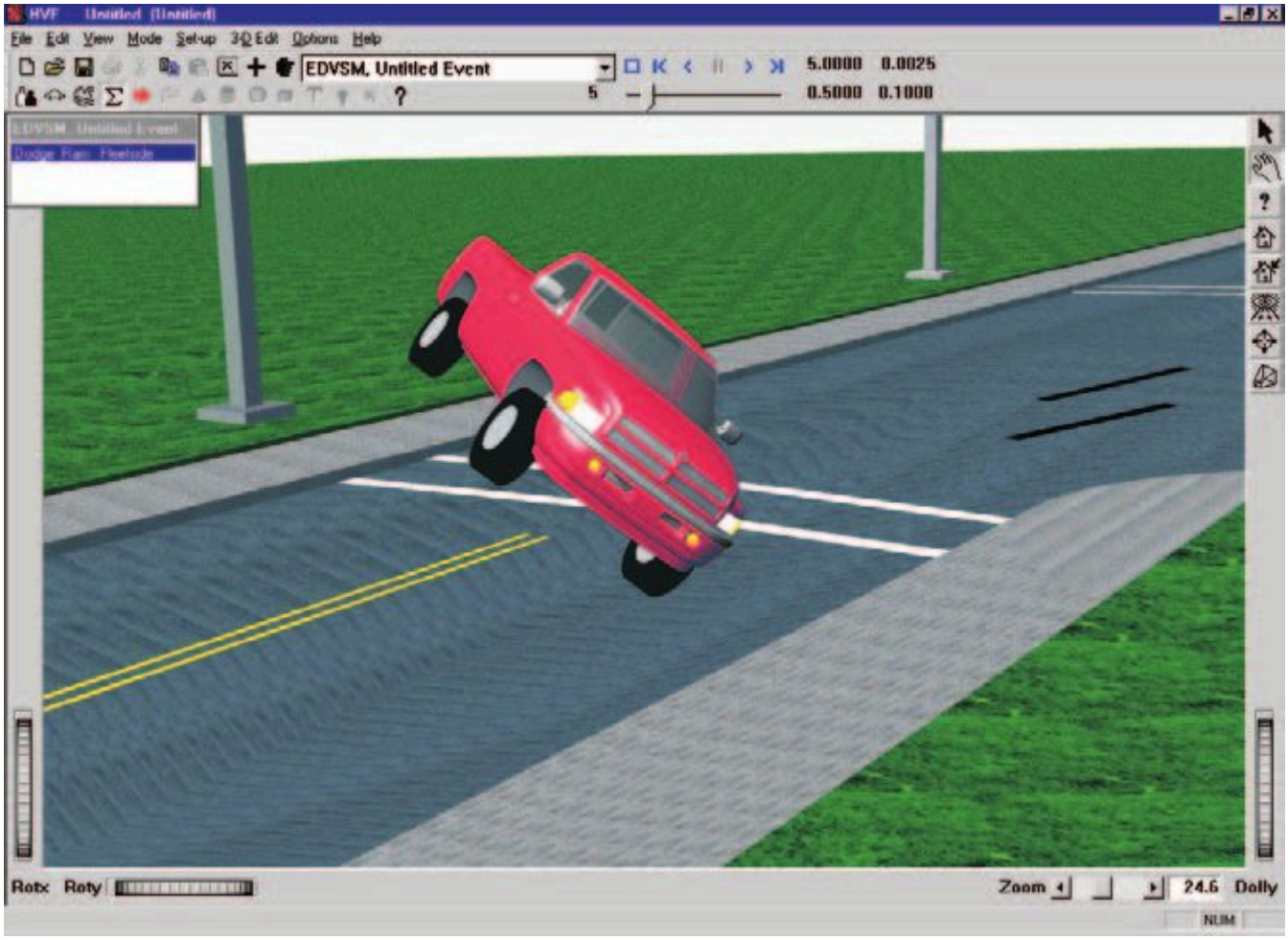


Figure 1-1: EDVSM Event.

EDVSM includes detailed models of braking systems to allow the study of vehicle brake system characteristics on vehicle behavior during severe driving maneuvers, such as that which might occur during accident avoidance. EDVSM also has a detailed drivetrain model that includes an engine, transmission and differential. The drivetrain model may be used for detailed studies of a vehicle's response to throttle inputs and gear selection.

Model Inputs

EDVSM inputs include one vehicle and an optional environment. Event set-up parameters include vehicle initial position and velocity, and various driver control options (steering, braking, throttle and gear selection).

Model Outputs

EDVSM output reports include Messages, Accident History, Vehicle Data, Program Control Data, Variable Output and Trajectory Simulations. The Variable Output groups include vehicle kinematics, tire forces, radius and longitudinal and lateral slip, wheel position, suspension deflection and forces, engine power, torque and RPM, transmission and differential ratios, and driver steering, throttle, brakes and gear selection inputs.

Validation

EDVSM was validated first by direct comparison with HVOSM to ensure the basic model was intact after porting the original FORTRAN code to C and making the model HVE-compatible. Additional validation was performed comparing EDVSM results to other models as well as direct comparison with controlled handling maneuvers. Validation results are reported in references 3 and 4.

Basic Procedure

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

- Use the Vehicle Editor to add one or more vehicles 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 EDVSM simulation model by performing the following steps:
- Choose one vehicle from the list of vehicles created earlier.
- Choose the EDVSM calculation model.
- Position the vehicle in the environment.
- Assign driver controls (Steering, Braking, Throttle, Gear Selection).
- Execute the simulation event.
- Modify the inputs as required to achieve the desired match between the simulation and actual event.
- Use the Playback Editor to view the various reports and trajectory simulations. If desired, produce a video output of the simulation.

Chapter 2 — EDVSM Program Input

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

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

Objects Overview

The objects used by the EDVSM model are:

- **Humans** - Humans are not simulated by EDVSM.
- **Vehicles** - One vehicle may be studied by EDVSM.
- **Environment** - Like the *real* world, EDVSM 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 EDVSM calculation model.

Vehicles

EDVSM uses one vehicle created using the HVE Vehicle Editor (see Figure 2-1). Vehicles are selected from the Vehicle Database by choosing the following attributes:

- **Type** - EDVSM supports the following vehicle types: *Passenger Car, Pickup, Van, Sport-Utility, Truck* and *Movable Barrier*.
- **Make** - EDVSM supports all available vehicle makes.
- **Model** - EDVSM supports all available vehicle models, within the limits defined by number of axles and drive axles; see below.
- **Year** - EDVSM supports all available vehicle years.
- **Body Style** - EDVSM 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 EDVSM. However, *Driver Location* must not be *None*; otherwise, the Driver Controls (Steering, Throttle, Brakes, Gear Selection) will not be available during Event mode.
- **Engine Location** - The Engine Location is not used by EDVSM. However, *Engine Location* must not be *None*; otherwise, the Throttle Table will not be available during Event mode.
- **Number of Axles** - EDVSM supports only 2-axled vehicles.
- **Drive Axle(s)** - EDVSM supports only *Axle 1* or *Axle 2* as the drive axle; 4-wheel drive vehicles are not supported.

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

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

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

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

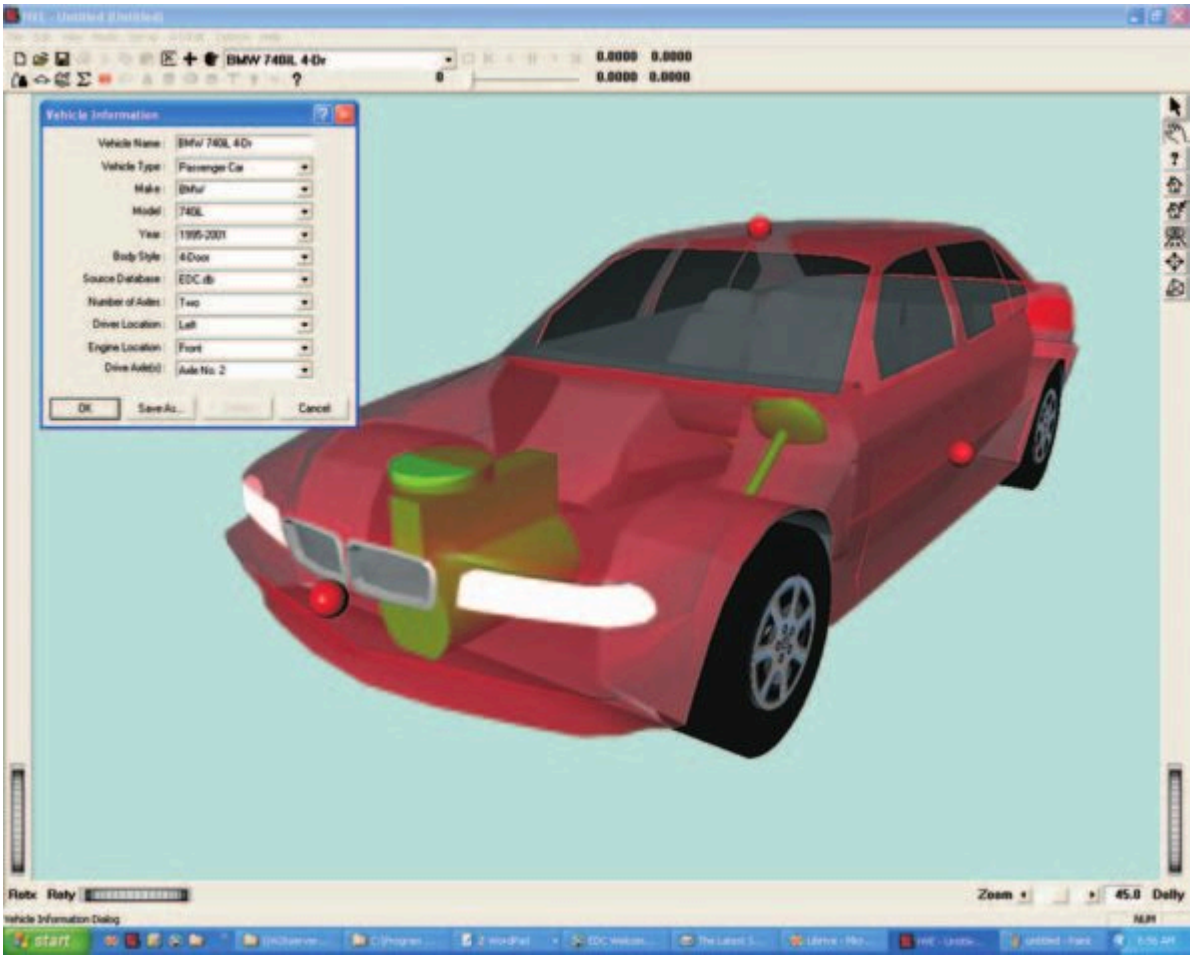


Figure 2-1: HVE Vehicle Editor.

The following vehicle parameter groups are used by EDVSM:

- Sprung Mass Group
- Inertias
- Move CG
- Drag Forces
- Unsprung Mass Group
- Wheel Location

- Tire Data
- Suspension Data
- Brake Data
- Steering System Group
- Brake System Group
- Drivetrain Group

> **NOTE:** The Exterior Data Group Parameters (Overall Dimensions, Structural Stiffness Coefficients) are not used by EDVSM.

The specific data used in each of the above parameter groups are defined in tables 2-1 through 2-4.

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 EDVSM

Parameter	Description
Sprung Weight	Weight of vehicle sprung mass
Sprung Mass Roll, Pitch and Yaw Inertia	Rotational inertias of sprung mass about the vehicle-fixed x, y and z axes, respectively
Move CG x,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).
Constant, Linear and Quadratic Drag Forces	Rolling resistance force coefficients. The quadratic term includes vehicle area (i.e., $C_d \times Area$) and is used in aerodynamic calculations.
NumVertices, Vertex x,y,z	x,y,z coordinates for each vertex in the vehicle 3-D Geometry file.

Inertias

EDVSM uses the vehicle sprung weight (converted to mass according to the current gravitational constant; see Environment), and the roll, pitch and yaw rotational inertias of the sprung mass. The total weight may be entered since it is the value traditionally obtained from data sources. The equations of motion require that the sprung mass be known. To obtain this value, EDVSM simply deducts the weight of the suspensions and wheels.

Move CG

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

> **NOTE:** Bilateral symmetry is assumed. Moving the CG in the +y or -y direction will have no effect on the EDVSM calculations.

Geometry File

The Geometry File is used by the EDVSM Body Model for computing forces and moments on the sprung mass during rollover. The vertex information in the 3-D Geometry file is automatically loaded into EDVSM and used during the calculations. See reference 7 for details.

Contact Surfaces

Contact Surface parameters are not used by EDVSM.

Belt Restraints

Belt Restraint parameters are not used by EDVSM.

Airbag Restraints

Airbag Restraint parameters are not used by EDVSM.

Inter-vehicle Connections

Inter-vehicle Connection parameters are not used by EDVSM.

Drag Forces

EDVSM uses a second-order polynomial to model drag forces that resist vehicle motion. Three terms are used. The rolling resistance constant is simply force resisting the vehicle's forward motion normally associated with tire rolling resistance. The second term has a linear velocity dependence, also normally associated with tire rolling resistance. The third term has a second-order velocity dependence, normally associated with aerodynamic drag.

> **NOTE:** The entered value for aerodynamic drag coefficient includes the frontal area of the vehicle! (I.e., rather than entering a typical value, such as C_d = 0.39, you should first multiply the value by the frontal area.) For example, if the frontal area was 3000 in², you would enter 0.39*3000, or 1170.

Unsprung Mass

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

Table 2-2 Vehicle Unsprung Mass Parameters Used By EDVSM

Parameter	Description
Wheel Location	Vehicle-fixed x,y,z coordinates for each wheel
Brake Push-out Pressure	The wheel cylinder pressure required to initiate brake torque
Brake Torque Ratio	The ratio of effective brake torque at the wheel to fluid pressure in the wheel cylinder
Proportion, Pstart	The brake master cylinder pressure at which proportioning begins
Proportion Ratio	The ratio of wheel cylinder pressure to master cylinder pressure after the onset of proportioning
Brake Designer Parameters	Parameters used by the HVE Brake Designer

Wheel Location

Although HVE provides values for the vehicle-fixed x,y,z coordinates of each wheel, EDVSM uses the following four parameters: 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; and tw_r, the rear track width.

> **NOTE:** EDVSM 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, EDVSM uses the total distance between right-side and left-side tires to calculate track width. Bilateral symmetry is assumed. Finally, EDVSM uses the average z_{wheel} for each axle to establish vertical wheel position for calculations.

Wheel Brake Parameters

EDVSM uses the push-out pressure and brake torque ratio. Proportioning may also be specified. All wheel brake parameters are assumed to be the same for the right and left side wheels. The parameters are used only if the

At Driver

Brake Table option is used during Event set-up. The specific parameters used by EDVSM are shown in Table 2-2.

EDVSM also fully supports the HVE Brake Designer. Refer to the Brake Designer Manual for more information.

Tire

The HVE tire parameters provide the following data groups:

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

EDVSM's use of these parameters is described below.

Physical Data

The Physical Data used by EDVSM are shown in Table 2-3. If the current tire deflection exceeds the maximum deflection, a fatal error occurs. This prevents the model from computing an excessive tire force. For example, give a tire deflection of 15 inches and reasonable values for tire deflection rates, EDVSM could easily predict a vertical tire force of 100,000 lb (about 450,000 N).

> **NOTE:** If EDVSM terminates due to excessive tire deflection when a tire hits a curb, try reducing the integration timestep and/or add a small slope to the curb.

The weight and spin inertia should include the rim and brake inertias.

Friction Table

The Friction Data used by EDVSM are shown in Table 2-3. EDVSM requires that friction data are provided for at least two loads and speeds.

> **NOTE:** If only one load and/or speed are provided for a given tire, EDVSM will automatically produce a duplicate set of friction data at a slightly greater load and speed.

The

In-use Factor

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

Table 2-3 Vehicle Unsprung Mass, Tire Parameters Used By EDVSM

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

Cornering Stiffness Table

The Cornering Stiffness data used by EDVSM are shown in Table 2-3. EDVSM does not use the F_y vs Slip Angle table, but instead uses the cornering stiffness parameter directly. EDVSM requires that cornering stiffness data are provided for at least two loads and two speeds. Like the Friction Data described above, if fewer values are supplied, EDVSM will generate the additional required parameters.

The

In-use Factor

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

> **NOTE:** If you are simulating a vehicle with a flat tire, you'll probably want to use the HVE Blow-out Model. See Event Set-up.

Camber Stiffness Table

The Camber Stiffness data used by EDVSM are shown in Table 2-3. EDVSM does not use the F_y vs Camber Angle table, but instead uses the camber stiffness parameter directly. EDVSM requires that camber stiffness data are provided for at least three loads and two speeds. Like the Friction Data described earlier, if fewer values are supplied, EDVSM will generate the additional required parameters.

The

In-use Factor

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

Slip vs Rolloff Table

EDVSM does not use the Slip-Rolloff data.

Suspension

The HVE Suspension parameters provide the following data groups:

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

EDVSM supports independent and solid axle suspensions. Independent suspension types do not use inertial properties (the weight of the suspension arms is ignored; the weight of the brake and wheel are included with the tire). Solid axle suspension types use different camber and roll-steer parameters. Spindle axis is only available for steerable wheels (see Steering System). EDVSM's use of these parameters is described below.

Springs and Shocks

EDVSM uses the ride rate at the wheel, not the spring rate of the spring. The ride rate for left and right side wheels is assumed to be the same. If different values are entered for left and right side wheels, EDVSM will compute and use the average.

Roll center height and lateral spring spacing apply only to solid axle suspensions.

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

Damping rate, like ride rate, applies at the wheel, not the shock location, and left and right side shocks are assumed to be the same.

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

Inertias

Inertial parameters apply only to solid axle suspensions, and do not include the brake assemblies or wheels (brake and wheel inertias are included with the tire). The Suspension Inertia data used by EDVSM are shown in Table 2-4.

Jounce and Rebound Stops

The linear and cubic deflection rate of the suspension stops is the effective value at the wheel. Left and right side suspension stops are assumed to be the same (again, the average is used). The Jounce and Rebound Stop data used by EDVSM are shown in Table 2-4.

Spindle Axis

If the Steer Degree of Freedom option is selected (see Event Set-up), the spindle axis information are used for each steerable wheel. These parameters include the steering Stop Angles and Stop Stiffness.

Camber and Half-track Change Tables

Camber and half-track tables apply only to independent suspension types. The properties for the right side and left side tires are assumed to be the same (again, the average is used). Solid axles do not use the tables, rather they use a single value that remains constant during the simulation. The camber and half-track data used by EDVSM are shown in Table 2-4.

Table 2-4 Vehicle Unsprung Mass, Suspension Parameters Used By EDVSM

Parameter	Description
Suspension Type	Solid Axle or Independent
Ride Rate, Front and Rear	Linear spring rate effective at the wheel
Auxiliary Roll Stiffness	Roll stiffness from an anti-sway bar
Roll Center Height	For solid axle suspensions, the distance from the CG to the roll axis at the suspension
Lateral Spring Spacing	For solid axle suspensions, the lateral distance between springs
Damping Rate, Front and Rear	Damping rate effective at the wheel
Coulomb Friction	Force required to initiate suspension movement
Friction Null Band	Suspension velocity required for full coulomb friction
Suspension Weight	For solid axle suspensions, the weight of the axle, not including tires, wheels and brakes
Suspension Roll/Yaw Inertia	For solid axle suspensions, the rotational inertia about the vehicle-fixed x and z axes
Jounce/Rebound Stop, Max Deflection	Deflection from equilibrium to jounce and rebound stops
Jounce/Rebound Stop Linear, Cubic Stiffness	Stiffness constants for rebound stops
Jounce/Rebound Stop Energy Ratio	Restitution for stop, defined as the ratio of the non-conserved energy to total energy absorbed by the suspension stop
Camber & Half-track Change	For independent suspensions, uses a table of Camber and Half-track Change vs suspension jounce and rebound. For solid axle suspensions, uses constant camber value.
Spindle Axis Data	Steering Stop Angles and Stiffness
Anti-pitch	Table of Anti-pitch force vs suspension jounce and rebound
Roll Steer	For solid axle suspensions, the ratio of wheel steer to sprung mass roll angle. For independent suspensions, Constant, Linear, Quadratic and Cubic coefficients defining relationship between wheel steer and wheel jounce/rebound

Anti-pitch

The Anti-pitch properties for the right side and left side tires are assumed to be the same (again, the average is used). The Anti-pitch data used by EDVSM are shown in Table 2-4.

Roll Steer

A Roll Steer vs Jounce/Rebound Table is used for independent suspension types; a single value is used for solid axles. The roll steer properties for the right side and left side tires are assumed to be the same (again, the average is used). The Roll Steer data used by EDVSM are shown in Table 2-4.

Exterior

EDVSM uses the Kv Stiffness value for roll-over simulations. The other Vehicle Exterior Data (Exterior Dimensions, A and B Stiffnesses) are not used by EDVSM.

Steering System Data

EDVSM uses the steering gear ratio if the

At Driver

Steering Table option is used during Event set-up. See Table 2-5. In addition, if the Steer Degree of Freedom option is selected (see Event Set-up), the Steering Column Inertia and Friction are also used.

Brake System Data

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

At Pedal

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

> **NOTE:** See also Wheel Brake Data (Unsprung Mass Parameters) for related information.

Drivetrain Data

The Drivetrain Data (engine torque vs RPM, transmission ratio, differential ratio) are used if the

Percent Wide-open Throttle

option is used during Event set-up. See Table 2-5. Otherwise, the Drivetrain Data are not used by EDVSM.

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

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

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

> **NOTE:** If the Differential Table contains more than one forward speed, EDVSM will report an incompatible drivetrain.

Table 2-5 Vehicle Exterior, Steering, Brake System and Drivetrain Parameters Used By EDVSM

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

Environment

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

- Visual Data
- Physical Data

Creating an Environment

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

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

The Visual and Physical attribute groups are defined below.

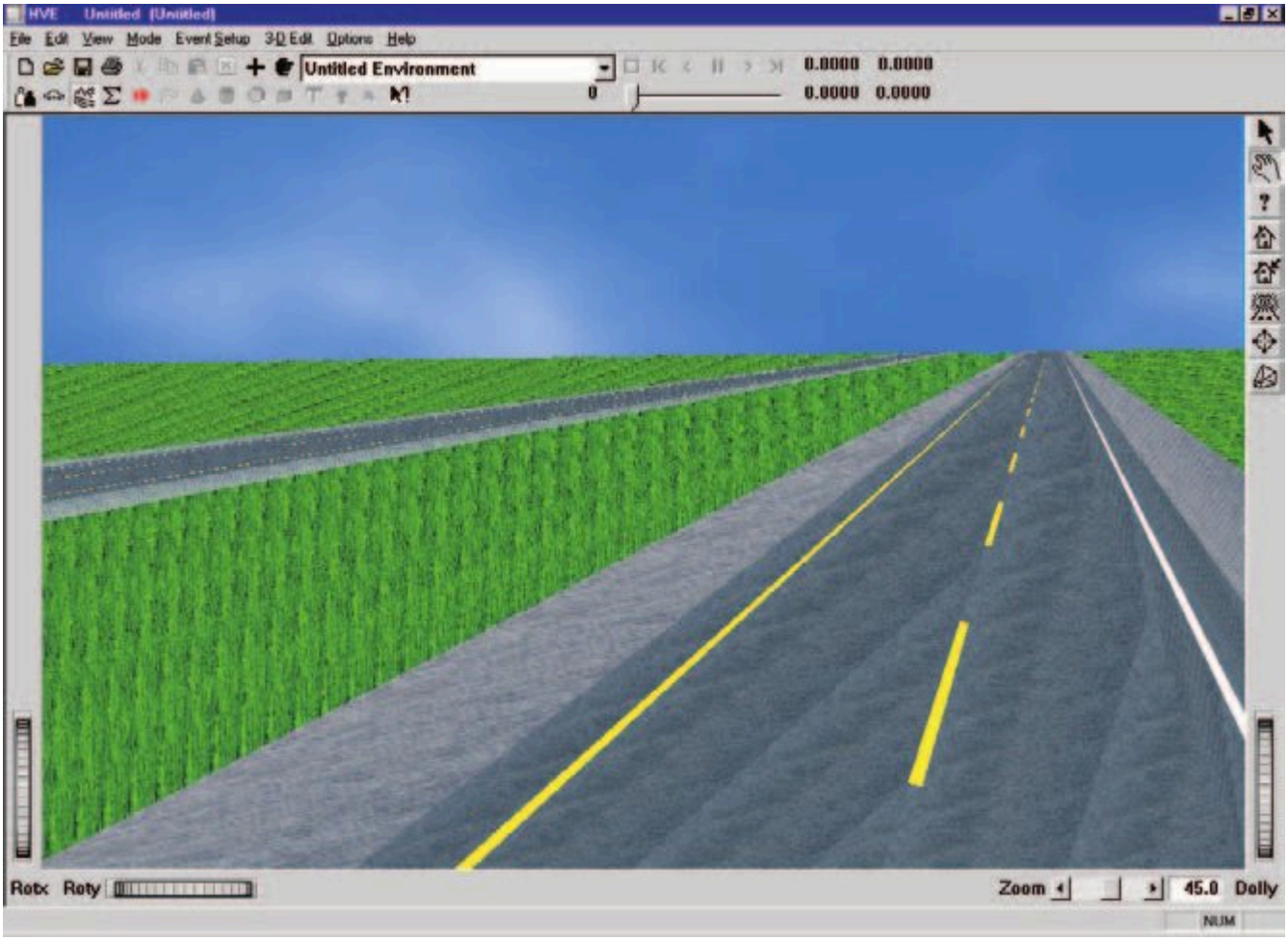


Figure 2-2: Environment Editor.

Visual Data

The following visual parameters may be edited:

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

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

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

Physical Data

The Physical Data groups are:

- Angle of X Axis

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

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

Table 2-6 Environment Model Parameters Used By EDVSM

Parameter	Description
Wind Speed and Direction	Velocity (magnitude and direction relative to the earth-fixed X axis) used in aerodynamics calculations.
Air Temperature	Ambient air temperature used in aerodynamic calculations.
Air Pressure	Ambient air pressure used in aerodynamic calculations.
Gravitational Constant	Local gravitational constant.
3-D Surface Geometry (Elevation, Surface Normal, Friction Factor)	The polygon database used to create the 3-D environment.

Angle Of X Axis

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

> **NOTE:** The angle is specified relative to true north. If you are using a compass to determine direction at the scene of an accident, you should provide a correction factor before entering this angle.

The angle of the X axis is used in the aerodynamics calculations to convert wind direction (which is entered according to true North) to the earth-fixed coordinate system (the direction required by the aerodynamics calculations in EDVSM). See Wind Speed and Direction, below.

> **NOTE:** The angle of the X axis affects how you visualize an EDVSM event because it affects the location of the sun.

Wind Speed and Direction

Wind Speed and Direction are not used by EDVSM.

> **NOTE:** Enter the wind direction relative to true north. EDVSM will convert the direction to the earth-fixed coordinate system according to the current Angle of X Axis.

Atmospheric Temperature and Pressure

Atmospheric Temperature and Pressure are used to calculate the density of the air. The density, in turn, is used in the aerodynamics calculations. Temperature and density are also used in the calculation of brake temperatures if the HVE Brake Designer is used.

Gravity Constant

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

3-D Surface Geometry

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

Rapid changes in surface elevation, such as curbs, during one integration timestep may cause severe tire force causing the run to terminate. If this occurs, you should try reducing the integration timestep or smoothing, to the degree possible, the surface.

Event

EDVSM uses the HVE Event Editor (see Figure 2-3) to create, set up and execute an event. Each of these topics is described below.

Creating An Event

An EDVSM event is created using the Event Information dialog.

To create an EDVSM event:

1. Choose Event Mode. The Event Editor is displayed.
2. Click *Add New Object*. The Event Information dialog is displayed.
3. Select one vehicle from the Active Vehicles list.
4. Select the calculation model, *EDVSM*, from the Calculation Model options list.
5. Enter an event name. A default name is supplied for the selected event. The name is user-editable, and does not affect calculations.

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

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

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

Setting Up an Event

EDVSM uses the following

event set-up

options:

- Position/Velocity
- Driver Controls

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

Position/Velocity

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

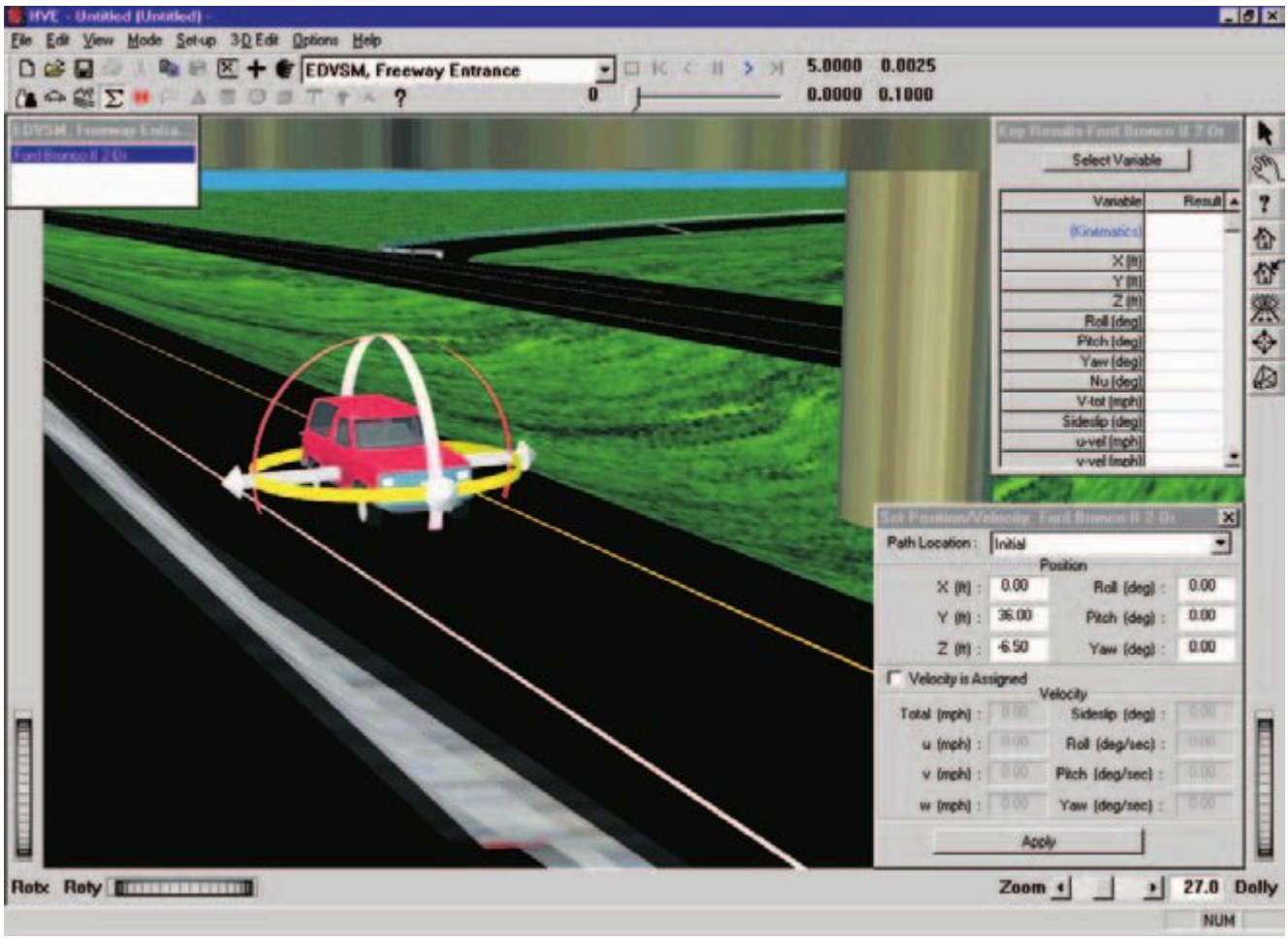


Figure 2-3: HVE Event Editor, setting up and executing an EDVSM event.

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

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

Driver Controls

EDVSM uses the following Driver Controls:

- **Steering** - A table of steering inputs as a function of time. The *At Driver* and *At Axle* options are supported.
- **Braking** - A table of braking inputs as a function of time. The *At Pedal* option is supported.
- **Throttle** - A table of throttle inputs as a function of time. The *Percent Wide-open Throttle* option is supported.
- **Gear Selection** - A table of gear changes as a function of time for the transmission (multi-speed differentials are not supported).

- **HVE Driver Model** - A closed-loop model that determines the driver steering inputs required to cause the vehicle to follow a desired path. The HVE Driver Model is described in the HVE User's Manual and in reference 8.

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

Table 2-7 Event Set-up Parameters used by EDVSM

Parameter	Description
Vehicle Initial Position	The earth-fixed X,Y,Z coordinates and roll, pitch, yaw angles of the vehicle at the start of the simulation
Vehicle Initial Velocity	The forward, lateral and vertical linear velocities, and the roll, pitch and yaw angular velocities at the start of the run.
Driver Controls, Steer Table	Steer Table Option; Steering Wheel Angle vs Time or Tire Steer Angle vs Time
Driver Controls, Brake Table	Brake Table Option; Brake Pedal Force vs Time
Driver Controls, Throttle Table	Throttle Table Option; Throttle Position vs Time
Driver Controls, Gear Table	Gear Table Option; Number of Shifts; Gear Selection vs Time
Driver Controls, HVE Driver	Path Description, General Parameters, Driver Descriptors, Neuromuscular Filter

Damage Profile

The Damage Profile Data are not used by EDVSM.

Payload

The Payload Data are not used by EDVSM. Payload inertias may be added to the vehicle inertias and the CG may be moved longitudinally and/or vertically using the Move CG dialog.

> **NOTE:** Lateral relocation of the CG is not supported by EDVSM.

Collision Pulse

The Collision Pulse data are not used by EDVSM.

Wheels

EDVSM supports the HVE Tire Blow-out Model. The inputs are the tire and duration for the blowout and stiffness and rolling resistance multipliers for the blown tire. The HVE Tire Blow-out Model is described in the HVE User's Manual (see Event Set-up options) and in reference 8.

EDVSM also supports the HVE Brake Designer. When the Brake Designer is used, the user can specify initial temperatures for the brake linings and drum. Refer to the HVE Brake Designer Manual for more information.

Accelerometers

EDVSM allows the user to supply up to five virtual accelerometers at user-defined x,y,z (vehicle-fixed) coordinates. The current acceleration output for each location is provided in the EDVSM output tracks (see Chapter 3, EDVSM Output).

Contacts

The Contacts data are not used by EDVSM.

Restraints

The Restraints data are not used by EDVSM.

Simulation Controls

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

Table 2-8 Simulation Control Parameters used by EDVSM

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).
Min Angular Velocity	The angular velocity used to terminate the run (if the linear and angular velocities are simultaneously less than these termination velocities, the run terminates).

Calculation Options



Figure 2-4: Calculation Options dialog for EDVSM.

EDVSM includes three Calculation options:

- Tire Model
- Steer Degree of Freedom

- Vehicle Body vs. Environment Contact

For the current, code-verified details of the Calculation Options dialog (control IDs, defaults and stored option values), see the EDVSM Calculation Options reference.

Tire Model

EDVSM provides three tire model options. These are described below.

- **Normal** - This is the default method. Tire forces are assumed to act at a point contact.
- **Radial Spring** - This method (not implemented) allows multiple contact points about the tire's circumferential perimeter. It allows for improved modeling of tire interaction with extremely non-uniform surfaces (e.g., potholes, curbs).
- **Sidewall Impact** - This method (not implemented) also uses the radial spring model, but in addition, allows forces to act on the side of the tire. This method is most applicable to sidewall vs curb impact, and similar interactions.

(updated: In the current version the Radial Spring and Sidewall Impact options remain unimplemented — they are disabled in the Calculation Options dialog, and the physics model rejects them if selected. Normal is the only usable Tire Model Method.)

Steer Degree of Freedom

The Steer Degree of Freedom (DOF) model has three options.

- **Off** - The steer degree of freedom is not included in the calculations. *(This is the default.)*
- **Normal** - Steering inputs are determined by forces and moments produced at the tire-terrain interface. The model is active during the entire event, over-riding any open-loop steer table.
- **Append** - This model (not implemented) operates the same way as the Normal option, except it is activated only after the last time entry in the open-loop steer tables.

(updated: Off and Normal select the two available steer-system solution modes. The Append option remains unimplemented — it is disabled in the dialog, and selecting it produces a fatal error and the event will not run.)

Vehicle Body vs. Environment Contact

The Vehicle Body vs. Environment Contact check box is used when the user intends to simulate the rollover of a vehicle where the body of the vehicle contacts the ground. If the vehicle rolls over in a simulation without the box checked, the event may terminate with unexpected results.

(updated: This option enables the HVOSM hardpoint body-mesh/terrain contact model and rollover simulation. It is off by default.)

GetSurfaceInfo Method

This option determines how the tire model searches for polygons beneath the tire. Refer to the HVE User's Manual for more information.

Executing An Event

To execute an EDVSM event, use the Event Controller, shown in Figure 2-3 as a component of the Event Editor, and again in Figure 2-5, below. 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 HVE's Options Menu to choose useful options, such as Key Results, Axes, Velocity Vectors and Skidmarks.

Chapter 3 — EDVSM Program Output

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

Overview

EDVSM 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** - A 3-D viewer containing dynamic, visual simulations of the vehicle trajectory during the run.
- **Damage Profile Simulations** - A 3-D viewer containing dynamic, visual damage simulation as it occurs during the run.

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

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

1. Choose Playback Mode. The Playback Editor is displayed.
2. Click *Add New Object*. The Report Window Information dialog is displayed, showing a list of all the current events in the case.
3. Select an EDVSM event from the list. Once an event is selected, the Report Type list is displayed, containing all the available reports for the selected event.
4. Select the desired report in the Report Type list. To open several reports at once, select more than one (*Select All* selects every report); each opens in its own Report Window.
5. If desired, edit the Name. A default name is supplied for the report window. The name is user-editable, and does not affect calculations.

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

1. Click *OK* to display the report.

Alpha-Numeric Reports

EDVSM produces the following alpha-numeric reports:

- **Messages** - A list of messages produced by the current run
- **Accident History** - A table of initial and final positions and velocities

- **Driver Controls** - A report of all the driver control inputs (Steering, Braking, Throttle, Gear Selection) for the current run.
- **Environment Data** - A table describing the environment physical and visual parameters used during the run.
- **Vehicle Data** - A series of tables containing the vehicle data used by EDVSM
- **Program Data** - A table containing program control information for the current run

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

Messages

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

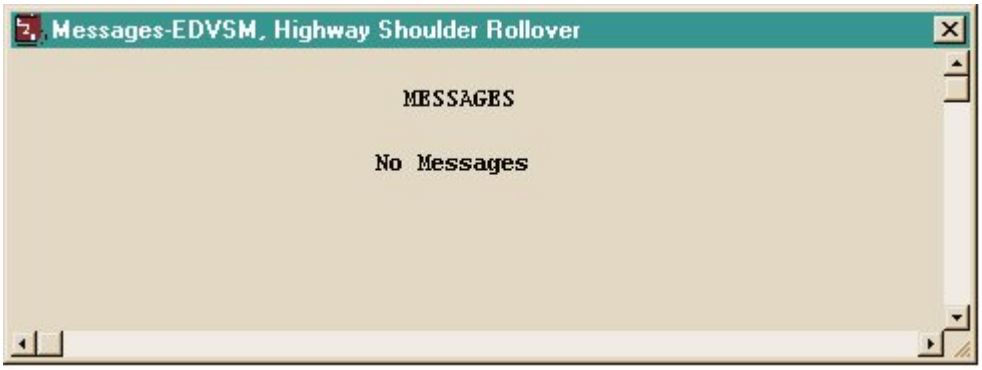


Figure 3-1: Typical Messages output report issued by EDVSM.

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 3-2. The report includes total distance traveled and total time, plus initial and final X, Y, PSI position and V-tot, u-vel, v-vel and yaw velocity.

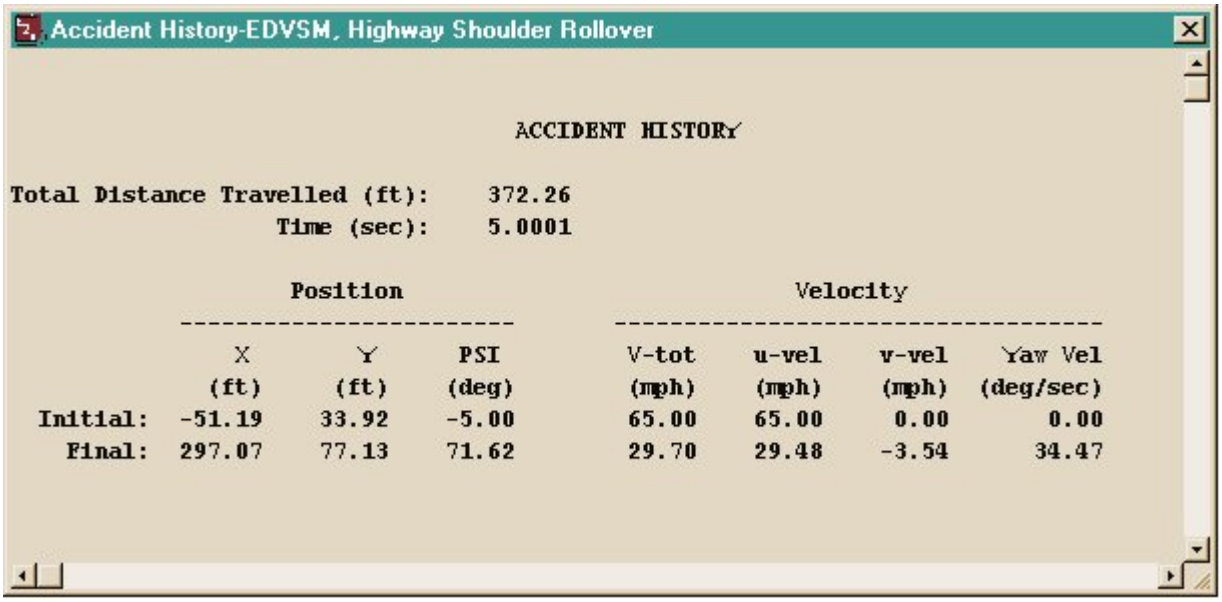


Figure 3-2: Typical Accident History output report issued by EDVSM.

Driver Controls

The Driver Controls Report displays a table of driver steering, braking, throttle and gear selections for the vehicle. A typical Driver Controls Report is shown in Figure 3-3 (Brake Table of Pedal Force vs time, Throttle Table by axle, Gear Table and Steer Table of Steering Wheel angle vs time).

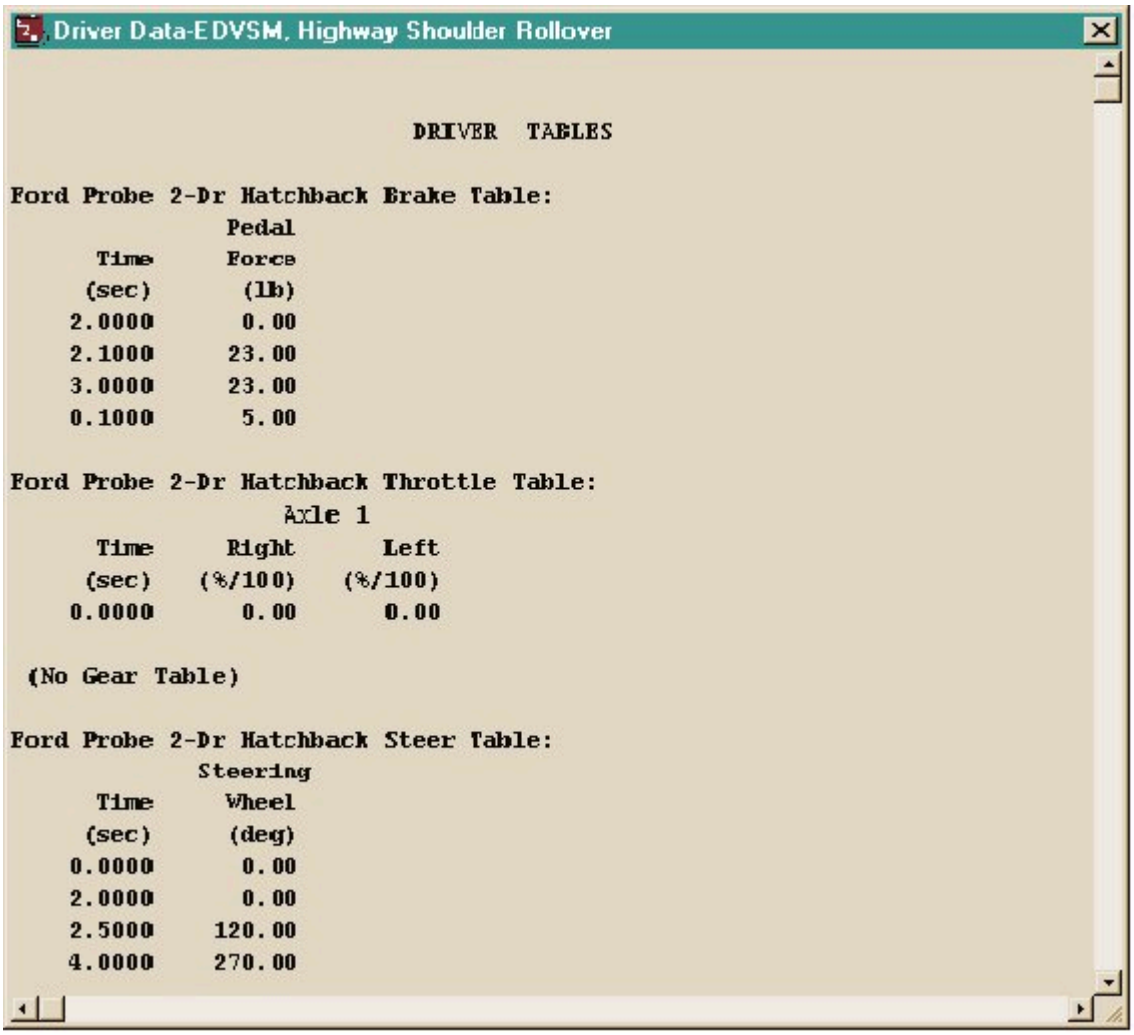


Figure 3-3: Typical Driver Controls output report issued by EDVSM.

Environment Data

The Environment Data Report displays the physical and visual information describing the environment (ambient temperature and pressure, gravity constant, 3-D geometry filename, number of polygons, GetSurfaceInfo method and minimum terrain elevation). A typical Environment Data Report is shown in Figure 3-4.

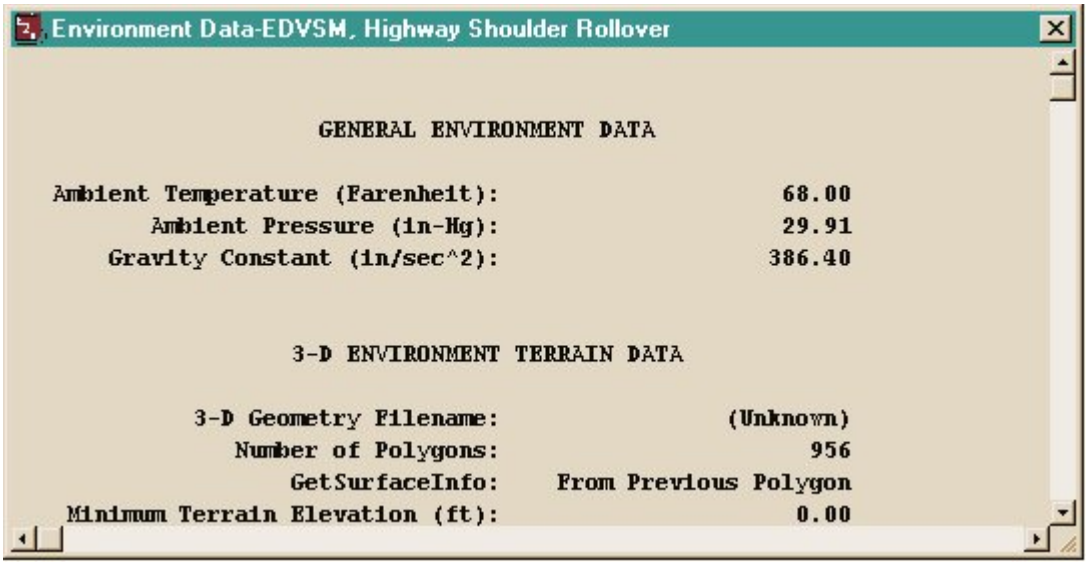


Figure 3-4: Typical Environment Data output report issued by EDVSM.

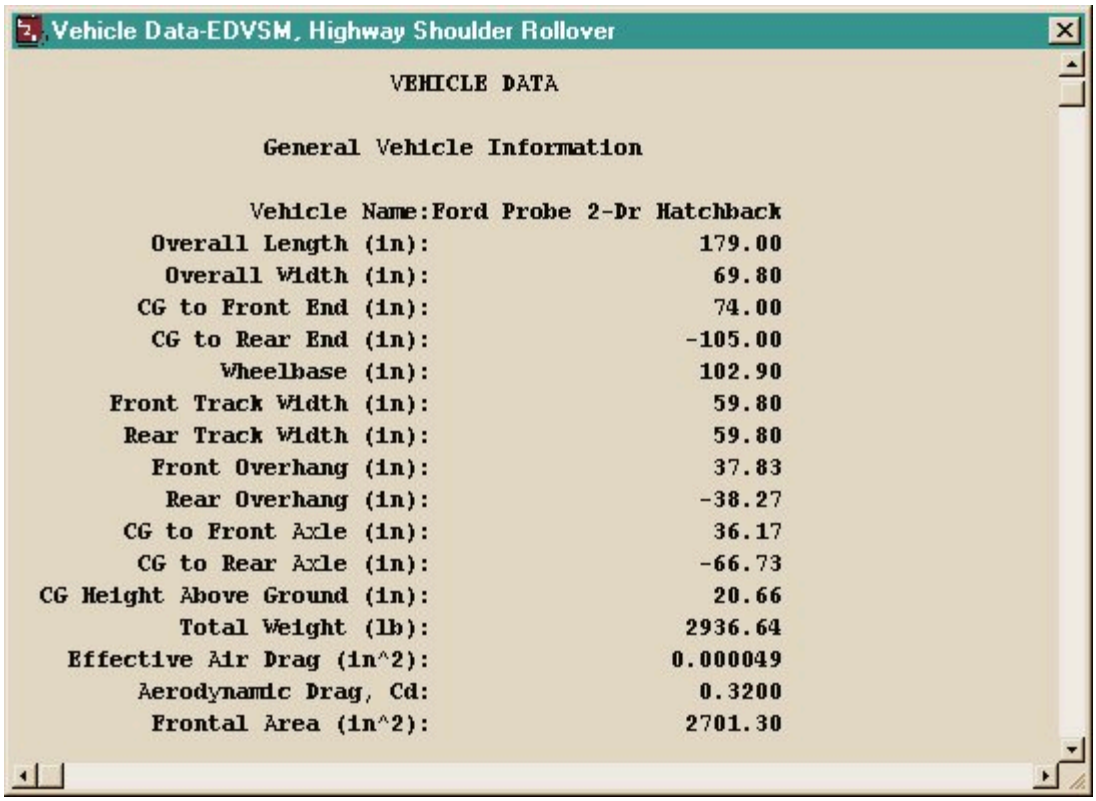
> **NOTE:** A detailed description of the vertex information is not practical, owing to its large size (a terrain often is composed of several thousand vertices). However, it is possible to view the terrain information (friction multiplier, slope, elevation and so forth) beneath each tire during the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

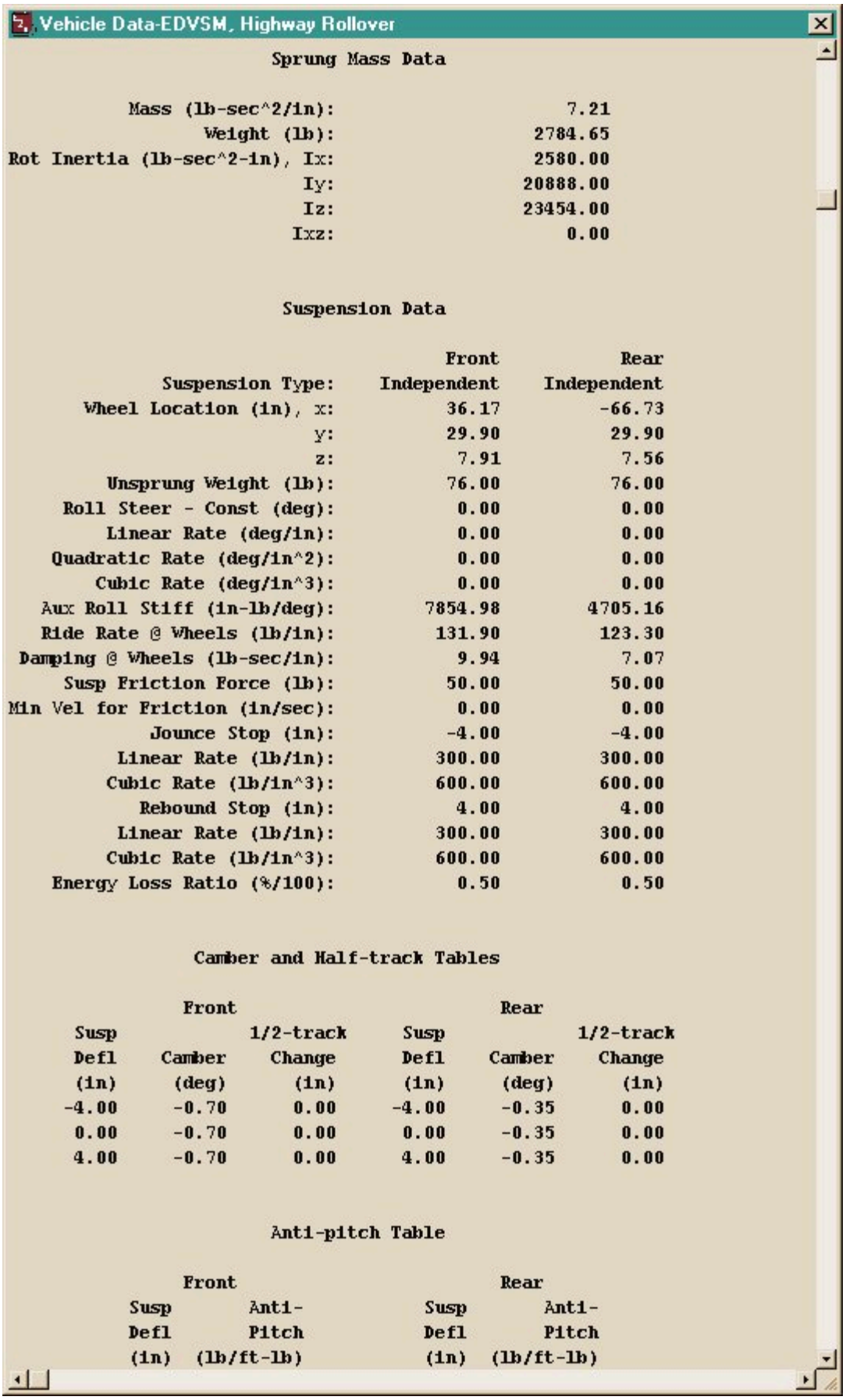
Vehicle Data

The Vehicle Data Report includes the following information:

- **Vehicle Dimensional and Inertial Properties** - The dimensional and inertial parameters as were used by EDVSM in the current event.
- **Suspension Properties** - The suspension parameters as were used by EDVSM in the current event.
- **Brake System Properties** - The brake system parameters as were used by EDVSM in the current event.
- **Tire Properties** - The tire parameters as were used by EDVSM in the current event.

A portion of a typical Vehicle Data Report is shown in Figures 3-5a, b, and c (a vehicle data report consumes several pages). The report begins with General Vehicle Information (overall length and width, CG-to-front/rear end, wheelbase, track widths, overhangs, CG-to-axle distances, CG height, total weight, aerodynamic drag data), followed by Sprung Mass Data (mass, weight, rotational inertias), Suspension Data (per-axle suspension type, wheel locations, unsprung weights, roll steer, auxiliary roll stiffness, ride and damping rates, suspension friction, jounce/rebound stops, energy loss ratio), Camber and Half-track Tables, Anti-pitch Table, Brake System Data (pedal ratio and per-wheel brake type, torque ratio, pushout pressure and proportioning data) and Tire Data (physical data, deflection rates, friction tables at each test load and speed, cornering and camber stiffness data).


Vehicle Data-EDVSM, Highway Shoulder Rollover
VEHICLE DATA
General Vehicle Information
Vehicle Name:Ford Probe 2-Dr Hatchback
Overall Length (in): 179.00
Overall Width (in): 69.80
CG to Front End (in): 74.00
CG to Rear End (in): -105.00
Wheelbase (in): 102.90
Front Track Width (in): 59.80
Rear Track Width (in): 59.80
Front Overhang (in): 37.83
Rear Overhang (in): -38.27
CG to Front Axle (in): 36.17
CG to Rear Axle (in): -66.73
CG Height Above Ground (in): 20.66
Total Weight (lb): 2936.64
Effective Air Drag (in^2): 0.000049
Aerodynamic Drag, Cd: 0.3200
Frontal Area (in^2): 2701.30



Vehicle Data-EDVSM, Highway Rollover

Sprung Mass Data

Mass (lb-sec^2/in):	7.21
Weight (lb):	2784.65
Rot Inertia (lb-sec^2-in), Ix:	2580.00
Iy:	20888.00
Iz:	23454.00
Ixz:	0.00

Suspension Data

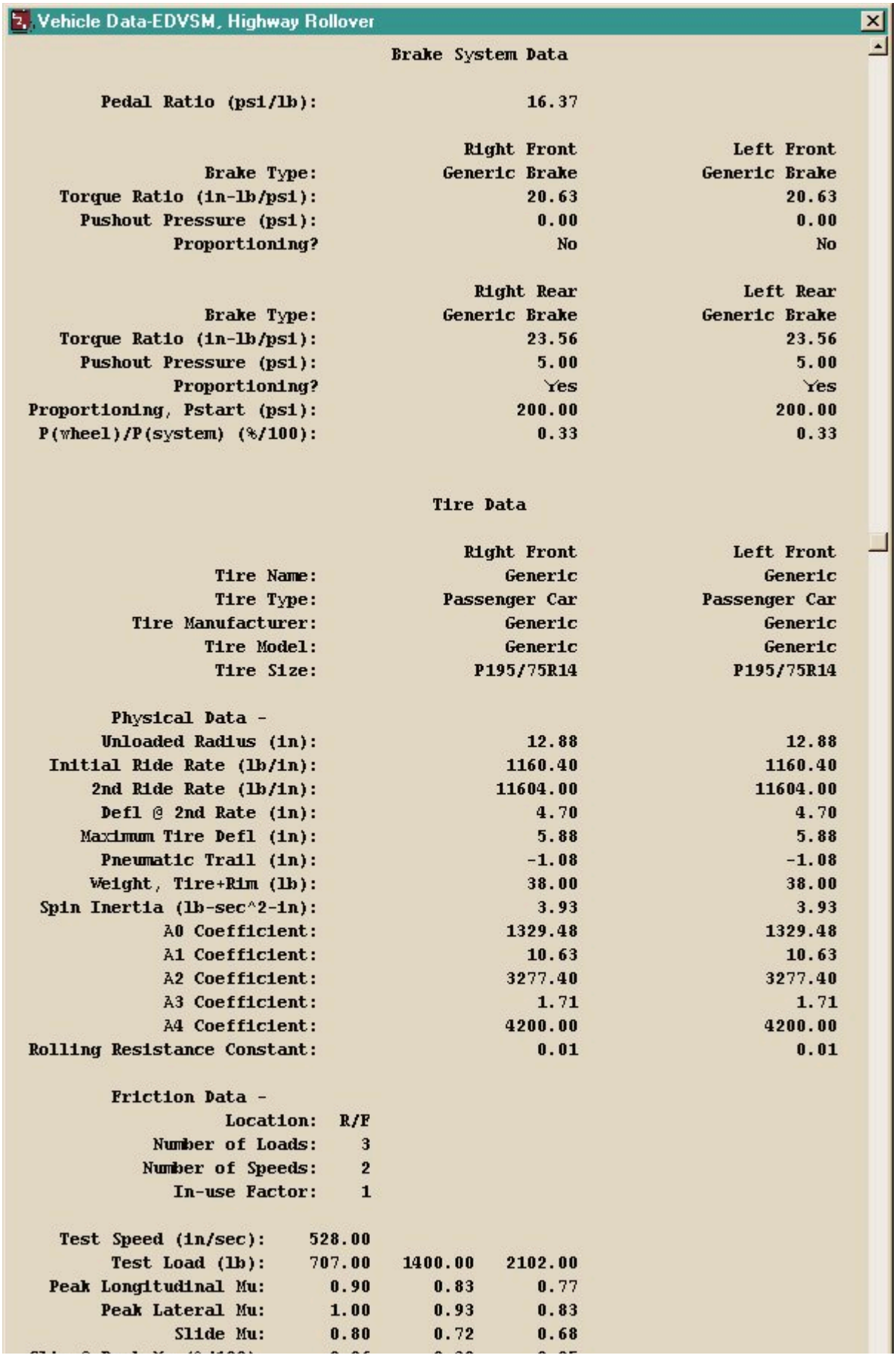
	Front	Rear
Suspension Type:	Independent	Independent
Wheel Location (in), x:	36.17	-66.73
y:	29.90	29.90
z:	7.91	7.56
Unsprung Weight (lb):	76.00	76.00
Roll Steer - Const (deg):	0.00	0.00
Linear Rate (deg/in):	0.00	0.00
Quadratic Rate (deg/in^2):	0.00	0.00
Cubic Rate (deg/in^3):	0.00	0.00
Aux Roll Stiff (in-lb/deg):	7854.98	4705.16
Ride Rate @ Wheels (lb/in):	131.90	123.30
Damping @ Wheels (lb-sec/in):	9.94	7.07
Susp Friction Force (lb):	50.00	50.00
Min Vel for Friction (in/sec):	0.00	0.00
Jounce Stop (in):	-4.00	-4.00
Linear Rate (lb/in):	300.00	300.00
Cubic Rate (lb/in^3):	600.00	600.00
Rebound Stop (in):	4.00	4.00
Linear Rate (lb/in):	300.00	300.00
Cubic Rate (lb/in^3):	600.00	600.00
Energy Loss Ratio (%/100):	0.50	0.50

Camber and Half-track Tables

Front			Rear		
Susp Defl (in)	Camber (deg)	1/2-track Change (in)	Susp Defl (in)	Camber (deg)	1/2-track Change (in)
-4.00	-0.70	0.00	-4.00	-0.35	0.00
0.00	-0.70	0.00	0.00	-0.35	0.00
4.00	-0.70	0.00	4.00	-0.35	0.00

Anti-pitch Table

Front		Rear	
Susp Defl (in)	Anti-Pitch (lb/ft-lb)	Susp Defl (in)	Anti-Pitch (lb/ft-lb)



Vehicle Data-EDVSM, Highway Rollover

Brake System Data

Pedal Ratio (psi/lb):	16.37

	Right Front	Left Front
Brake Type:	Generic Brake	Generic Brake
Torque Ratio (in-lb/psi):	20.63	20.63
Pushout Pressure (psi):	0.00	0.00
Proportioning?	No	No

	Right Rear	Left Rear
Brake Type:	Generic Brake	Generic Brake
Torque Ratio (in-lb/psi):	23.56	23.56
Pushout Pressure (psi):	5.00	5.00
Proportioning?	Yes	Yes
Proportioning, Pstart (psi):	200.00	200.00
P(wheel)/P(system) (%/100):	0.33	0.33

Tire Data

	Right Front	Left Front
Tire Name:	Generic	Generic
Tire Type:	Passenger Car	Passenger Car
Tire Manufacturer:	Generic	Generic
Tire Model:	Generic	Generic
Tire Size:	P195/75R14	P195/75R14
Physical Data -		
Unloaded Radius (in):	12.88	12.88
Initial Ride Rate (lb/in):	1160.40	1160.40
2nd Ride Rate (lb/in):	11604.00	11604.00
Defl @ 2nd Rate (in):	4.70	4.70
Maximum Tire Defl (in):	5.88	5.88
Pneumatic Trail (in):	-1.08	-1.08
Weight, Tire+Rim (lb):	38.00	38.00
Spin Inertia (lb-sec^2-in):	3.93	3.93
A0 Coefficient:	1329.48	1329.48
A1 Coefficient:	10.63	10.63
A2 Coefficient:	3277.40	3277.40
A3 Coefficient:	1.71	1.71
A4 Coefficient:	4200.00	4200.00
Rolling Resistance Constant:	0.01	0.01

Friction Data - Location:	R/F		
Number of Loads:	3		
Number of Speeds:	2		
In-use Factor:	1		
Test Speed (in/sec):	528.00		
Test Load (lb):	707.00	1400.00	2102.00
Peak Longitudinal Mu:	0.90	0.83	0.77
Peak Lateral Mu:	1.00	0.93	0.83
Slide Mu:	0.80	0.72	0.68

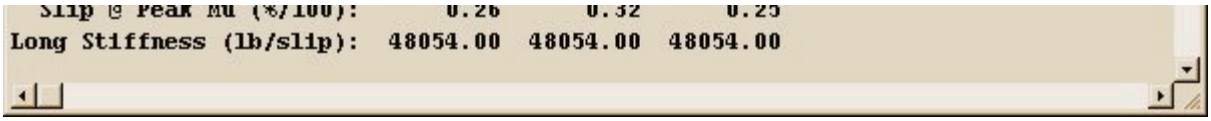


Figure 3-5a/b/c: Typical Vehicle Data output report issued by EDVSM.

Program Data

The Program Data Report includes the following information:

- **Simulation Controls** - Integration parameters used for the current event
- **General Information** - EDVSM version number and the built-in constants used for the current event

A typical Program Data Report is shown in Figure 3-6. The Simulation Controls section reports the integration method (Fixed Runge-Kutta), maximum simulation time, normal integration timestep, output interval, and the linear and angular termination velocities. The General Information section reports the EDVSM version number, wheel spin integration constant, terminal wheel spin velocity, pitch index angle and driveline inertia.

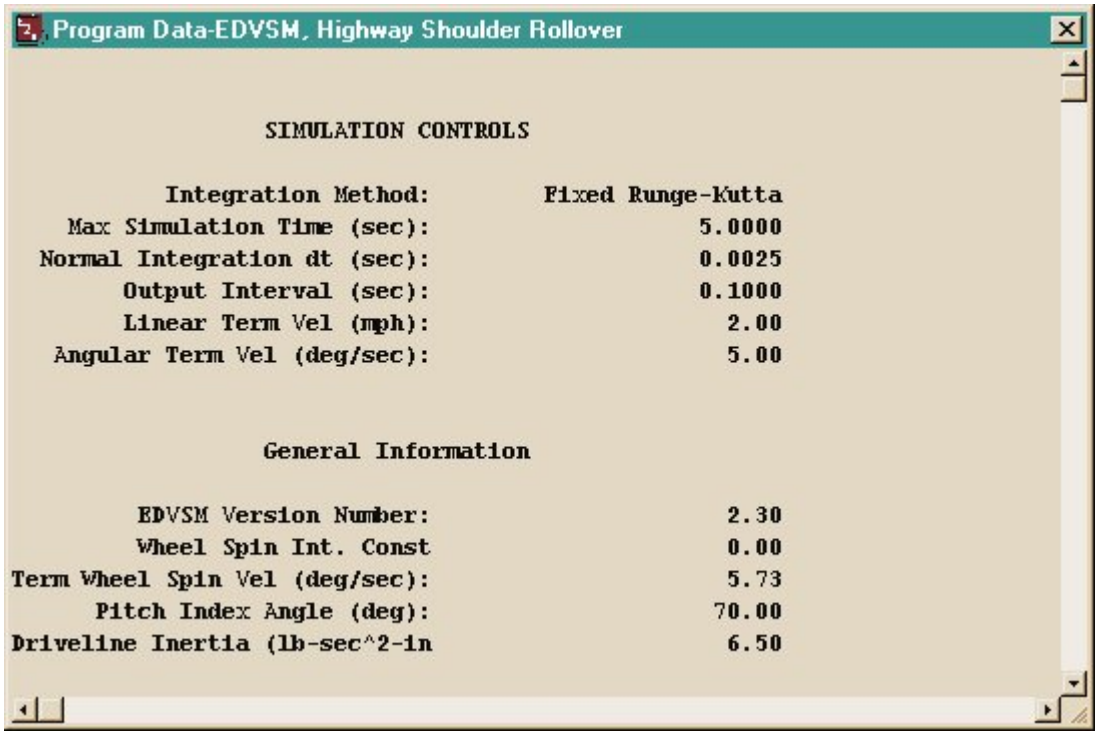


Figure 3-6: Typical Program Data output report issued by EDVSM.

Graphic Reports

EDVSM 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

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

Vehicle Output Groups

- **Kinematics** - Position, velocity and acceleration for the vehicle sprung mass
- **Kinetics** - Forces and moments acting on the sprung mass
- **Accelerometers** - Linear accelerations at user-specified locations on the vehicle
- **Tire** - The tire output parameters existing at the tire contact patch (compare with Wheel Output, below)
- **Wheel** - The wheel output parameters existing at the wheel's hub (compare with Tire Output, above)
- **Drivetrain** - Current levels of driving torque and other information related to the drivetrain
- **Driver** - Current levels of driver inputs (steering, braking, throttle and gear ratios)

An example of a Variable Output table is shown in Figure 3-7. A detailed listing of each Variable Output parameter produced by EDVSM is found in Table 3-1. For more information about HVE Variable Output parameters, refer to the HVE Operations 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; Total linear velocity, u,v,w components; Sideslip, course angles; p,q,r angular velocity; Total linear accel, fwd, side, vert components; u-dot, v-dot, w-dot linear components; p-dot, q-dot, r-dot angular components
Kinetic Data	ΣF_x, ΣF_y, ΣF_z (Suspension); ΣM_x, ΣM_y, ΣM_z (Suspension); ΣF_x, ΣF_y, ΣF_z (Collision); ΣM_x, ΣM_y, ΣM_z (Collision); F_x (Aerodynamic)
Accelerometer Data	Total linear accel; forward, Lat, Vert components for each accelerometer
Tire Data	X,Y,Z position of tire contact patch; $F_{x'}$, $F_{y'}$, $F_{z'}$ of tire contact patch; Loaded Tire Radius; Longitudinal Slip; Slip Angle; Skid Flag
Wheel Data	x,y,z location of wheel; Camber, Steer angle of wheel; Wheel Spin Velocity; F_x, F_y, F_z of wheel; Jounce/Rebound displacement, velocity; Spring, Damping and Anti-pitch Suspension Force; Drive and Brake Torque at wheel; Brake Pressure at wheel
Drivetrain Data	Engine Speed, Power and Torque; Transmission and Differential Numeric Ratio
Driver Data	Steering wheel angle; Throttle position; Brake Pedal Force and Master Cylinder Pressure; Transmission and Differential Gear Selection

Variable Output-EDVSM, Highway Shoulder Rollover

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

Time (sec)	Ford Probe 2-D p-dot (deg/sec^2)	Ford Probe 2-D q-dot (deg/sec^2)	Ford Probe 2-D r-dot (deg/sec^2)	Ford Probe 2-D Axle 1, Righ Fz' (tire) (lb)	Ford Probe 2-D Axle 1, Left Fz' (tire) (lb)	Ford Probe 2-D Axle 2, Righ Fz' (tire) (lb)	Ford Probe 2-D Axle 2, Left Fz' (tire) (lb)
2.7600	25.3	-4.7	36.6	-366.6	-1620.8	-30.8	-868.5
2.7700	28.1	-4.9	33.7	-354.4	-1630.2	-27.5	-875.3
2.7800	30.9	-5.2	30.8	-342.2	-1639.5	-24.2	-882.2
2.7900	33.8	-5.4	27.8	-330.1	-1648.9	-20.9	-889.0
2.8000	36.6	-5.7	24.9	-317.9	-1658.2	-17.7	-895.9
2.8100	40.6	-5.5	23.2	-308.1	-1660.7	-16.3	-893.3
2.8200	44.7	-5.4	21.5	-298.3	-1663.1	-14.9	-890.7
2.8300	48.7	-5.2	19.7	-288.4	-1665.6	-13.5	-888.1
2.8400	52.8	-5.0	18.0	-278.6	-1668.0	-12.1	-885.5
2.8500	56.8	-4.9	16.3	-268.8	-1670.5	-10.7	-882.9
2.8600	60.8	-4.7	14.6	-259.0	-1672.9	-9.3	-880.2
2.8700	64.9	-4.5	12.9	-249.2	-1675.4	-7.9	-877.6
2.8800	68.9	-4.4	11.1	-239.4	-1677.8	-6.5	-875.0
2.8900	73.0	-4.2	9.4	-229.6	-1680.2	-5.1	-872.4
2.9000	77.0	-4.1	7.7	-219.8	-1682.7	-3.7	-869.8
2.9100	77.3	-4.7	6.2	-213.2	-1691.3	-7.4	-869.6
2.9200	77.6	-5.4	4.7	-206.5	-1699.9	-11.1	-869.4
2.9300	77.8	-6.0	3.1	-199.9	-1708.5	-14.8	-869.2
2.9400	78.1	-6.7	1.6	-193.3	-1717.1	-18.4	-868.9
2.9500	78.4	-7.4	0.1	-186.7	-1725.8	-22.1	-868.7

Figure 3-7: Typical Variable Output report produced by EDVSM.

Trajectory Simulations

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

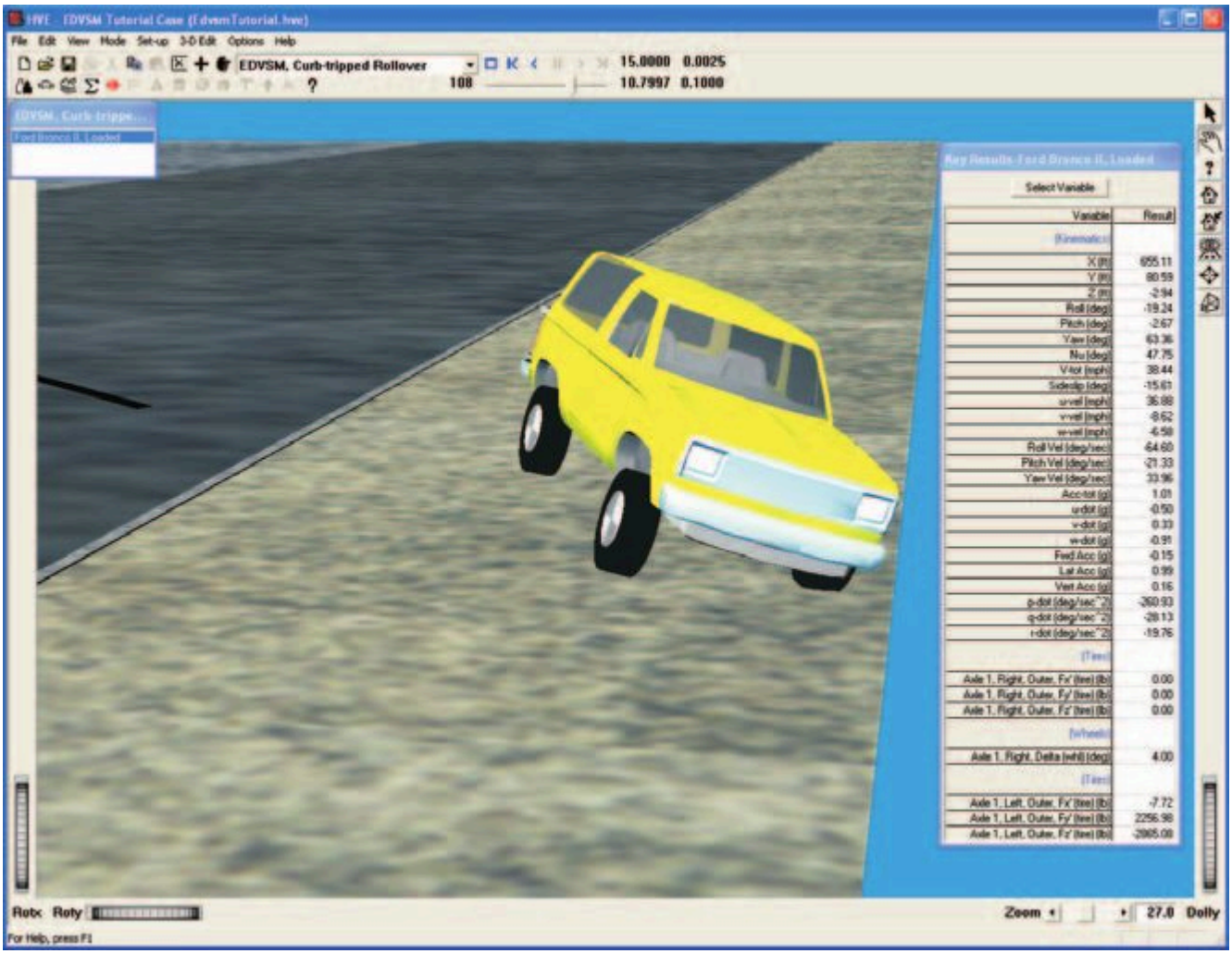


Figure 3-8: Typical Trajectory Simulation output produced by EDVSM.

Displaying a Trajectory Simulation

The Trajectory Simulation is controlled using the Playback Controller (see Figure 3-9).



Figure 3-9: Playback Controller.

The Playback Controller's buttons have the following functions:

- **Reset** - Returns to the start of the simulation and reinitialize 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

> **NOTE:** The Playback Controller also includes additional features used for creating video. Refer to the HVE User's Manual, Playback Editor and Video Output sections, for further details.

Damage Profile Simulations

EDVSM produces a damage profile simulation of the current event. The damage profile simulation is a 3-D visualization of the 3-D vertex data stored in the Damage output group in the Variable Output Table.

> **NOTE:** The Damage output group is not currently displayable in the Variable Output table.

An example of a damage profile simulation is shown in Figure 3-10.

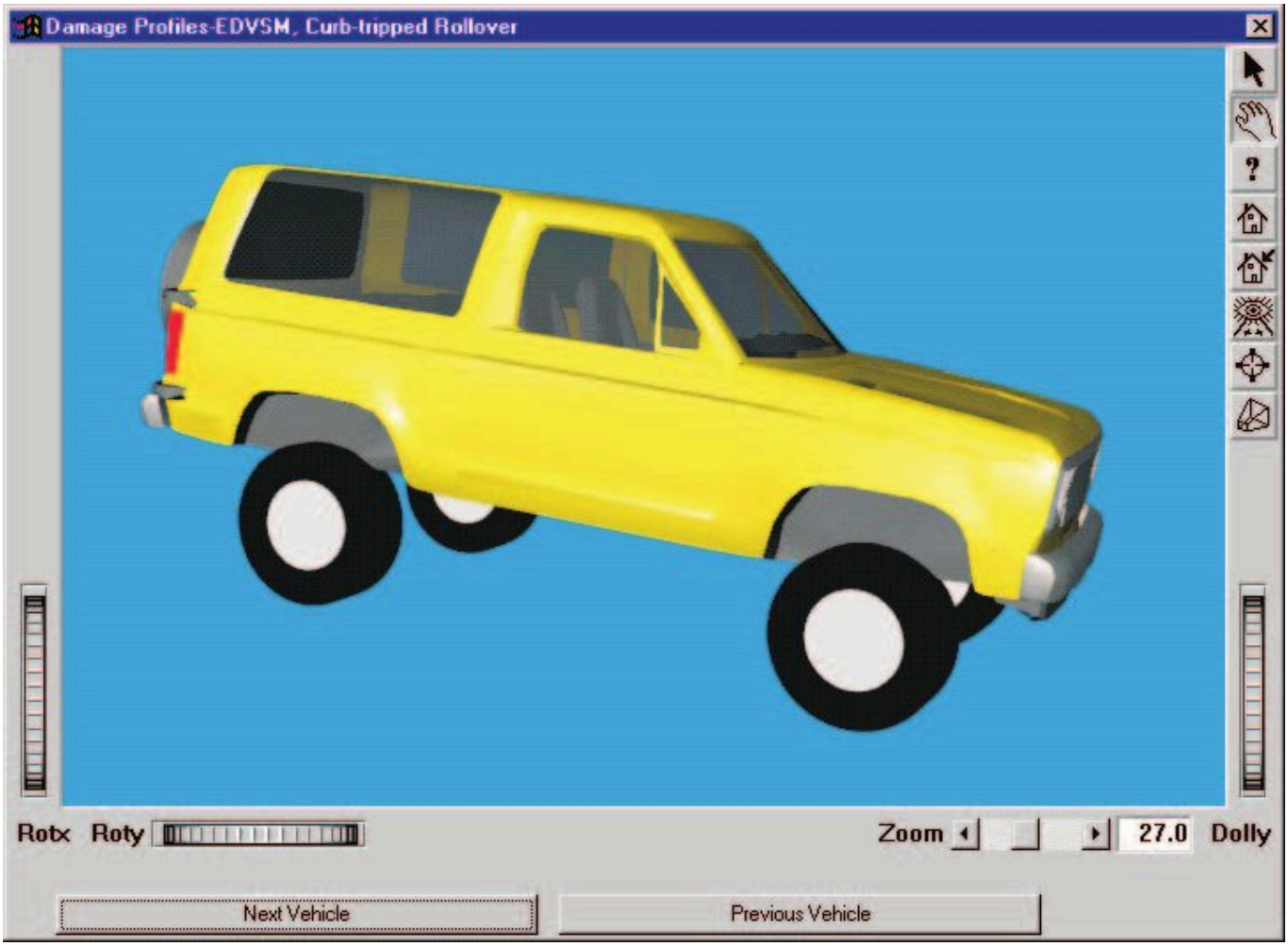


Figure 3-10: Typical Damage Profile output produced by an EDVSM rollover simulation.

To display a Damage Profile simulation use the Event Controller (see Figure 3-9), just as in the Trajectory Simulation.

> **NOTE:** Because the Event Controller is enabled by the Trajectory Simulation, you must have the corresponding Trajectory Simulation open in order to "play" the Damage Profile.

Chapter 4 — Calculation Method

Basic Vehicle Model

The vehicle model used by EDVSM was originally developed for the HVOSM. The reader is referred to original program documentation [1-3] for a detailed description of the model. Validation of EDVSM is published in [4].

Degrees of freedom

EDVSM carries eleven degrees of freedom:

Group	Count	Description
Sprung mass	6	Three translations and three rotations of the vehicle body
Suspension	4	A vertical displacement and a roll rotation at each of the front and rear axles
Steering	1	The steer degree of freedom described later in this chapter

Each wheel additionally carries a spin degree of freedom, advanced separately from the main solution.

For a solid axle, the axle's vertical displacement and roll angle combine to give the displacement at each wheel:

$$\delta_{Left} = \delta_{Axle} + \frac{T}{2}\phi_{Axle}, \qquad \delta_{Right} = \delta_{Axle} - \frac{T}{2}\phi_{Axle}$$

where T is the track width. For an independent suspension the two wheels are uncoupled and each carries its own displacement directly.

Equations of motion

The six sprung-mass equations and the four suspension equations are coupled through the inertia of the vehicle, so they are assembled into a single ten-by-ten system and solved together at each timestep:

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

where $\mathbf{M}$ is the generalized mass matrix, rebuilt each timestep because it depends on the current suspension displacements and vehicle orientation, and $\mathbf{F}$ collects the tire, suspension, aerodynamic and gravitational contributions together with the Coriolis and centrifugal terms. The system is solved by Gaussian elimination; a singular matrix terminates the run.

The remaining states follow by kinematics rather than by solving equations of motion. The vehicle's orientation rates come from the body-fixed angular velocities through the standard Euler relations,

$$\dot{\phi} = p + (q\sin\phi + r\cos\phi)\tan\theta$$

$$\dot{\theta} = q\cos\phi - r\sin\phi$$

$$\dot{\psi} = (q\sin\phi + r\cos\phi)\sec\theta$$

and the earth-fixed position rates come from resolving the body-fixed velocity through the vehicle's direction cosine matrix:

$$\dot{\mathbf{X}} = \mathbf{A}\,\mathbf{u}$$

> **NOTE:** The $\sec\theta$ in the yaw rate is singular at a pitch angle of 90 degrees. This is inherent to the Euler angle sequence and is the reason the model is not suited to extreme pitch attitudes.

(updated: earlier editions covered only the steering system and referred the reader to the HVOSM documentation for everything else.)

Suspension forces

The force at each wheel station is the sum of a spring force and a friction force. The spring is linear within its free travel and stiffens sharply beyond it:

$$F_{Spring} = \begin{cases} k\,\delta + \lambda[k_e(\delta - \omega_e) + k_e'(\delta - \omega_e)^3], & \delta > \omega_e \\ [6pt] k\,\delta, & \omega_c \le \delta \le \omega_e \\ [6pt] k\,\delta + \lambda[k_c(\delta - \omega_c) + k_c'(\delta - \omega_c)^3], & \delta < \omega_c \end{cases}$$

where k is the suspension rate, ω_e and ω_c are the extension and compression stop displacements, and k and k' with subscripts e and c are the linear and cubic rates of the extension and compression stops. The cubic term is what gives a stop its progressive feel rather than a hard step in rate.

The factor λ applies **only to the stop term**, and only while the stop is unloading — that is, while the displacement and its rate have opposite signs. It is the suspension's stop energy-dissipation factor. Setting it to 1 makes the stop perfectly elastic; a value below 1 makes the stop absorb energy, which is what a real bump stop does.

Damping is Coulomb rather than viscous:

$$F_{Friction} = \begin{cases} \frac{C_f}{\varepsilon}\,\dot{\delta}, & |\dot{\delta}| < \varepsilon \\ [10pt] C_f\,\operatorname{sgn}\dot{\delta}, & |\dot{\delta}| \ge \varepsilon \end{cases}$$

where C_f is the Coulomb friction force and ε the friction velocity band. The band exists purely to avoid a discontinuity at zero velocity: without it a vehicle standing still would never settle, because the friction force would chatter between $\pm C_f$.

> **NOTE:** There is no viscous damper rate in the EDVSM suspension model. All suspension damping comes from the Coulomb friction force and from the stop dissipation factor. A shock absorber's rate must therefore be represented through the Coulomb friction value, which is an approximation — it produces a force independent of velocity rather than proportional to it.

Aerodynamic and road-load force

A single longitudinal resistance force is applied to the sprung mass, opposing forward motion:

$$F_x = -(C_1\,u|u| + C_2\,u + C_3\,\operatorname{sgn} u)$$

where u is the vehicle's forward velocity. The three terms are the conventional road-load breakdown: C_1 is the aerodynamic drag term, which grows with the square of speed; C_2 is a velocity-proportional term; and C_3 is a constant rolling term. The force is applied only above a forward speed of 1 in/sec, so that a stationary vehicle is not pushed backwards.

> **NOTE:** No aerodynamic side force, lift or moment is computed. The resistance acts along the vehicle's forward axis only.

Numerical integration

The equations of motion are advanced with a fixed-step method: a fourth-order Runge-Kutta start followed by a fixed-step Adams-Moulton predictor-corrector.

> **NOTE:** Unlike EDVDS, EDSVS and EDVTS, which halve the timestep when the predictor and corrector disagree, EDVSM's step is fixed — there is no automatic bisection and no convergence criterion to exceed. A manoeuvre that would cause those programs to subdivide will instead be integrated at the entered timestep, so the Vehicle Trajectory Integration Timestep matters more here. Reduce it and confirm the result is unchanged before relying on a run with rapid transients, curb strikes or large suspension excursions.

Driver inputs

Steering, braking and throttle come from the driver control tables, or — when the **Path Follower** is selected in Driver Controls — from HVE's closed-loop driver model, which computes the steering needed to follow the desired path. That model is shared across the HVE programs and is described in the HVE User's Manual and in reference 8 of this manual, not here.

Tire forces

EDVSM carries two separate tire models. A **radial spring model** produces the vertical force, and is what allows the vehicle to climb a curb or drop into a pothole: the tire is represented as a ring of radial springs, and the vertical force is the assembled reaction of every spring in contact with the terrain, so the force depends on the shape of the ground beneath the tire and not merely on the height of the wheel centre. The spring rate increases beyond a user-entered deflection to represent the tire bottoming on its rim.

The **shear forces** — longitudinal and lateral — are computed from the friction available at the contact patch.

The longitudinal friction coefficient varies with longitudinal slip, s. Below the slip at which friction peaks, s_p, it rises to the peak value. Above it, the coefficient falls along a parabola from the peak value to the sliding value at full lock:

$$\mu_x(s) = \mu_{Slide} + (\mu_{Peak} - \mu_{Slide})\left(\frac{s-1}{s_p-1}\right)^2, \qquad s_p \le s \le 1$$

The parabola is constructed with its vertex at $s = 1$, so the friction curve flattens as the wheel approaches full lock rather than continuing to fall.

The longitudinal force is then

$$F_x = -\mu_x F_z \operatorname{sgn} u_{Ground}$$

and the lateral force available is what is left of the friction envelope:

$$F_{s,max} = \sqrt{(\mu_y F_z)^2 - \varepsilon F_x^2}, \qquad \varepsilon = \left(\frac{\mu_y}{\mu_x}\right)^2$$

> **NOTE:** This is an *ellipse*, not the friction circle used by EDSMAC, EDSVS and EDVTS. The factor ε is the squared ratio of the lateral to the longitudinal friction coefficient, so the envelope is circular only where the two coefficients are equal. Where a tire's longitudinal and lateral friction differ — which is the normal case — EDVSM will not give the same combined-slip behaviour as the friction-circle programs for otherwise identical tire data.

The Fiala model is then applied to that remaining capacity through the non-dimensional sideslip parameter $\bar{\beta}$, formed from the tire's cornering stiffness, the slip angle and the available lateral force:

$$F_s = \begin{cases} F_{s,max}\left(\bar{\beta} - \dfrac{\bar{\beta}|\bar{\beta}|}{3} + \dfrac{\bar{\beta}^3}{27}\right), & |\bar{\beta}| < 3 \\ [10pt] F_{s,max}\ \operatorname{sgn}\bar{\beta}, & |\bar{\beta}| \geq 3 \end{cases}$$

A wheel is flagged as skidding when the Fiala model saturates, or when the longitudinal slip passes the peak — in either case only if the vertical load exceeds the minimum load for a skidmark, so that a lightly loaded wheel does not draw a mark.

A rolling resistance moment opposes wheel rotation once the spin rate exceeds a small threshold:

$$M_{Roll} = -C_{RR}\ F_z\ r\ \operatorname{sgn}\omega$$

Wheel spin

Each wheel carries a spin degree of freedom, advanced separately from the main ten-by-ten solution. The torque balance at a wheel is

$$I_{Spin}\ \dot{\omega} = T_{Drive} + T_{Brake} - F_x\ r + M_{Roll}$$

where T_{Drive} is that wheel's share of the axle torque and r is the wheel's rolling radius.

> **NOTE:** The two wheels of a driven axle are not independent. The differential couples them, so each wheel's spin acceleration depends on the brake torque, tire force and rolling resistance at **both** wheels of the axle. A wheel that loses traction therefore affects the spin of its partner, which is what allows the model to reproduce one-wheel spin on a split-friction surface.

Brake torques are limited at low wheel speed, so that a nearly stopped wheel cannot be driven backwards by its own brake.

Steering System

The steering system in EDVSM includes the steering gear ratio (steer angle at the steering wheel divided by the steer angle at the axle). This ratio is used when the

At Steering Wheel

steer table option is selected.

EDVSM also incorporates an extended version of HVOSM's Steer Degree of Freedom model. The Steer Degree of Freedom model is activated by selecting the

Normal

option in EDVSM's Calculation Options dialog (see the EDVSM Calculation Options reference).

> **NOTE:** The Append option is not supported by EDVSM.

The engineering model used by the Steer Degree of Freedom option is shown in Figure 4-1. The linkage is assumed to be rigid, thus the angular acceleration about the steering axis is the same for right-side and left-side wheels. External steer forces are generated at the tire-road interface, thus producing a moment about each tire's steering axis according to the tire's pneumatic trail. The moments are resisted by steer system inertia and internal coulomb friction. Steering is limited by right and left steering stops at each wheel.

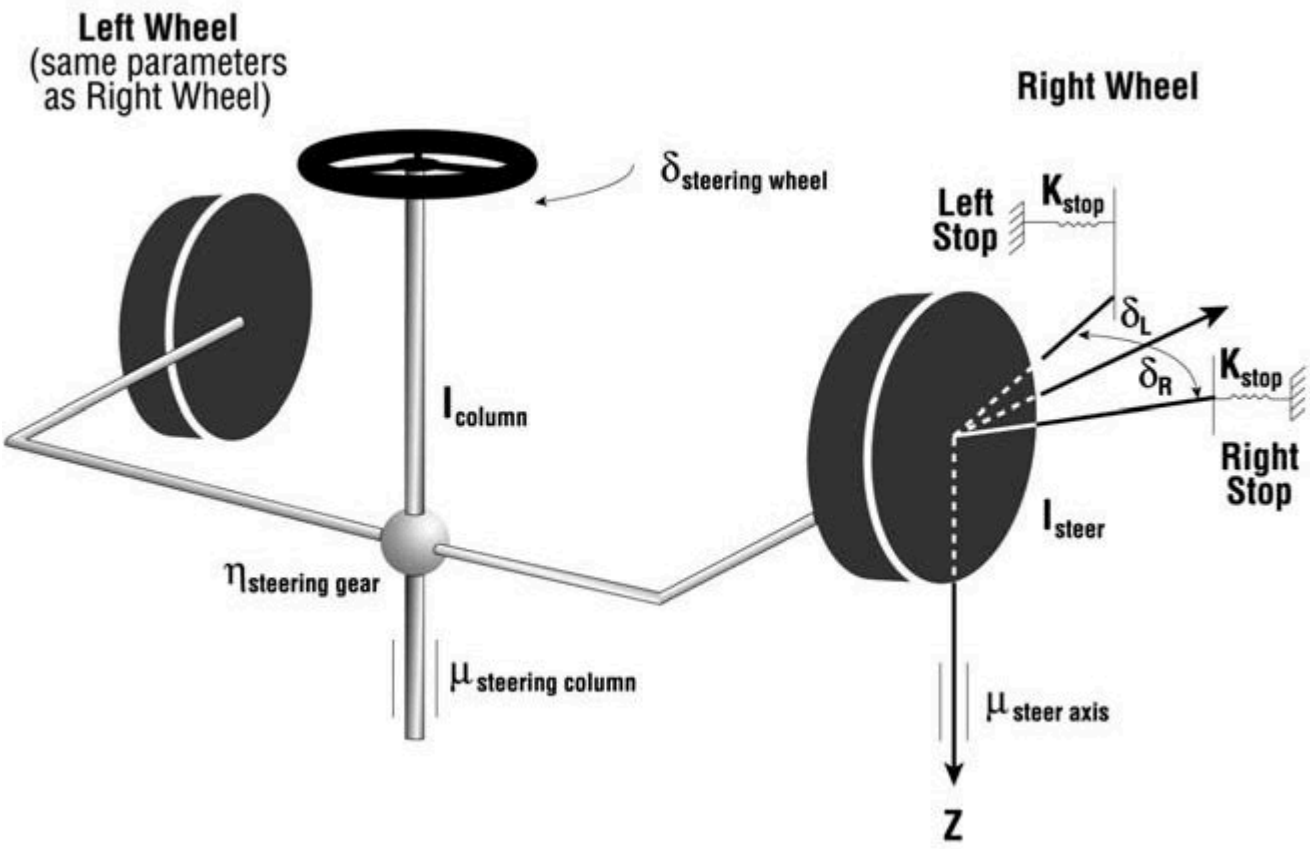


Figure 4-1: EDVSM steering system model used for the steer degree of freedom.

Application of Newton's 2nd law to the steering system, ignoring inertial coupling effects, results in

$$\sum M_{Steering} = I_{Steering}\,\ddot{\delta}$$

where

Symbol	Definition
$\sum M_{Steering}$	Sum of external moments acting on steering system components
$I_{Steering}$	Total rotational inertia of steering system components
δ	Steer angle of each steerable wheel about its steerable axis (thus, $\ddot{\delta}$ is the angular acceleration)

The sum of external moments is

$$\sum M_{Steering} = M_{Stops} + M_{Steer\ Axis\ Friction} + M_{Steering\ Column\ Friction} + M_{Tires}$$

where

Symbol	Definition
M_{Stops}	Moments about wheel steer axis produced by contact with steering stops
$M_{Steer\ Axis\ Friction}$	Moments about wheel steer axis produced by coulomb friction in the steering ball joints or king pin
$M_{Steering\ Column\ Friction}$	Moment about the steering column axis produced by coulomb friction between the steering shaft and bushings or bearings
M_{Tires}	Moments about the wheel steer axis produced by the tire forces and pneumatic trail at the tire-ground shear interface (contact patch)

Steering Stop Torque

Steer angles are limited by steering stops at the right- and left-side wheels. Each wheel's steering stops limit the steer angle for both right and left steering inputs for a given wheel; the right-steer and left-steer stop angles are assumed to be equal.

> **NOTE:** The user-entered value for the right steering stop is used as the stop angle for both left and right turns.

The steering stop torque at each stop is

$$M_{Stop} = \begin{cases} -K_{Stop}(|\delta_{Steer}| - \delta_{Stop})\operatorname{sgn}\delta_{Steer}, & |\delta_{Steer}| > \delta_{Stop} \text{ and } \operatorname{sgn}\dot{\delta}_{Steer} = \operatorname{sgn}\delta_{Steer} \\ [6pt]0, & \text{otherwise} \end{cases}$$

(updated: earlier editions gave the stop torque as a positive multiple of the overtravel. The torque opposes the overtravel, and it is released as soon as the wheel begins to turn back out of the stop, however far into the stop it still is.)

where

Symbol	Definition
K_{Stop}	Steering stop mechanical stiffness for specified steering stop
δ_{Steer}	Steer angle at wheel
δ_{Stop}	Angle of steering stop

The above equations are for right steer; a steer to the left produces the same torque magnitude but opposite in direction. The general characteristic for steer axis torque is shown in Figure 4-2.

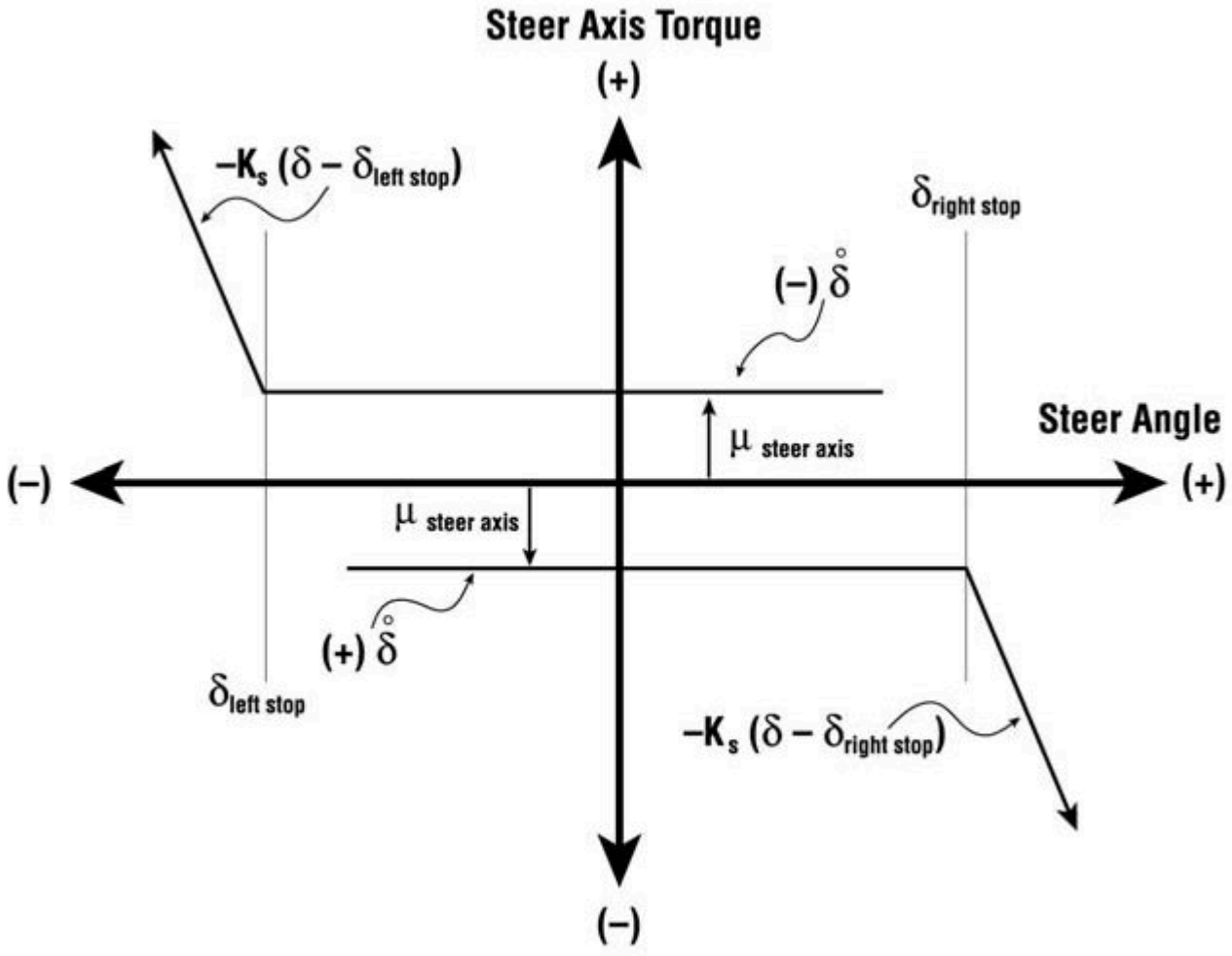


Figure 4-2: Steer axis friction and stop torque vs. steer angle.

Steer Axis and Steering Column Friction Torque

Friction torque is also produced by rotation of the wheel about its steer axis and by rotation of the steering shaft in the steering column bushings. However, no torque is produced unless the steer velocity is non-zero. Thus, a minimum value of steer velocity is required to develop the assigned frictional torque. This minimum steer velocity is called a friction *null band*. The combined steering friction torque for each wheel is

$$M_{SteerAxis+SteeringColumn} = \begin{cases} 0, & \text{for } |\dot{\delta}_{Steer}| \le \varepsilon \\ -(\mu_{SteerAxis} + 0.5\,\mu_{Steering\,Column})\operatorname{sgn}\dot{\delta}_{Steer}, & \text{for } |\dot{\delta}_{Steer}| > \varepsilon \end{cases}$$

(updated: earlier editions gave the friction torque without the sign that makes it oppose the steer velocity. Note also that the torque switches on abruptly at the null band rather than being blended through zero, so the null band should not be set larger than necessary.)

The steering column friction torque is referred to the wheel steer axis through the steering gear ratio before the half is taken, and half of the result is applied at each of the two wheels.

where

Symbol	Definition
ε	Steering friction null band
$\mu_{Steer\ Axis}$	Steer axis friction torque for each wheel
$\mu_{Steering\ Column}$	Steering column friction torque

Tire-Ground Torque

Forces at the tire-ground shear interface are the external input to the steering system. Because these forces do not act through the steer axis at its intersection with the ground plane (see Figure 4-3), an external moment about the steer axis is produced.

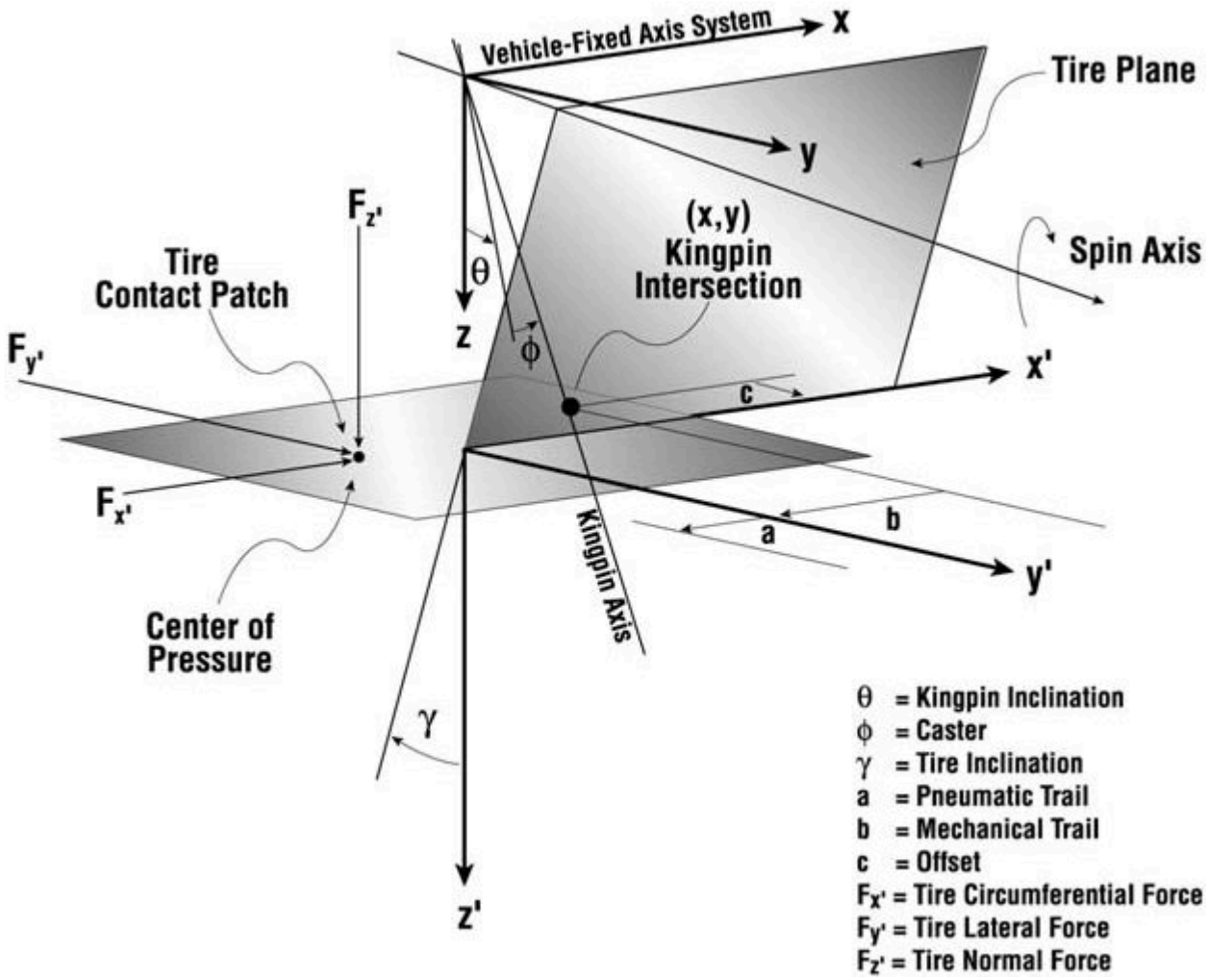


Figure 4-3: Close-up view of torque-producing mechanism at tire-ground shear interface.

Inspection of Figure 4-3 reveals the idealized point of application of the tire force, F_x, F_y, F_z, acts at a distance $b - a$ in the x' direction, and c in the y' direction, from the wheel steer axis intersection with the ground plane.

> **NOTE:** EDVSM assumes the offset, c, and mechanical trail, b, are zero.

The external moment thus produced about the steer axis at each tire is

$$M_{Tire} = -F_x(r_y + r_z\gamma) + F_y(r_x + (T_P + T_M)\cos\delta_G\cos\theta_x) + F_z(r_x\gamma)$$

where

Symbol	Definition
F_x, F_y, F_z	Vehicle-fixed tire force components
r_x, r_y, r_z	Vehicle-fixed components of distance from wheel center to tire-ground contact point
T_P	Tire pneumatic trail (a in Figure 4-3)
T_M	Mechanical trail (b in Figure 4-3; assumed = 0)
γ	Inclination angle (angle from tire z' axis to ground surface normal)
δ_G	Wheel vehicle-fixed steer angle relative to ground plane
θ_x	Angle from vehicle x-axis to ground plane

> **NOTE:** Unlike SIMON, EDVSM does not include a gyroscopic precession moment about the steer axis from the spinning wheels, and it does not include a scrub radius term. The mechanical trail really is treated as zero.

(updated: this note describes the scope of the EDVSM steering model relative to the more detailed treatment in SIMON.)

*(updated: hydroplaning is **not** modeled by EDVSM. The HVE physics library provides hydroplaning models (NASA, NASA-TTI, Gallaway), but only SIMON and EDSMAC4 invoke them; EDVSM offers no Hydroplaning Model calculation option, and any water-related tire output variables it reports are unused placeholders. See SIMON — Hydroplaning Model.)*

Steering System Rotational Inertia

The rotational inertia of the entire steering system is

$$I_{Steering} = I_{Steer,Rt} + I_{Steer,Lt} + I_{Column} \times \eta$$

where

Symbol	Definition
$I_{Steer,Rt}$	Total steer rotational inertia for right-side wheel: tire + rim + any steering portion of brake
$I_{Steer,Lt}$	Total rotational inertia for left-side wheel
I_{Column}	Total rotational inertia of steering column, including steering gearbox
η	Steering gear ratio

The steering column friction torque is scaled by the same ratio.

Chapter 5 — EDVSM Tutorial

Description

This tutorial is based on the EDVSM validation study described in SAE Paper No. 970895 [4]. The validation study includes a curb-tripped rollover of a Ford Bronco II. In this tutorial, we extend this validation study by illustrating how a tire blow-out at various wheel positions affects the vehicle response.

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

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

This basic procedure is described in detail in this tutorial.

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

Getting Started

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

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

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

- ON: Show Key Results
- OFF: Show Axes
- OFF: Show Contacts
- OFF: Show Velocity Vectors
- ON: Show Skidmarks
- OFF: Show Targets
- ON: AutoPosition
- Units equals U.S.
- Render Options:

- Show Humans as *Actual*
- Show Vehicles as *Actual*
- *Phong* Render Method
- Complexity equals *Object*
- Render Quality equals *5*
- 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.

Our goal is to use EDVSM to simulate a handling experiment conducted by the University of Missouri [6]. This tutorial shows us how to perform this simulation.

Creating the Vehicle

First let's add the vehicle to our case. The vehicle is a yellow 1984 Ford Bronco II:

- 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). The Ford Bronco II is a 4-wheel drive vehicle, but we're going to select 2-wheel drive for the tutorial.

- Using the option buttons, click each button to choose the following vehicle from the Vehicle Database:
- Type = *Sport-Utility*
- Make = *Ford*
- Model = *Bronco II*
- Year = *1984-1991*
- Body Style = *2-Door*
- Source Database = *Tutorial.db*
- Drive Axle = *Axle 2*

> **NOTE:** The Ford Bronco II is a 4-wheel drive vehicle. Because it was used in 2-wheel drive mode during the handling experiments, we must edit the default Drive Axle option.

- Edit the default name; enter `Ford Bronco II, Loaded`.
- Click *OK* to add *Ford Bronco, Loaded* to the Active Vehicles list.

The Ford Bronco II is displayed in the viewer, as shown in Figure 5-1.

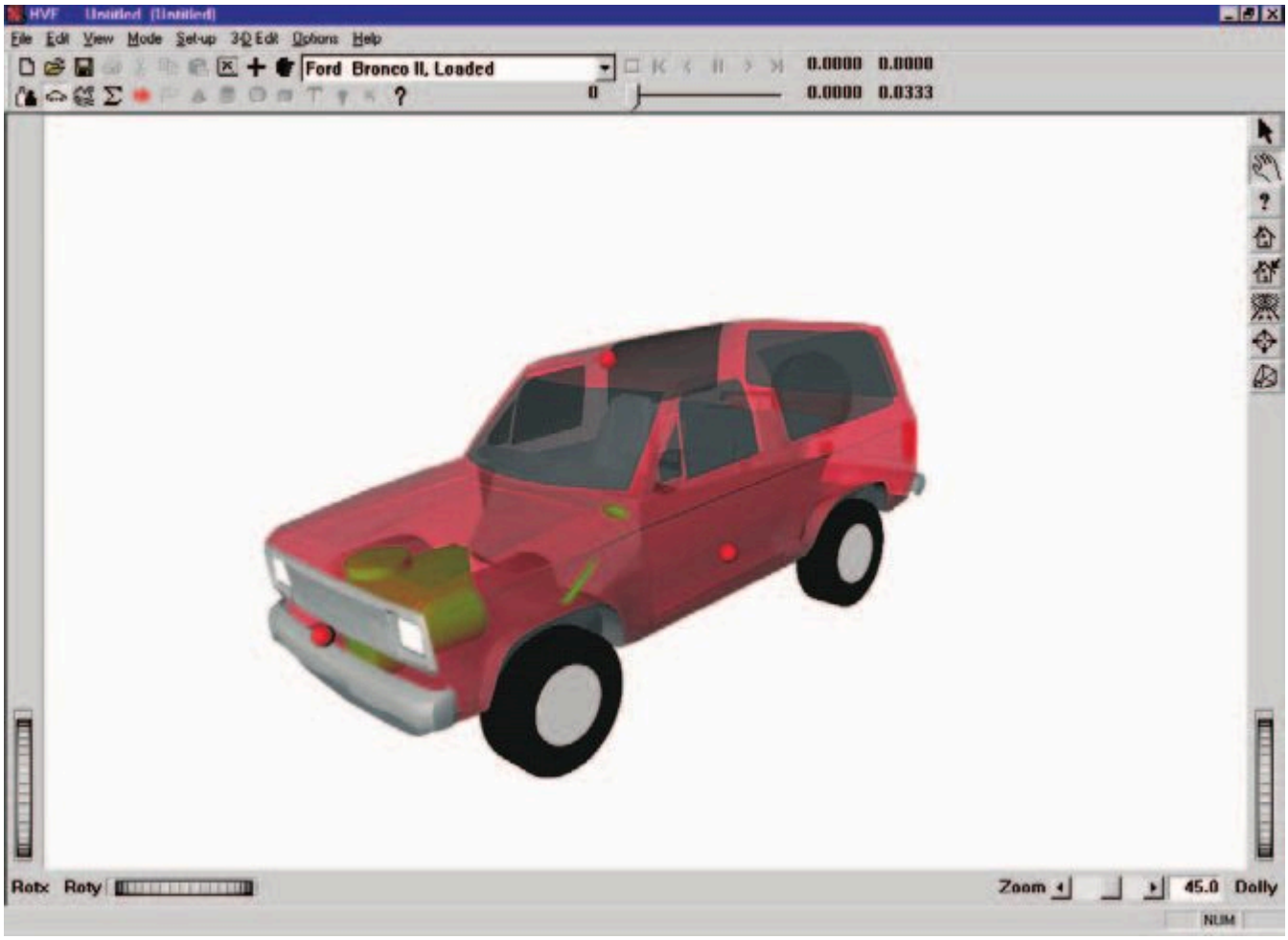


Figure 5-1: Ford Bronco II, Loaded before editing.

Editing the Vehicle

Next, we will edit the vehicle to change its color and inertias (the test vehicle was fitted with outriggers to prevent a catastrophic rollover; these outriggers and other test equipment affected the vehicle's inertial properties). In addition, we'll add an anti-sway bar to the rear suspension, and disable the left, front brake (this was done as part of the handling experiment to help ensure directional control and test repeatability).

To edit the color, perform the following steps:

- Click on the CG and choose *Color*. The Vehicle Color dialog is displayed (see Figure 5-2), 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 yellow area. To lighten the vehicle, click on the intensity slider and drag it to the far right end of the range.

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

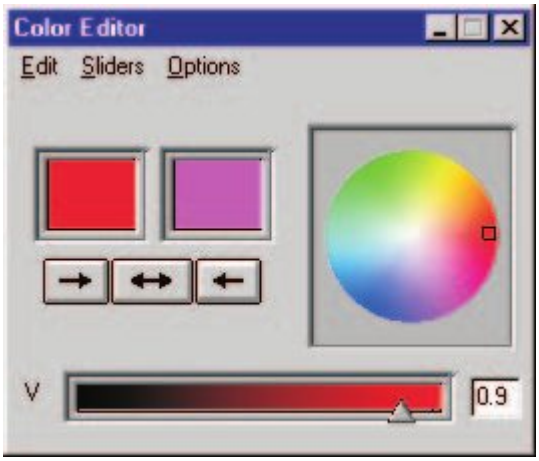


Figure 5-2: Vehicle Color dialog, used for assigning the vehicle color.

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

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

Next, let's change the weight and rotational inertias to account for the outriggers installed on the test vehicle to prevent rollover. Perform the following steps:

- Click on the CG and choose *Inertias*. The Inertias dialog is displayed, and we're ready to change the vehicle's inertias.
- In the *Total Weight* text field, replace the existing weight, 3594, with the measured (test) value, `4329.2` lb.

> **NOTE:** The dialog might initially display 3593.906, or a similar number, because the weight is actually divided by the current gravity constant and stored as mass. Extra precision results when the mass is multiplied by the current gravity constant and redisplayed.

- In the *Sprung Inertia, Roll* text field, replace the existing roll inertia, 3133.83, with the measured value, `5372.4` lb-sec²-in.
- In the *Sprung Inertia, Pitch* text field, replace the existing pitch inertia, 21680.97, with the measured value, `23666.9` lb-sec²-in.
- In the *Sprung Inertia, Yaw* text field, replace the existing yaw inertia, 23239.0, with the measured value, `26100.85` lb-sec²-in.

The Inertias dialog now appears as shown in Figure 5-3.

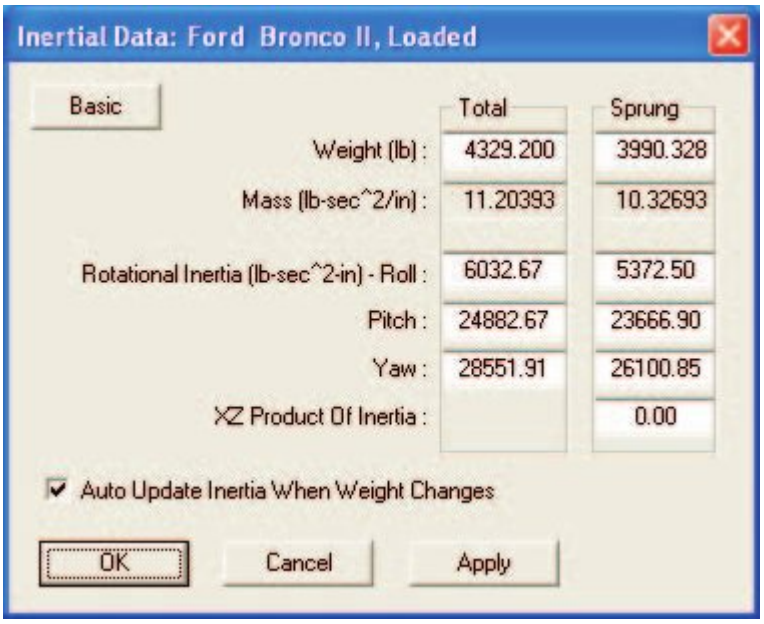


Figure 5-3: Vehicle Inertias dialog, used for editing the current weight and roll, pitch and yaw rotational inertias.

- Make sure the checkbox for *Auto Update Inertia When Weight Changes* is not selected, as you do not want to overwrite your input values.
- Press *OK* to accept the new weight and rotational inertias.

Next, let's add a 1-inch anti-sway bar at the rear suspension:

- Click on either rear wheel. The Wheel pop-up menu is displayed.
- Choose *Suspension*. The Suspension Information dialog for the selected wheel is displayed (see Figure 5-4).
- Choose *Springs and Shocks*. The Springs and Shocks dialog for the selected wheel is displayed.
- In the *Auxiliary Roll Stiffness* data field, replace the existing value, 0.00, with the calculated value for a 1-inch anti-sway bar, `1310.0` in-lb/deg. The dialog now appears as shown in Figure 5-5.

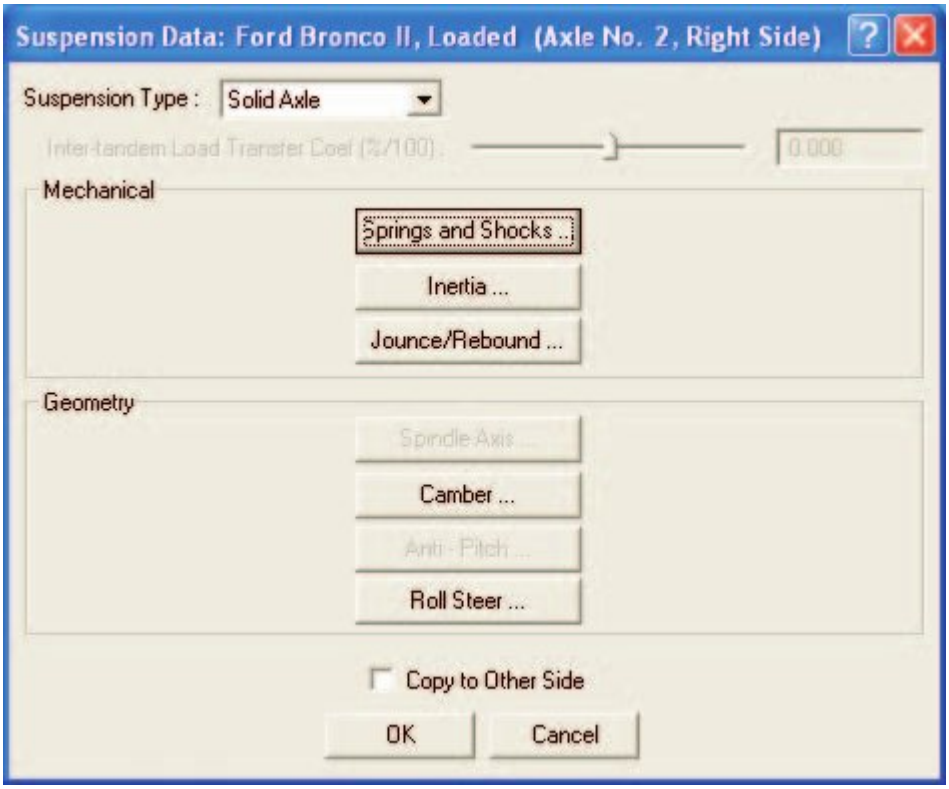


Figure 5-4: Vehicle Suspension Information dialog, used for selecting various suspension data groups for editing.

- Press *OK* to accept the new auxiliary roll stiffness.
- Press *OK* again to remove the Suspension Information dialog.

Finally, let's disable the left front brake by setting its brake torque ratio to zero:

- Click on the left front wheel. The Wheel pop-up menu is displayed.
- Choose *Brake*. The Brake Assembly dialog for the left front wheel is displayed.
- In the *Torque Ratio* data field, replace the existing value, 27.66 in-lb/psi, with the desired value, `0.0`, to disable the left front brake. The dialog now appears as shown in Figure 5-6.
- Press *OK* to accept the modified brake torque ratio for the left front wheel.

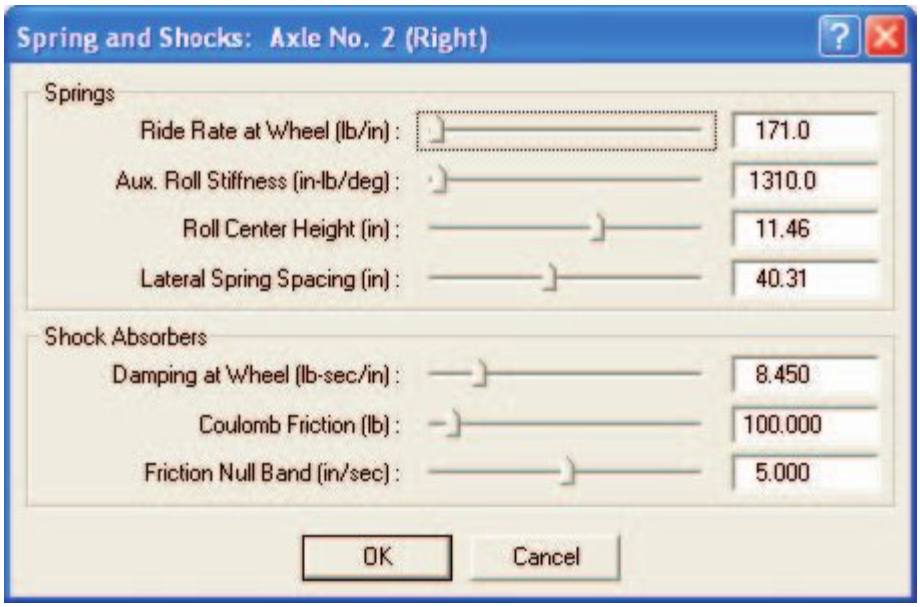


Figure 5-5: Springs and Shocks dialog, used for editing the current auxiliary roll stiffness due to the anti-sway bar.

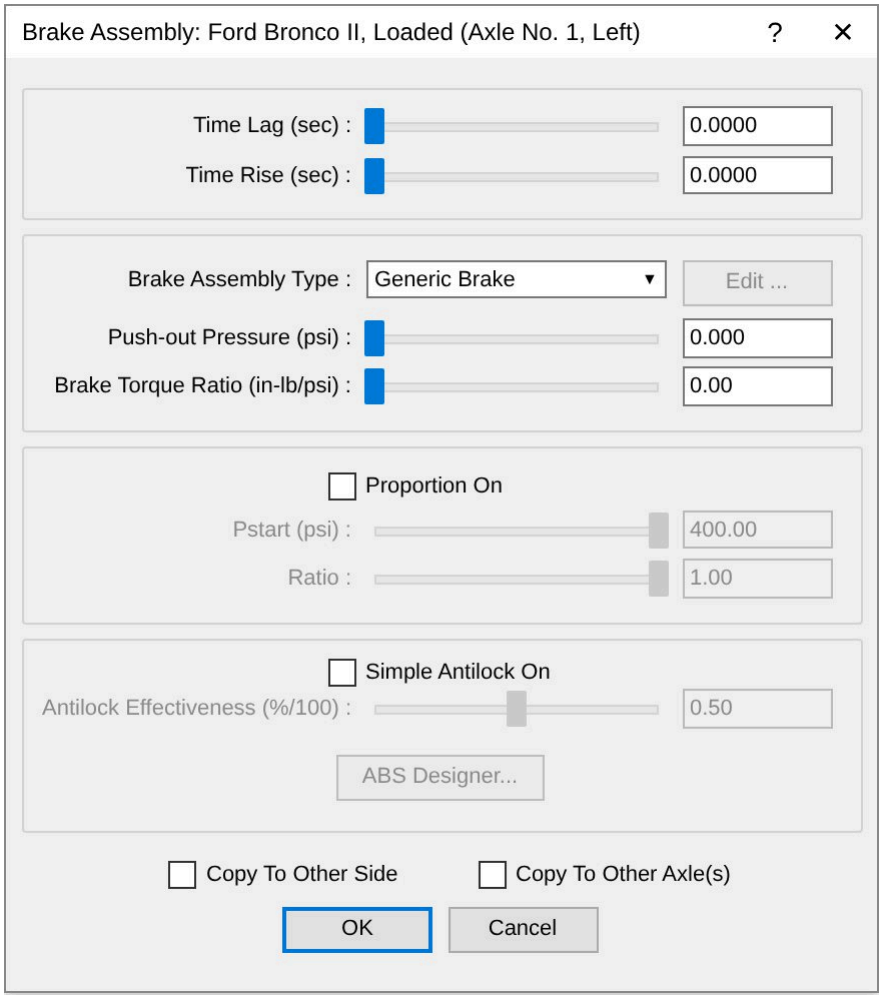


Figure 5-6: Wheel Brake dialog, used for editing the brake parameters for the left front wheel.

The vehicle is now ready for use in our events. Using the viewer thumb wheel, rotate and look at the vehicle. Note that the thumb wheels rotate the vehicle about the *viewer* axes, not the *vehicle* axes.

> **NOTE:** Remember HVE's 3-D viewers have 2 modes: Pick and Manipulate (the icon in the upper right corner of the viewer displays the current mode). In Pick mode, you can use the thumb wheels to adjust the view. In Manipulate mode, you can use the left mouse button to rotate the view and the middle mouse button to pan back and forth. Refer to the HVE User's Manual, Overview (Window Manager Basics) for more information about using HVE's viewer controls.

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 *Jefferson City, Missouri, USA*. The latitude (38.58N), longitude (92.20W) and GMT, hours from the prime meridian (-6.00), are displayed for the selected location.
- Edit the date and time of the experimental study, `7/11/93` and `1500`, respectively.
- Edit the angle from *true north* to the earth-fixed X axis in our environment, `165` 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.

- Edit the default environment name; enter `Jefferson City Airport`.
- 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 Files)*. A list of environment geometry files using the HVE file format is displayed in a list box. Double-click on *EDVSMValidAASHTOCurb.h3d* to choose the environment file and remove the dialog.
- Press *OK*.

The selected environment is added to our case and displayed in the Environment Viewer (see Figure 5-7). Use the viewer thumb wheels to view the scene.

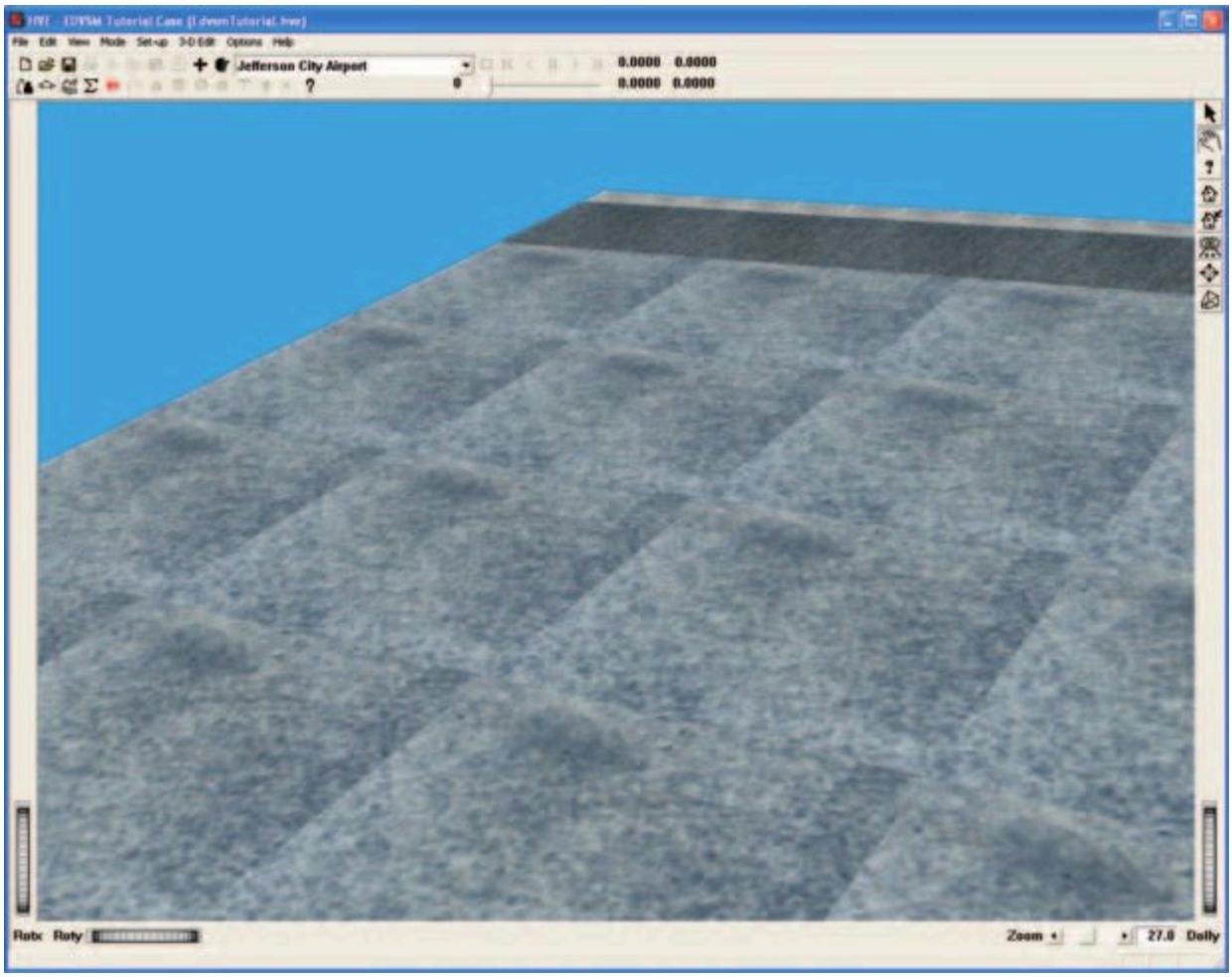


Figure 5-7: 3-D Environment used for our EDVSM tutorial.

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, replace Untitled with `EDVSM Tutorial Case`.

> **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 `EdvsmTutorial`.
- Click *SAVE*. The current case data are saved in the `hve/supportFiles/case` subdirectory.

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

Creating the Events

As mentioned at the outset of the tutorial, our EDVSM tutorial includes several events. The first event is a curb-tripped rollover prepared as part of the EDVSM validation project. The next four events simply use the first event, and introduce a blow-out at each of the four tires.

Rollover Validation Event

To create the rollover 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 *Ford Bronco II, Loaded* from the Active Vehicles list.
- Select *EDVSM* from the *Calculation Method* options list.
- Enter a name for the event, `Curb-tripped Rollover`.

> **NOTE:** HVE will append the name of the calculation method to the event name, thus the complete event name will become "EDVSM, Curb-tripped Rollover."

- Press *OK* to display the event editor.

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

- Using the Event Editor dialog, select *Ford Bronco II, Loaded* from the Event Humans & Vehicles list, then choose *Set-up* from the menu bar and select *Position/Velocity*. The Ford Bronco is displayed at the earth-fixed origin.
- If the Bronco is not visible in the viewer, use the *Dolly* thumb wheel to dolly back until the Bronco becomes visible. Then, pan the viewer until the vehicle is in the center of the viewer, and dolly back in (a good exercise in using viewers!).
- Click on the vehicle's X-Y manipulator (see Figure 5-8), wait for it to turn bright yellow (indicating it has been selected), and drag it to its initial position, X=`123` ft, Y=`0` ft. Its initial heading angle is 0 degrees and need not be modified.

> **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 enough of the entire scene.

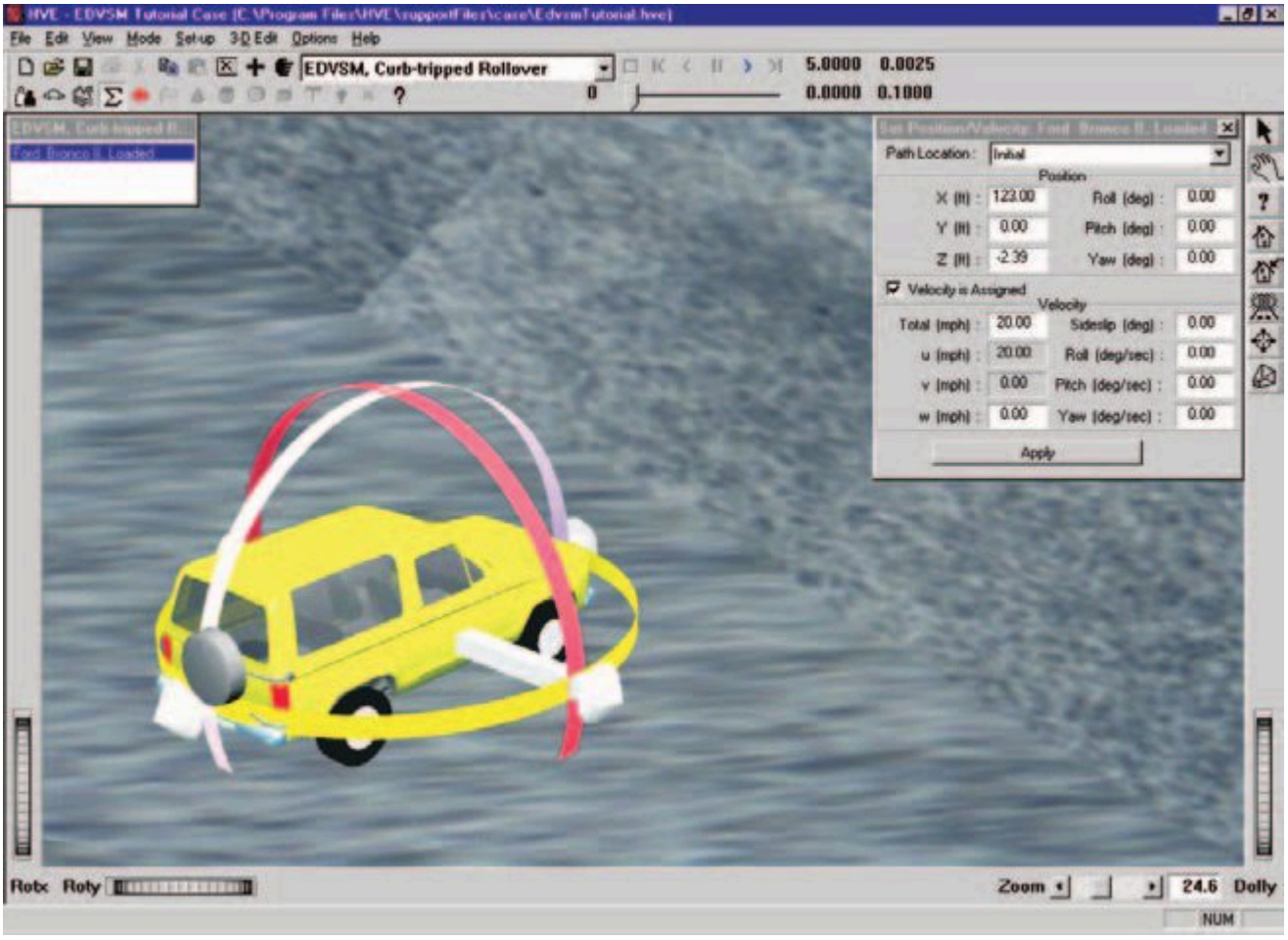


Figure 5-8: Vehicle positioning using the HVE Event Editor. The manipulators can be used to drag and drop the vehicle into position.

> **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 5-8).
>
> **NOTE:** If you can't position the vehicle at the exact coordinates, simply enter them in the dialog (in fact, it's often easier to directly enter the coordinates using the dialog).

- Click the *Velocity Is Assigned* checkbox. Enter the initial velocity, `20` mph.

> **NOTE:** Remember to press Apply or \<Enter> after entering a value; otherwise the value is not assigned!

The vehicle initial conditions are now established. Let's enter the driver controls. The steering inputs were obtained from the validation study [reference 4]. However, the throttle, brake and gear selection were not documented in the study and were determined by repeated adjustments until the correct vehicle acceleration was achieved.

Steering Input

To enter the steer angles, perform the following steps:

- Click on the Set-up Menu, select *Driver Controls*. The Driver Controls dialog is displayed with an empty steer table.
- Click on the *Table* option list and choose the *At Axle* option.
- Enter the steer angles for the front wheels, as shown below:

Table 5-1: Steer Table entries for the Ford Bronco.

Time (sec)	Steer Angle at Axle (deg), Right Front	Steer Angle at Axle (deg), Left Front
0.00	0.00	0.00
7.42	0.20	0.20
7.97	1.19	1.19
8.63	3.50	3.50
10.21	4.00	4.00
12.00	4.00	4.00

The steering table is now ready for our event.

Throttle Input

To enter the throttle table, perform the following steps:

- Click on the Driver Controls dialog's *Throttle* tab. The Throttle Table is displayed.
- Click on the *Table* option list and choose the *Wide-open Throttle* option.
- Enter the throttle position, as shown below.

Table 5-2: Throttle Table entries for the Ford Bronco.

Time (sec)	Throttle Position (Percent WOT)
0.00	0.78
5.30	0.78
7.50	0.60
10.30	0.57
10.40	0.00

The throttle table is now ready for our event.

Gear Selection Input

To enter the gear selection, perform the following steps:

- Click on the Driver Controls dialog's *Gear* tab. The Gear Selection Table is displayed.
- Click on the *Number of Shifts* option list and choose *1 Shift*.
- Enter the time and gear selection, as shown below:

Table 5-3: Gear Selection table entries for the Ford Bronco.

Time (sec)	Gear Selection
0.00	Shift Into 2nd

> **NOTE:** The gear selection and throttle tables were created by trial and error as required to match the experimental and simulated velocity profiles.

Brake Input

To enter the brake input, perform the following steps:

- Click on the Driver Controls dialog's *Brakes* tab. The Brake Table is displayed.
- Click on the *Table Is* option list and choose Pedal *Force*.
- Enter the brake pedal force, as shown below:

Table 5-4: Brake Table entries for the Ford Bronco.

Time (sec)	Brake Pedal Force (lb)
10.30	0.00
10.40	10.75

- Press *OK* to accept the driver control tables.

The driver control inputs are now complete.

Simulation Controls

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 `15` seconds.
- Press *OK* to update the simulation controls.

Calculation Options

In this event, we intend to simulate the rollover of a vehicle where the body of the vehicle may contact the ground. We need to activate the *Vehicle Body vs. Environment Contact* subroutine by checking the *Vehicle Body vs. Environment Contact* checkbox in the Calculation Options dialog (see the EDVSM Calculation Options reference for a description of all EDVSM calculation options).

- Click on the Options menu and choose *Calculation Options*. The Calculation Options dialog is displayed.
- Click the checkbox for *Vehicle Body vs. Environment Contact*.
- Press *OK* to update the calculation options.

Key Results

Let's look at some Key Results during execution:

- If the Key Results window is not displayed, choose *Show Key Results* from the Options menu.
- Drag the Key Results window to a convenient location, where it does not block the view but still allows access to the viewer thumb wheel controls (in case we want to change the view).

- Click on *Select Variables* in the *Ford Bronco II, Loaded* Key Results window. The Variable Selection dialog for *Ford Bronco II, Loaded* is displayed.

The vehicle kinematics are already selected. Let's add *Tire Fx', Fy', Fz'* and *Steer Angle* to the Key Results window:

- Click *Tires, Axle 1, Right, Outer* from the variable group list. The Variable Selection list for the right front tire is displayed (see Figure 5-9).

> **NOTE:** For calculation methods that support dual-tired vehicles, you can select the 'Inner' or 'Outer' tire; however, EDVSM does not support dual tires.

- Select *Fx', Fy', and Fz'* tire forces from the list.

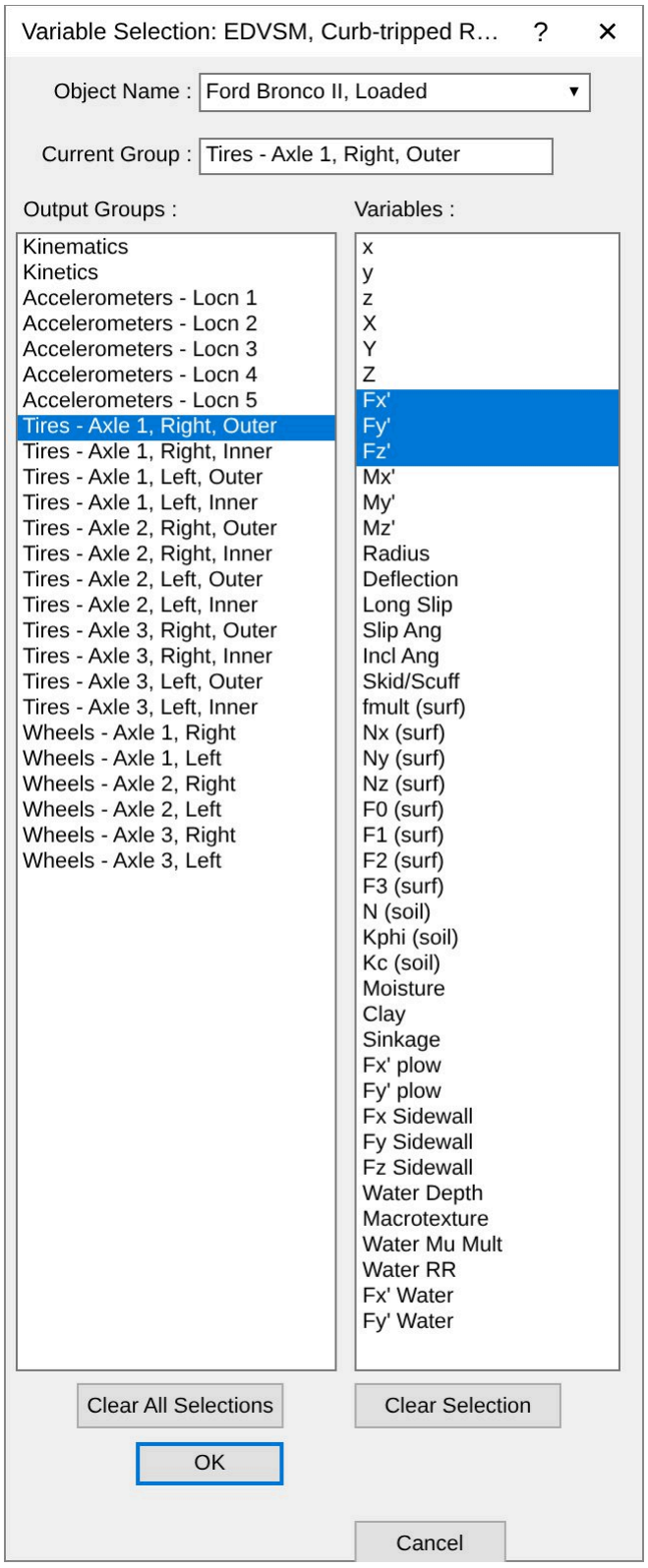


Figure 5-9: Key Results Variable Selection dialog, used for selecting variables to be displayed in the Key Results window.

- Repeat the above steps by choosing the tire forces for the left front, right rear and left rear tires.

Now, let's add the wheel steer angles to our Key Results window:

- Click *Wheels, Axle 1, Right* from the variable group list. The Variable Selection list for the right front wheel is displayed.
- Choose *Delta* from the Variable Selection list.
- Repeat the above steps to choose Delta for the left front wheel.
- Press *OK* to add the selected variables to the Key Results window.

Now, we're ready to execute the event.

- Using the Event Controller, click *Play* to execute the event. Allow the event to run until the vehicle strikes the curb and rolls over.

> **NOTE:** The simulation terminates with an error because the vehicle travels beyond the terrain boundary.

The EDVSM event is shown in Figure 5-10.

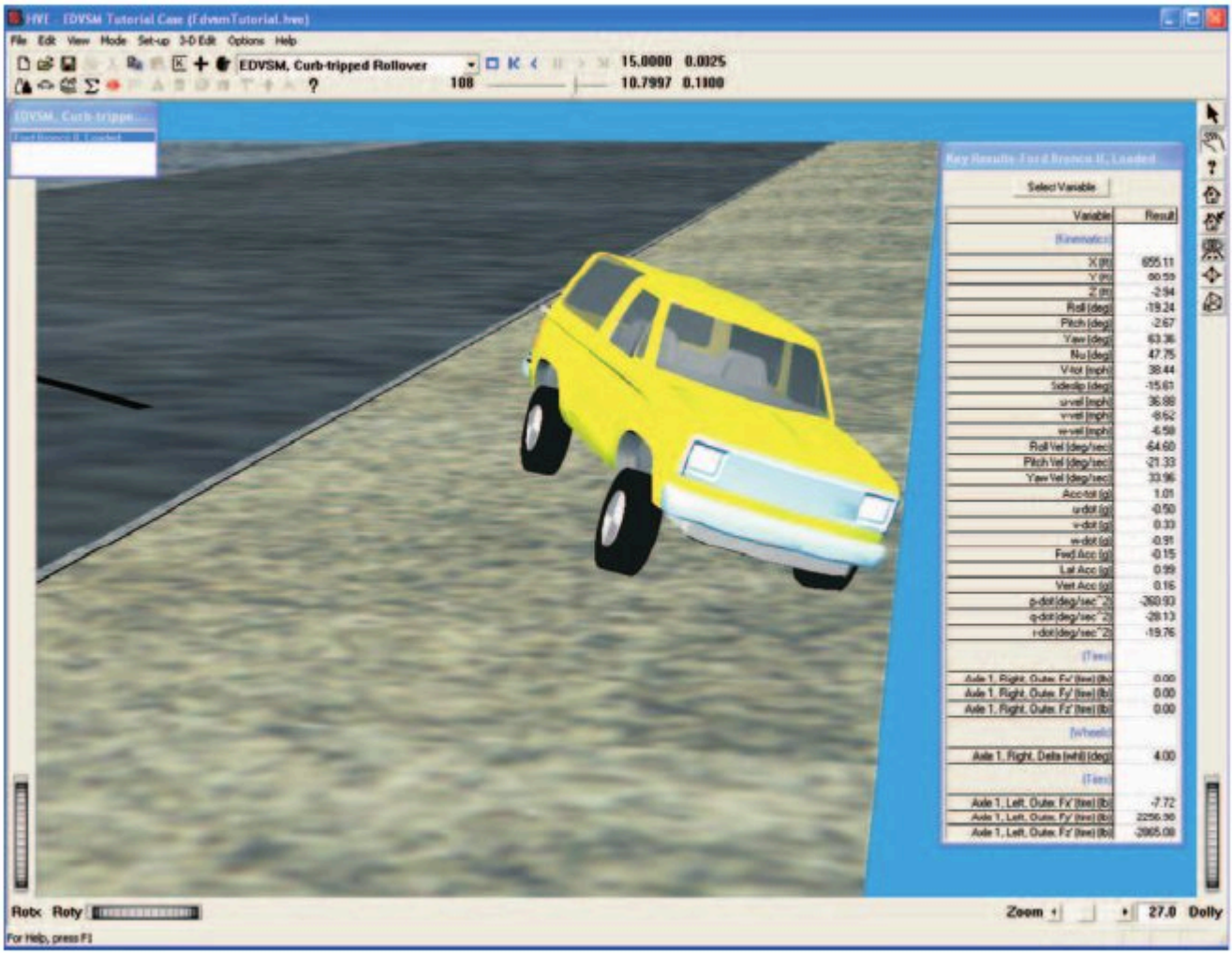


Figure 5-10: HVE Event Editor executing the EDVSM Curb-tripped Rollover event.

> **NOTE:** While the event is executing, watch the current results in the Key Results windows.

We have now completed the first event.

Creating Tire Blow-out Simulations

The next four events in our Tutorial use EDVSM to study the vehicle's response to a loss of pressure at various tire locations during a cornering maneuver. In this parameter study, we will change only the wheel location at which the blow-out occurs, so any difference in vehicle response is attributable solely to the location of the blown tire. To simplify our study, we'll use the current environment.

To study the effect of a blow-out at the right front tire, perform the following steps:

- Click on *Add New Object*. The Event Information dialog is displayed.
- Select *Ford Bronco II, Loaded* from the Active Vehicles list.
- Select *EDVSM* from the *Calculation Method* options list.
- Edit the event name: `R/F Tire Blow-out`.
- Press *OK* to display the event editor.

Now, we're ready to set up (i.e., supply

position, velocity, driver controls and tire blow-out parameters

) for the right front tire blow-out event.

- Choose *Set-up* from the menu bar and select *Position/Velocity*. The Ford Bronco is displayed at the earth-fixed origin.
- Using the Position/Velocity dialog, enter the vehicle's initial position, X=`123` ft, Y=`0` ft. Its initial heading angle is 0 degrees and need not be modified.
- Click the *Velocity Is Assigned* checkbox. Enter the initial velocity, `50` mph.

The vehicle initial conditions are now established. Let's enter the driver controls. Only steering inputs need to be supplied. To enter the steer angles, perform the following steps:

- Choose *Set-up* from the menu bar and select *Driver Controls*. The Driver Controls dialog is displayed with the default steer table. The default steer table option, *At Steering Wheel*, is the option we'll use in our study.
- Enter the steering wheel angles, as shown below:

Table 5-5: Steer Table entries for the EDVSM Blow-out Studies events. (The same table will be used for all blow-out simulation events.)

Time (sec)	Steer Angle at Steering Wheel (deg)
1.00	0.0
1.50	45.0

- Press *OK* to accept the steer table.

Now, let's set up the HVE Tire Blow-out Model.

- Choose *Set-up* from the menu bar and select *Wheels*. The Wheels dialog is displayed with the Tire Blow-out information (see Figure 5-11).
- Click on the *Axle No.* option list and choose *Axle No. 1*. Click on the *Right* side radio button. Click in the *Tire is Blown* check box. The default blow-out parameters for the right front tire are displayed.
- Enter the *Start Time*, `3.0` seconds.

- Enter the *Duration*, `0.2` seconds.
- Enter the *Stiffness Factor*, `0.10`.

> **NOTE:** The Stiffness Factor reduces the tire's radial tire stiffness, cornering stiffness and camber stiffness.

- Enter the Rolling Resistance Factor, `10`.

> **NOTE:** The Rolling Resistance Factor increases the tire rolling resistance.

- Press *OK* to apply the tire blow-out parameters.

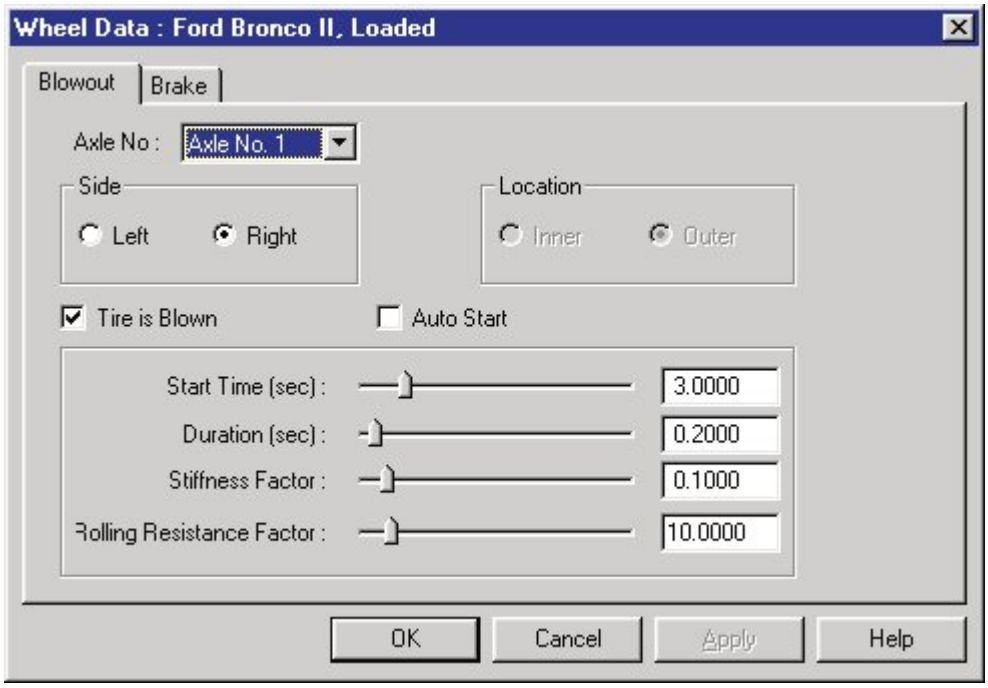


Figure 5-11: HVE Wheels dialog with Tire Blow-out Model option.

Now, we're ready to execute the event.

- Using the Event Controller, click *Play* to execute the event to simulate the loss of pressure at the right front tire. Allow the event to run until the simulation terminates at t = 5.00 seconds.

The EDVSM event is shown in Figure 5-12.

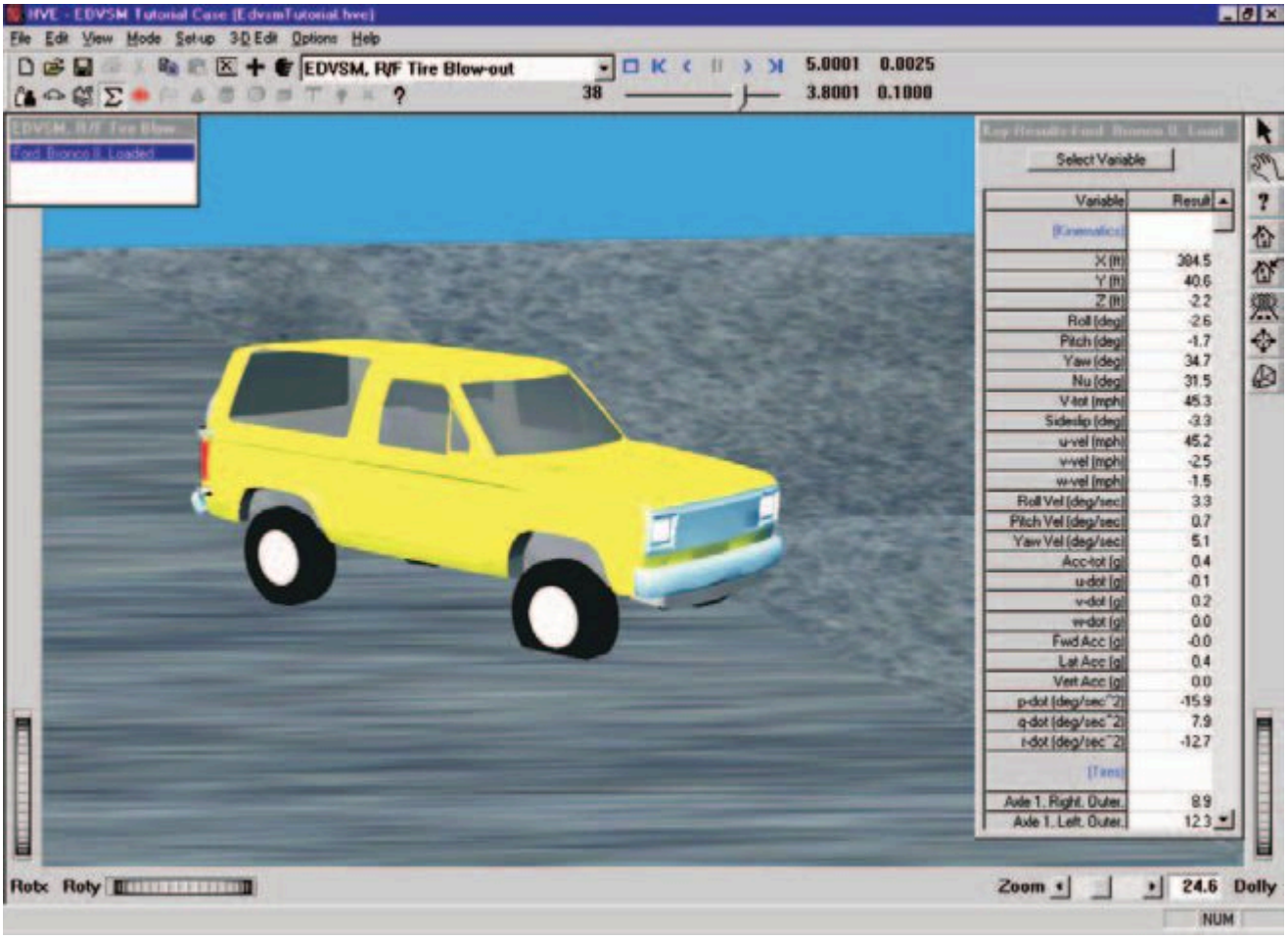


Figure 5-12: HVE Event Editor executing the EDVSM R/F Tire Blowout simulation.

> **NOTE:** While the event is executing, watch the current results in the Key Results windows.

To study the effect of a blow-out at the left front tire, perform the following steps:

- Click on *Add Event*. The Event Information dialog is displayed.
- Select *Ford Bronco II, Loaded* from the Active Vehicles list.
- Select *EDVSM* from the *Calculation Method* options list.
- Enter a name for the event, `L/F Tire Blow-out`.
- Press *OK* to display the event editor.

Repeat the steps used in the previous event to set up our left front tire blow-out simulation:

- Choose *Set-up* from the menu bar, select *Position/Velocity*.
- Directly enter the vehicle's initial position, X=`123` ft, Y=`0` ft. Its initial heading angle is 0 degrees and need not be modified.
- Click the *Velocity Is Assigned* checkbox. Enter the initial velocity, `50` mph.

To enter the steer angles, perform the following steps:

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

- Enter the steering wheel angles, as shown earlier in Table 5-5.
- Press *OK* to accept the steering table.

Now, let's set up the HVE Tire Blow-out Model.

- Choose *Set-up* from the menu bar and select *Wheels*. The Wheels dialog is displayed with the Tire Blow-out information.
- Click on the *Axle No.* option list and choose *Axle No. 1*. Click on the *Left* side radio button. Click in the *Tire is Blown* check box. The default blow-out parameters for the left front tire are displayed.
- Enter the *Start Time*, `3.0` seconds.
- Enter the *Duration*, `0.2` seconds.
- Enter the *Stiffness Factor*, `0.10`.
- Enter the Rolling Resistance Factor, `10`.
- Press *OK* to apply the tire blow-out parameters.

Now, we're ready to execute the event.

- Using the Event Controller, click *Play* to execute the event to simulate the loss of pressure at the left front tire. Allow the event to run until the simulation terminates at t = 5.00 seconds.

The EDVSM event is shown in Figure 5-13.

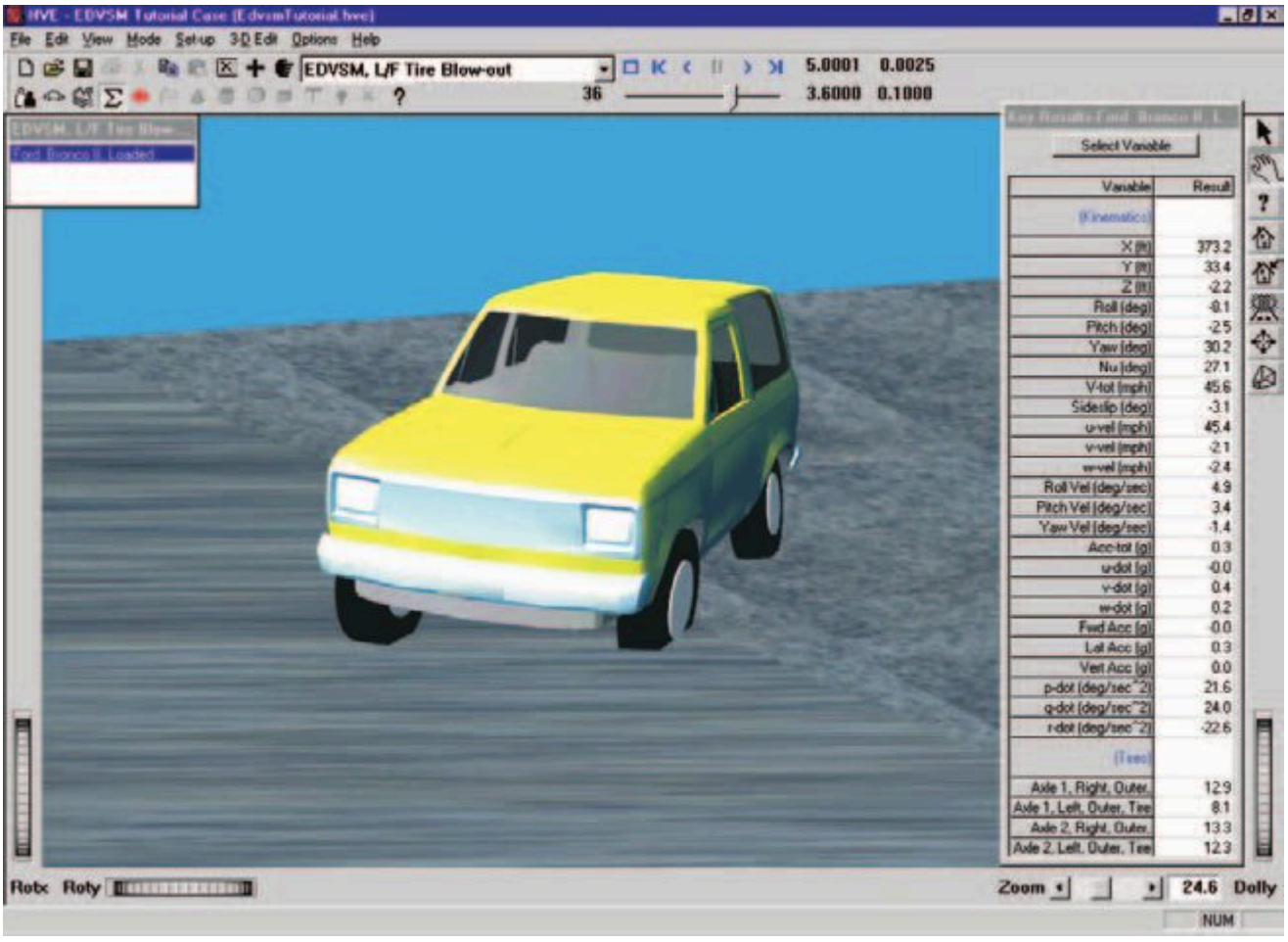


Figure 5-13: HVE Event Editor executing the EDVSM L/F Tire Blowout simulation.

> **NOTE:** While the event is executing, watch the current results in the Key Results windows.

To study the effect of a blow-out at the right rear tire, perform the following steps:

- Click on *Add Event*. The Event Information dialog is displayed.
- Select *Ford Bronco II, Loaded* from the Active Vehicles list.
- Select *EDVSM* from the *Calculation Method* options list.
- Enter a name for the event, `R/R Tire Blow-out`.
- Press *OK* to display the event editor.

Repeat the steps used in the previous event to set up our right rear tire blow-out simulation:

- Choose *Set-up* from the menu bar, select *Position/Velocity*.
- Directly enter the vehicle's initial position, X=`123` ft, Y=`0` ft. Its initial heading angle is 0 degrees and need not be modified.
- Click the *Velocity Is Assigned* checkbox. Enter the initial velocity, `50` mph.

To enter the steer angles, perform the following steps:

- Click on the *Set-up* Menu, select *Driver Controls*. The Steering Table dialog is displayed.
- Enter the steering wheel angles, as shown earlier in Table 5-5.
- Press *OK* to accept the steering table.

Now, let's set up the HVE Tire Blow-out Model.

- Choose *Set-up* from the menu bar and select *Wheels*. The Wheels dialog is displayed with the Tire Blow-out information.
- Click on the *Axle No.* option list and choose *Axle No. 2*. Click on the *Right* side radio button. Click in the *Tire is Blown* check box. The default blow-out parameters for the right rear tire are displayed.
- Enter the *Start Time*, `3.0` seconds.
- Enter the *Duration*, `0.2` seconds.
- Enter the *Stiffness Factor*, `0.10`.
- Enter the Rolling Resistance Factor, `10`.
- Press *OK* to apply the tire blow-out parameters.

Now, we're ready to execute the event.

- Using the Event Controller, click *Play* to execute the event to simulate the loss of pressure at the right rear tire. Allow the event to run until the simulation terminates at t = 5.00 seconds.

The EDVSM event is shown in Figure 5-14.

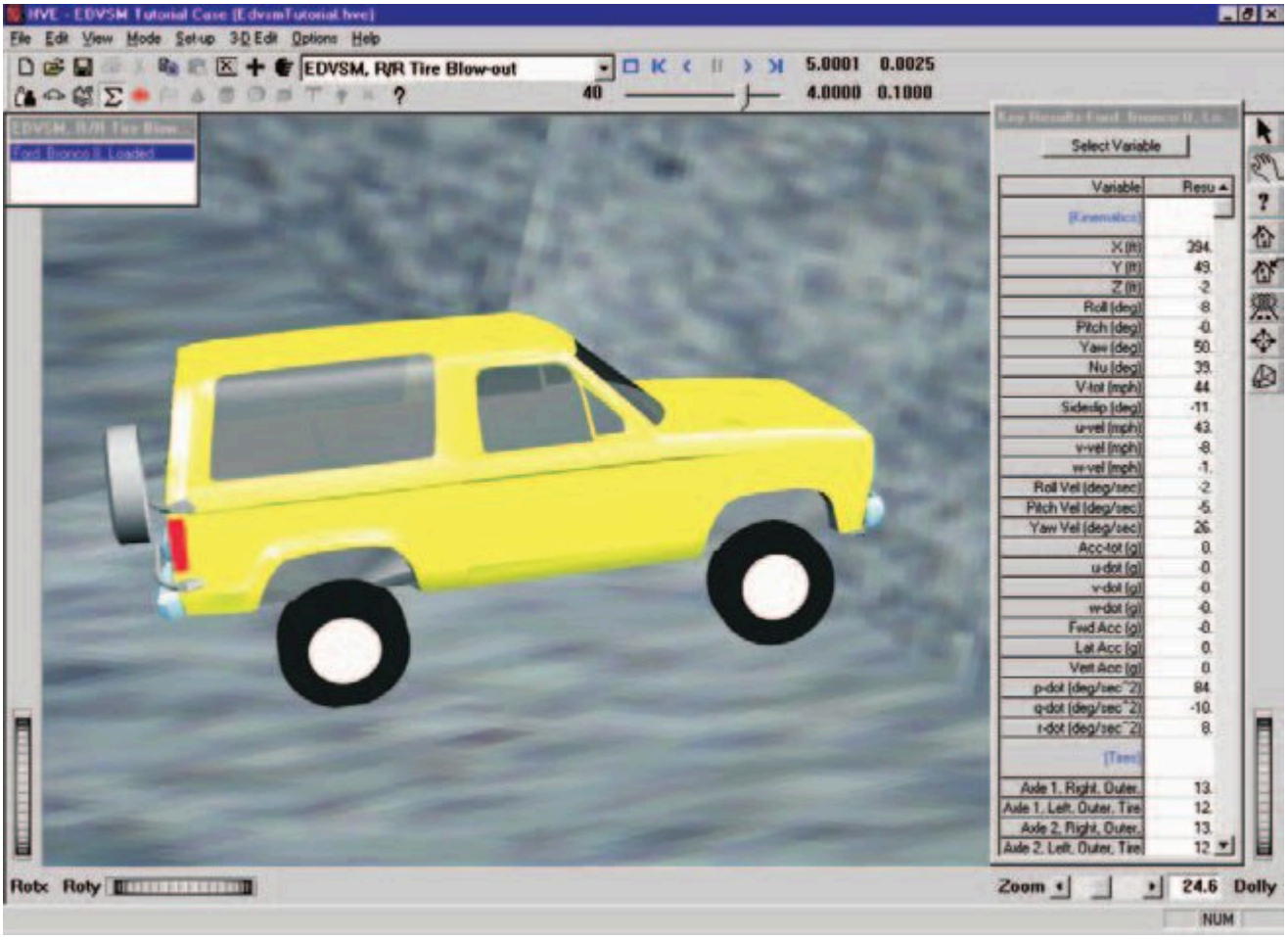


Figure 5-14: HVE Event Editor executing the EDVSM R/R Tire Blowout simulation.

> **NOTE:** While the event is executing, watch the current results in the Key Results windows.

To study the effect of a blow-out at the left rear tire, perform the following steps:

- Click on *Add Event*. The Event Information dialog is displayed.
- Select *Ford Bronco II, Loaded* from the Active Vehicles list.
- Select *EDVSM* from the *Calculation Method* options list.
- Enter a name for the event, `L/R Tire Blow-out`.
- Press *OK* to display the event editor.

Repeat the steps used in the previous event to set up our left rear tire blow-out simulation:

- Choose *Set-up* from the menu bar and select *Position/Velocity*.
- Directly enter the vehicle's initial position, X=`123` ft, Y=`0` ft. Its initial heading angle is 0 degrees and need not be modified.
- Click the *Velocity Is Assigned* checkbox. Enter the initial velocity, `50` mph.

To enter the steer angles, perform the following steps:

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

- Enter the steering wheel angles, as shown earlier in Table 5-5.
- Press *OK* to accept the steering table.

Set up the HVE Tire Blow-out Model.

- Choose *Set-up* from the menu bar and select *Wheels*. The Wheels dialog is displayed with the Tire Blow-out information.
- Click on the *Axle No.* option list and choose *Axle No. 2*. Click on the *Left* side radio button. Click in the *Tire is Blown* check box. The default blow-out parameters for the left rear tire are displayed.
- Enter the *Start Time*, `3.0` seconds.
- Enter the *Duration*, `0.2` seconds.
- Enter the *Stiffness Factor*, `0.10`.
- Enter the Rolling Resistance Factor, `10`.
- Press *OK* to apply the tire blow-out parameters.

Now, we're ready to execute the event.

- Using the Event Controller, click *Play* to execute the event to simulate the loss of pressure at the left rear tire. Allow the event to run until the simulation terminates at t = 5.00 seconds.

The EDVSM event is shown in Figure 5-15.

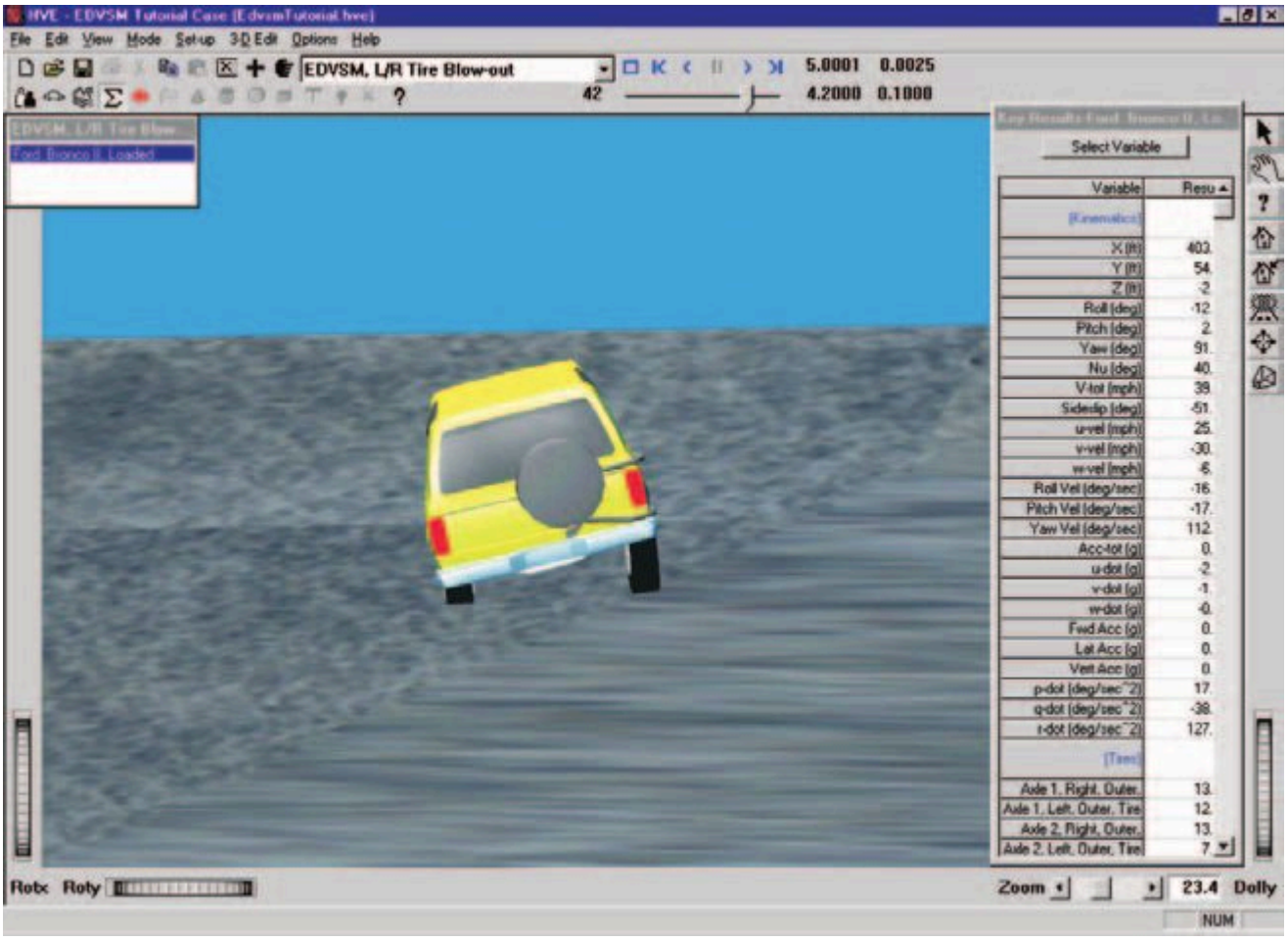


Figure 5-15: HVE Event Editor executing the EDVSM L/R Tire Blowout simulation.

> **NOTE:** While the event is executing, watch the current results in the Key Results windows.

We have now created four events simulating a tire blow-out. The only difference in these events is the location of the blown tire. Thus, any differences in vehicle behavior are attributable solely to the location of the blown tire.

Observations

Note the vehicle is in a right turn, thus the vertical tire force is shifted from the right-side to the left-side tires. As a result, the left-side (outside) tires are more heavily loaded and produce a greater portion of the cornering force.

It follows, then, that a blow-out in the left-side tires should have a greater effect on vehicle handling and controllability. This fact is confirmed by the simulation results.

Note also the difference in vehicle cornering response for blow-outs at the front tires compared to the rear tires. Front tire blow-outs cause the vehicle to *tend* to maintain a straight-ahead path, or *plow*. This is generally referred to as an *understeer* characteristic. For rear tire blow-outs, the vehicle tends to become unstable and spin out. This is generally referred to as an *oversteer* characteristic. Oversteer is generally considered an undesirable characteristic, although a small tendency for oversteer is often designed into high-performance vehicles.

Spend a few minutes reviewing each event, noting how the location of the blown tire affects response. You'll find this procedure useful the next time you need to reconstruct an accident involving a tire blow-out.

It is quite instructive to look carefully at all tire forces ($F_{x'}$, $F_{y'}$, $F_{z'}$) before, during and after the blow-out to learn exactly how a blown tire affects vehicle behavior.

> **NOTE:** Look carefully; you'll see a lot of interesting phenomena taking place.

You might also find it interesting to change the amount and timing of the steering and introduce braking to observe the effect on vehicle behavior for the various blown-tire locations. The blow-out model is extremely powerful!

One final, but very important point: This tutorial involves a Ford Bronco II. This particular vehicle was selected because it was included in a rigorous validation study involving vehicle rollover [6]. In this study, the vehicle was subjected to extremely violent experimental conditions (i.e., curb-tripped impact) in an effort to induce a rollover response. The Ford Bronco II's response to these conditions, as well as to the tire blow-out simulations included in this tutorial, is substantially the same as the response of other multi-purpose vehicles.

Viewing Results

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

EDVSM produces the following reports:

- **Messages** — A list of messages produced by the current run
- **Accident History** — A table of initial and final positions and velocities
- **Environment Data** — A list of the visual and physical environment parameters used by EDVSM
- **Vehicle Data** — A series of tables containing the vehicle data used by EDVSM, including tire blow-out information
- **Program Data** — A table containing program control information

- **Variable Output** — A table containing user-selectable, time-dependent simulation results
- **Trajectory Simulation** — A 3-D visualization of the event, displayed at a user-selectable time interval
- **Damage Profiles** — A 3-D visualization of the vehicle damage, displayed at a user-selectable time interval

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

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

> **NOTE:** Our tutorial uses the Curb-tripped Rollover event to illustrate the procedures for viewing output reports. You can use the same procedures for viewing reports for any of the events in the case.

Report Windows

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

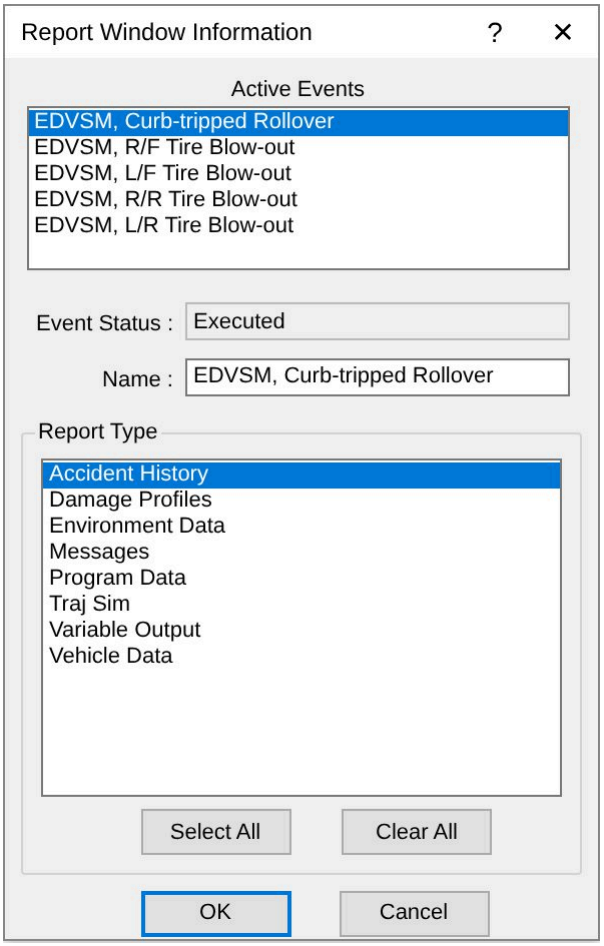


Figure 5-16: Report Window Information dialog, showing the name of each event in the current case.

To view the reports produced by the

EDVSM, Curb-tripped Rollover

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed, as shown in Figure 5-16, and includes a list of the active events (*EDVSM, Curb-tripped Rollover* is the event whose output we'll review in this tutorial).

The Report Window Information dialog also includes the user-editable *Report Window Name* text field and the *Report Type* list.

- Select *EDVSM, Curb-tripped 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

EDVSM, Curb-tripped Rollover

event.

Messages

EDVSM produces a number of messages, depending on the outcome of the event. For a complete listing and explanation of the messages, refer to Chapter 6.

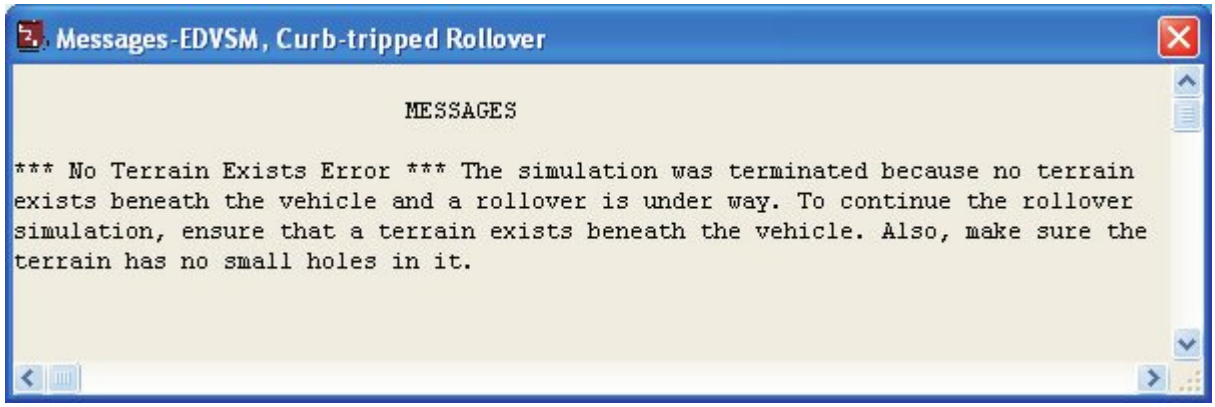


Figure 5-17: Messages report for EDVSM, Curb-tripped Rollover.

To view the Messages report produced by the

EDVSM, Curb-tripped Rollover

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed, and includes a list of the active events.
- Select *EDVSM, Curb-tripped Rollover* from the Active Events list.
- In the *Report Type* list, select *Messages*.
- Press *OK*.

The Messages report is displayed for the

EDVSM, Curb-tripped Rollover

event, as shown in Figure 5-17.

Accident History

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

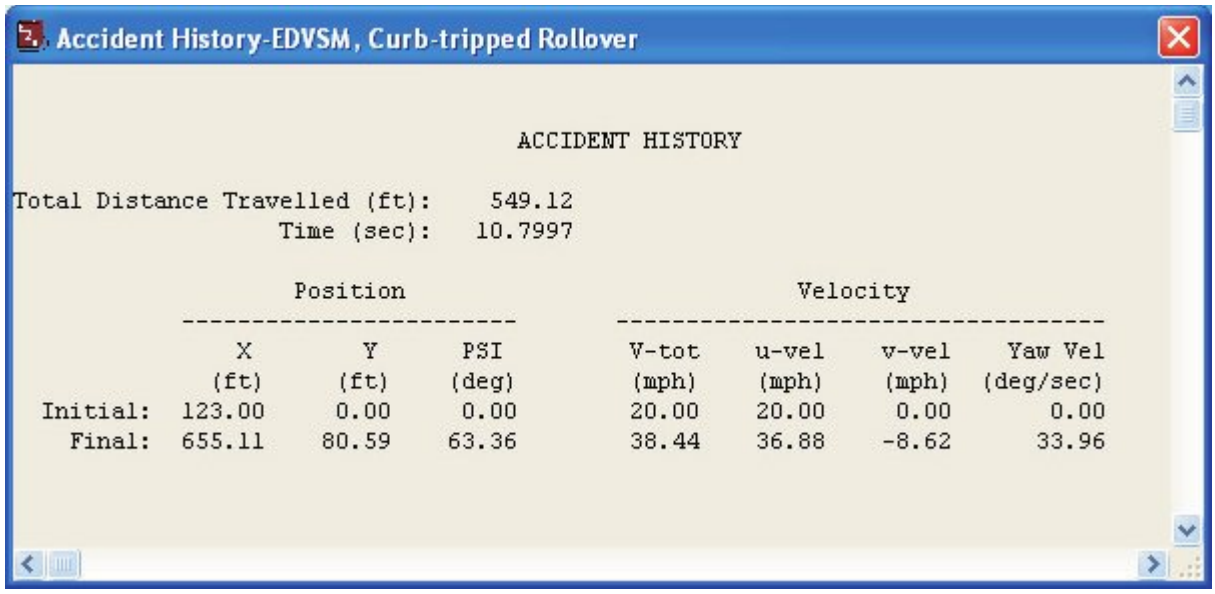


Figure 5-18: Accident History report for EDVSM, Curb-tripped Rollover.

To view the Accident History report for the

EDVSM, Curb-tripped Rollover

event, perform the following steps:

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

The Accident History report is displayed for the

EDVSM, Curb-tripped Rollover

event, as shown in Figure 5-18.

Environment Data

The Environment Data report displays the physical and visual parameters describing the environment.

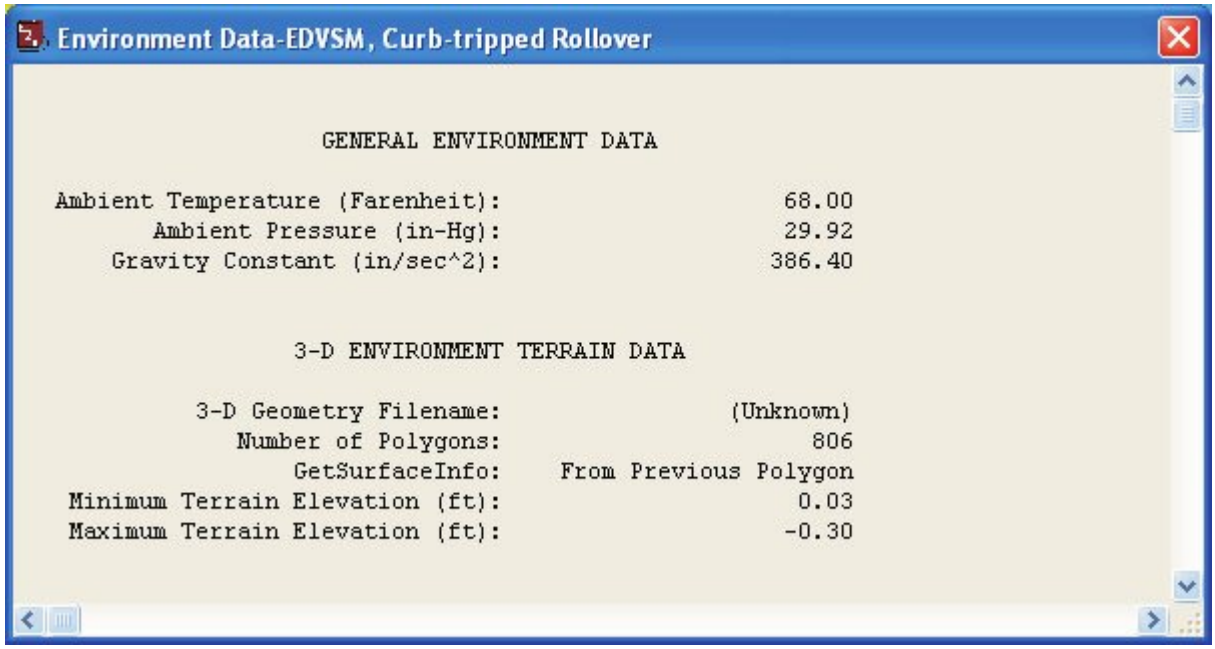


Figure 5-19: Environment Data report for EDVSM, Curb-tripped Rollover.

To view the Environment Data report for the

EDVSM, Curb-tripped Rollover

event, perform the following steps:

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

The Environment Data report is displayed for the

EDVSM, Curb-tripped Rollover

event, as shown in Figure 5-19.

Vehicle Data

The Vehicle Data report for EDVSM contains all the vehicle data groups (Sprung Mass, Suspension, Tire, Brake and Driver Controls).

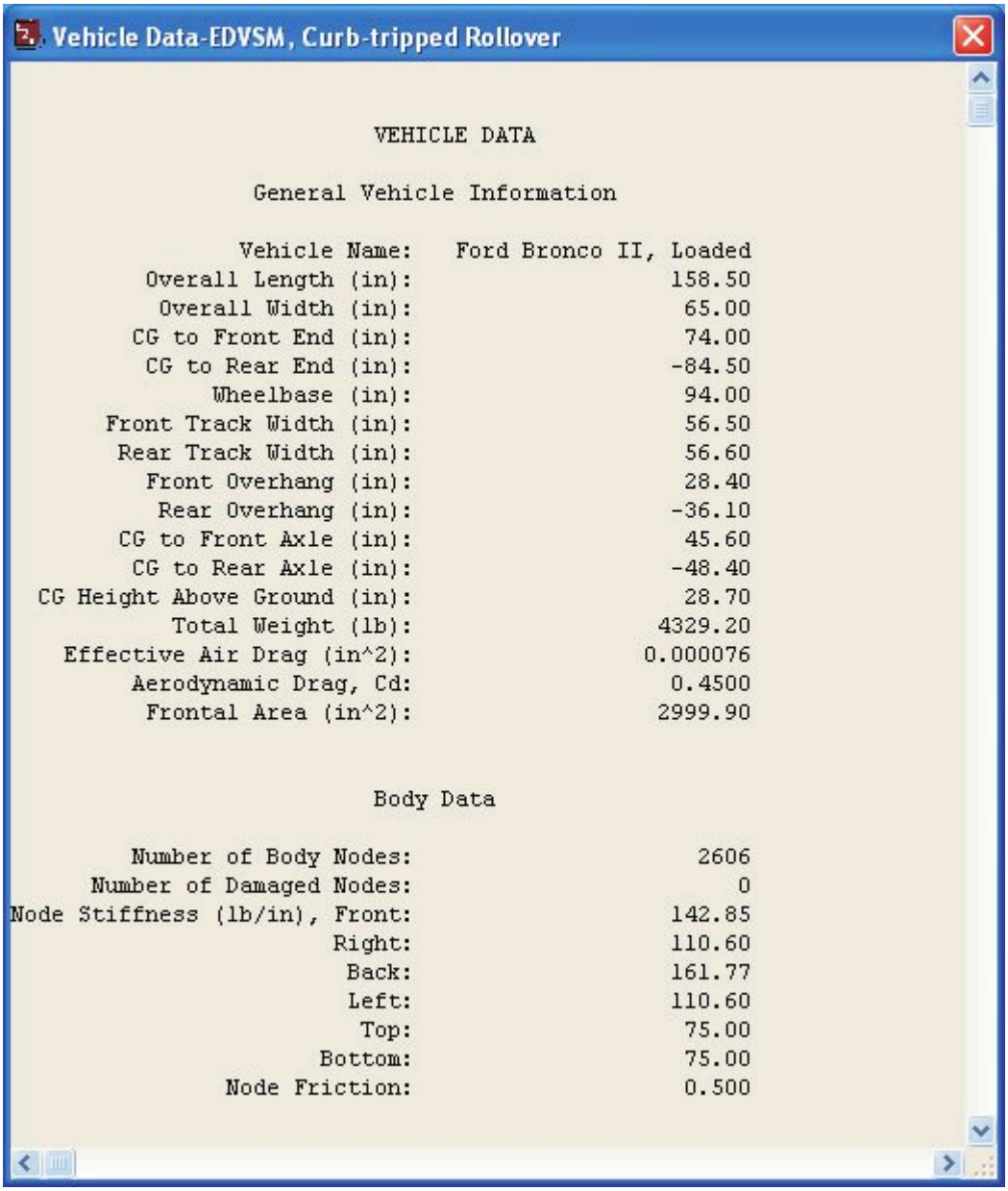


Figure 5-20: Vehicle Data report for EDVSM, Curb-tripped Rollover.

To view the Vehicle Data report for the

EDVSM, Curb-tripped Rollover

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed.
- Select *EDVSM, Curb-tripped 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

EDVSM, Curb-tripped Rollover

is shown in Figure 5-20.

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

Program Data

The Program Data report includes the simulation control parameters and other run-time information.

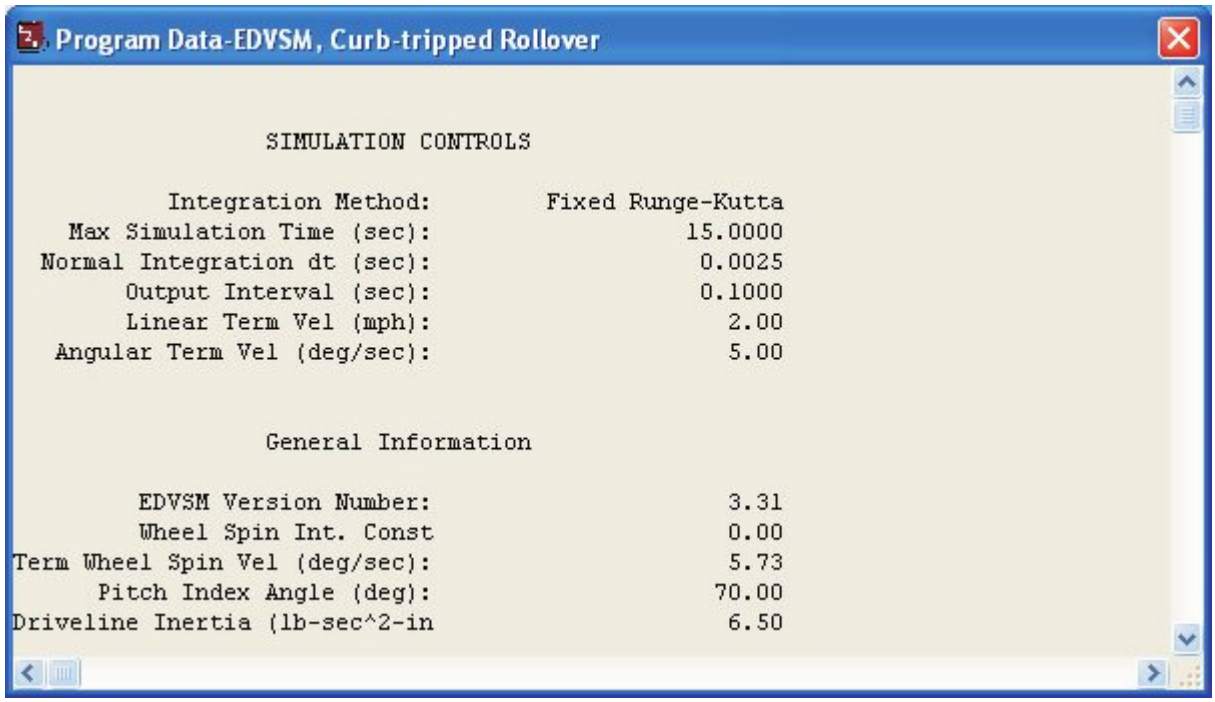


Figure 5-21: Program Data report for EDVSM, Curb-tripped Rollover.

To view the Program Data report for the

EDVSM, Curb-tripped Rollover

event, perform the following steps:

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

The Program Data report is displayed for the

EDVSM, Curb-tripped Rollover

event, as shown in Figure 5-21.

Variable Output

The Variable Output report is a table of user-selectable, time-dependent simulation results for the current event. To view the Variable Output report for the

EDVSM, Curb-tripped Rollover

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed.

- Select *EDVSM, Curb-tripped Rollover* from the Active Events list.
- In the *Report Type* list, select *Variable Output*.
- Press *OK*.

The Variable Output report is displayed for the

EDVSM, Curb-tripped 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 EDVSM study is to illustrate a rollover sequence. To document the resulting path, as well as some other pertinent results, let's select the CG path coordinates, velocity and acceleration from the Variable Selection dialog.

- Click on *Select Variables* in the *Ford Bronco II, Loaded* Variable Output window. The Variable Selection dialog for *Ford Bronco II, Loaded* is displayed, as shown in Figure 5-22.

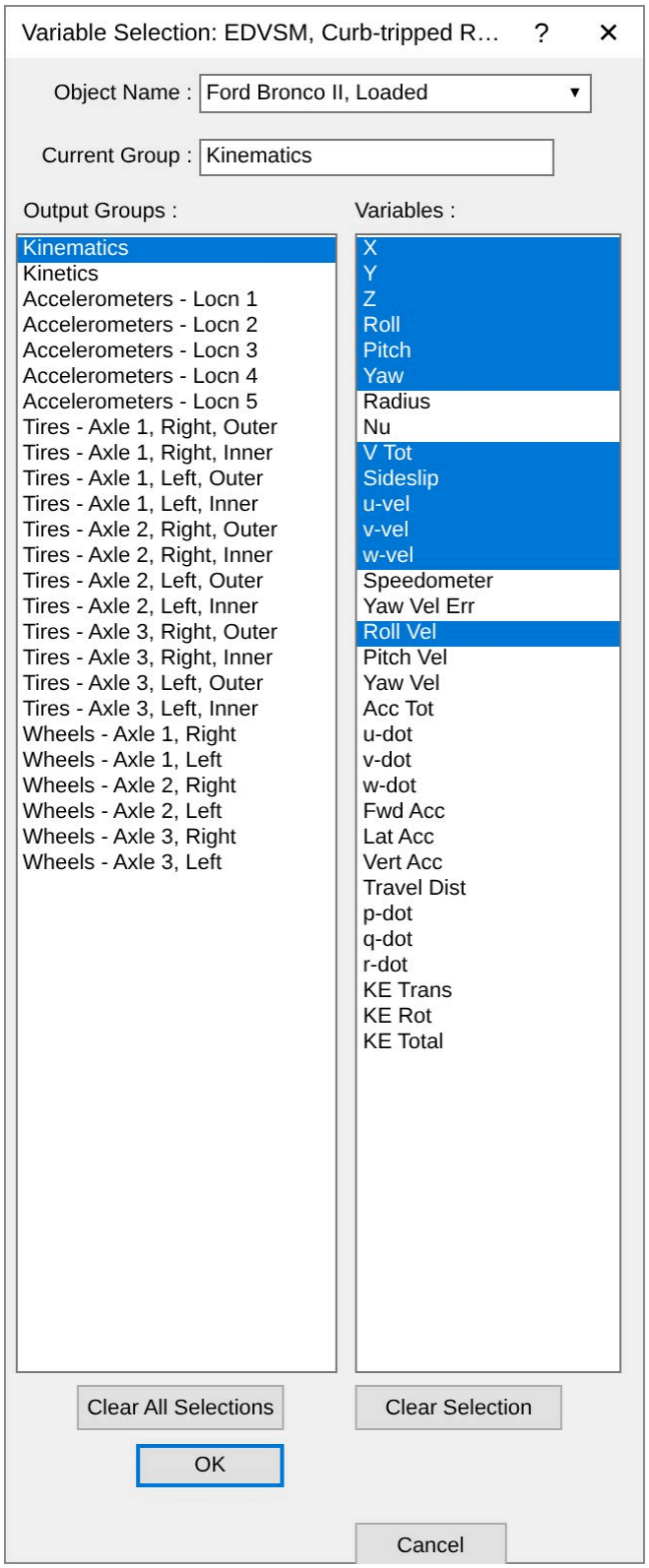


Figure 5-22: Variable Selection dialog, used for selecting results displayed in the Variable Output table.

The Kinematics Output group is the default selection and the Kinematics variable list is displayed. Let's add *X, Y, Yaw* and *Path Radius* to the Key Results window:

- Select *X, Y, Z, Roll, Pitch, Yaw, V-tot, Sideslip, u-vel, v-vel, w-vel, Roll Vel, Pitch Vel, Yaw Vel, Acc-tot, Fwd Acc, Lat Acc, Vert Acc, p-dot, q-dot* and *r-dot* from the list.

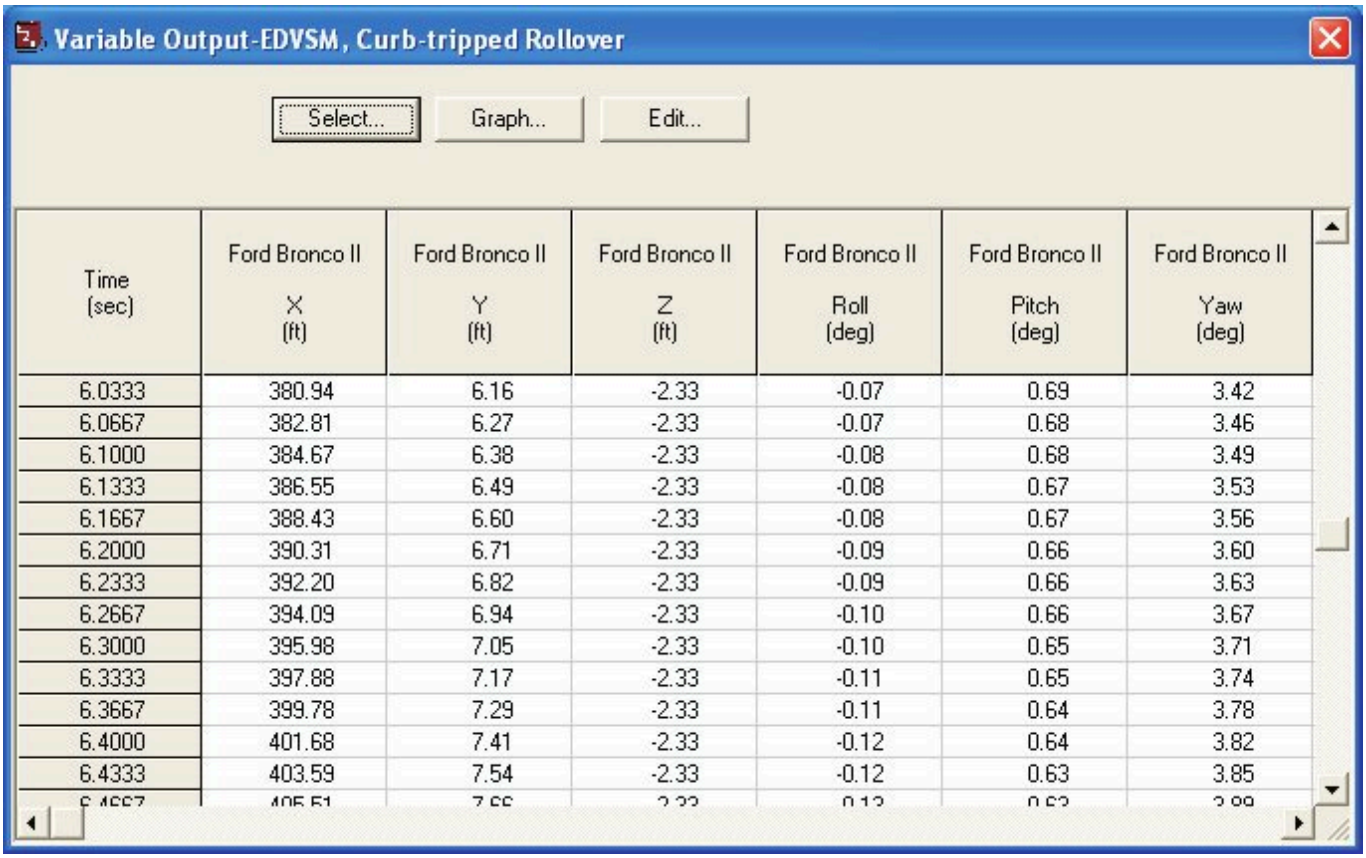
> **NOTE:** Feel free to add additional variables to the Variable Output window. You might be especially interested in the tire forces.

- Press *OK* to add the selected variables to the Variable Output table.

The Variable Output report for the

EDVSM, Curb-tripped Rollover

event now includes the selected results (see Figure 5-23).



Time (sec)	Ford Bronco II X (ft)	Ford Bronco II Y (ft)	Ford Bronco II Z (ft)	Ford Bronco II Roll (deg)	Ford Bronco II Pitch (deg)	Ford Bronco II Yaw (deg)
6.0333	380.94	6.16	-2.33	-0.07	0.69	3.42
6.0667	382.81	6.27	-2.33	-0.07	0.68	3.46
6.1000	384.67	6.38	-2.33	-0.08	0.68	3.49
6.1333	386.55	6.49	-2.33	-0.08	0.67	3.53
6.1667	388.43	6.60	-2.33	-0.08	0.67	3.56
6.2000	390.31	6.71	-2.33	-0.09	0.66	3.60
6.2333	392.20	6.82	-2.33	-0.09	0.66	3.63
6.2667	394.09	6.94	-2.33	-0.10	0.66	3.67
6.3000	395.98	7.05	-2.33	-0.10	0.65	3.71
6.3333	397.88	7.17	-2.33	-0.11	0.65	3.74
6.3667	399.78	7.29	-2.33	-0.11	0.64	3.78
6.4000	401.68	7.41	-2.33	-0.12	0.64	3.82
6.4333	403.59	7.54	-2.33	-0.12	0.63	3.85
6.4667	405.51	7.66	-2.33	-0.13	0.63	3.89

Figure 5-23: Variable Output report for EDVSM, Curb-tripped Rollover, displaying the selected results.

Trajectory Simulation

Let's display a trajectory simulation for this event. To view the Trajectory Simulation for the

EDVSM, Curb-tripped Rollover

event, perform the following steps:

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

The Trajectory Simulation viewer is displayed for the

EDVSM, Curb-tripped Rollover

event (see Figure 5-24). The viewer shows the vehicle at its initial position.

To visualize the motion, perform the following steps:

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

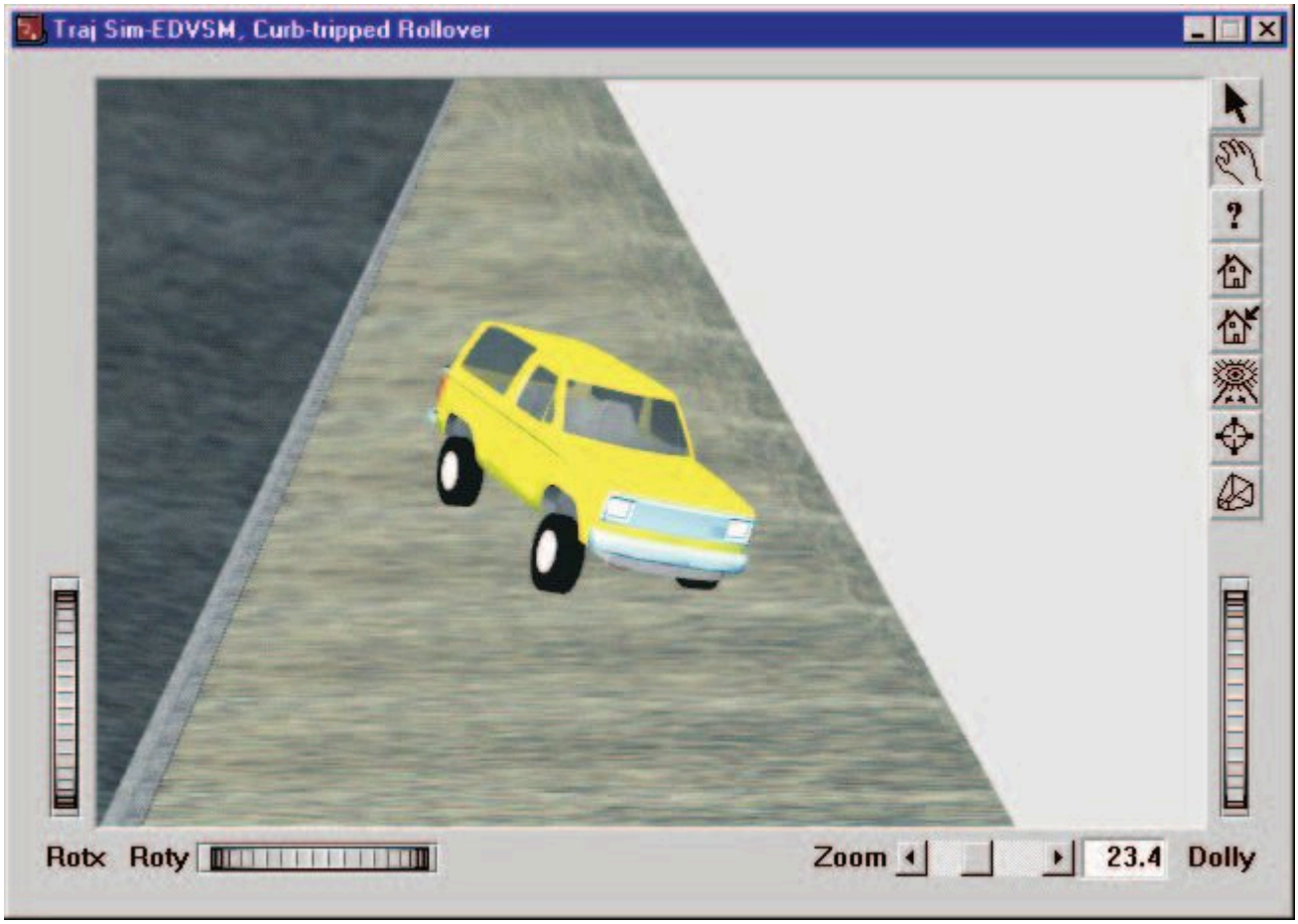


Figure 5-24: Trajectory Simulation for EDVSM, Curb-tripped Rollover, displaying the vehicle at the moment of rollover.

Damage Profiles

Finally, let's display the damage profile simulation for the event. To view the Damage Profiles for the

EDVSM, Curb-tripped Rollover

event, perform the following steps:

- Click *Add New Object*. The Report Window Information dialog is displayed.
- Select *EDVSM, Curb-tripped Rollover* from the Active Events list.
- In the *Report Type* list, select *Damage Profiles*.

- Press *OK*.

The Damage Profiles simulation viewer is displayed for the

EDVSM, Curb-tripped Rollover

event (see Figure 5-25). The vehicle is displayed in its initial condition. To visualize the damage to the vehicle, use the Event Controller in the same manner as for the Trajectory Simulation.

> **NOTE:** Because the Trajectory Simulation enables the Event Controller, you must have a Trajectory Simulation open for this event in order to "play" the Damage Profile.

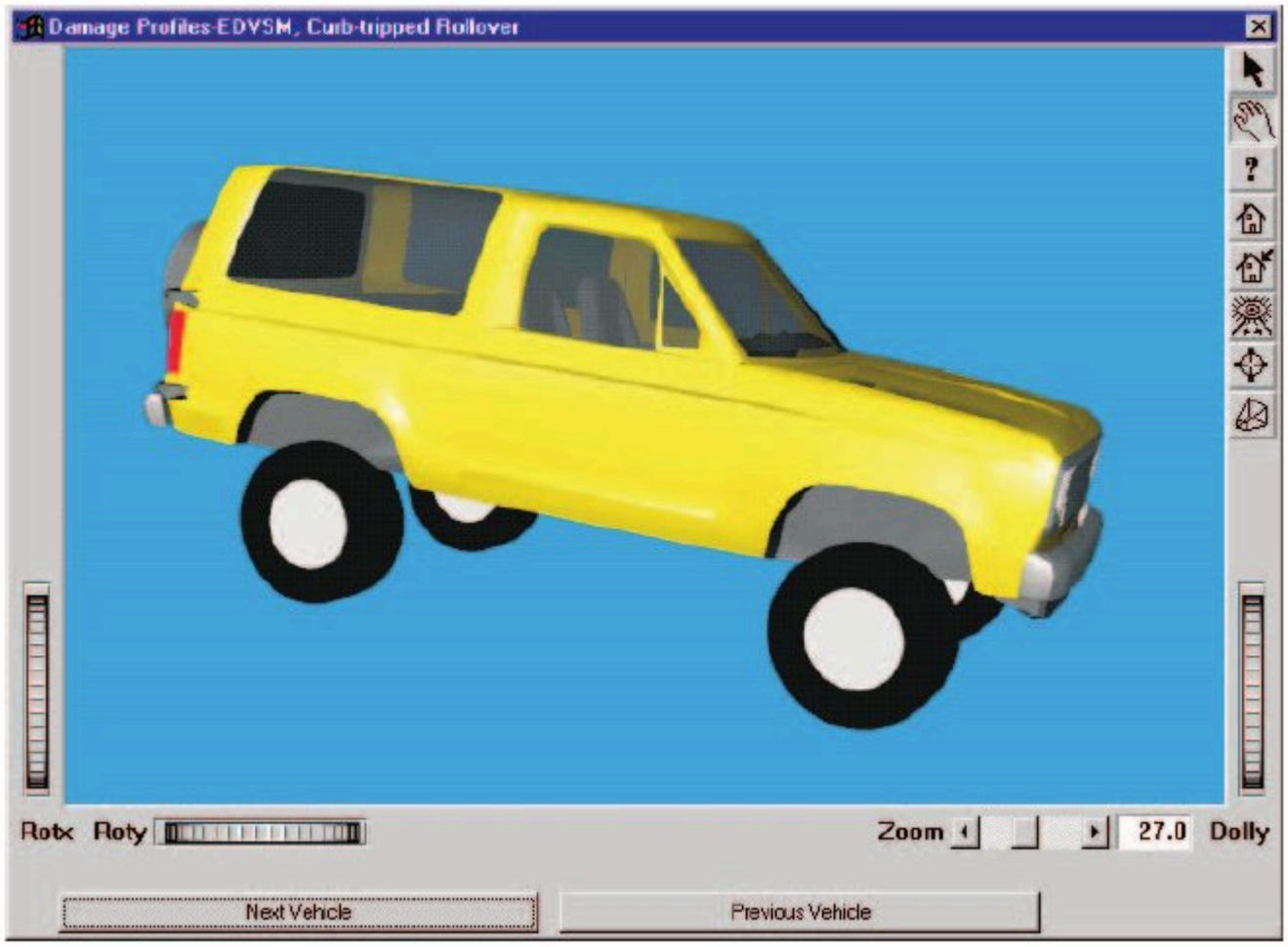


Figure 5-25: Damage Profile for EDVSM, Curb-tripped Rollover, displaying the vehicle at the end of the simulation.

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 - EDVSM, Curb-tripped 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 upper 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 the HVE User's Manual for more information.
>
> **NOTE:** The font size of both the printed reports and screen display may be edited by clicking on the Options menu and choosing Preferences. Use the Font Size option list to change the size.

Chapter 6 — Messages

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

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

Errors issued by EDVSM appear in the EDVSM 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 which are inconsistent or incompatible with basic program assumptions.
- **Diagnostic Messages (Level 2)** — These messages 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 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 EDVSM are listed below. Each message includes a description or nature of the cause, the level of the message (Informative, Diagnostic or Fatal), and the recommended action to eliminate the problem. If you receive an error message not listed below, first check to see if it is an HVE or operating system message by referring to the HVE Appendix or your computer's operating system manual. If the message is not listed in either place, please contact EDC immediately with the offending error.

(updated: This catalog has been brought into line with the messages issued by the current version of EDVSM. All messages from the original manual are still present. One message has been added since the Fifth Edition — the second Integration Error, concerning the Velocity Convergence Criterion — and the GetSurfaceInfo() Error text has been shortened; both are noted below.)

No Messages

This is the result of normal termination. No action by the user is necessary.

*** Integration Error *** The simulation was terminated because of an integration error in the tire force calculations.

(Level 1 - Fatal)

This error occurs due to an error in the wheel spin equations of motion. The error suggests an excessive spin acceleration. This might result from excessive drive or brake torque or from an incorrect (small) wheel spin inertia. Confirm the wheel torques in the Key Results or Variable Output. Confirm the spin acceleration in the Vehicle Data output report.

*** Integration Error *** 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)

(updated: This message was added after the Fifth Edition of the manual; it is issued by the current version.)

It is issued when the integrator's velocity-convergence check cannot satisfy the user-assigned Velocity Convergence Criterion within the assigned Maximum Number of Bisections. (Note that EDVSM runs the Fixed Runge-Kutta integrator; the velocity-convergence bisection path applies only to the variable-timestep Adams-Moulton integrator.) Restore these Simulation Controls parameters to values near their defaults (Velocity Convergence approximately 0.1, Maximum Bisections approximately 10).

***** Suspension Force Error *** The simulation was terminated because of a singular matrix in the suspension force equations. Send the offending case to EDC for evaluation.**

(Level 1 - Fatal)

This error occurs due to excessive suspension force. This can be the result of an excessive integration timestep (see Simulation Controls, Trajectory Timestep). The problem might also occur during an excessively dynamic maneuver (such as crashing into the ground after falling several hundred feet). This type of event is beyond the scope of the EDVSM simulation model as it would probably result in catastrophic damage to the vehicle structure.

***** Excessive Tire Force Error *** The simulation was terminated because an excessive tire deflection was encountered. A tire hit a tall curb or other significant elevation change (an elevation change greater than the maximum allowed tire deflection; see Vehicle Editor, Tire Physical Properties). If the elevation change is not instantaneous, reducing the integration timestep may solve the problem.**

(Level 1 - Fatal)

The EDVSM tire model assumes a point contact between the tire and road. As the terrain elevation changes, the tire does not roll onto a curb or similar surface, rather it changes the contact point in a single timestep. This can result in an instantaneous tire deflection greater than the section height of the tire. Note that this also occurs in real events — causing rim damage and/or tire failure. This is beyond the scope of the EDVSM tire model. The user should understand the complexity of simulating rim failure. In general, such a simulation would require a non-linear finite element analysis.

***** Singular Matrix Error *** The simulation was terminated because of a singular matrix in the sprung mass equations. Send your offending case to EDC for evaluation.**

(Level 1 - Fatal)

This message indicates errant data, probably zero mass or rotational inertia for the sprung mass. Such a condition is normally prevented by the range checking that occurs in the HVE Vehicle Editor. However, a defective vehicle data file could also cause this problem. Carefully review the vehicle data report for suspicious data.

***** Excessive Roll or Pitch *** The simulation was terminated by function Tmcnst() because the current roll or pitch angle exceeded the allowable limit.**

(Level 1 - Fatal)

This is a debugging message and is not enabled in the production release of EDVSM.

***** Derivative Error *** The simulation was terminated in function Tmcnst() because the current derivatives (accelerations) are too large. This usually indicates an excessive or unexpected force was applied to the vehicle sprung mass.**

(Level 1 - Fatal)

This message is issued when the vehicle axis indexing scheme fails, normally the result of a sudden, large acceleration. The cause may be related to excessive tire and/or suspension forces. Check the Key Results or Variable Output report for the current tire and suspension results for a sudden and excessive force at one or more wheel locations.

***** Radial Tire Model Error *** The simulation was terminated in the radial tire model because the number of deflection increments was too large.**

(Level 1 - Fatal)

The Radial Tire Model is not implemented in this version of EDVSM. Thus, this message will not occur.

(updated: confirmed — the current physics rejects the Radial Spring tire model option; see the EDVSM Calculation Options reference.)

***** Excessive Integration Timestep *** The simulation was terminated because the selected integration timestep was too large. Reduce the value to 0.01 sec or less (Simulation Controls dialog).**

(Level 1 - Fatal)

This message is self-explanatory. EDVSM uses the Trajectory Integration Timestep in the Simulation Controls dialog. The default value is 0.0025 sec.

***** Excessive Vehicle Roll *** The simulation was terminated by function VsmMain() because the current roll angle exceeded the allowable limit.**

(Level 1 - Fatal)

This is a debugging message and is not enabled in the production release of EDVSM.

***** GetSurfaceInfo() Error *** The simulation was terminated because GetSurfaceInfo() failed.**

(Level 1 - Fatal)

This is a debugging message and is not enabled in the production release of EDVSM.

(updated: the original manual quoted this message as "...because GetSurfaceInfo() failed to return a valid surface description."; the current message text is shortened to "...because GetSurfaceInfo() failed.")

***** Excessive Engine Speed *** The simulation was terminated because the current engine speed (RPM) was greater than the maximum RPM specified for the engine (see Vehicle Editor, Drivetrain Data, Engine Power/Torque Table). This problem might occur if the wheels leave the ground during a heavy throttle application; in this case the problem may be eliminated by reducing the throttle input (see Driver Controls, Throttle Table). The problem might also occur while driving in a low gear if the driver has a 'lead foot'.**

(Level 1 - Fatal)

If the vehicle is in gear (as determined by the Driver Controls, Gear Table), the current engine speed is calculated. The current engine speed must not exceed the maximum engine speed in the Drivetrain Data. The current engine speed is available in the Key Results or Variable Output report (see Drivetrain output group). A possible cause of this error is starting a vehicle in first gear at a speed of, say, 50 mph.

***** No Terrain Exists Error *** The simulation was terminated because no terrain exists beneath the vehicle and a rollover is under way. To continue the rollover simulation, ensure that a terrain exists beneath the vehicle. Also, make sure the terrain has no small holes in it.**

(Level 1 - Fatal)

If the rollover model is enabled, EDVSM searches the entire environment 3-D geometry for the terrain properties beneath each vehicle vertex. This message is issued when no terrain is found beneath a vertex. Although it may appear that a surface exists, it can sometimes be difficult to see small holes in the surface. Try zooming in for a closer inspection.

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

(Level 1 - Fatal)

The HVE Driver Model calculates the current steer velocity. If this value is greater than the allowable, the simulation is terminated. The error can be eliminated by increasing the user-defined Maximum Steer Velocity. However, the user should also consider the driver's ability when assigning this data.

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

(Level 1 - Fatal)

The current lateral acceleration calculated by EDVSM is compared with the user-defined Driver Comfort Level (which is expressed as a lateral acceleration). If the current lateral acceleration is greater than the user-defined maximum, the simulation is terminated.

Note that the default value of Comfort Level is 0.4 g. This is not to be confused with vehicle/driver capability, which is much greater. The Comfort Level is a human factors issue and varies from driver to driver.

Chapter 7 — References

1. Segal, D.J., "Highway-Vehicle-Object Simulation Model - Volume 1. Users Manual," US DOT, Federal Highway Administration Report No. FHWA-RD-76-162, Calspan Corporation, February, 1976.

2. Segal, D.J., "Highway-Vehicle-Object Simulation Model - Volume 3. Engineering Manual - Analysis," US DOT, Federal Highway Administration Report No. FHWA-RD-76-164, Calspan Corporation, February, 1976.

3. Segal, D.J., "Highway-Vehicle-Object Simulation Model - Volume 4. Validation," US DOT, Federal Highway Administration Report No. FHWA-RD-76-165, Calspan Corporation, February, 1976.

4. Day, T.D., "Overview of the EDVSM 3-D Vehicle Simulator," SAE Paper No. 970958, Society of Automotive Engineers International Congress, Detroit MI, 1997.

5. *HVE User's Manual*, Engineering Dynamics Corp., Beaverton, Oregon, October, 1997.

6. Nalecz, A.G., Lu, Z., d'Entremont, K.L., "Effects of Light Truck and Roadside Characteristics on Rollover - Volumes I through VI," University of Missouri-Columbia, DOT Report No. DOT HS 808-408 through DOT HS 808-413, NHTSA, Washington, DC, 1994.

7. Day, T., "Applications and Limitations of 3-Dimensional Vehicle Rollover Simulation," SAE Paper number 2000-01-0852, presented at the Society of Automotive Engineers International Congress and Exposition, March, 2000, Detroit.

8. Day, T., Metz, L., "The Simulation of Driver Inputs using a Vehicle Driver Model," SAE Paper number 2000-01-1313, presented at the Society of Automotive Engineers International Congress and Exposition, March, 2000, Detroit.

Chapter 8 — Index

(updated: The original printed manual contained a page-number index. Page references are meaningless in this Markdown edition, so the index below maps the original topics to their chapters. Use your viewer's text search within each chapter for precise locations.)

Topic	Where to look
3-D Surface Geometry	Chapter 2 — Environment
3-D Visualization, Trajectory Simulation	Chapter 3, Chapter 5
Accelerometers	Chapter 2 — Event Set-up
Accident History report	Chapter 3, Chapter 5
Airbag / Belt Restraints	Chapter 2 — Sprung Mass
Aerodynamic Drag / Drag Forces	Chapter 2 — Sprung Mass
Anti-pitch, Roll Steer	Chapter 2 — Suspension
Atmosphere (Temperature, Pressure)	Chapter 2 — Environment Physical Data
Brake System, Brake Table, Brake Designer	Chapter 2, Chapter 5
Calculation Method (physics)	Chapter 4
Calculation Options (Tire Model, Steer DOF, Body vs. Environment Contact)	Chapter 2; Calculation Options reference
Camber / Cornering Stiffness tables	Chapter 2 — Tire
Coordinate Systems (Earth-fixed, Vehicle-fixed)	Chapter 2 — Event
Coulomb Friction (steering)	Chapter 4 — Steering System
Curbs / curb-tripped rollover	Chapter 5, Chapter 6
Damage Profiles	Chapter 3, Chapter 5
Driver Controls (Steer, Throttle, Brake, Gear tables)	Chapter 2, Chapter 5
Drivetrain / Engine / Transmission	Chapter 2 — Drivetrain Data
Environment (creating, Visual/Physical Data, Wind, Gravity)	Chapter 2 — Environment
Error / Fatal / Diagnostic / Informative messages	Chapter 6
Event (creating, set-up, execution)	Chapter 2 — Event, Chapter 5
Friction Table, Friction Multiplier	Chapter 2 — Tire
GetSurfaceInfo()	Chapter 2 — Calculation Options, Chapter 6
HVOSM heritage	Chapter 1, Chapter 4
Inertias (vehicle, steering system)	Chapter 2, Chapter 4
Integration (timestep, errors)	Chapter 2 — Simulation Controls, Chapter 6
Jounce and Rebound stops	Chapter 2 — Suspension
Key Results	Chapter 2, Chapter 5
Messages report	Chapter 3, Chapter 6
Output Reports (all types)	Chapter 3
Payload, Collision Pulse, Contacts	Chapter 2 — Event Set-up
Playback Editor / Controller	Chapter 3, Chapter 5

Topic	Where to look
Printing reports	Chapter 5 — Printing
Program Data report	Chapter 3, Chapter 5
Simulation Controls	Chapter 2, Chapter 5
Springs and Shocks, Ride Rate, Roll Center	Chapter 2 — Suspension
Steer Degree of Freedom	Chapter 2, Chapter 4
Steering System (gear ratio, stops, friction, trail)	Chapter 4
Tire Blow-out Model	Chapter 2, Chapter 5
Tires (physical data, stiffness tables, Slip vs Rolloff)	Chapter 2 — Tire
Trajectory Simulation	Chapter 3, Chapter 5
Tutorial	Chapter 5
Validation	Chapter 1, Chapter 5
Variable Output / Variable Selection	Chapter 3, Chapter 5
Vehicle Data report	Chapter 3, Chapter 5
Vehicle Editor (adding/editing vehicles)	Chapter 2 — Vehicles, Chapter 5
Wheel Location, Unsprung Mass	Chapter 2 — Unsprung Mass
Wheel Spin	Chapter 1, Chapter 6
Wind Speed and Direction	Chapter 2 — Environment