TruckSim® 8 Math Models

TruckSim 8 provides highly efficient custom computer programs optimized for solving equations in math models that represent the dynamic behavior of vehicles. The VehicleSim® architecture includes the built-in VS command language that can add new capabilities at run time to customize and extend the math models. Further, the models work with other software (Simulink, LabView, ETAS ASCET, Custom C/C++ programs, Visual Basic, etc.) for automation or extensions to the math models.

Vehicle Math Models

Nonlinear Properties and Tables

- Nonlinear properties are typically specified with VS tables. These can be set to use constants, linear coefficients, nonlinear tables with linear or spline interpolation, and in some cases, 2D spline interpolation. Altogether, 16 calculation options are available.
- When simpler methods are selected (coefficients or linear interpolation), the simulations can run even faster.

Control Inputs

- All control inputs can be specified using built-in model options. They can also be defined by equations at runtime using VS commands. Or, they can be imported from other software such as Simulink, LabView, ASCET, or custom programs written in C, VB, etc.
- Built-in steering control can be specified with open-loop steering wheel angle or a driver model that follows a path relative to a road centerline.
- Brake and throttle control can be specified as open-loop functions of time. Alternatively, a speed-controller can be used to control throttle and brakes to follow a target speed relative to either time or position along the road.
- Gear shifting and clutch controls can be specified as open-loop functions of time. Alternatively, automatic shifting and clutch control can be used.

Wind and Aerodynamic Effects

- Aerodynamic forces and moments are applied to the sprung masses (lead unit and load-carrying trailers).
- These forces and moments are nonlinear tabular functions of aerodynamic slip.
- Ambient wind speed and heading can be set with tables, runtime equations, or imported from other software.

3D Road Geometry and Friction

- Horizontal geometry of a road design path is defined by X-Y coordinates. They are fitted by a spline to define a continuously curved horizontal path. They are also used to define station (distance along the path).
- Vertical geometry of the design path is defined by a sequence of elevation values as a function of station — the longitudinal distance along the road centerline.
- Off-center elevation relative to the design path is specified with a 2D table, based on station and lateral distance from the design path. Two tables are used to help separate design geometry (superelevation, ditches, road camber, etc.) from special features (bumps, potholes, etc.) or roughness data.
- The road can have variable width, allowing an extra dimension for the 2D mapping of elevation. This allows highly efficient descriptions of complex geometries such as lane merging, ruts and ditches that "wander," variable-width banked turns, etc.
- Road profiles are included that follow the vehicle, to enable the use of high-frequency measured roughness data without requiring a fully detailed 3D map.
- Friction is specified relative to the design path with a variable-width 2D table based on station and lateral distance from the path.
- Road geometry can be imported from other software or defined by equations that are added at runtime.
- The VS API includes functions to provide access to the 3D road geometry for user-supplied equations for model extensions or additional outputs.
- An alternative to the road concept is a 3D ground surface specified with a grid of X, Y and Z values.

Suspensions

- TruckSim suspension models have full nonlinear kinematical behavior and are asymmetric.
- TruckSim includes independent and solid axle suspensions.
- Every suspension has compliance in the lateral and longitudinal directions, and every wheel has toe and camber compliance effects.
- All compliances can be represented with a linear coefficient or a nonlinear table.

- Suspension springs are nonlinear and include hysteresis due to friction. The characteristics depend on the static load, to properly represent air spring behavior.
- Separate forces are included for bump stops.
- Suspension roll moments include a nonlinear auxiliary roll moment to account for roll stiffness/compliance beyond the effects of the springs.
- Dampers are nonlinear.
- Tandem and tridem suspensions include static load distributions, dynamic load transfer, and load transfer due to brake torque.
- TruckSim obtains roll and jacking forces as the natural results of full 3D kinematical curves and compliance effects for independent and solid-axle suspension.

Frame Twist and Suspended Cabs

- Each vehicle math model is available with either rigid sprung masses or frame with twisting compliance that connect the bodies to the suspensions and engine.
- The models with frame twist also include suspended cabs in the lead unit.

Steering System

- The steer of each wheel from the steering system is added to the steer due to suspension kinematics and compliance effects.
- The steer due to the steering system is obtained by combining nominal gear ratio with nonlinear tables that can be measured or obtained with simulated K&C tests.
- The steering model includes compliances in the steering column and tie rod. The steer is also modified by axle wrap, roll, and jounce.
- Steer torque at the steering wheel is obtained by calculating the total steering moment about the kingpins for the front wheels.
- Special equations are used for low-speed conditions to simulate ground friction steer torque.

Brake System

- The control input pressure from the master cylinder is proportioned for each actuator as a nonlinear function of pressure and wheel dynamic load.
- Hydraulic/air dynamics are modeled with a first-order transient lag, plus a pure time delay for open-loop pressure controls.
- Brake torque is a nonlinear function of pressure.
- A simple ABS controller is included.
- Special equations handle wheel lockup to obtain the correct reaction torque and avoid numerical instability.

Tires

- TruckSim includes several tire models. It is ready to run with a table-based basic model, an extended model (more tables for camber effects), the Pacejka 5.2 version of the magic formula, and MF-Tyre from TNO.
- TruckSim is also ready to run with MF-Swift from TNO and Ftire from COSIN (extra licenses are required from TNO and COSIN, respectively, to use their models).
- Dual tires are available for all wheels.
- The built-in models use nonlinear tables to represent lateral force, longitudinal force, aligning moment, and overturning moment as functions of slip, load, and camber.
- Lateral and longitudinal forces and moments are combined in the built-in models using combined slip theory as published by Pacejka and Sharp.
- Variable friction conditions are handled using similarity, to maintain both linear and limit properties of the tire. Separate coefficients are used for X and Y components.
- Dynamics due to rolling are included using relaxation length for lateral and longitudinal slip.
- Special equations are used to maintain realistic tire behavior at low speeds, when the assumptions of a rolling tire would otherwise cause numerical problems.
- External tire models can apply forces at either the ground contact point or the wheel center.
- Different models can be applied to different tires of the same vehicle.

Powertrain

- TruckSim has detailed powertrain models for variable drive settings (4x2, 4x4, 6x2, 6x4, 6x6, etc.) with up to four drive axles on the lead unit. Alternatively, a simple speed control is available in which power is applied directly to the wheels on the lead unit.
- Engine torque is defined with a 2D table that relates torque to throttle input and crankshaft angular velocity.
- Fuel consumption is defined with a 2D table.
- The engine feeds torque to the transmission either through a hydraulic torque converter or through a mechanical clutch.
- The transmission converts torque and speed based on the current gear selection, with spin inertias and efficiencies that depend on the gear selection.
- The torque from the transmission goes to a differential for a single-axle drive system. With two-axle drive systems, the transmission applies torque to a center unit (e.g. transfer case) with a torque bias. Additional transfer cases are added for 3- and 4-axle drive system.

- The transfer case unit and differential models are similar. All have four model options:
  1. Always locked. In this case the locking is modeled with a torsional spring and damper.
  2. Viscous coupling. In this case the torque differential is defined with a table based on the speed difference.
  3. Coupling is applied using a clutch. The differential clutch has built-in control logic (i.e. LSD: limited slip differential) that can be used, or it can be controlled externally. This can be with or without viscous coupling.
  4. Yaw control differential system, which involves two clutches with reduction gears in parallel over a differential. The system allows control of the torque distribution between left and right, or front and rear. This can be with or without viscous coupling.
- Each transfer case has a torque bias that can be used with any of the above non-locked options.
- Twin-clutch is an alternative to an axle differential. The system involves a gearbox in the middle of the axle and two clutches between each wheel and the gearbox.
- Torsional compliance of the driveline is characterized by a natural frequency and damping ratio.

Sensors and Traffic

- The models include virtual sensors that detect various types of vehicle motion, including acceleration, speed, and previews of vehicle position on the road ahead.
- Up to 99 moving objects can be added that are updated automatically to convert simple road-based commands into full 3D geometry. The objects can be recycled for extensive runs, to reappear after they go out of view.
- Motion of an object can be constant, set with algebraic equations, set with differential equations, or imported from third-party software such as Simulink.
- Up to 20 range and detection sensors can be included that detect the moving objects.
- Each sensor-object interaction involves 11 variables that can be exported to external controllers (e.g., ADAS).
- Objects can block each other (occlusion). The sensors detect only the portion of an object that is within the field of view.

Solver Program Input and Outputs

Input Data Files

- The solver programs read all inputs from text files that are generated automatically by TruckSim (users typically do not view them). The files can be controlled from within TruckSim or externally.
- Input files use a simple keyword-based format called the Parsfile. A typical TruckSim solver program handles thousands of keywords when processing input files.
- Parsfiles support the INCLUDE capability, allowing many advanced applications such as design of experiment (DOE), sensitivity, and customized automation methods.
- Values can be assigned directly to model parameters with numbers. Users can also specify values with numerical expressions (e.g., 1/16) or symbolic algebraic expressions involving other model variables (e.g., `-LX_CG_SU`).
- The solver programs process VS commands at run time that define new variables, add equations to the model, change units for variables, and otherwise extend the original TruckSim model to meet custom requirements.
- The models include reference points and associated forces and moments that can be defined at runtime to extend the model.

Output Variables

- The solver programs generate from 800 to thousands of output variables, depending on the type of vehicle, number of moving objects, and number sensors.
- Any subset of the list of variables can be specified at run time, to control the size and organization of output files.
- New output variables and equations can be defined at runtime using VS commands.
- All variables are described in documentation files in both text and spreadsheet format. TruckSim also includes a GUI for browsing and selecting variables.
- Output variables are used for several purposes:
  - Make plots that show vehicle behavior.
  - Input to post-processing software.
  - Provide motion information for the animator.
  - Possible inputs for external model extensions.
  - Use in “events” or other VS commands.

Working with Simulink® and External Models

- On Windows machines, the math models are standard DLL files (32-bit and 64-bit) that run in many ways:
  - TruckSim runs the models directly.
  - The models run as blocks in workspaces such as MATLAB/Simulink, LabVIEW, ASCET, etc.
  - The models run under the control of custom programs that can load and control DLL files.

- Multiple instances of a math model can run simultaneously in Simulink and other environments to simulate multiple vehicles that interact dynamically.
- C/C++ can be used to accessing thousands of variables and extend the math models using the VS API.
- MATLAB, Visual Basic (VB), and other languages can run the models for automation and extend the models.
- Math model solver programs are compiled to native code for real-time systems to interface with RT test control software (dSPACE, QNX, Linux RT, etc.).

Input Variables

- Values from external models or hardware in the loop can be imported into TruckSim. Optional inputs include most forces and moments, fluid pressures, control variables, ground geometry under each tire, etc.
- The 2-axle vehicle models can import over 350 variables. Those with trailers can import many more.
- Most of the import variables can be combined with native internal variables. At run time, users can specify one of three actions for each activated import variable:
  1. replace the native variable,
  2. add to the native variable, or
  3. multiply with the native variable.
- TruckSim provides a browser for activating import variables from the lists of all those that are available.
- New import variables can be defined at run time with VS commands to pass through information from other software such as Simulink.

Export Variables

- All variables available for writing to output files are also available for export to other software (e.g., Simulink).
- Variables are exported only if they are activated at run time. Most external models (Simulink, LabVIEW, etc.) that use TruckSim receive only a small number of the potential variables that TruckSim can export, simplifying the integration with other software.
- TruckSim provides a browser for activating export variables from the lists of all those that are available.
- New export variables can be defined at run time using VS commands.

Multibody Model Specifications

State Variables and Degrees of Freedom

- The sprung mass of the motor vehicle is a rigid body with six degrees of freedom (DOF).
- Each wheel has one spin DOF.
- Each independent suspension has two multibody DOF — the vertical movements of the wheel centers.
- Each solid-axle suspension has two independent multibody DOF — the axle bounce and roll.
- Other suspension motions, such as pitch, camber, lateral position, etc., are constrained as nonlinear functions of the independent variables.
- Each suspension has six compliance DOF.
- The brake fluid in each actuator has one DOF.
- Each tire has two dynamic DOF: one for lagged lateral slip, the other for lagged longitudinal slip.
- The engine crankshaft has one DOF, and the engine torque has a dynamic lag in response to throttle change.
- Fuel consumption has one DOF.
- Every suspension spring and tire has a friction DOF, as does the steering system.
- Each wheel has a low-speed (parking lot) steering friction DOF.
- Power steering boost has a DOF.
- The ABS system has one DOF per brake actuator.

Equation Form

- The equations of motion in the TruckSim math models are derived (by machine via VS Lisp) from first principals for full nonlinear 3D motions of multiple connected rigid bodies.
- The equations of motion are ordinary differential equations (ODE's) that are "non-stiff" and can be solved with most numerical integration methods.
- The built-in VS library provides five methods for solving the ODE's. These include three second-order methods (Adams-Bashforth, Adams-Moulton, and Runge-Kutta), plus third- and fourth-order Adams-Moulton methods.
- All methods run at a fixed time step and work well for real-time applications with hardware in the loop (HIL).
- The algorithms work well with measured and sampled data sources (tables), eliminating the need for spline interpolation for most tables used in the models. (However, spline interpolation is supported to provide a full range of runtime options.)
- The native equations are compiled with extensive optimizations (from VS Lisp) and are embedded in the solver programs where they maintain their high efficiency regardless of what other software that might be running concurrently (e.g., Simulink).