

Modular Vehicle Models

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CarSim, TruckSim, and BikeSim contain VehicleSim (VS) Solver dynamic libraries with Modularity functions that construct VS Math Models for vehicles or other mechanical systems, based on the specifications set in input files. The VS Math Models then solve the equations of motion for the model and generate output variables of interest.

The general operation of VS Math Models is described in the VS Math Models Reference Manual; this document describes the modules in CarSim, TruckSim, and BikeSim that are available for constructing a custom VS Math Model to simulate one or more vehicles.

Modular Multibody Models

The vehicle models used in BikeSim, CarSim, and TruckSim involve multiple rigid bodies that are connected. The equations of motion for multibody models are machine-generated at Mechanical Simulation by a symbolic multibody program called VS Lisp (originally called AutoSim). With 30 years of continued use and development, VS Lisp is routinely used to generate highly optimized equations of motion customized for specific 3D multibody systems that occur frequently as sub-system modules in full vehicle models for motorcycles, cars, and trucks.

VS Solver libraries include multiple modules made from machine-generated code, plus hand-written multibody code for assembling the modules into a full vehicle model, plus libraries of models of other elements in the vehicle model such as springs, brakes, tires, steering systems, powertrain components, and controllers. These resources are used to construct a VS Math Model with a specific vehicle layout, and possibly selected optional features.

Multibody Vehicle Models for CarSim and TruckSim

CarSim and TruckSim include three types of multibody modules:

1. **Lead Unit Sprung Mass.** All lead-unit modules have a sprung mass with six degrees of freedom (DOF), aerodynamic effects, no suspensions, possibly actions from a trailing hitch, and possibly actions from user-defined forces and moments.

2. **Trailer Sprung Mass.** All semitrailer modules have a sprung mass with a leading hitch, aerodynamic effects, no suspensions, possibly actions from a trailing hitch, and possibly actions from user-defined forces and moments.
3. **Suspension.** All suspension modules a single suspension with four DOF with a means to connect to a sprung mass. There are two basic suspension types: generic, in which the left and right move up and down independently (with possible arbitrary coupling of the two sides); and solid axle. Separate suspension modules are provided for suspensions with or without full active 3D steering of the wheels.

Both products include an option for representing frame twist. In a model with frame twist, separate modules are defined that account for two rails in a sprung mass that pitch out-of-phase to represent the frame twist. These modules have the extra features:

- Sprung masses (lead or semitrailer): each sprung mass module includes the two rails as rigid bodies, constrained to pitch out-of-phase, and adding one DOF to the model.
- Suspensions: the suspension models attach to the frame rails rather than the basic sprung mass.

Layout of the Vehicle: Units and Axles

Table 1 lists the multibody modules in CarSim and TruckSim.

Table 1. Existing vehicle modules.

Module	Code	Product	Type
Lead unit w. 6 DOF	<i>none</i>	Specific	Lead-unit sprung mass
Lead w. engine	E_	CarSim	
Lead w. rails	F_		
Lead w. rails + suspended cab	F_	TruckSim	
Semi	<i>none</i>	Both	Semitrailer sprung mass
Semi w. rails	F_		
Solid axle, steered	S	Both	Suspension
Solid axle for rails, steered			
Generic/independent, steered	I		
Generic/independent for rails, steered			
Solid axle, not steered	S		
Solid axle for rails, not steered			
Generic/independent, not steered	I		
Generic/independent for rails, not steered			
Twist beam (legacy)	T	CarSim	
Twist beam for rails (legacy)			
Virtual steer, independent	V		
X DOF, generic/independent, steered	I		
X DOF, generic/independent, not steered			

There are some differences between the two products:

- CarSim supports the option to have lead-unit sprung mass with engine mounts and a separate engine body. This adds 12 DOF to the sprung mass module.
- TruckSim includes a suspended cab on the lead unit sprung mass with frame twist. This adds four DOF, in addition to the one DOF added by the frame twist.
- CarSim includes a suspension with a virtual steer axis. Wheel motions (including steer) are defined with 2D kinematical tables with jounce and steering rack travel as the independent variables.
- CarSim includes Generic suspensions with an extra X (longitudinal) DOF, with and without steering.

The VS Solver library has a function to define a stripped-down VS Math Model with a minimum of system parameters and a few commands. That model reads a Simfile and Parsfiles, and extends the model when it reads a command `MODEL_LAYOUT` with a text description. The text definition specifies the number of vehicles, the number of vehicle units, the number of suspensions on each unit, and the category of each suspension. The `MODEL_LAYOUT` text descriptions is assembled using the characters shown in the table, along with underscore characters ‘_’ to separate suspensions that are not part of a tandem or tridem, and double-underscores ‘__’ to separate vehicle units. Some example `MODEL_LAYOUT` descriptions:

- `I_I` specifies a vehicle with generic/independent front and rear suspensions.
- `I_SS` specifies a vehicle with generic/independent front and a tandem rear with solid axles.
- `F_I_S` specifies a vehicle with frame twist, a generic/independent front suspension, and a solid rear axle. If the vehicle is in TruckSim, it also has a suspended cab.
- `E_I_I` specifies a CarSim vehicle with a suspended engine body and generic/independent suspensions front and rear.
- `S_SS__SSS` specifies a combination vehicle whose lead unit has a solid front axle and rear tandem with two solid axles, towing a trailer with a tridem suspension with three solid axles.

The `MODEL_LAYOUT` description is used by the VS Math Model to add many keywords to an internal database for parameters and variables related to the sprung masses, suspensions, wheels, brakes, and other parts of the vehicle model. That database is used to parse more input information read from Parsfiles, setting values for many of the parameters.

A CarSim or TruckSim VS Solver functions can assemble a VS Math Model for a vehicle using a lead unit with two or more suspensions, and multiple semitrailers, each with at least one suspension. The methods for combining modules allow multiple instances of a module to be added (e.g., multiple suspensions in a TruckSim vehicle).

The CarSim browser GUI supports two-axle motor vehicles, and semitrailers with one, two, or three suspensions. The TruckSim GUI supports up to five axles in the motor vehicle, and

semitrailers with up to four axles. The VS Solvers support VS Math Models with almost unlimited combinations; examples are provided in the TruckSim database showing how vehicles can be constructed with more than five axles on the lead unit, and more than four semitrailers.

Additional Suspension Options

Other keywords are used to determine which specific module should be used to provide solver equations for a suspension. For example, Table 1 shows four modules that have the code `S` (solid axle suspension), with differences depending on whether the suspension is attached to a sprung mass with frame twist, and whether the suspension has wheels that can be steered.

The four options supported in TruckSim for solid and generic/independent suspensions are handled after the Parsfiles have been read, but before the initialization is performed. Two conditions are considered to determine which of the four possible suspension modules are used for a specific axle:

1. If the sprung mass has frame twist, the choice is reduced to two options (steered or unsteered) that connect the suspension to rails attached to the sprung mass.
2. If this is axle 1, or if the parameter `OPT_STEER_EXT` for the axle is not 1, then the suspension is steered. Otherwise, it is unsteered.

These two conditions combine to cover the four possible suspension modules.

For CarSim, an additional consideration for a generic/independent suspension is whether the command `DEFINE_SUSP_X_DOF` had been applied for the axle. If so, one of the X DOF modules is installed. (This option is not supported for sprung masses with frame twist.)

Connecting Modules Between Vehicle Units

A vehicle with one or more trailers has multiple vehicle units. The hitches that connect hitch points on the two connected units are modeled with three sets of translational springs and dampers in the X, Y, and Z directions of the sprung mass coordinate system of the trailing unit.

The translational spring-damper pairs exist to keep the distance between the hitch points in the two vehicle units small. In most cases, exact displacement is not of interest. The stiffness and damping should be high enough that the displacement is very small, but not so high that the model becomes numerically unstable and crashes. Our main concern is how the frequencies of the DOFs relate to the vehicle at large. Accordingly, the spring and damper coefficients are specified using parameters for frequency and damping ratios: `HITCH_FREQ` (Hz) and `HITCH_ZETA` (damping ratio). The default value used for all such connections are 40 Hz for frequencies, and 0.1 for damping ratios.

In versions prior to 2018.0, hitches had rigid connections that prevented translational deflection. When comparing results from 2018.0 and newer to older versions, small differences in the motions will exist due to the hitch deflections (typically a few millimeters).

Multiple Vehicles in a Single VS Math Model

Starting with version 2020.1, CarSim and TruckSim can construct VS Math Models with up to four vehicles, each with its own lead unit. This capability is not supported by the GUI; examples shipped in the databases show how to set up a model with multiple vehicles.

The main reasons for including multiple vehicles in a single VS Math Model involve simulations involving interactions of vehicles, where they can detect each other and respond accordingly.

Multibody Vehicle Models for BikeSim

BikeSim includes two types of multibody modules:

1. **Front Part.** The front of the model has everything from the front steering head to the front wheel, with all connecting linkages and rotations.
2. **Rear Part.** The rear part of the model includes the sprung mass, the rear suspension, and the rider.

Table 2 lists the multibody modules in CarSim and TruckSim.

Table 2. Existing vehicle modules.

Module	Code	Part
Telescopic fork with frame flexibility	<code>fixed_caster</code>	Front
Telescopic fork without frame flexibility	<code>rigid_fixed_caster</code>	
Variable-caster fork with frame flexibility	<code>variable_caster</code>	
Variable-caster fork without frame flexibility	<code>rigid_variable_caster</code>	
Two-wheeled front with frame flexibility	<code>three_wheeled</code>	
Two-wheeled front without frame flexibility	<code>rigid_three_wheeled</code>	
Frame, rider, rear swing arm	<code>none</code>	Rear
Frame, rider, rear swing arm with flexibility	<code>_flex</code>	

The code used for the vehicle layout is made by combining the front and rear codes. If the rear module has a swing arm with no flexibility in twist, the code is simply that for the front part, e.g., `fixed_caster` for a bike with a simple telescopic front fork with frame flexibility. If the rear has flexibility, then the code ends with `_flex`, e.g., `fixed_caster_flex`.