Mechanical Simulation
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Gravity and Acceleration Fields

The CarSim and TruckSim vehicle models include a uniform gravitation field that may be adjusted to provide advanced simulation options. An example is shown in which the method is used to include road grade using import variables.

Gravity and the Acceleration Field

The 3D multibody vehicle models in CarSim include a gravitation field that is nominally constant vector oriented down in the global Z direction, $-\mathbf{n}_Z$. The other directions for the global reference frames are $\mathbf{n}_X$ and $\mathbf{n}_Y$. Using a constant `G` and scale factor `R_GRAVITY` (lines 93 and 100 in an example TruckSim Echo file, Figure 1), the gravity vector is:

$$\text{Gravity vector} = -\texttt{G*R\_GRAVITY}\ \mathbf{n}_Z$$

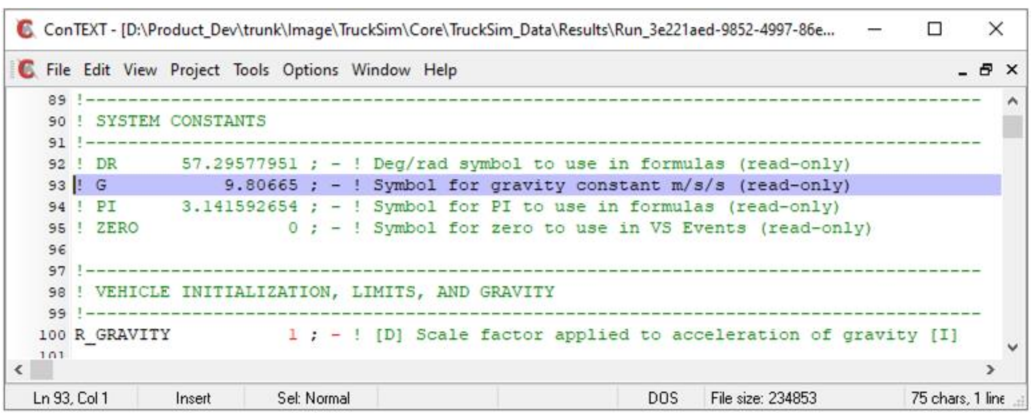


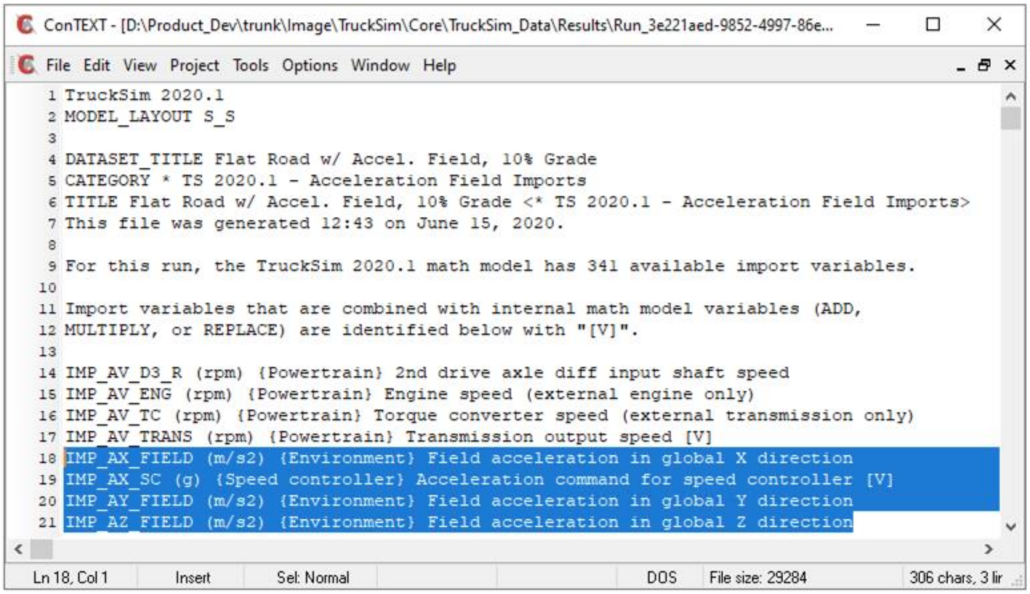
Figure 1. Echo file showing gravity constant G and scaling parameter R_GRAVITY.

The parameter `R_GRAVITY` scales the gravity vector, with the default value of 1.0. Other values have been used to simulate rovers on other planets, with lower gravity.

The amplitude `G*R_GRAVITY` applies for the dynamic vehicle models in CarSim and TruckSim, and is also used to calculate suspension loads, spring loads, and tire loads, used to obtain initial spring and tire deflections.

CarSim and TruckSim also include three Import variables that are available for advanced users to go beyond the physical environment, to include an acceleration with three Import variables (lines 18, 20, and 21, Figure 2).

These are used to add acceleration to the global reference frame. The math for an acceleration field in the multibody model is the same for the math for the gravity field, and in fact, the gravity effect is programmed as an acceleration field because it is highly efficient computationally.



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ConTEXT - [D:\Product_Dev\trunk\Image\TruckSim\Core\TruckSim_Data\Results\Run_3e221aed-9852-4997-86e...
File Edit View Project Tools Options Window Help
TruckSim 2020.1
MODEL_LAYOUT S_S

DATASET_TITLE Flat Road w/ Accel. Field, 10% Grade
CATEGORY * TS 2020.1 - Acceleration Field Imports
TITLE Flat Road w/ Accel. Field, 10% Grade <* TS 2020.1 - Acceleration Field Imports>
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For this run, the TruckSim 2020.1 math model has 341 available import variables.

Import variables that are combined with internal math model variables (ADD,
MULTIPLY, or REPLACE) are identified below with "[V]".

IMP_AV_D3_R (rpm) {Powertrain} 2nd drive axle diff input shaft speed
IMP_AV_ENG (rpm) {Powertrain} Engine speed (external engine only)
IMP_AV_TC (rpm) {Powertrain} Torque converter speed (external transmission only)
IMP_AV_TRANS (rpm) {Powertrain} Transmission output speed [V]
IMP_AX_FIELD (m/s2) {Environment} Field acceleration in global X direction
IMP_AX_SC (g) {Speed controller} Acceleration command for speed controller [V]
IMP_AY_FIELD (m/s2) {Environment} Field acceleration in global Y direction
IMP_AZ_FIELD (m/s2) {Environment} Field acceleration in global Z direction
Ln 18, Col 1   Insert   Sel: Normal   DOS   File size: 29284   306 chars, 3 lir
```

Figure 2. Three import variables used to define an acceleration field.

Effectively, the multibody vehicle model is subject to the gravity field extended with the acceleration field, using the sign convention:

Gravity vector = -G*R_GRAVITY $\mathbf{n}_z$ + AX_FIELD $\mathbf{n}_x$ + AY_FIELD $\mathbf{n}_y$ + AZ_FIELD $\mathbf{n}_z$

These import variables have been used to study some quasi-static conditions of a racecar subject to constant lateral acceleration, and a vehicle going on a straight road subject a gravity vector modified to mimic a road grade.

Mimicking a Road Grade with an Acceleration Field

Consider a road surface that is flat but not level, subject to the default value of gravity G (R_GRAVITY = 1). The left part of Figure 3 shows the side view of a road surface that has a 10% grade (i.e., it goes up in elevation 1m for every 10m of horizontal position). In this case, the gravity vector (shown in blue) is not perpendicular to the surface, but is angled back relative to the surface by the same grade.

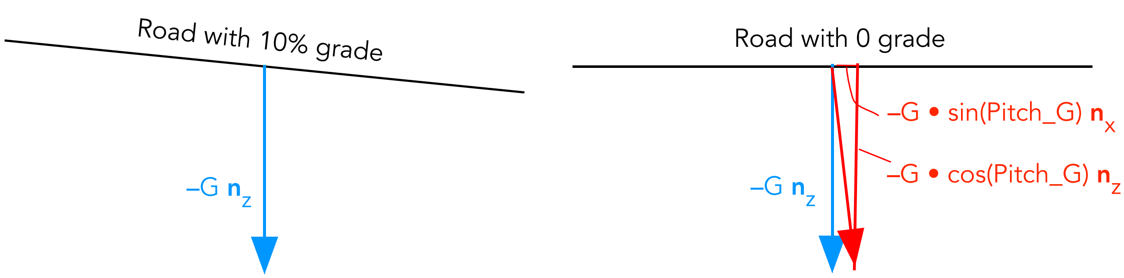

Figure 3. Using an acceleration field to mimic a road grade.

Now consider the right-hand part of the figure, in which the same geometric relationship is given between the road surface and a revised gravity vector, shown in red. The same relationship is obtained if the gravity vector is modified with acceleration field components to have the same magnitude G, but rotated to the rear by the angle Pitch_G = $\tan^{-1}(0.1)$.

Figure 4 shows some VS Commands to define an output variable Grade_Rd with units of percent and an equation for Pitch_G, added with an EQ_IN command in case the grade is changed during the simulation.

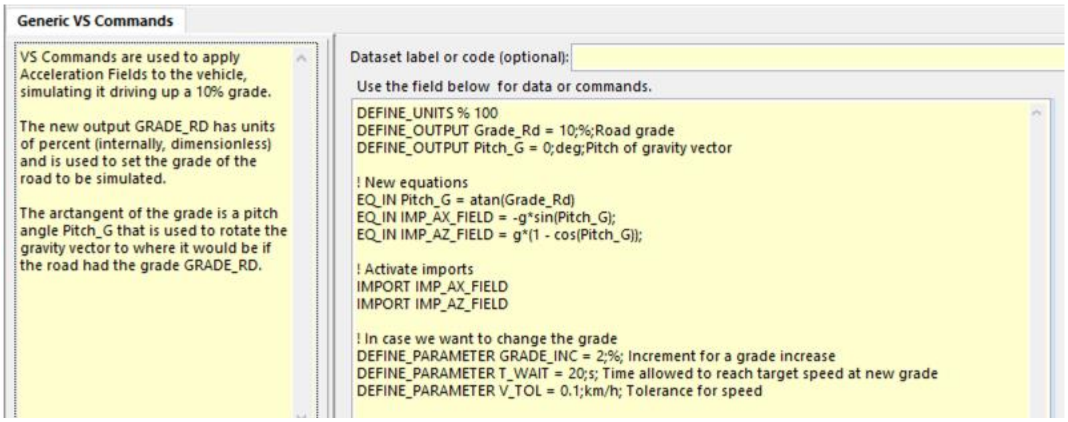

Figure 4. VS Commands used to adjust the gravity vector.

The import variables IMP_AX_FIELD and IMP_AZ_FIELD are activated using the IMPORT command, and are calculated each time step using the equations:

IMP_AX_FIELD = -G*SIN(PITCH_G)

IMP_AZ_FIELD = G*(1 -COS(PITCH_G))

Given that the gravity vector (blue) already is present with a magnitude -G $\mathbf{n}_Z$, the IMP_AZ_FIELD variable just needs to nudge the vector to be shorter: G*COS(PITCH_G)).

Figure 5 shows how the commands appear in the Echo file.

Figure 6 overlays plots from two runs in TruckSim. One uses a road with a 10% grade, and the other uses the acceleration field import variables. In comparing plots, nearly identical results are obtained for the vehicle speed and the tire forces on the drive axle.

Two differences are shown, and both are expected. The plot of vehicle Pitch for the road with a 10% grade includes the starting pitch of the road (–5.71059°). The plot for the level road shows an angle close to zero, based only on the distribution of the sprung mass weight on the front and rear suspensions, and longitudinal acceleration. The other difference is that the variable Vx, plotted with other speed variables. Vx is defined as the velocity component of the vehicle center of mass, in a direction perpendicular to global $\mathbf{n}_Z$. With the road that has a 10% grade, the component of velocity is reduced by a factor cos(Pitch_G). In the case of the level road, the measures of speed are in the same direction.

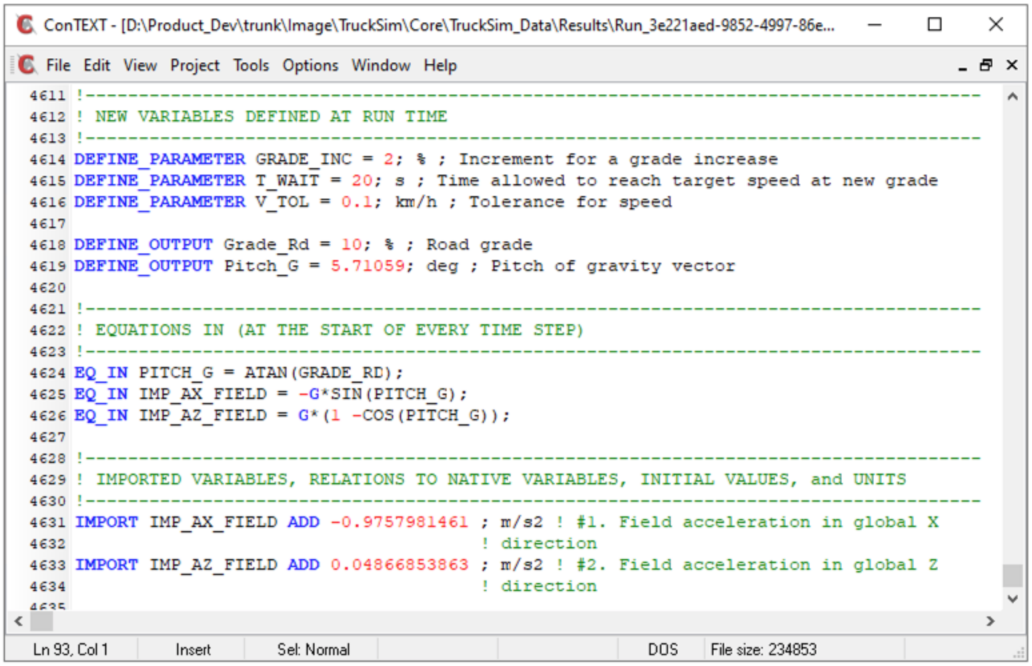

Figure 5. Echo file showing VS Commands.

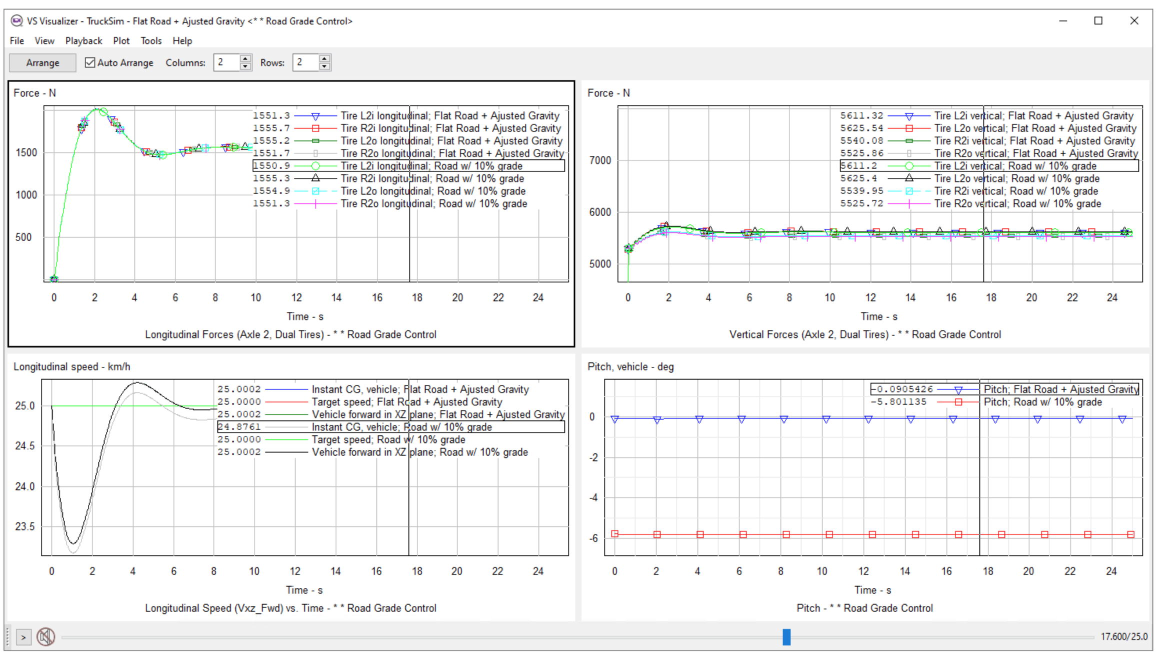

Figure 6. Comparison of road with 10% grade to level road with adjusted gravity field.

A potential advantage of the manipulation of gravity using the imported acceleration field components is that advanced simulations may be set up in which the road grade is adjusted several time in a run. One way is to import the `Grade_Rd` from external software such as Simulink; another is to use VS Events to increment `Grade_Rd` if the vehicle can achieve a target speed at the old grade.

The VS Command dataset not only defined the output variables `Grade_Rd` and `Pitch_G`, it also defined three parameters: `GRADE_INC`, `T_WAIT`, and `V_TOL`. These are used in another simulation in which Events are used to simulate a variety of road grades.

Figure 7 shows an **Events** dataset named **Set New Grade**, which increments the `Grade_Rd` variable using the parameter `GRADE_INC`. This dataset also sets a timer `T_EVENT` to start from the current time. When the clock has advanced to `0.2*T_WAIT`, a Parsfile is loaded for the **Events** dataset **Check Speed** (Figure 8).

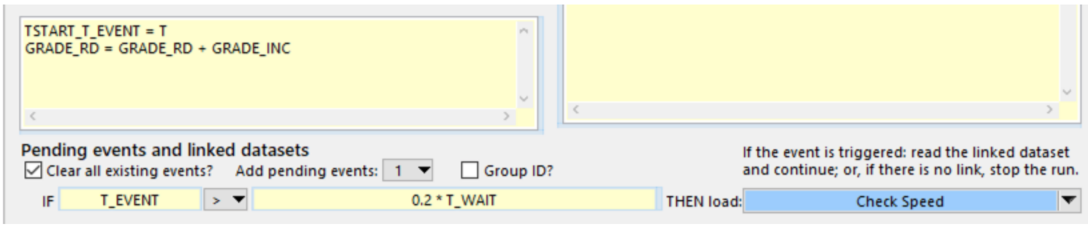

Figure 7. Event dataset "Set New Grade" to adjust the road grade and create a Pending Event.

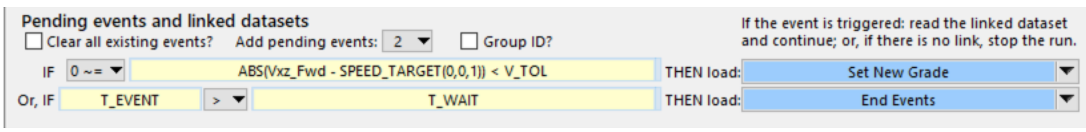

Figure 8. Event dataset "Check Speed" to make pending Events to continue or stop.

The **Check Speed** dataset defines two pending Events. The first is triggered if the vehicle forward speed is within a tolerance of the target speed. The second is triggered if a specified wait time has been reached, with the speed not within the tolerance. In this case, the run is terminated.

Figure 9 shows results for this simulation, in which the effective road grade is incremented many times.

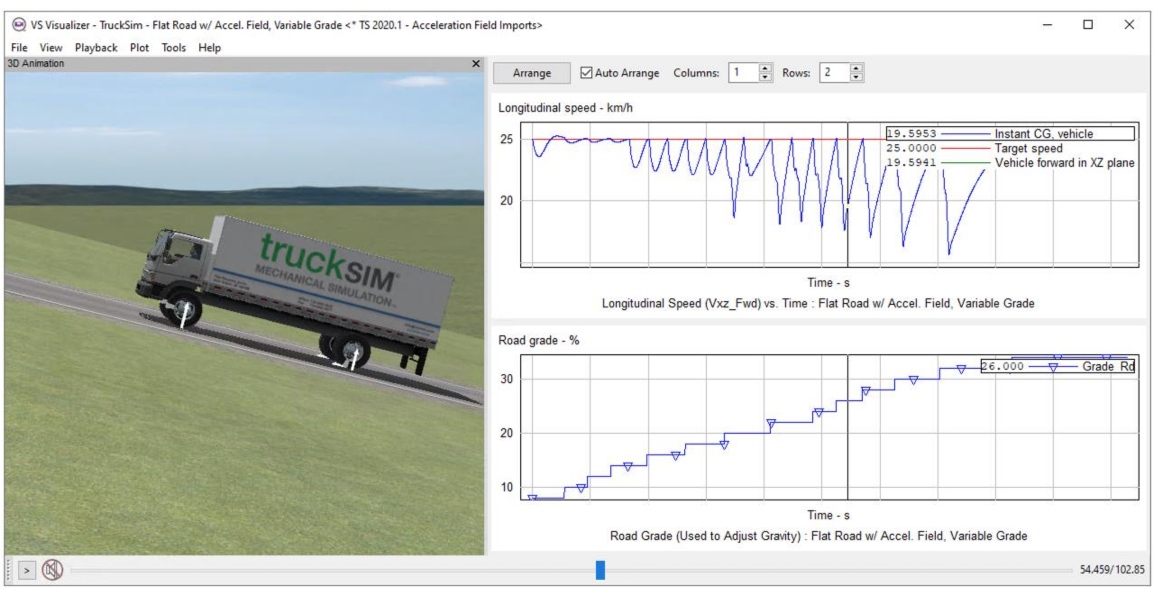

Figure 9. Simulation in which the effective road grade is incremented many times.