Getting Started Using Universal Mechanism: Railway Vehicle Dynamics

This manual leads you through the basic possibilities of Universal Mechanism software in simulation of railway vehicle dynamics. It assumes that you studied the **gs_UM.pdf**[1] chapter, which is devoted to general concepts of simulation using Universal Mechanism, and know how to fulfill simple operations: create a new model, add graphical objects, bodies and joints, generate and compile equations of motion.

Firstly, example of the simulation of a single wheelset is discussed, and then creating the model of the two-axel vehicle is shown. The last section is devoted to creating the scanning project for the evaluation of the critical speed of the vehicle.

[1] http://www.umlab.ru/download/50/eng/gs_um.pdf

1. Simulation of a single wheelset dynamics

1.1. Creating the model

Create new object to simulate

1. Select the **File** | **New object** menu command.

Setting model parameters

2. Select the **Object** item in the *Tree of elements*.
3. Select **Railway vehicle** in the **Type of object** group of the *Inspector* (optional parameter in UM50).
4. Set **Generation of equations** to **Numeric-Iterative**.

Note. The v0 parameter (speed of the vehicle) is added automatically to the identifier list after choosing the railway object type.

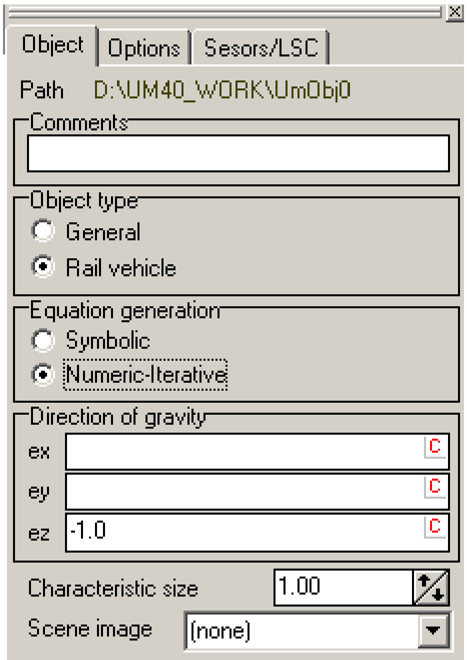
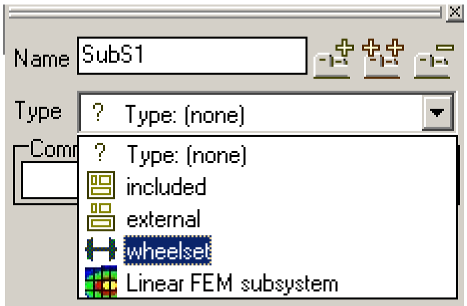


Figure 1.1. Object options

Adding new wheelset

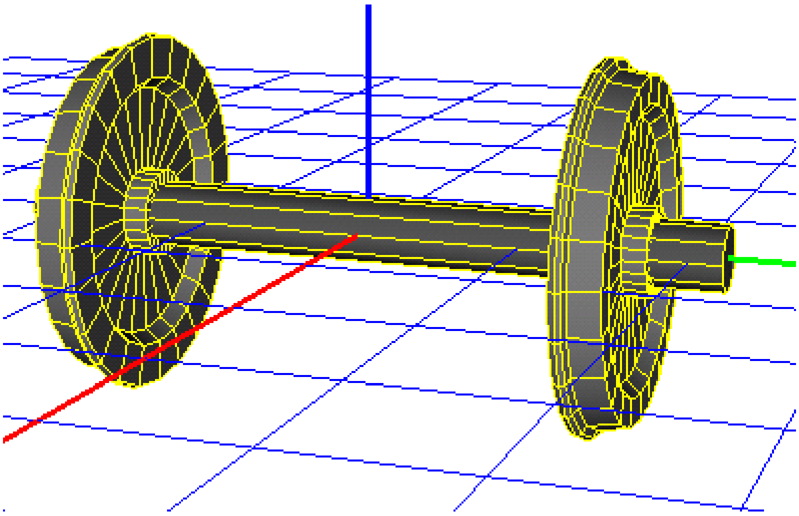
Wheelset is the one of the standard UM subsystems. The following steps are necessary to create a new wheelset.

5. Select the **Subsystems** item in the *Tree of elements*.
6. Add a new subsystem by the button in the *Inspector*.



7. Select the type of the subsystem - **wheelset**.

Now you can see the wheelset in the animation window.



8. Rename the wheelset. Set the **Name** parameter to **Wheelset**.
9. Save the model with the name **WSet** by the **File | Save as** menu command.

The model is ready to be loaded in the simulation program (UM Simulation).

10. Run simulation program. From the menu **Object** select **Simulation** or use the button.

1.2. Simulation of the wheelset dynamics

1.2.1. Preparing environment for the simulation of railway vehicle dynamics

To perform the simulation of a rail vehicle, it is necessary to set the following data:

- wheel and rail profiles;
- vertical and lateral profiles of the track irregularities.

The following profiles are set by default:

- the new Russian locomotive wheel profiles, the *newlocow.wpf* file;
- the Russian R65 new rail profile, the *r65new.rpf* file.

Setting wheel and rail profiles

1. From menu **Analysis** select **Simulation** or use the F9 key. **Object simulation inspector** appears.
2. Select the **Rail/Wheel** tab.
3. Point to the **Profiles** and then **Profile files** tabs, see Fig. 1.2.
4. For **Left rail** and **Right rail** load one the desired ***.rpf** file.
5. Point to the **Profiles** | **Wheels** tabs
6. Click the  button (add profile to list) and select the desired ***.wpf** file**,** for example **newwagnw.wpf**.
7. Select the **Wheels** tab.
8. Click the right mouse button on the table of wheel profiles and select **Assign to all/newwagnw**, see Fig. 1.3.
9. Click the  button. Window with rail and wheel profiles appears.

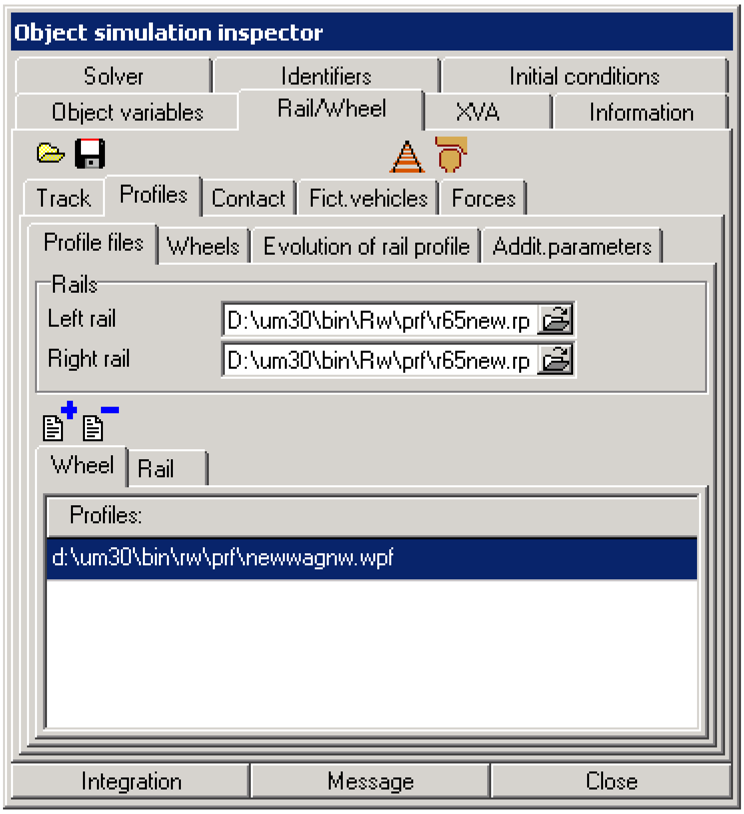


Figure 1.2. Rail and wheel profiles

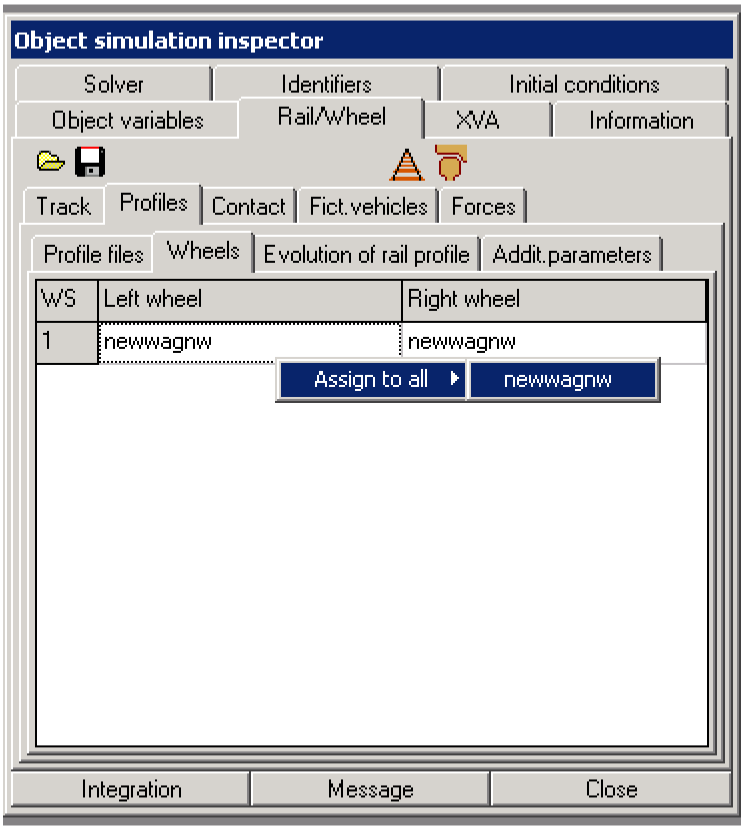


Figure 1.3. Rail and wheel profiles

Setting track irregularities

1. Point to **Object simulation inspector**, or press F9.
2. Select **Rail/Wheel / Track / Irregularities**.
3. Set the **Uneven** track type
4. Open files of irregularities as it is shown in the table below.

Field	File
Left rail (Z)	aprg11.way
Right rail (Z)	aprg11.way
Left rail (Y)	kolomvn.way
Right rail (Y)	kolomvn.way

1.2.2. Simulation of the motion

Set ideal even way

1. Select **Object simulation inspector**, you can also use F9.
2. Point to **Rail/Wheel / Track / Irregularities** tab.
3. Set **Track type** to **Even**.
4. Point to **Macrogeometry** tab.
5. Set **Track type** to **Tangent**.

Animation of rail/wheel contact

Open the window for animation rail/wheel contact forces and turn on animation of contact forces.

1. To open the window for rail/wheel animation use menu command **Tools/Animation of contact** or the  button.

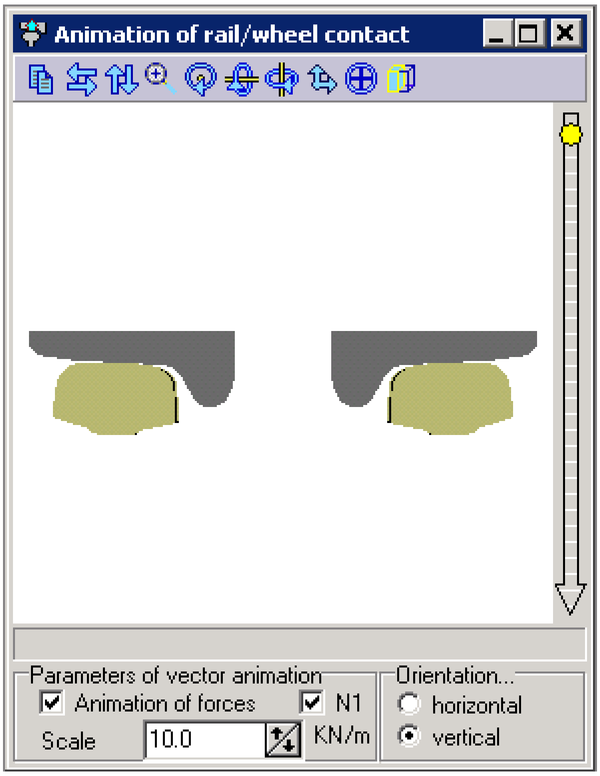
   The rail/wheel contact window appears.

2. Turn on **Animation of forces** and **N1**.

In order to get quite large-scale vectors of forces we need to change scale of vectors.

3. Set **Scale** to **10** (kN/m).

Note. Forces are shown after the simulation of wheelset dynamics starts.


Animation of rail/wheel contact
Parameters of vector animation
Animation of forces
N1
Scale
10.0
KN/m
Orientation...
horizontal
vertical

Stationary motion

Before simulation starts we need to set parameters of the numerical method.

1. Select **Object simulation inspector**, F9.
2. Point to the **Solver** tab.
3. Set **Solver** to **Park**.
4. Set **Error tolerance** to **4E-8**.
5. Click **Integration**.

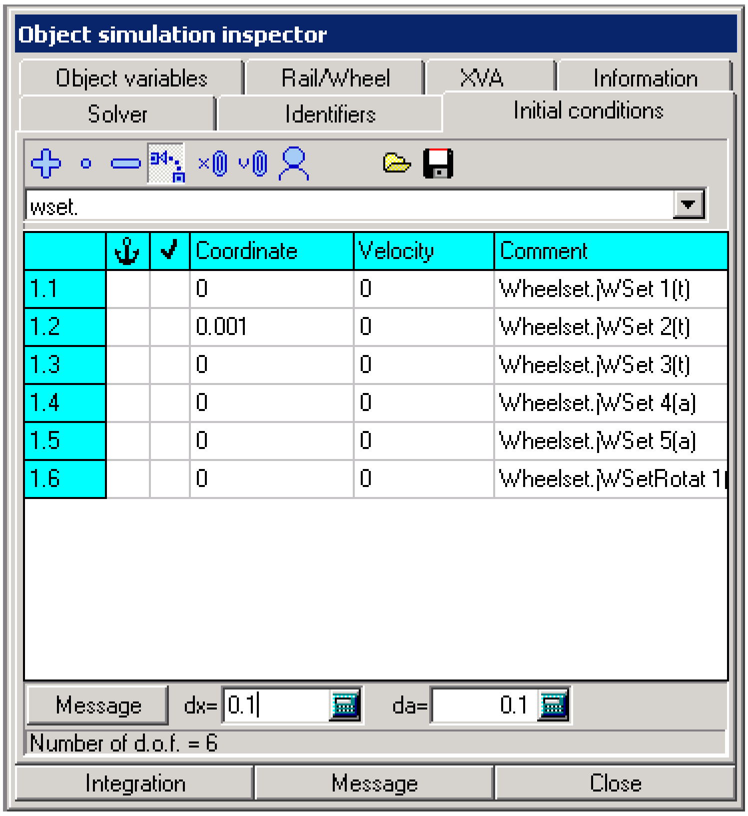
If all coordinates are zero, a stationary regime of motion occurs: the wheelset does not move in the lateral direction and does not rotate about the vertical axis. The contact forces are constant.

6. After simulation finishes **Pause** window appears. Click **Interrupt**.

Perturbed motion

Now we'll shift the wheelset from the steady state and analyze its dynamics.

1. Select **Object simulation inspector**.
2. Point to **Initial conditions** tab.
3. Set second (1.2) coordinate to 0.001 (m). Press **Enter**.



4. Start simulation. Make sure that the wheelset is instable - a small perturbation of initial position leads to self-excited vibrations.

Repeat the simulation to obtain plots for coordinate Y of the wheelset and for the angle of rotation about Z axis.

5. Open a new **graphical window**.
6. Open **Wizard of variables**.
7. In the **Wizard of variables** select the **Coordinates** tab.
8. Select **Wheelset/jWSet/1.2**.
9. Click the  to create the variable and set it to the container of variables.
10. Repeat the previous two steps for the **Wheelset/jWSet/1.5**.

11. Drag variables to the graphical windows.
12. Start simulation of motion.

Plots of the lateral position of the wheelset and its turning angle relative to the vertical axis are shown.

Note. If you have too many open windows use **List of windows**, menu command **Windows/List of windows**.

Set initial speed of the vehicle and simulation time.

1. Select **Object simulation inspector**, point to **Identifiers** tab.
2. Set **Expression** for the **v0** to **10** m/s.
3. Select the **Solver** tab, set **Simulation time** to **20** seconds.
4. Start simulation of motion.

You see that the wheelset is unstable as well but the period of oscillation increases.

2. Creating the model of the railcar

Here we consider development of a simplified model of a railcar. The main simplification is absence of the traction engines. You can find this model in the **\samples\rail vehicles\ac4**[1] directory.

2.1. Basic elements of the model

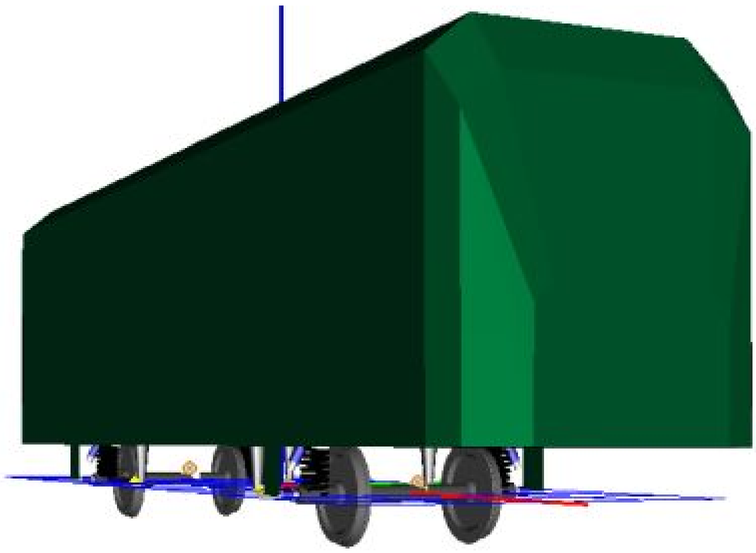


Figure. 2.1. UM model of the ac4 railcar

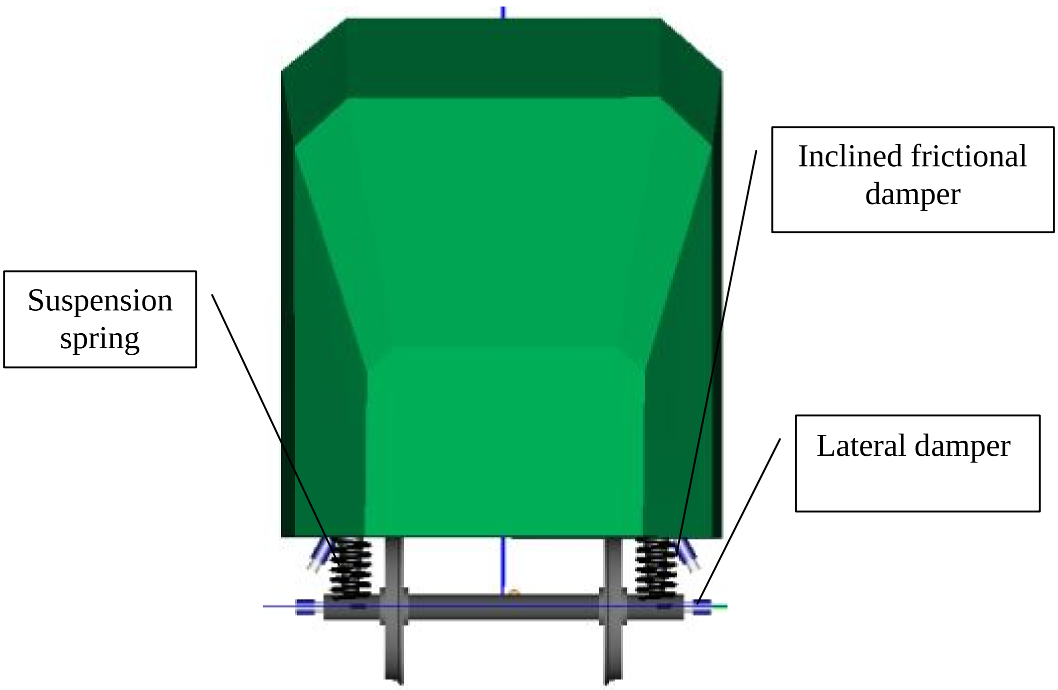


Figure 2.2. Basic elements of the model

[1] Model is also available at http://www.umlab.ru/download/50/ac4.zip

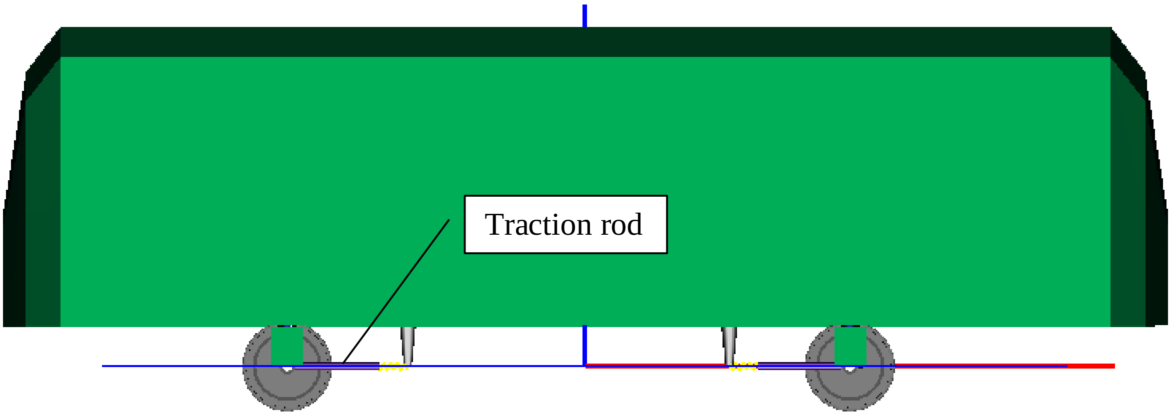


Figure 2.3. Basic element of the model

The model consists of the following elements.

1. Two standard UM subsystems – wheelsets.
2. Four graphic objects (car body, damper, spring, traction rod).
3. One body – car body.
4. One joint introducing car body coordinates.
5. Twelve bipolar force elements (4 inclined and 4 lateral dampers, 4 traction rods).
6. Four special force elements of the spring type as suspension springs.

2.2. Creating new object

1. Run **UM Input** program.
2. Create a new object by clicking the  button or by the **File/New object** menu command.
3. Save the empty object by clicking the **File / Save as…** menu command.

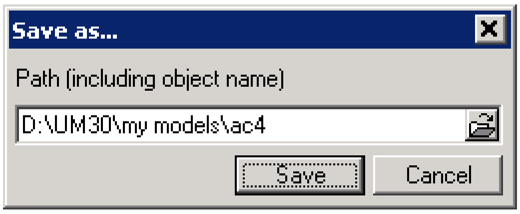


Figure 2.4. Save dialog

Select a desirable directory including the object name (ac4, Fig. 2.4). You can use any letters in the path except the object name where Latin letters and digits can be used only. The terminal directory in the path (with the object name, ac4) will contain all information about the model as well as working files.

4. Select the **Object** item in the tree of elements and set **Type of object** to **Railway vehicle**, Figure 2.5 (optional parameter in UM50).

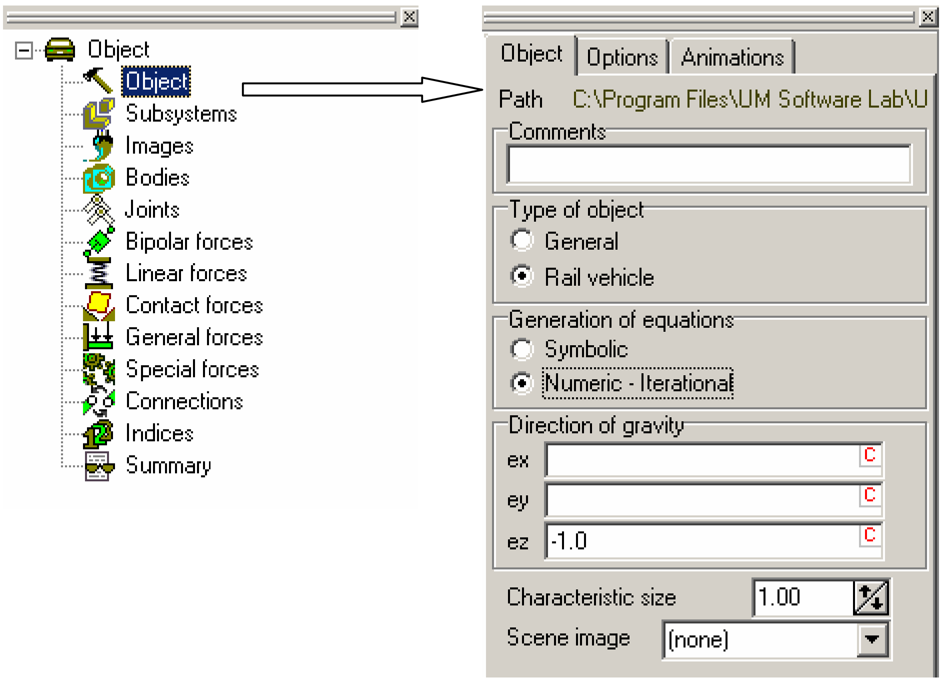


Figure 2.5. Type of object – railway vehicle

While describing the object elements use the button in the toolbar of the animation window to switch the object image modes: full object mode and separate element mode.

2.3. Creating wheelsets

General information about a wheelset as a standard subsystem can be found in Chapt.8, Sect. *Wheelset.*

1. Select **Subsystems** in the element tree (Fig. 2.6, left) and add a subsystem by clicking the button on the data inspector, rename it to **WheelSet1** and choose the type of the subsystem – **wheelset** (Fig. 2.6, right). Wheelset appears in the animation window and the data in inspector reflect its current geometrical and inertia parameters.

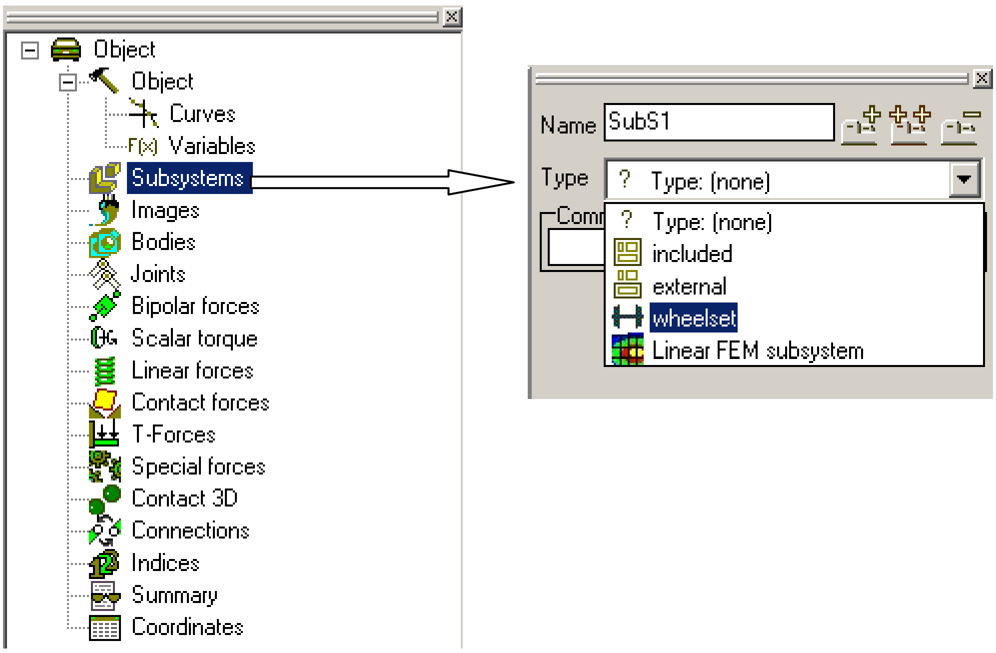


Figure 2.6. Adding a standard subsystem – “wheelset”

Some of the wheelset parameters can be corrected right here, see Fig. 2.7).

2. Set **Axle length** to 2.2 m (Fig. 2.7, left).

   If necessary, here you can change semi base and the running radius.

3. Set the wheelset position relative to the car body center the vehicle. Select the **Position** tab and set **Position/x** to **l1**. Press **Enter** and input l1 = **3.29** m. The identifier appears in the list of identifiers together with the standard identifier *v*0

(initial vehicle speed). You can modify values of identifiers in the list any time you wish.

4. Here the user can decide where the origin of the reference frame (SC0) is located: either on the rail head level or on the wheelset axle level. In the second case, the wheelset should be shifted along the Z-axis on the wheel running radius, 0.45m in our case (**z** coordinate of the translation vector on the **Position** tab). If the z coordinate of the subsystem shift is zero, the SC0 origin is located on the wheelset axle level like in the figure below.

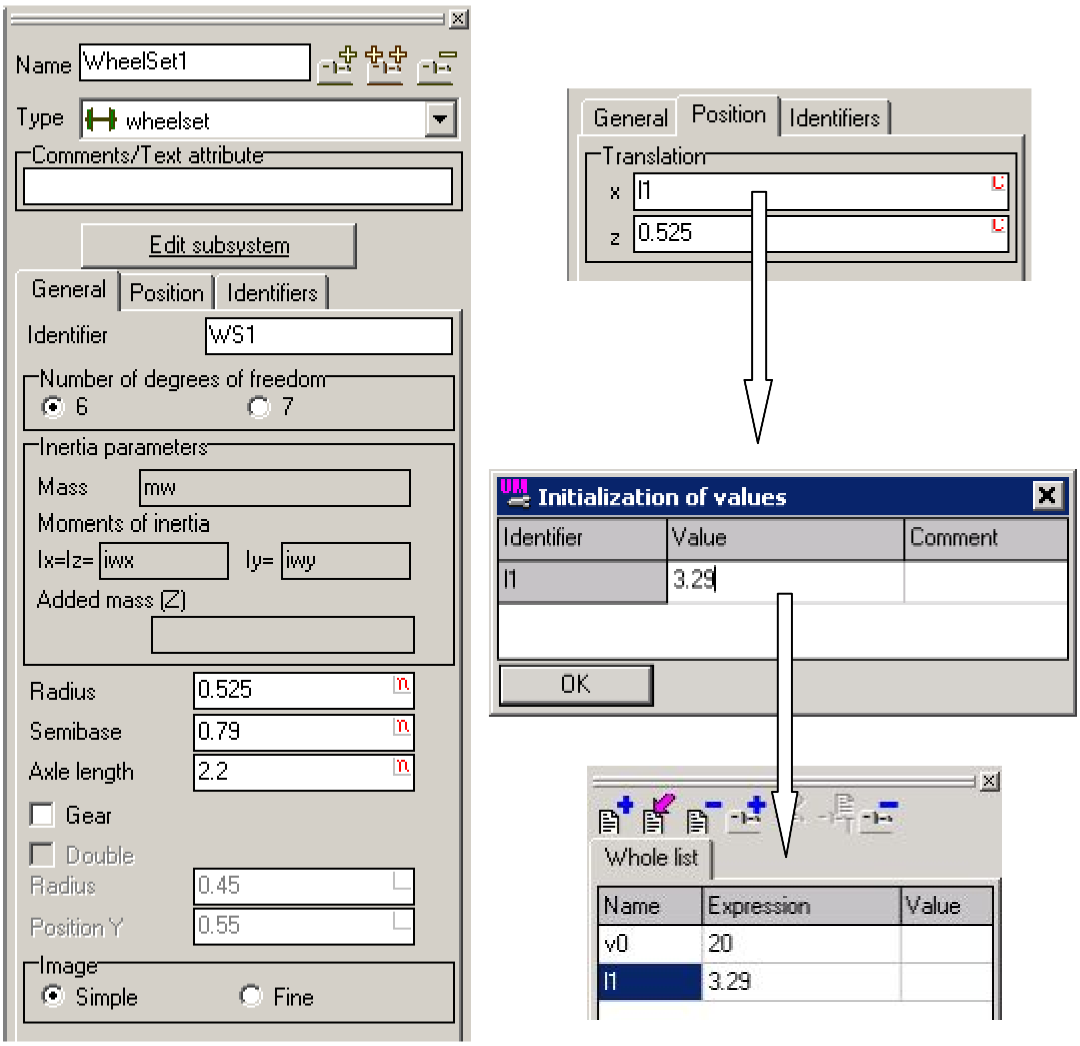


Figure 2.7. Wheelset parameters

Inertia data of wheelset

1. To modify inertia parameters of the wheelset click the **Edit subsystem** button. New constructor window appears.

Do the following steps.

2. Select the **WSet** body in the tree of elements.
3. Set **Mass** to **mw** and moments of inertia relative to X and Z axes to **iwx**. Numerical values of the parameters set to **mw = 3650** kg, **iwx = 1000** kgm^2;
4. Select the **WSetRotat** body and set moment of inertia relative to Y axis to **iwy = 500** kgm^2.

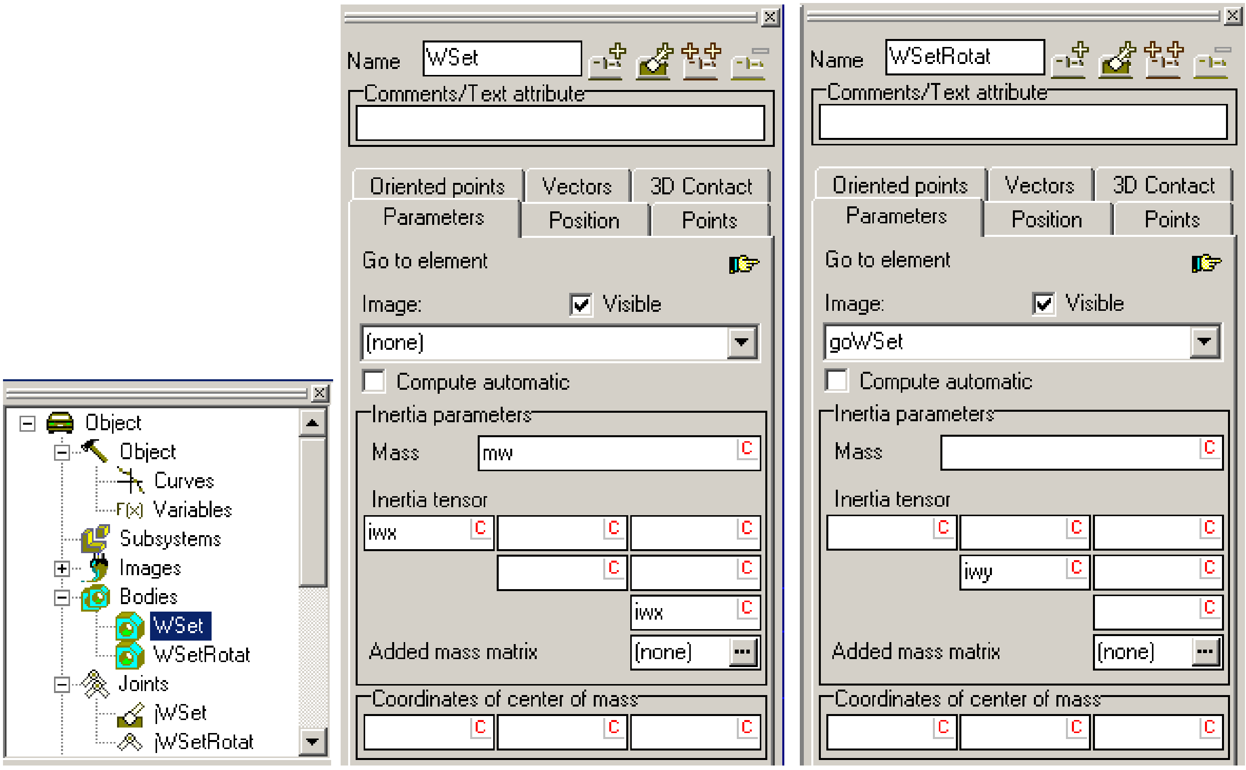


Figure2.8.Inertia parameters of wheelset base and gyrostat

Notes. Moment of inertia of the wheelset base (the WSet body) relative to the Y-axis is ignored.

Only moment of inertia relative to the Y-axis is allowed for the gyrostat (the WSetRotat body).

5. Close the object **WheelSet1** by the **Accept** button, see Fig. 2.9.

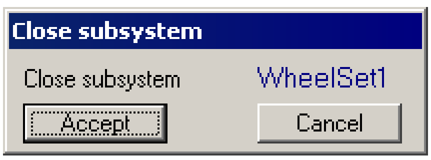


Figure 2.9. Changes confirmation

The data inspector reflects the new inertia parameters of the wheelset.

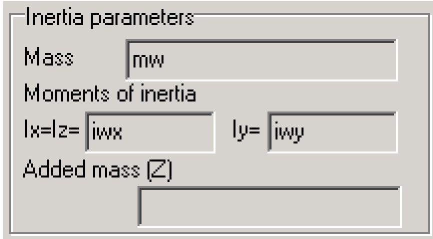
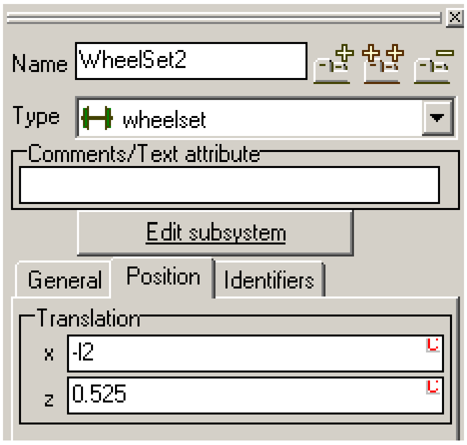


Figure 2.10. Wheelset parameters after modification

Creating the second wheelset

1. To create the trailing wheelset copy the leading wheelset by clicking the  button. Change the **Name** to **WheelSet2** and identifier of the new wheelset to **WSet2**. Set the wheelset location on the **Position** tab as **-l2**, where l2 = 3.71 m. Use the expression -*l*2 (minus *l*2) to set the negative coordinate.



2. Description of the wheelsets is complete. Save the object using the **File/Save** menu command.

2.4. Creating graphical objects

It is important to remember that one graphic object (GO) can be assigned to any number of elements having the same image. For instance, a GO ‘spring’ is assigned to four suspension springs as their image. The same statement is valid for dampers and traction rods.

1. Select **Images** element in the tree of elements. Now the list of graphical objects is empty.

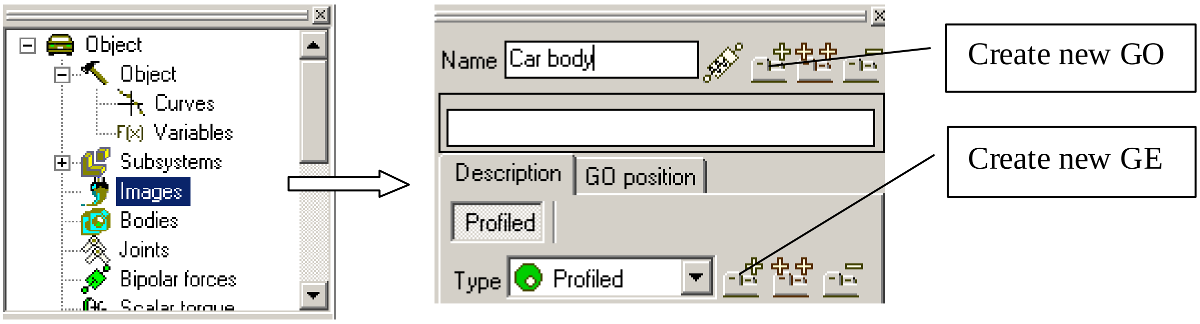


Figure 2.11. Images: buttons and their functions

2.4.1. Car body

2. Let us load the car body image. From the **Edit** menu select **Read from file** and select the **{um_root}\bin\graph\BodyGO.umi** file in the open dialog. This graphical object will be loaded and added to the list of graphical objects.
3. Select this graphical object. Rename it to ‘**Car body’**.
4. Select the **Description/Parameters/Profile** and set **Scale Y** to **0.9** (Fig. 2.12, left).
5. Select the **Description/Parameters/Axis curve** and set **Length** to **14.5** m.
6. Select the **Description/GE Position** tab and set **Translation/z** to **0.5**. Note that if a GO is assigned to a body, SC of the GO always coincides with the SC of the body.

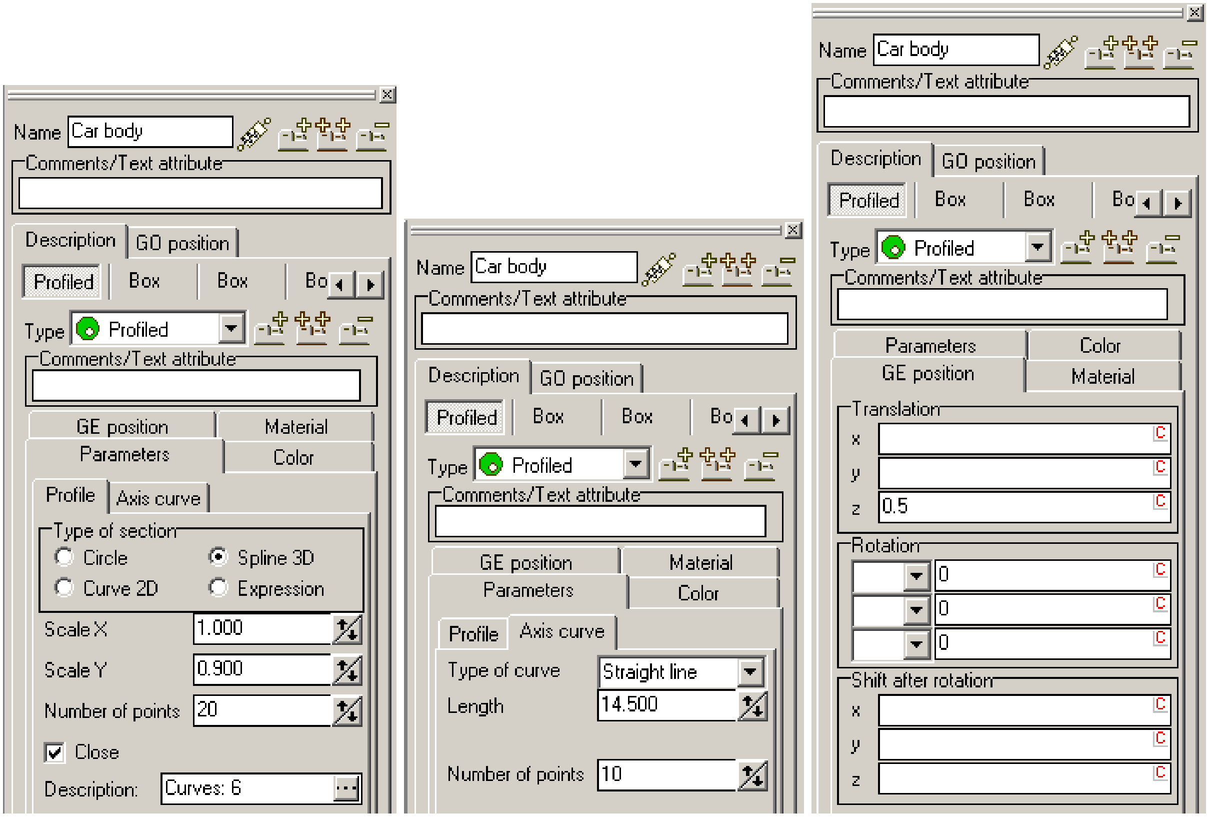


Figure 2.12. Car body image parameters

Now we should add to the GO some bracing details, i.e. some graphic element (GE), where suspension elements will be attached. Of course, it is not necessary but a good graphics improves the quality of the object representation. These GE should have the same color as the car body. The simplest way to do this consists in copying the car body image.

7. Click the  button in the *lower row* to add a new GE equal to the previous one (do not click the button in the *upper row*, it creates a new GO). Change the type of the element to **Box** instead of **3D profile** and set the box parameters (Fig. 2.13, left) and position (Fig.2.13, right). The box will be used for visualization of lateral damper attachments.

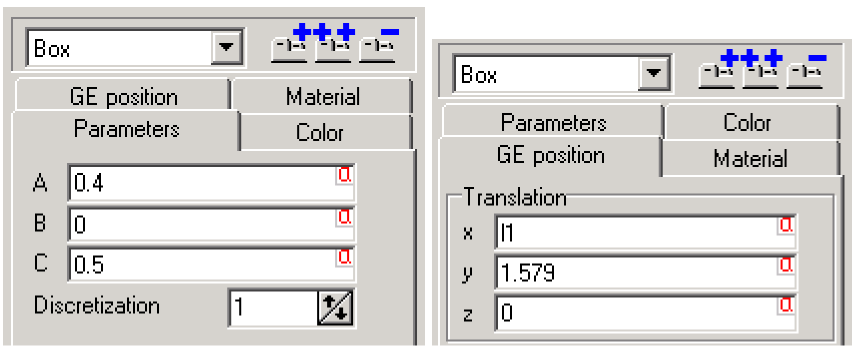


Figure 2.13. Element of the car body

8. Now we duplicate the box to create parts quite similar to the previous one but having different locations. Click the button in the second row to copy the box and change its position to **(l1, -1.579, 0)**. Repeat this operation two times with positions

(-l2, 1.579, 0),

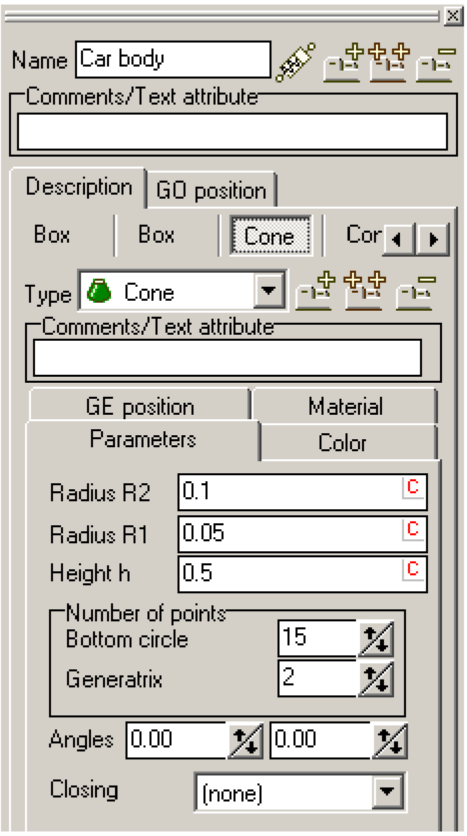
(-l2, -1.579, 0).

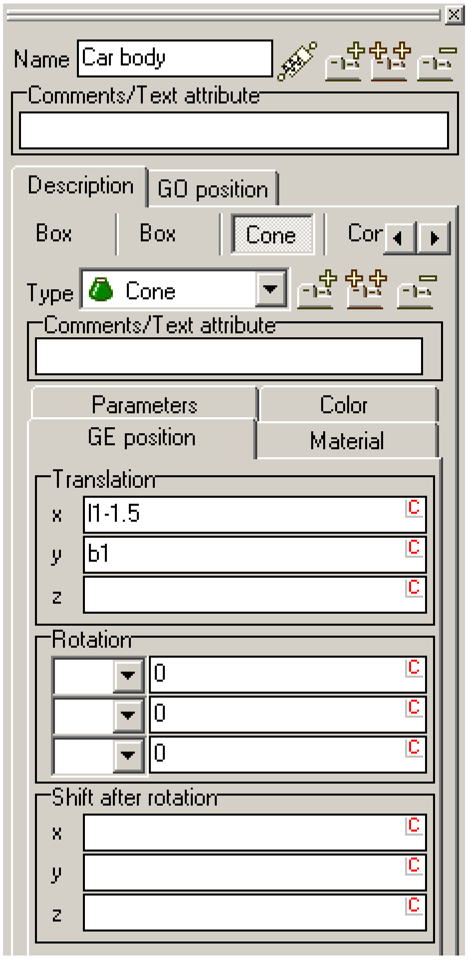
9. Last details of the image include four bracing elements for traction rods. Create a new GE by clicking the in the second row, select the **Cone** type and set its parameters and position as it is shown in the figures below (identifier **b1** has value **1.1** m). After that duplicate the element three times and set the following positions:

(l1-1.5, -b1, 0),

(-l2+1.5, b1, 0),

(-l2+1.5, -b1, 0).





Now the image looks like this:

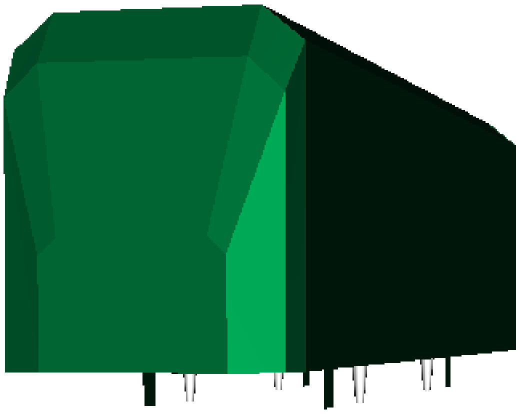


Figure 2.14. Car body: main view

2.4.2. Spring, damper

Spring

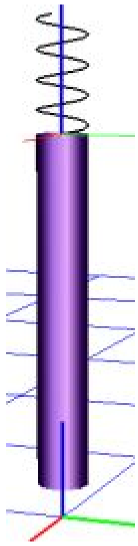
1. Create the second *graphical image* clicking the  button in the upper row.
2. Select **Spring** in the combo box. Leave default values for all parameters.

Damper

3. From the **Edit** menu select **Read from file**. Select the **{um_root}\bin\graph\Damper.umi** in the load dialog box.
4. Rename the graphical object to **Damper**.

Note. Note that images of force elements in the simplest case have 1 m length along Z-axis. Program manages its length and orientation automatically.

2.4.3. Traction rod



Unlike the previous graphic objects we will describe this image fully as a set of graphic elements.

1. Add the fourth GO to the list by clicking the button in the upper row and rename it as ‘**Traction rod**’.
2. Add a graphic element (GE) by clicking the button in the *second* row. Choose its type ‘**Cone**’.
3. Fill out the **Parameters** tab as it is shown in Fig. 2.15.

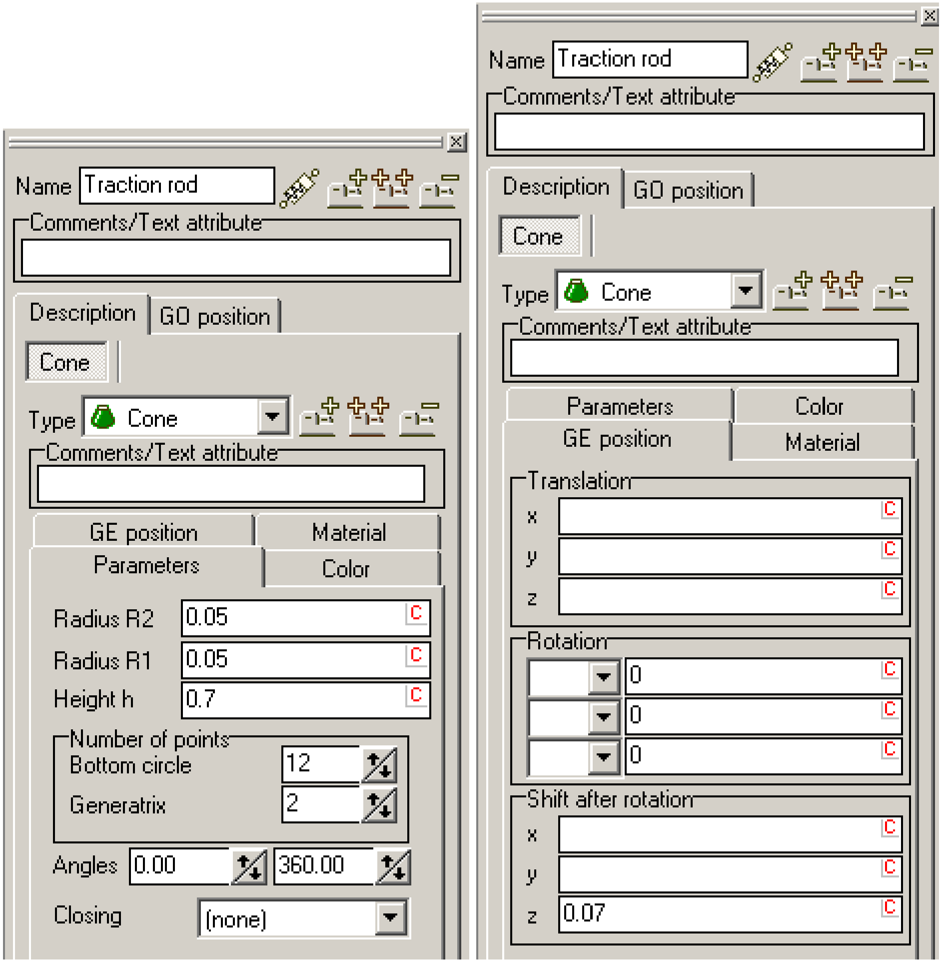


Figure 2.15. Traction rod: cone

4. Set a proper **diffuse** color on the **Color** tab.
5. Select the **GE position** tab and set **Shift after rotation/z=0.07**.
6. Add the second GE by clicking in the second row of buttons. Set its type **Spiral**.
7. Set the spiral parameters as it's shown in the Fig. 2.16, left.

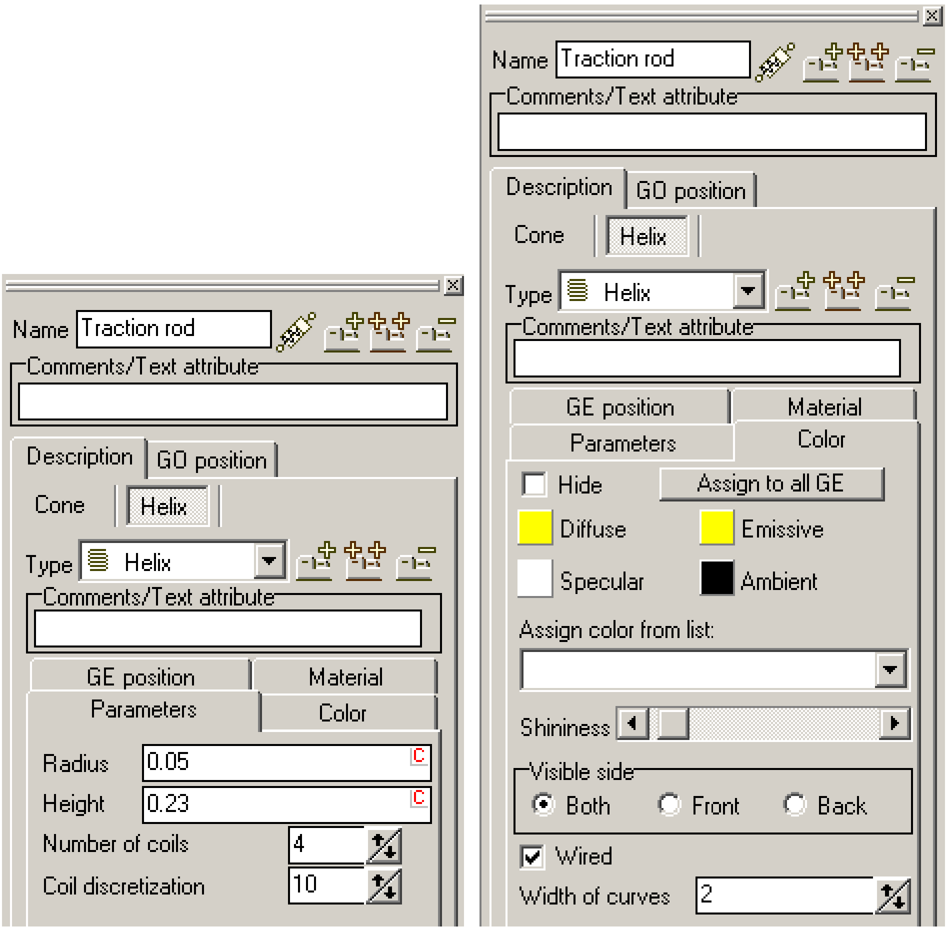


Figure 2.16. Traction rod: spiral

8. Choose black color as **diffuse** color. Turn on **Wired** and **Width of curves** set to **2,** see Fig. 2.16, right.
9. Select the **GE Position** tab and set **Translation/z** to **0.77**.

2.5. Adding car body

Now we will add the car body and its inertial parameters to the object. Note that creation of the body image (the **Car body** GO) in the previous section does not mean that you have added the car body itself. You have added a picture to the list of pictures, nothing more. The car body appears in the model if you add the corresponding element to the list of bodies and set its coordinates.

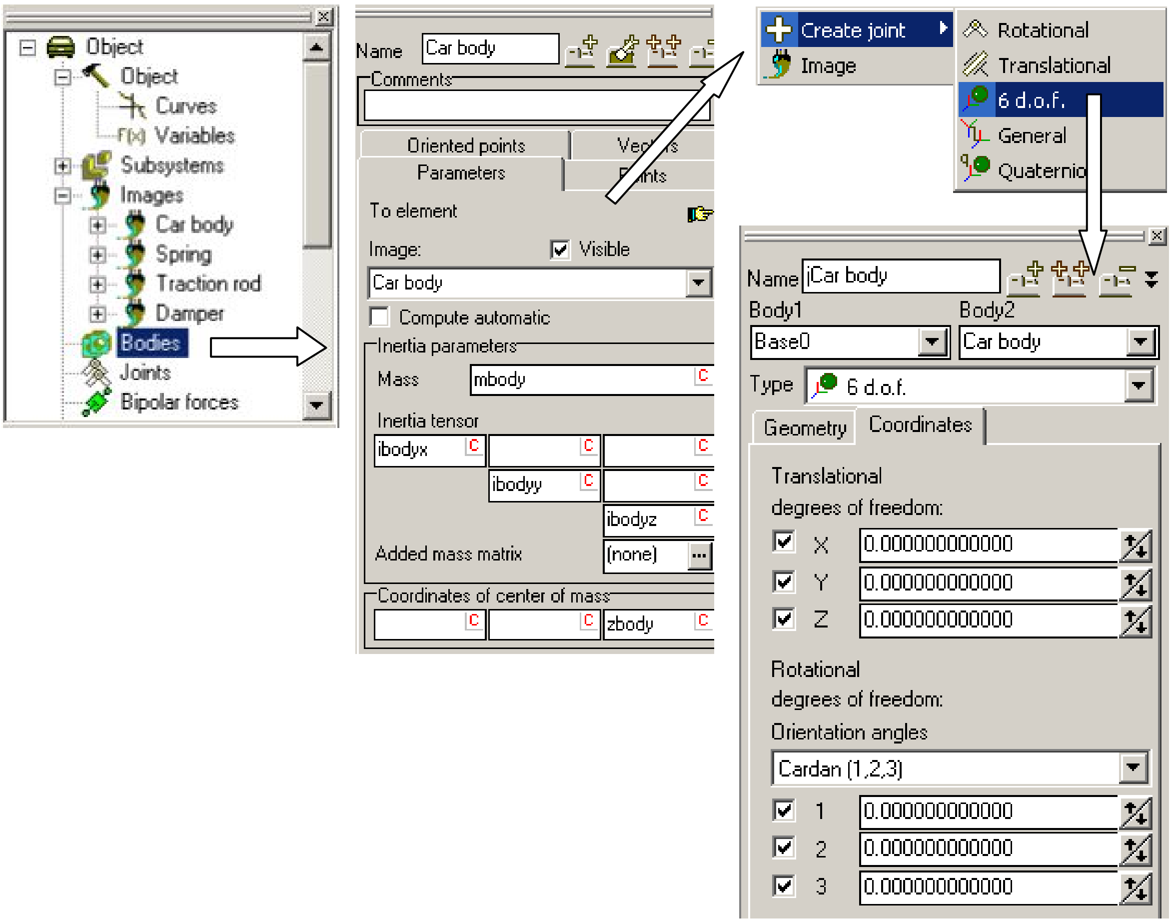


Figure 2.17. Adding car body and its joint

1. Select the **Bodies** item in the tree of elements and add a new body by clicking the  button. Rename it as **Car body**.
2. Fill out the inspector window like Fig. 2.17: choose the corresponding image from the list, set inertia parameters as identifiers:

mbody = **38300** kg,

ibodyx = **140000** kgm^2,

ibodyy = **626000** kgm^2,

ibodyz = **599000** kgm^2,

zbody = **1** m.

3. **Adjust a joint** by clicking the ☞ button and select its type **6 degrees of freedom**. The corresponding joint (jCar body) will be added to the list of joints. The joint assigns 6 coordinates to the body: three Cartesian coordinates in SC0 and three angles of orientation in the sequence 1, 2, 3 (sequence of rotations about X, then Y and finally Z axes).

2.6. Adding force elements

2.6.1. Springs

The simplest way to create a spring consists in using a special force element Spring (Chapt.2, Sect. *Special forces / Spring*, Chapt. 3, Sect. *Input of force elements / Special forces / Spring*).

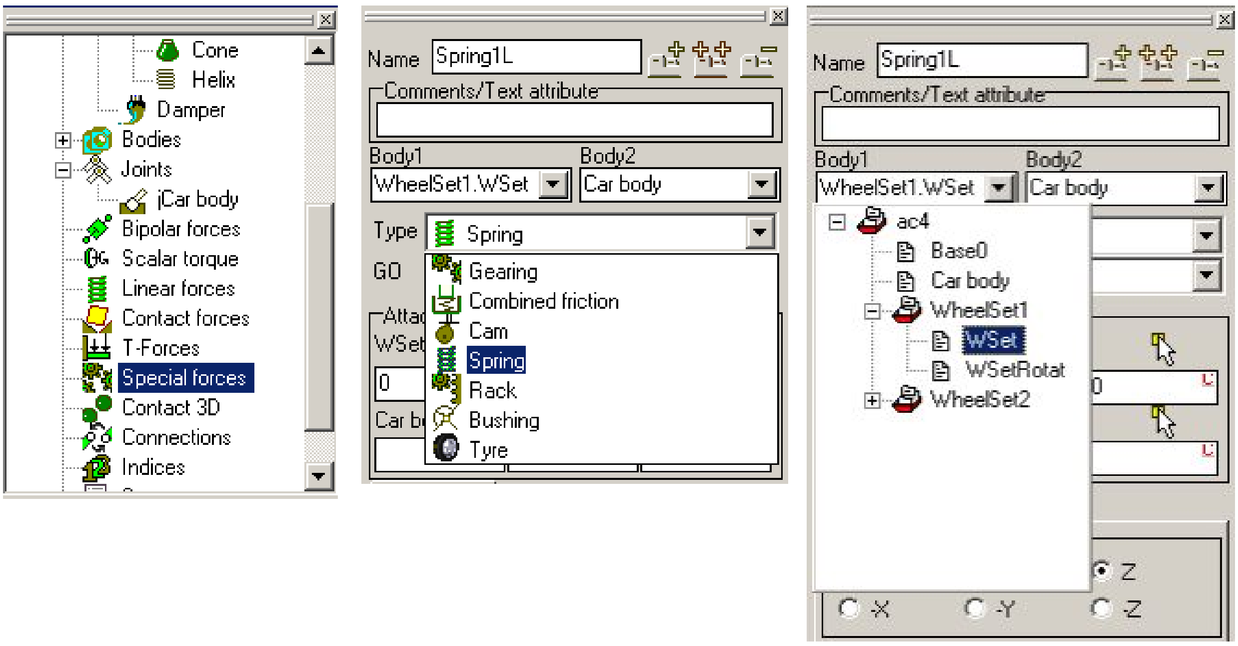


Figure 2.18. Creating spring

1. Select the **Special forces** tab (Fig. **Ошибка! Источник ссылки не найден.**, left) and add the first element corresponding to the front left spring by clicking the button. Rename it as “**Spring1L**”. Set its type **Spring** (Fig.**Ошибка! Источник ссылки не найден.**, center).
2. Set bodies connected by the spring: **WheelSet1.Wset** (base of the leading wheelset) and **Car body** (Fig.**Ошибка! Источник ссылки не найден.**, right). Assign the GO **Spring**.
3. Set coordinates of attachment point to the wheelset **(0, b1, 0)** and height of the spring under the static load **0.5** m (the **Length** parameter). Check the automatic

calculation of the second attachment point (the **Autocomputing for the 2nd body** check box), Fig. 2.19, left. As a result, the spring takes its final position in the animation window. Now click the **Compute for the second body** button, the coordinates of attachment point for the second body are visualized **(3.29, 1.1, 0.5)**.

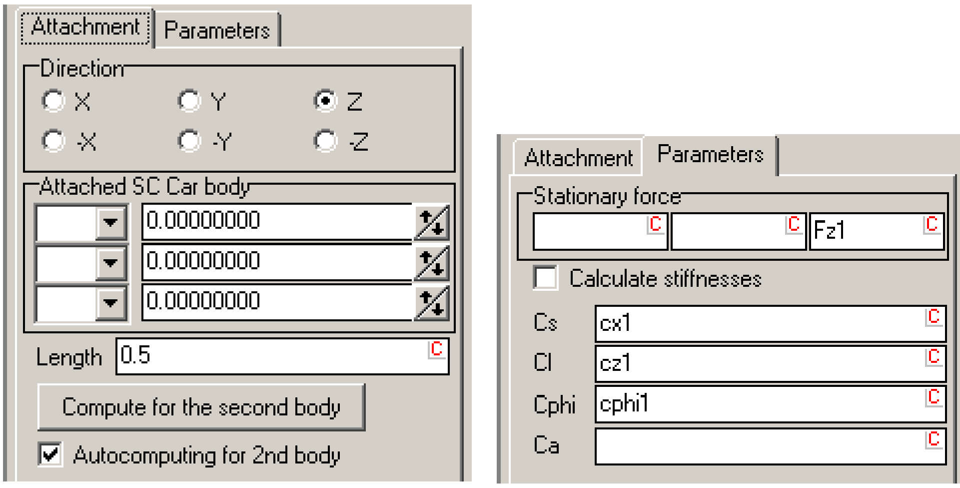


Figure 2.19. Parameters of spring

4. Set the shear (lateral) **Cs**, longitudinal (vertical) **Cl** and bending **Cphi** stiffness with identifiers **cx1** = **740000** N/m, **cz1** = **754000** N/m, **cPhi1** = **11000** Nm/rad.

5. Set the static load for the spring. Set Z component of the **Stationary force** to **Fz1**. Initialize **Fz1** first by zero value.

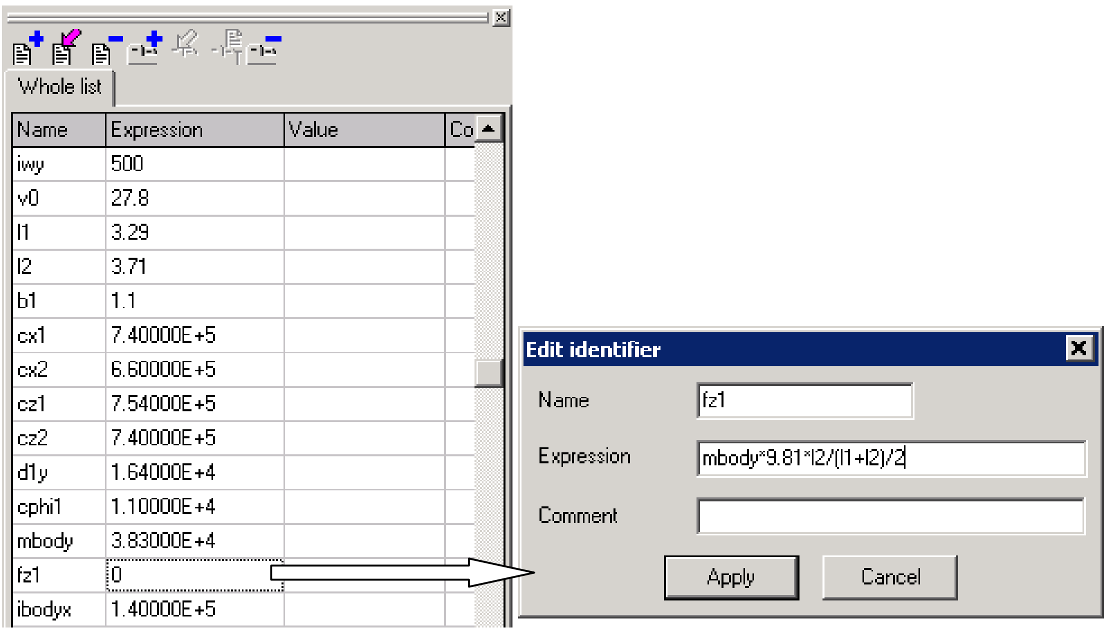


Figure 2.20. Static spring force as an expression

It is quite clear that the static load for the front springs is a function of the body mass as well as longitudinal positions of wheels, which are set with the help of identifiers **mbody**, **l1**, **l2**. Now it is possible to express the static load value in terms of these identifiers

Fz1 = **mbody*9.81*l2/(l1+l2)/2**.

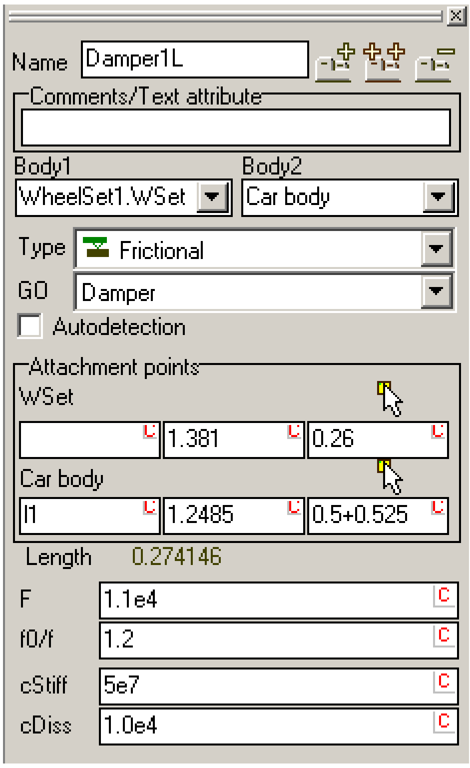
6. To insert this expression instead of the value of the identifier, double click by the left mouse button on the corresponding (**Fz1**) row of the identifier list and write down the expression in the appeared window (Fig. 2.20).
7. Copy the first spring by the  button. Rename it as ‘**Spring1R**’ (front right spring).
8. Change the sign for the Y-coordinate of the spring attachment to the wheelset, **-b1** instead of **b1**.
9. Copy the first spring again to create the third spring. Rename it Spring2L. Set the first body WheelSet2.Wset (base of wheelset 2). Change stiffness to

   cx2 = 660000; cz2 = 740000, cPhi2 = 10500 Nm/rad.
10. Set the stationary force as the **Fz2** identifies. Initialize it to zero and then double click on the Fz2 identifier in the **List of identifier** and set **Fz2** = **mbody*9.81*l1/(l1+l2)/2**.
11. Copy the *third* spring. Rename it with **Spring2R** (trailing right spring). Change the sign for the Y-coordinate of the spring attachment to the wheelset, **-b1** instead of **b1**.

2.6.2. Inclined dampers

Bipolar force elements should be used to add inclined frictional dampers to the model, Chapt.2, Sect. *Bipolar forces*, Chapt.3, Sect. *Input of force elements | Input of bipolar force elements*.

1. Select the **Bipolar forces** in the tree of elements and add the first bipolar force. Rename it to **Damper1L**.
2. Set all parameters like it's shown in the figure below.



Other tree dampers are added by copying, renaming and correcting attachment point coordinates as well as the first body for the rear dampers.

3. The second damper **(Damper1R)**, attachment points

   (0, -1.381, 0.26) and **(l1, -1.2485, 0.5)**.
4. The third damper (**Damper2L**), the first body WheelSet2.Wset, attachment points

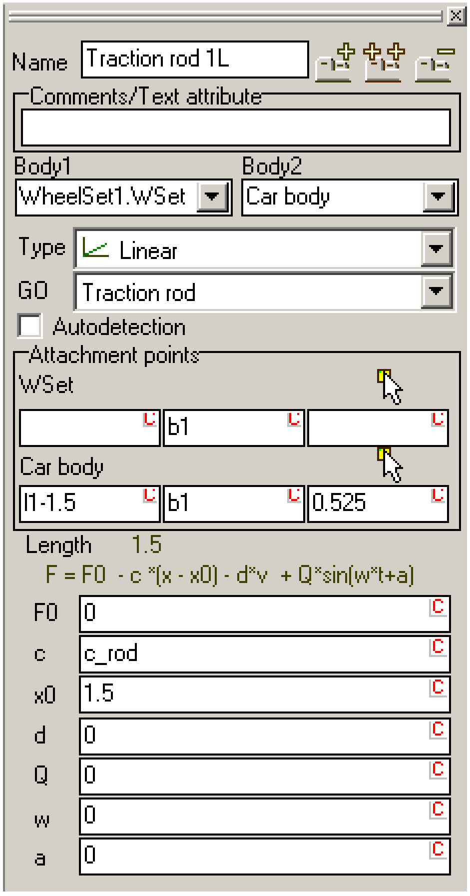
   (0, 1.381, 0.26) and **(-l2, 1.2485,0.5)**.
5. The last damper (**Damper2R**), the first body **Wheelset2.Wset**, attachment points

   (0, -1.381, 0.26) and **(-l2, -1.2485, 0.5)**.

2.6.3. Traction rods

Traction rods producing a force along the rod exclusively are modeled by bipolar force elements. Let the element length in the undeformed state be 1.5 m.

1. Add the next bipolar element; rename it to **Traction rod 1L** (front left rod). Set the element type **Linear**.
2. Follow the figure to describe the element (**c_rod** = **2.5E7** N/m).



Other tree rods are added by copying, renaming and correcting attachment point coordinates as well as the first body for the rear rods.

3. The second rod (**Traction rod 1R**), attachment points

   (0, -b1, 0) and **(l1-1.5, -b1, 0)**.

4. The third rod (**Traction rod 2L**), the first body WheelSet2.Wset, attachment points

   (0, b1, 0) and **(-l2+1.5, b1, 0)**.

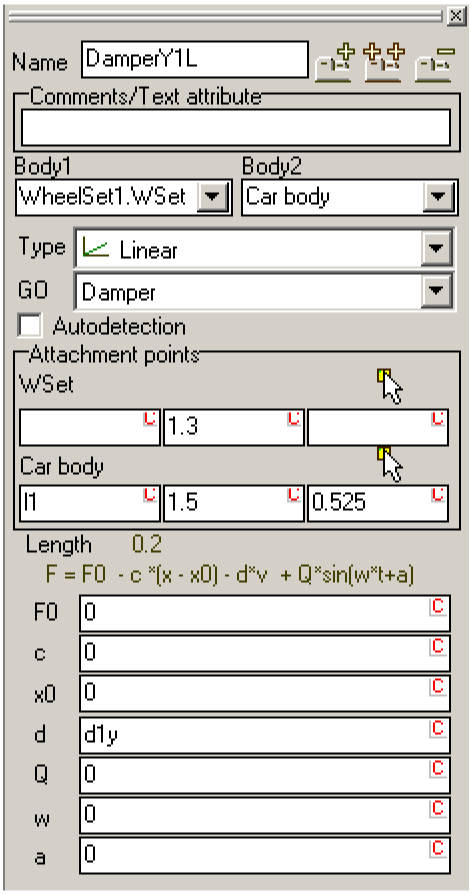
5. The last rod (**Traction rod 2R**), the first body WheelSet2.Wset, attachment points

   (0, -b1, 0) and **(-l2+1.5, -b1, 0)**.

2.6.4. Lateral dampers

Description of the lateral dampers is quite analogous to the description of the frictional dampers and the lateral traction rods.

1. Add the next bipolar force element, rename it to **DamperY1L**;
2. Use the figure below to describe the element (**d1y** = **16400** Ns/m).



3. The second lateral damper (**DamperY1R**), attachment points

   (0, -1.3, 0) and **(l1, -1.5, 0)**.
4. The third lateral damper (**DamperY2L**), the first body Wset2.Wset, attachment points

   (0, 1.3, 0) and **(-l2, 1.5, 0)**.
5. The last lateral damper (**DamperY2R**), the first body Wset2.Wset, attachment points

   (0, -1.3, 0) and **(-l2, -1.5, 0)**.

The model of the railcar is ready.

3. Scanning: implementation to railway vehicle dynamics

Here we discuss how to create and fulfill scanning project and then to analyze the obtained results. As an example, scanning project for railcar AC4 (**{um_root}\samples\rail vehicles\ac4**) is used.

Creating the AC4 model is considered in details in the previous section, see. sect. 2.

Scanning tool is a component of the **UM Optimization** module. To check if your UM installation has **UM Optimization** module please select the **Help/About** menu command. The **About** dialog appears. There you can find the list of the installed UM modules.

Before starting scanning project please make sure that a model of the railcar AC4 is on your computer. You can find it in the **{um_root}\samples\rail vehicles\ac4** directory, download it from the Internet (http://www.umlab.ru/download/50/ac4.zip) or create the model like it's shown in the previous section.

Completely described scanning project, which is considered in this section, is available here: http://www.umlab.ru/download/50/scan1.zip.

3.1. Creating scanning project

Here a scanning project for railcar AC4 is considered. The aim of this scanning project is to determine the critical speed of the railcar.

3.1.1. Preface

There are lots of criteria that engineers take into account during carrying out researches and optimization of parameters for railway vehicles. Stability of the railway vehicle is the one of the most important criteria of dynamical properties of the vehicle. Nowadays the most common estimation of the stability of the railway vehicle is its critical speed.

Here the approach, which helps us to estimate the critical speed of the vehicle numerically with the help of series of computer experiments, is shown. We will run the railcar with the various velocities on the even track with the single lateral irregularity at the beginning of the track. Amplitude of the irregularity is 20 mm and its length is 10 m. Then we will analyze lateral oscillations of the vehicle and will see if the single irregularity leads to stable or instable motion.

One of the informative characteristics is the lateral position of a wheelset relative to track axis or rather power of the lateral oscillation of the wheelset, that can be estimated as root mean square (RMS) of the process.

Plots of lateral position of the first wheelset of the rail car are shown for v0 = 30 m/s (see Fig. 3.1, in black) and 90 m/s (in green). It is obvious that the railcar is stable for v0=30 m/s and instable for 90 m/s. RMS of the lateral oscillations of the first wheelset depending on vehicle speed is shown in the Fig. 3.2. One can see stable, transition and instable zones there.

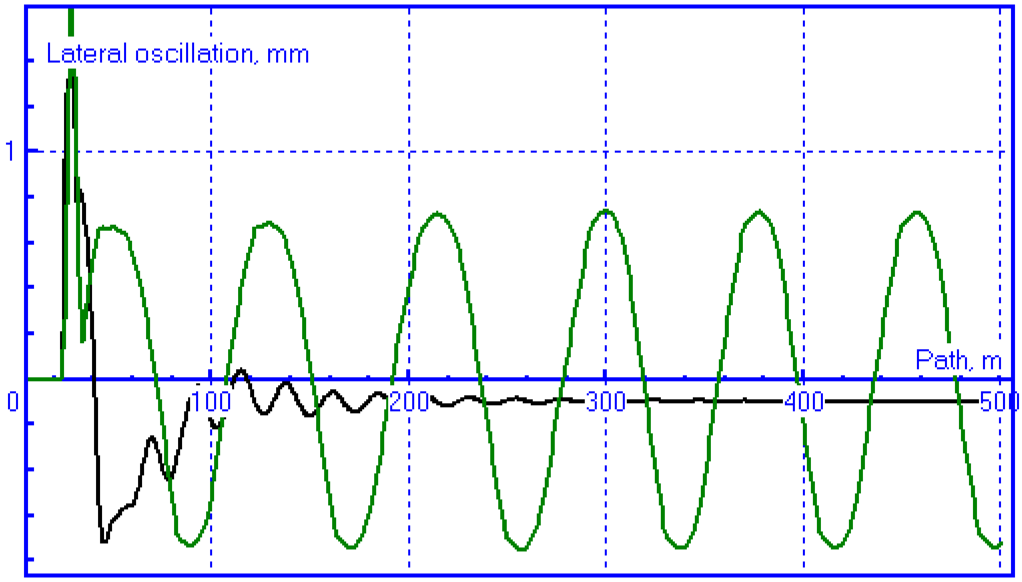


Figure3.1. Lateral oscillation of a wheelset

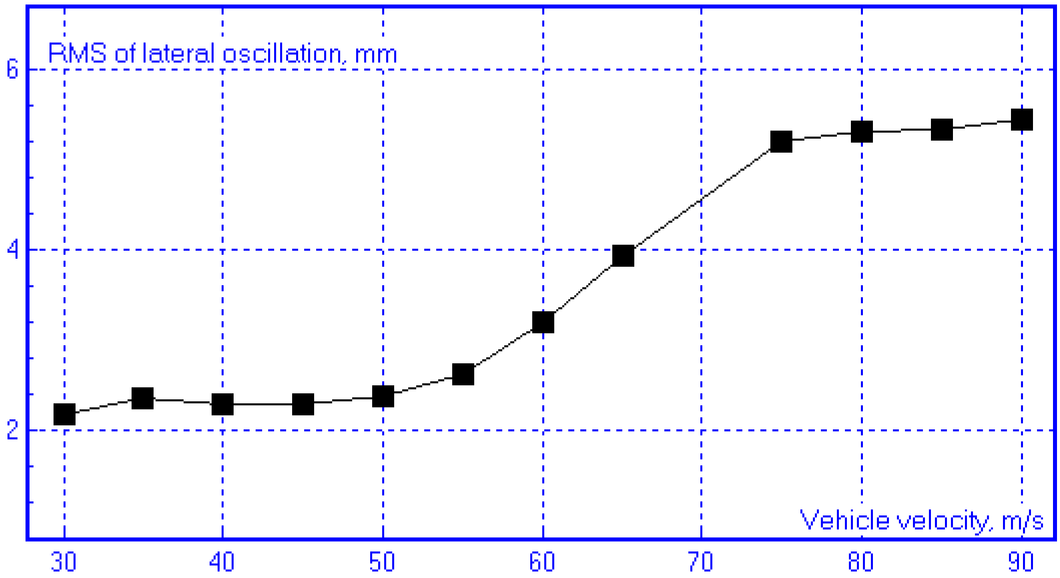


Figure 3.2. RMS of lateral oscillations in dependence of vehicle speed

3.1.2. Creating new scanning project

1. From the **Advanced analysis** menu point to **Scanning: new project**.
2. Input the full path to the scanning directory including name of the project, Fig. 3.3.

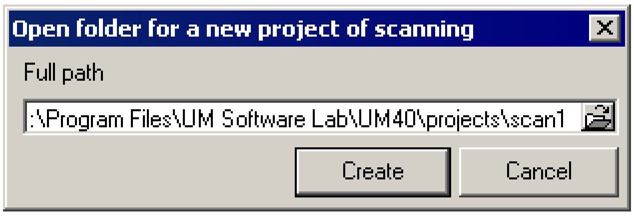


Figure 3.3. Folder for a new scanning project

3. Press the **Create** button. The window of the new project appears, Fig. 3.4.

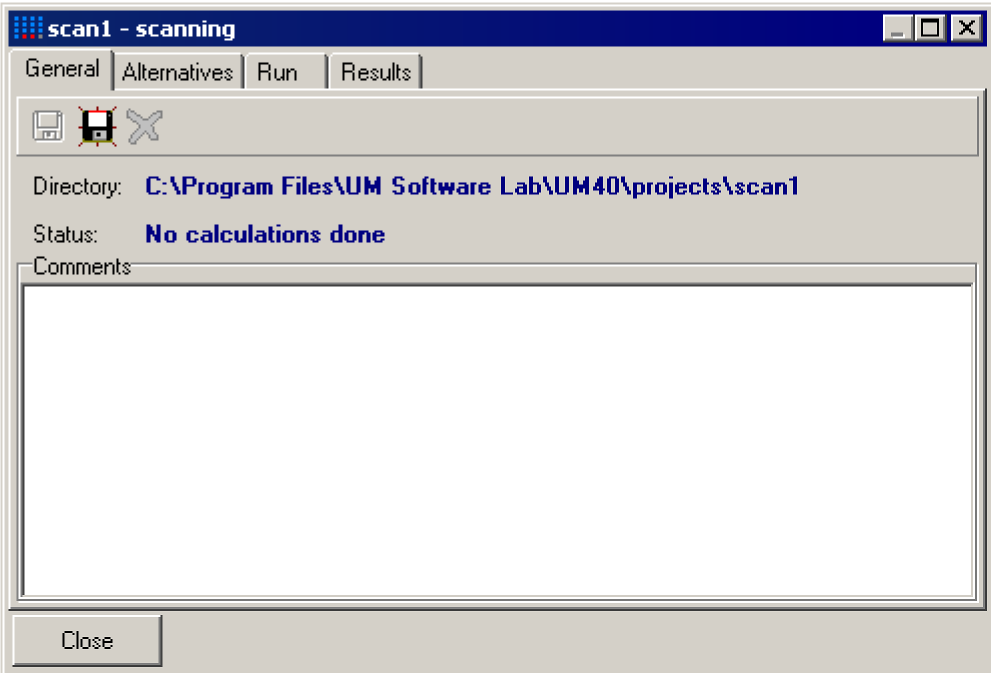


Figure 3.4. New scanning project

3.1.3. Loading a model

1. Select the **Alternatives** tab.
2. Click the  button (add family of alternatives).
3. In the open dialog choose the AC4 railcar model.

   The model is loaded and added to the list of **Family of alternatives**, Fig. 3.5.

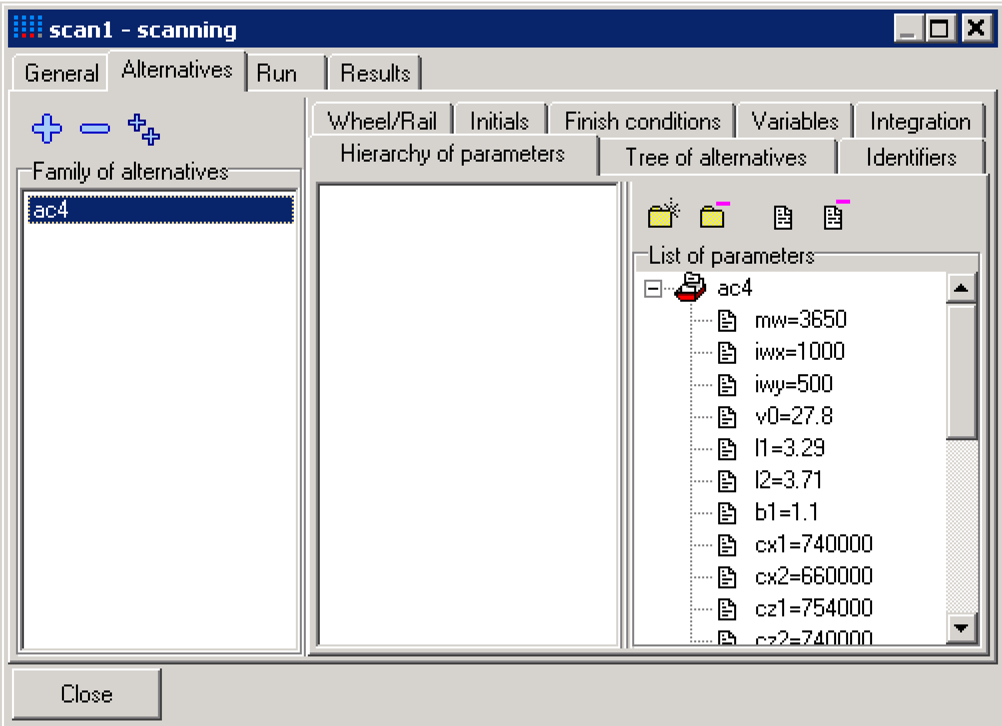


Figure 3.5. Scanning project: adding new model

3.1.4. Hierarchy of parameters

In this project we will scan dynamical properties of the railcar for only one parameter – speed of the vehicle.

1. In the **List of parameters** click **v0**.
2. In the new window **Parameter values** input values from 30 up to 90 m/s with the step is 5 m/s. Click **OK**.

New group of the parameters appears on the **Hierarchy of parameters** tab. Thus, 13 numerical experiments will be done. Now we come to common settings for all of these experiments.

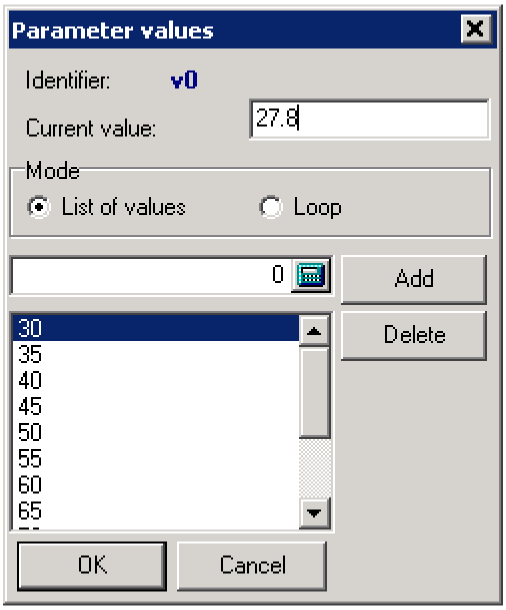


Figure 3.6. Values of parameters

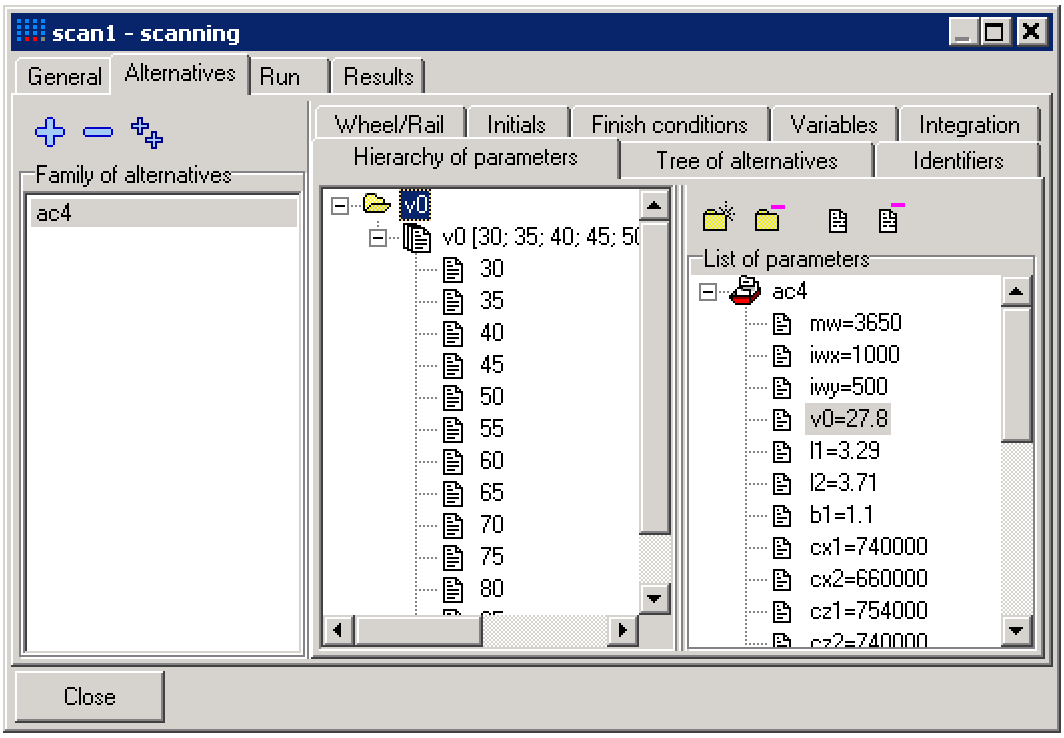


Figure 3.7. Scanning project: hierarchy of parameters

3.1.5. Railway configuration

It is necessary to set railway configuration according to sect. 3.1.1.

1. Firstly, let's define track irregularities. Select the **Alternatives / Wheel/Rail / Track / Irregularities** tab. Open file **NoIrregularities.way** for vertical irregularities (Z) and **g10_20.way** (see Fig. 3.8) in lateral (Y) direction, see Fig. 3.9.
2. Load rail profiles from the **r65new.rpf** file, and set **newlocow.wpf** profile for all wheels, see Fig. 3.10.

Every numerical experiment will be done with such railway configuration.

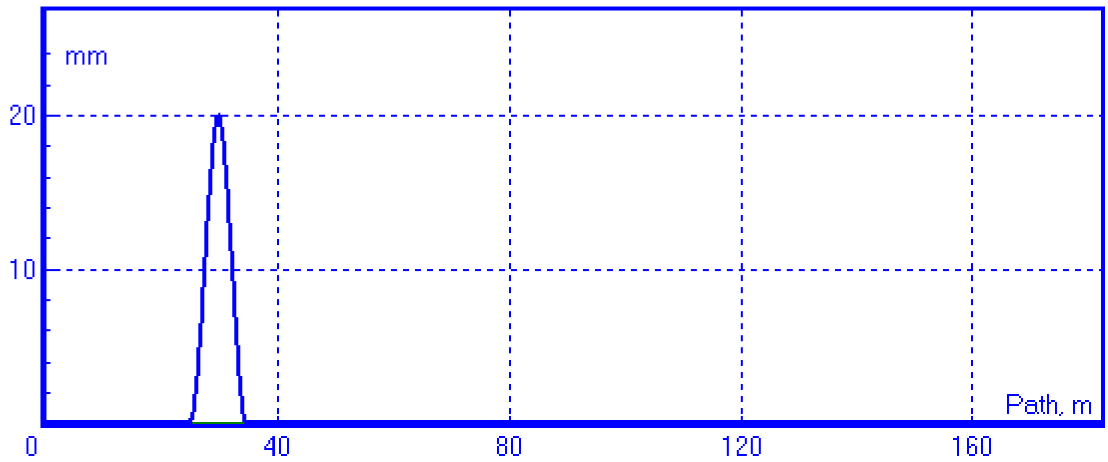


Figure 3.8. Single lateral irregularity. File **g10_20.way**

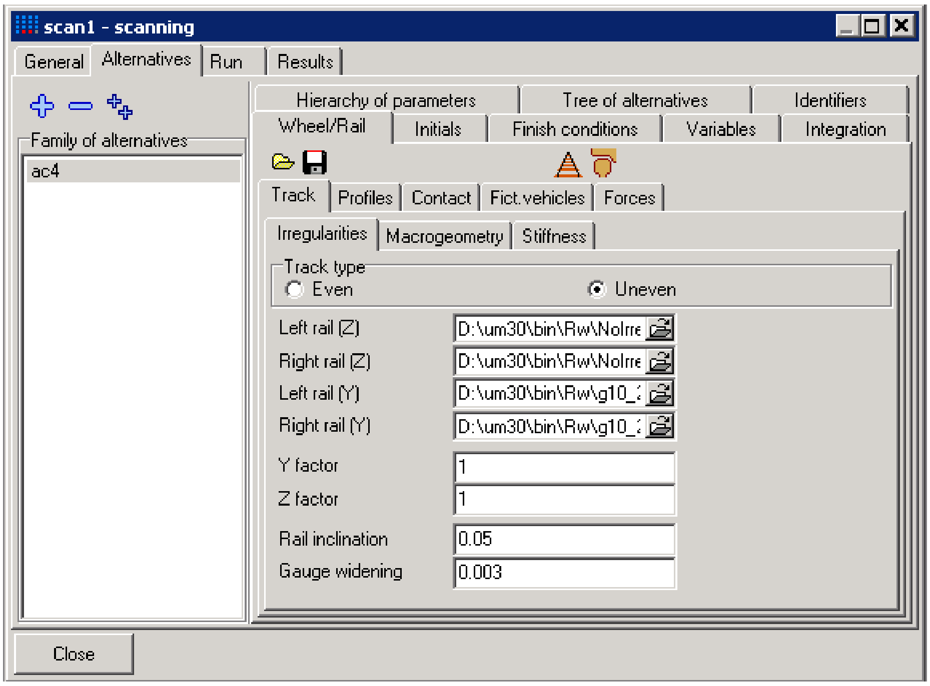


Figure 3.9. Railway track irregularities

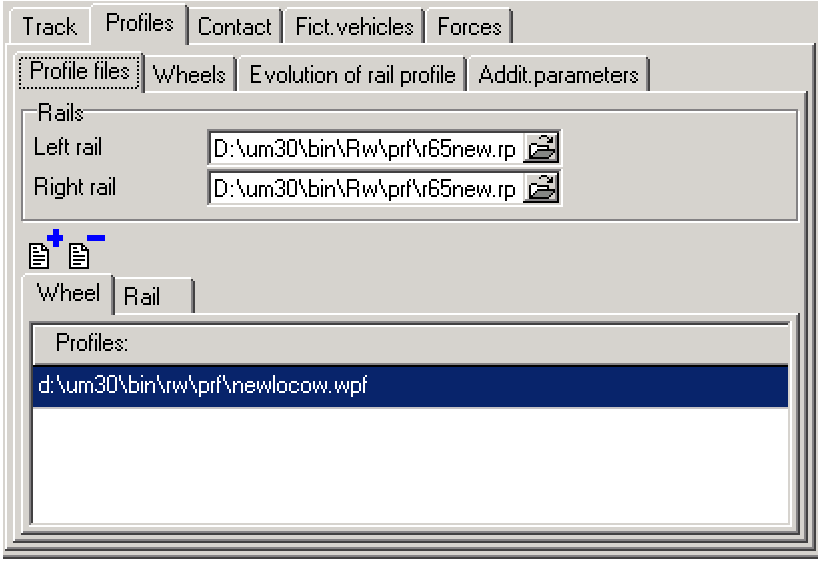


Figure 3.10. Rail and wheel profiles

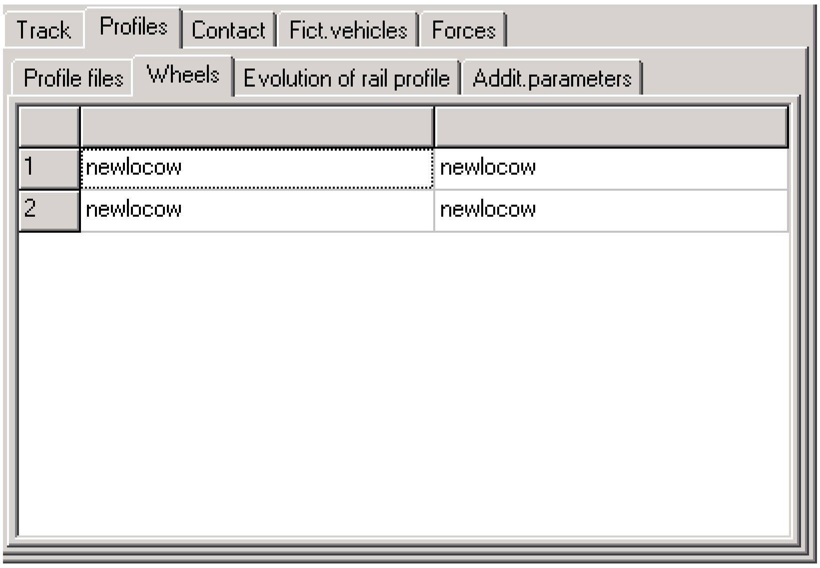


Figure 3.11. Wheel profiles

3.1.6. Finish conditions

Here you can describe finish conditions for each numerical experiment in the current family (see Fig. 3.12). Finish conditions are formulated in the following way: "Interrupt a numerical experiment if at least one of the conditions is satisfied". Using scanning project you can set finish condition as

Variable [Condition] Numerical value.

You can use any variable from the **Wizard of variables** as stop criterion. By default, for the railway vehicle the following finish condition is formulated:

Path – Vehicle path from the simulation start >= 300 m.

It means every numerical experiment finishes when vehicle goes 300 m.

1. Select the **Alternatives/Finish conditions** tab.
2. Increase vehicle path up to **500** m, see Fig. 3.12.

Note. If you need to use any other variable as finish criterion you should create that variable using **Wizard of variables** and drag it to the field with a variable on the **Finish conditions** tab.

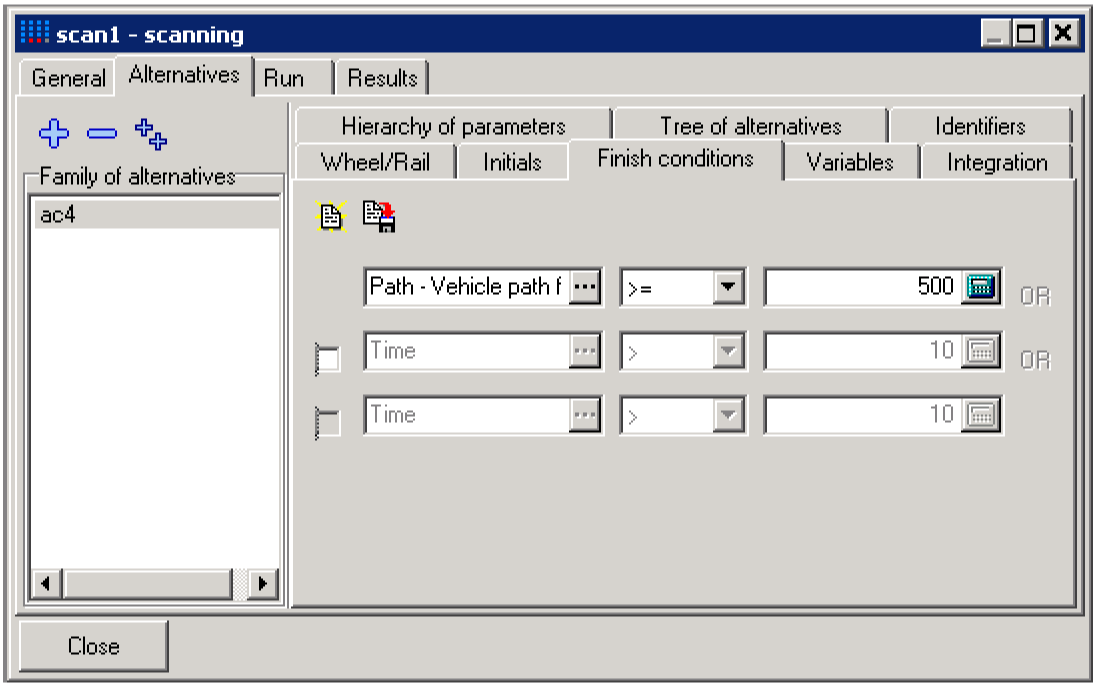


Figure 3.12. Finish conditions

3.1.7. Variables to save

1. Select the **Alternatives/Variables** tab.

Here you should form a *list of variables* (see Sect. 4.3.3), which will be stored for every numerical experiment. Variables from this list will be available as results of the scanning project.

2. Rename the **No name** tab to **Stability**, use button.
3. Open **Wizard of variables.**
4. Point to the **Liner var.** tab, select the **WheelSet1.Wset** body, from the **Component** group select **Y** (lateral direction). Create (button) this variable and drag it into the **Stability** tab.
5. Point to the **Wizard of variables/Railway** tab. Select **Path** variable from the list of characteristics. Create this variable and drag it into the **Stability** tab.

After all the **Variables** tab has to look like in the Fig. 3.13.

6. Close **Wizard of variables**.

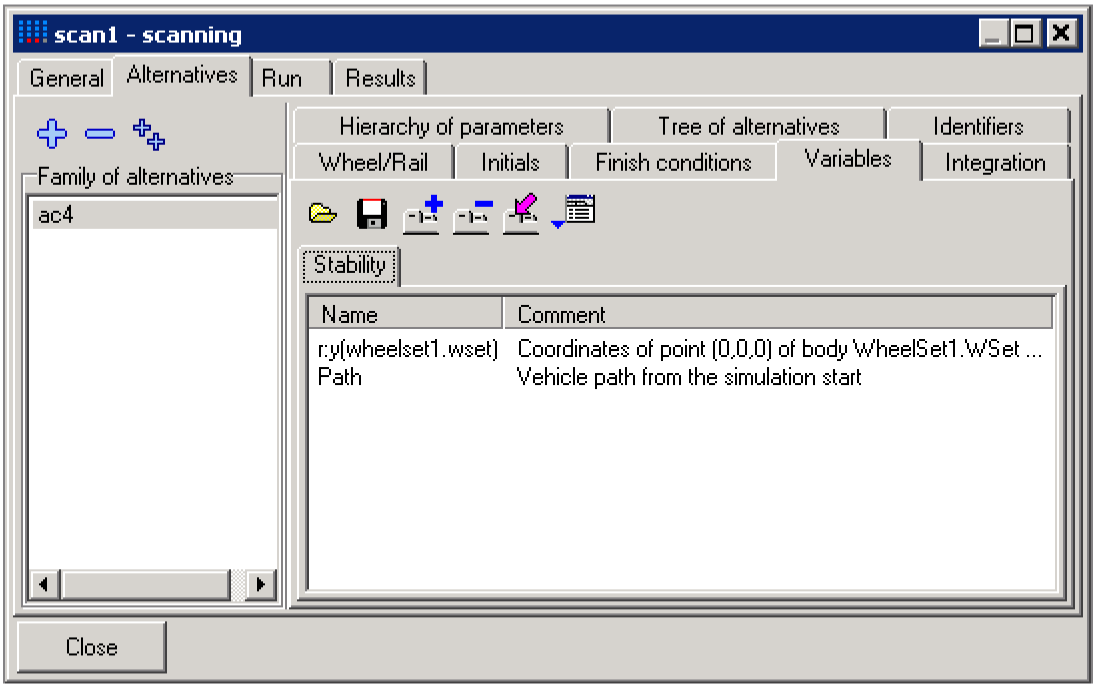


Figure 3.13. Scanning project: auto save variables

Now your scanning project is ready to run.

3.2. Running the project

1. Select the **Run** tab.
2. If you did not make any mistake during description the project you can see "**Error not found**" message in the **Report box**.
3. Click the **Run** button.

Fulfilment of the scanning project starts. **Report** outputs time of the start and finish of every numerical experiment. The railcar model is rather simple one. That's why every experiment takes you about 2-10 seconds in dependence of the speed of your computer.

4. When project is done the message "**Calculation of the project of scanning is over**".

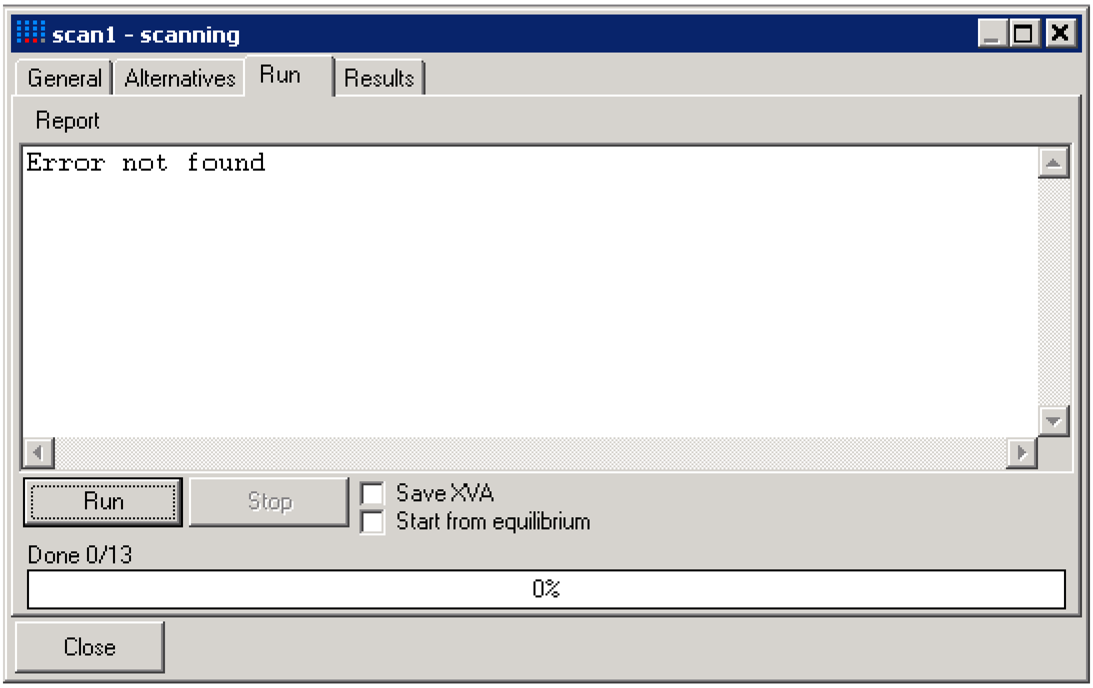


Figure 3.14. Scanning project: running

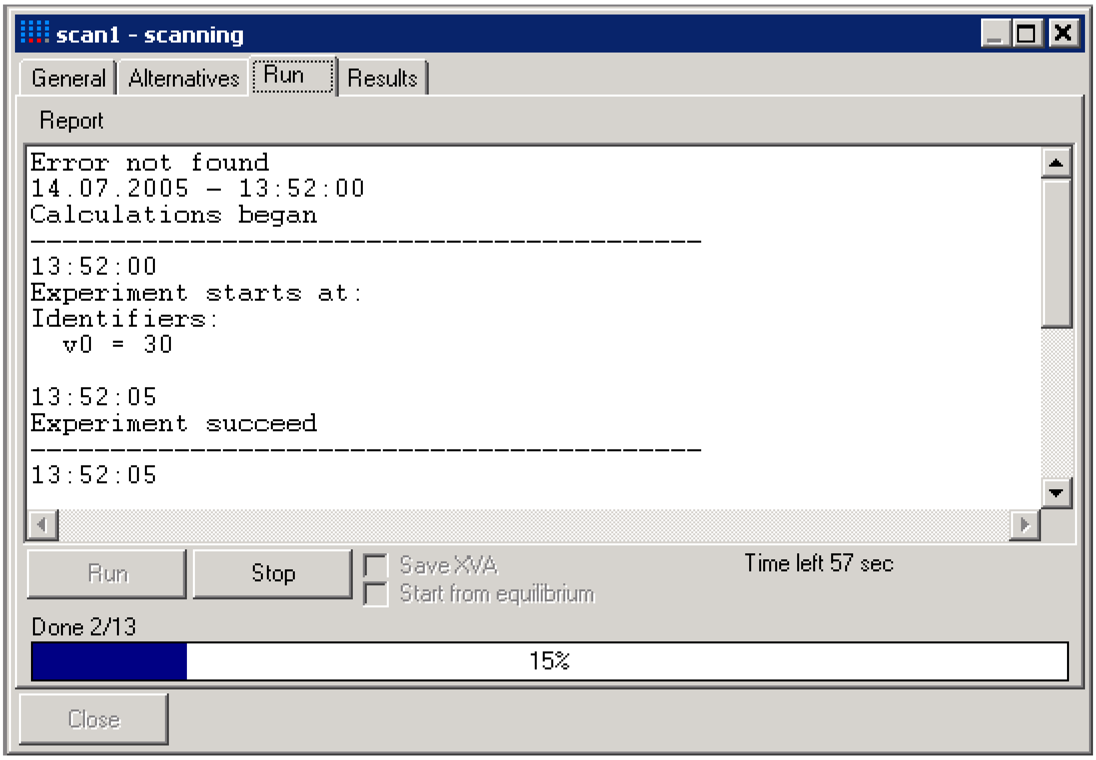


Figure 3.15. Scanning project: running

3.3. Analyzing obtained results

3.3.1. Results of separate experiments

Now we come to the analyzing of the railcar dynamics. Our analysis is based on the results of the scanning project we you have just finished.

1. Select the **Results/ac4** tab, see Fig. 3.16.

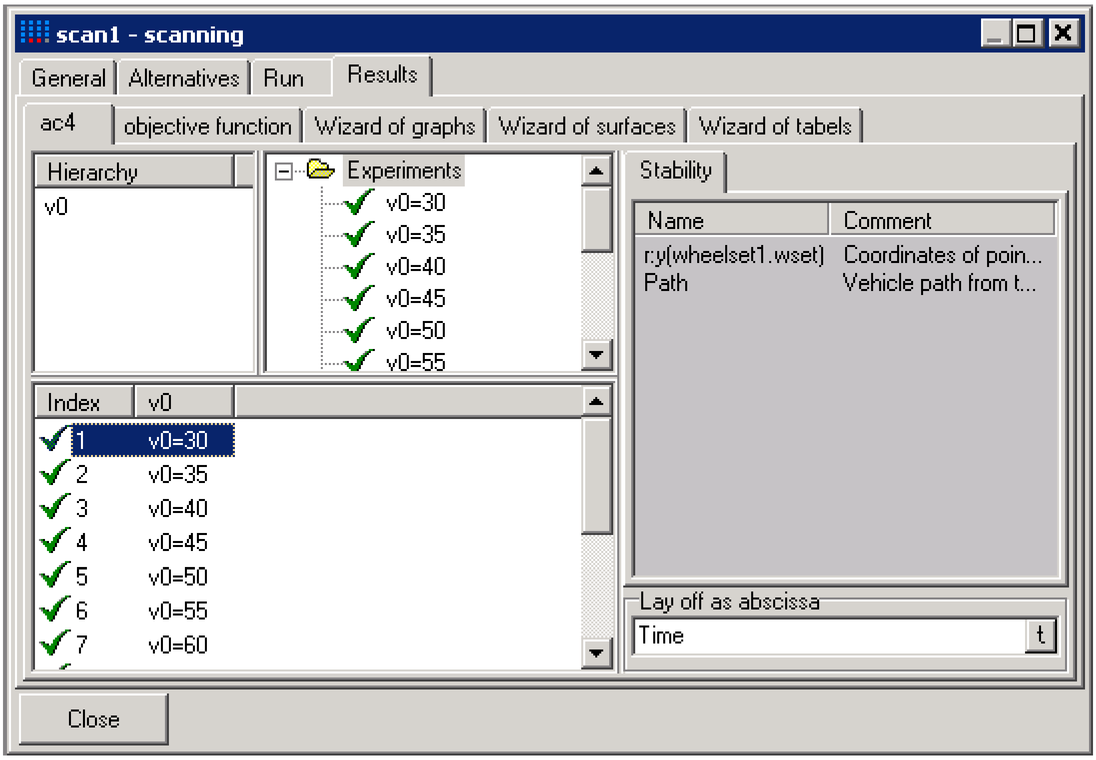


Figure 3.16. Scanning project: results

Lets have a look at the results of several single experiments. We will compare results for lateral oscillation of the first wheelset at 30 and 90 m/s.

It is more convenient to lay **Path** off as abscissa because the vehicle runs the same way 500 m with different velocities for different time.

2. Select the **Path** variable in the list of variables and drag it to the **Lay off as abscissa** box, see Fig. 3.17.

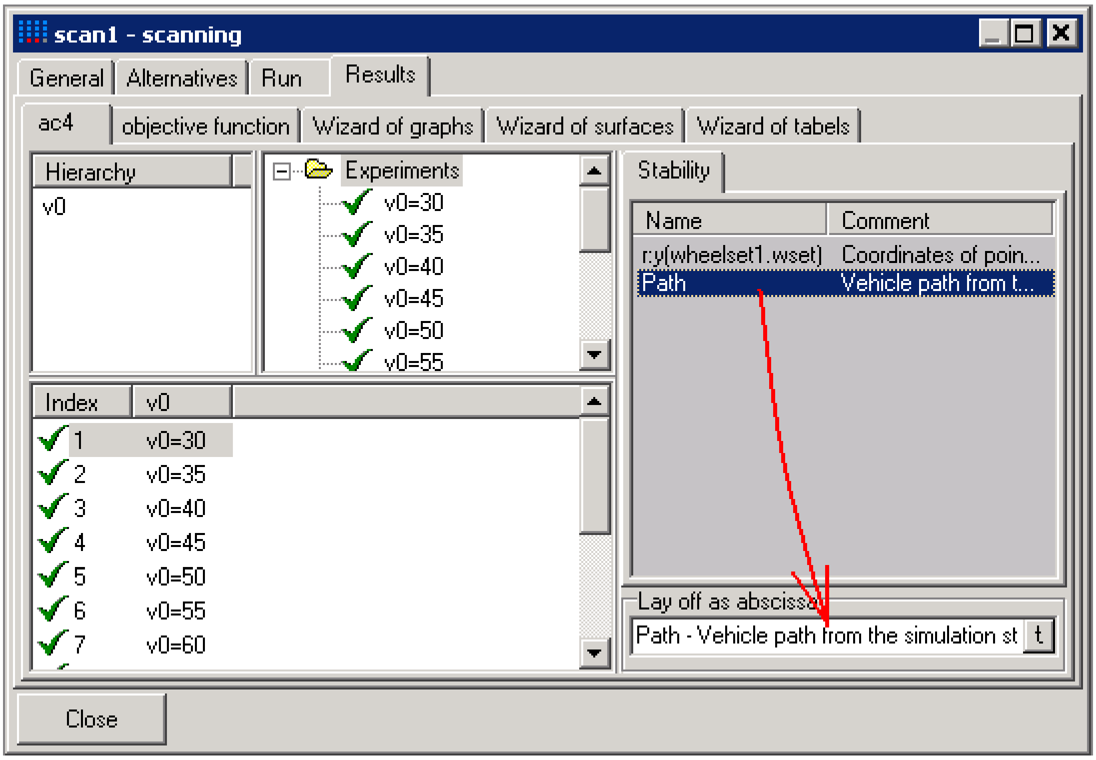


Figure 3.17. Lay **Path** off as abscissa

3. Open new **Graphical window**.
4. Select scanning project window again, and select the experiment "**v0 = 30**" on the **ac4** tab.
5. Select the **r:y(wheelset1.wset)** variable in the list of variables and drag it to the graphical window.
6. Select another experiment – "**v0 = 90**" and drag the same **r:y(wheelset1.wset)** variable to the graphical window, see Fig. 3.18.

It is quite clear, Fig. 3.18, those lateral oscillations that rose by singular lateral irregularity diminish in the long run at 30 m/s, but at 90 m/s reach maximum amplitude. In other words the railcar is stable at 30 m/s and instable at 90 m/s.

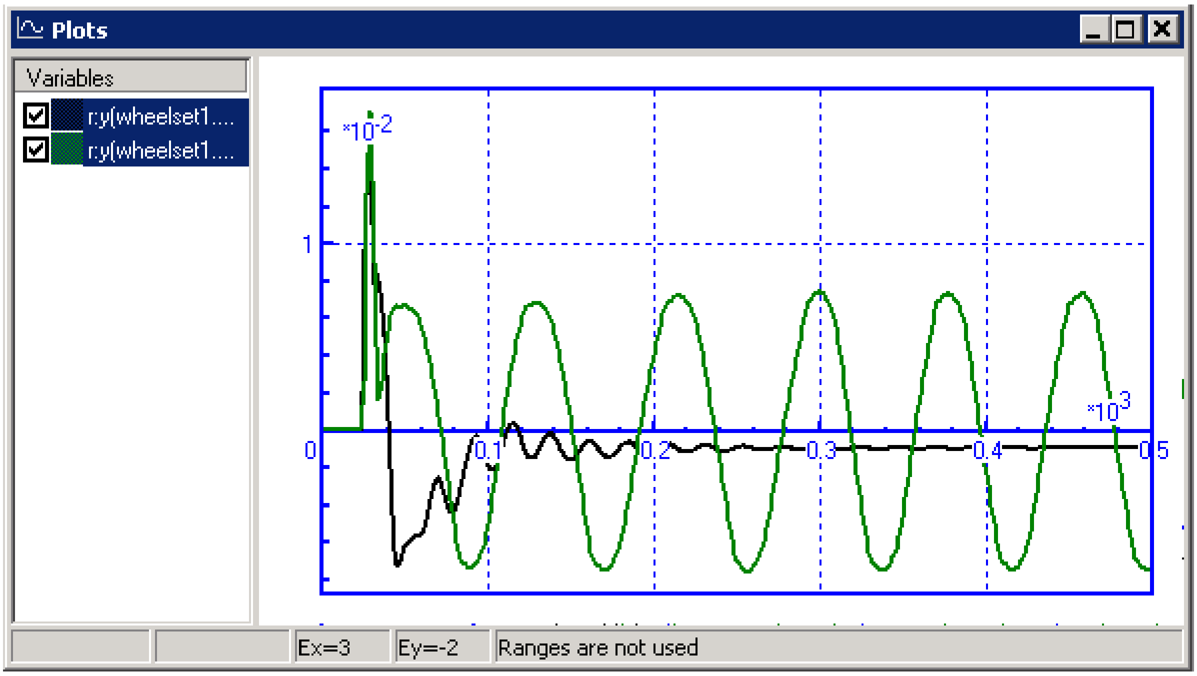


Figure 3.18. Lateral oscillations of the first wheelset
in black – 30 m/s, in green – 90 m/s.

3.3.2. Summary graphs

There are several tools for overall analysis in scanning project: summary graphs, tables and surfaces. Here let's plot the dependence of the RMS of the lateral oscillations of the first wheelset on speed of the vehicle. Such graph is shown in the Fig. 3.2.

1. Select the **Results/Wizard of graphs** tab.
2. Select the **r:y(wheelset1.wset)** variable in the list of variables
3. Set **Functional** to **RMS** (Root mean square).
4. Set **Parameter** to **v0**.
5. Click  in the top of the window to create summary graph.

This summary graph clearly shows us that critical speed of the vehicle is in the 55..75 m/s interval.

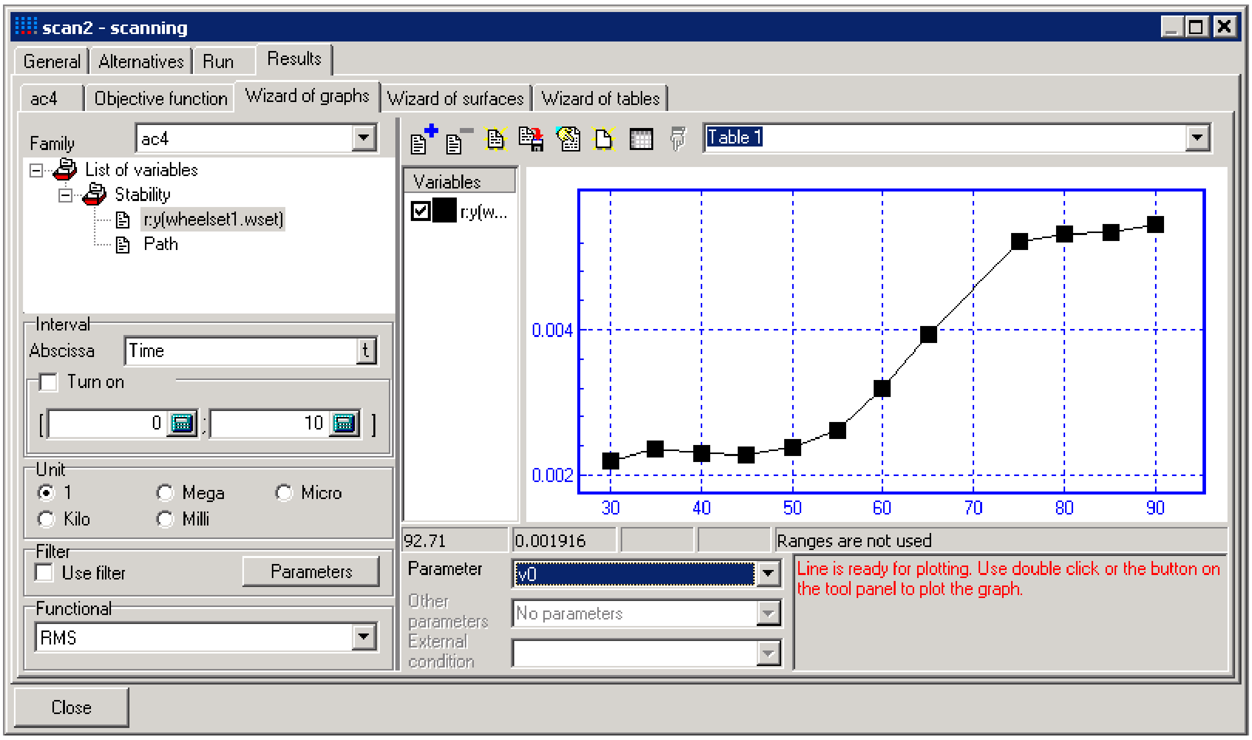


Figure 3.19. Wizard of summary graphs