**UNIVERSAL MECHANISM 6.0** 



# Development of Models and Dynamic Analysis of Tracked Vehicles

Getting started

2010

Basic principles of development of models of tracked vehicles and their dynamic are discussed.

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# Getting started: development and dynamic analysis of tracked vehicles in UM



Fig. 1 Model of TV

This document helps the user to get experience in development of models and simulation of tracked vehicle (TV) in UM. The model, which development is discussed, is shown in Fig. 1.

It is assumed that the user has already studied the document devoted to introduction in UM (file  $gs_UM.pdf^1$ ) and can create and analyze simple models.

This document does not contain complete information about simulation of TV in UM. More detailed information can be found in Chapter 18 of the user's manual, file **18\_UM\_Caterpillar.pdf**.

The ready TV model considered in this document is located in the directory {Path to UM}\Samples\Tracked vehicle\gsTV

<sup>&</sup>lt;sup>1</sup> <u>http://www.umlab.ru/download/50/rus/gs\_um.pdf</u>

# 1. Development of TV model

# 1.1. Prototype





Fig. 2 Data on prototype of TV

A Russian light crawler transporter is considered as the prototype of the model. Fig. 2 shows some geometric data related to the tracks [1].

We would remind that this document is developed to help the user in studying UM Caterpillar module. That is why we will not follow the exact design data of the prototype.

# 1.2. Creating new object and track subsystem

🖨 Object	<u> </u>	🖌 🖉 🛞 🔅 🛞 🏶
F(x) Variables		
Attributes		
Subsystems		
👋 Images 🕂 🕂 Add ele	ment to group "Subsys	stems" 🔹 ? Type: (none)
Bodies		😬 included
🛛 🕭 Joints		旹 external
🖋 Bipolar forces		🖶 wheelset
<b>O</b> G Scalar torques		🌆 Linear FEM subsystem
📲 Linear forces	and a second	🐼 Bearing
C Ounter at famous		Cotone il or

Fig. 3 Adding new subsystem "Caterpillar"

1) Run UMInput.exe and create a new UM object by **File** | **New object** menu command or by the 🗅 button on tool panel.

- 2) Save the model by the **File** | **Save as** command or by the **File** button.
- 3) Add a track as a subsystem of the **Caterpillar** type
  - select the **Subsystems** item in the element list
  - click the right mouse button on this item and select the Add element to group "Subsystems" | Caterpillar, Fig. 3.

As a result, the **Track wizard** appears in the object inspector.

4) Rename the subsystem to **Left track**.

# 1.3. Track structure

Name Left trac	*	<u></u>		
Type 💿 Cate	erpillar	*		
Comments/T	ext attribute C			
	Edit subsystem			
Parameters	Position Ider	ntifiers		
Identifier	Subs1			
Rollers	Sprocket	Idler		
Structure	Track	Suspension		
-Sprocket po	osition			
Rear	() Fr	ont		
Track positi	on			
💿 Left	⊖ Ri	ght		
Suspension	subsystems	6 1/4		
Rollers		0 1/		
Track links		108 1		

Fig. 4 Parameters of track structure

Open the Parameters | Structure tab of the wizard, Fig. 4.

1) The modeled TV has a torsion bar suspension with six road wheels. Each of the wheels is described by a standard subsystem, Chapter 18, Sect. Torsion bar suspension. Thus, number six must be set in the **Suspension subsystems** box.

- 2) The TV has no support rollers; zero value is set in the corresponding box.
- 3) Number of track links is 108.

# 1.4. Adding suspension

Structure	Suspension			
Type of susper	nsion	-		
torsion_bar_w	heel		*	
Generate	:			
Number of sub	systems			
Parameter	Value			
R	٥.35			
W	0.3			
Xc1	0			
Xc2	0			
Xc3	0			
Xc4	0			
Xc5	0			
Xc6	0			

Fig. 5 Uninitialized values of suspension geometry parameters

#### Open the Parameters | Suspension tab, Fig. 6.

1) As we have pointed out six suspension units (subsystems), the table of geometrical parameters of suspension contains the same number of longitudinal coordinates of the subsystems (Xc1...Xc6). Besides, the road wheel radius (R) and width (W) must be set in this table. All parameters are in meters. The suspension unit type is specified on the same tab as torsion\_bar\_wheel, i.e. the default value.

Structure	Structure Track	
Type of suspe		
torsion_bar_w	/heel	*
Generati	•	
Number of sub	osystems	
Parameter	Value	
R	0.335	
W	0.3	
Xc1	0.775	
Xc2	1.5	
Xc3	2.245	
Xc4	2.99	
Xc5	3.735	
Xc6	4.445	

Fig. 6 Value of suspension geometry parameters for the MT-L transporter

Following the data in Fig. 2 fill in cells of the tab as in Fig. 6. Note, that the origin of SC0 in the X-direction is located on the level of the sprocket center.

![](_page_6_Picture_10.jpeg)

Fig. 7 First variant of suspension

2) Click the **Generate** button to create the suspension according to the specified parameters; the suspension appears in the animation window, Fig. 7

Parameters	Position	Identifi	ers	
Left track				•
Whole list	Spro	ocket	l	ller
Track	Rollers	S	uspe	ension
Name	Express	ion	Vali	le
I_road_arm	0.36			
alpha_stat	20			
f_stat	70			
f_dyn	110			
lrear arm	-1			

Fig. 8 Selected identifiers of torsion bar suspension

🔀 Identifiers of the same name 🔀
<ul> <li>✓ Left track.l_road_arm (0.36)</li> <li>✓ Right track.l_road_arm (0.5)</li> <li>✓ Left track.Bogie1.l_road_arm (0.5)</li> <li>✓ Left track.Bogie2.l_road_arm (0.5)</li> <li>✓ Left track.Bogie3.l_road_arm (0.5)</li> <li>✓ Left track.Bogie4.l_road_arm (0.5)</li> <li>✓ Left track.Bogie5.l_road_arm (0.5)</li> <li>✓ Left track.Bogie6.l_road_arm (0.5)</li> </ul>
OK Cancel

Fig. 9 Assignment of numeric values for identifiers in subsystems

3) Now some parameters of the suspension must be modified. Open the **Identifiers** | **Suspension** tab of the wizard, Fig. 8. Set the length of the torsion arm 0.36m (the identifier  $l_road_arm$ ). All the suspension subsystems contain identifiers with the same name, a window appears in which the user must check the subsystems, for which the identifier value will be changed by the new one, Fig. 9. By default, the new value is assigned to all identifiers of the same name.

We will not change the default values of identifiers, which define the position of the suspension in static state (*alpha\_stat*) as well as the static and dynamic travel of wheels ( $f_stat$ ,  $f_dyn$ , Chapter 18, Sect. Torsion bar suspension).

🔀 Identifiers of the same name  🔀
🗹 Left track.rear_arm (1)
🗹 Right track.rear_arm (-1)
🗹 Left track.Bogie1.rear_arm (-1)
🗹 Left track.Bogie2.rear_arm (-1)
🗹 Left track.Bogie3.rear_arm (-1)
Left track.Bogie4.rear_arm (-1)
V Left track.Bogie5.rear_arm (-1)
Left track.Bogie6.rear_arm (-1)
OK Cancel

Fig. 10 Road arm orientation

As it is shown in Fig. 2, five road arms has a backward orientation but the front one, which has a forward orientation. So far, all arms in our model are oriented forward. The orientation is defined by the identifier  $rear\_arm=\pm 1$ . The value +1 corresponds to the backward orientation. To set the necessary values of this identifier in the subsystems, set  $rear\_arm =+1$  in the cell in Fig. 8 and press Enter. Uncheck the assignment of the new value in the lower row, Fig. 10. As a result, orientation of five road arms will be changed, Fig. 11.

![](_page_8_Figure_2.jpeg)

Fig. 11 Suspension with modified parameters

# 1.5. Adding sprocket

Rollers	Sprocke	t	ldler			
Profile	Number of p	point	s: 5 🔛			
Genera	te 📃 🔳	]				
Estimated rac	Estimated radius 268.6					
Parameter Value						
N sprocket te	eth	15				
Sprocket/Track step ratio						
Width		0.3				
Xc		0				
Zc		0.6				

Fig. 12 Geometric parameters of sprocket

![](_page_9_Figure_6.jpeg)

Fig. 13 Tooth profile

Open the **Parameters** | **Sprocket** tab, Fig. 12.

- 1) Assign a tooth profile by the built-in curve editor:
  - open the editor by the  $\square$  button, Fig. 13 •
  - read the preliminary created file with profile •

{Путь к UM}\bin\Caterpillar\Profiles\Sprocket1.spf

by the 🗁 button.

2) Set number of teeth,  $t_w/t_t$  ratio and geometric parameter: width of the wheel, the vertical and longitudinal coordinates of the wheel center, Fig. 12.

3) Use the 🔳 button to preview the sprocket, Fig. 14. Note the sprocket radius is computed automatically by the link length,  $t_w/t_t$  ratio and number of teeth so that the final variant can differ from the current one.

![](_page_10_Figure_3.jpeg)

4) Add the sprocket to the model by the **Generate** button, Fig. 15.

# 1.6. Adding idler

Rollers	Sprocket	ldler
Type of idler v	with tension mec	hanism
idler_crank_s	imple	*
Generat	e	
Parameter	Value	
R	0.255	
W	0.3	
Xc	5.125	
Zc	0.495	

Fig. 16 Parameters of idler

#### Open the **Parameters** | **Idler** tab, Fig. 16

- 1) Select a simplified model of the idler on a crank: idler\_crank\_simple.
- 2) Set geometrical parameters of the idler in meters as in Fig. 16: radius, width and coordinates of the center.
- 3) Add the idle to the model by the **Generate** button, Fig. 17.

![](_page_11_Picture_9.jpeg)

Fig. 17 Adding idler with tension device

# 1.7. Adding track chain

Structure	Track	Suspension
-Track envelo	pe	
🖾 Lengtł	n of envelope	12.072
Estimation of	link length	0.11166
Estimation of	error in length	0.0008
Current error i	n length	-0.0002
Track link tr	acklink_bushir	ng 🗸
Generate		
Joint type		
○ Rigid	Flexible	Parallel
Profile		5
Parameter	Value	
L	0.11167	
W	0.3	
	0.00	

Рис. 18 Tack chain parameters

Open the **Parameters** | **Track** tab, Fig. 18.

- Use **tracklink\_bushing** joint type.
- Set track link length, which is evaluated by the program in the 'Estimation of link length' box.
- Click the Generate button, Fig. 19.

![](_page_12_Figure_10.jpeg)

# 1.8. Adding shock absorbers

![](_page_13_Picture_4.jpeg)

Description of process.

1) Use the Edit subsystem button to open a window with description of the track, Fig. 20.

![](_page_13_Picture_8.jpeg)

Fig. 21 Menu command for adding an element from file

2) Add a shock absorber model from the UM database by the **Edit** | **Read from file** command, Fig. 21. Select the file

{Path to UM}\bin\Caterpillar\Dampers\Damper1.

![](_page_13_Figure_12.jpeg)

Fig. 22 Image and nonlinear characteristics of shock absorber

![](_page_14_Figure_3.jpeg)

Fig. 23 Shock absorbers characteristics form [1]

The file contains the description of a nonlinear shock absorber as well as its image, Fig. 22. The force vs. velocity characteristics of the element is similar to one of that in [1], Fig. 23.

Name Rear damper	- <u>-</u> + <u>+</u>	<u>r</u>	Name	Front damp	ər		-1-	÷ + <u>+</u> + <u>+</u> +	-1-5
Comments/Text attr	ibute C		Com	iments/Text at	ttribute C—				_
Body1	Body2		Bodyl	1		Body2			
Local hull	Bogie6.Road arm	-	Local	l hull	<b>_</b>	Bogie1.R	oad arm	1	-
GO Damper		*	GO	Damper					*
Autodetection			Au	utodetection					
Attachment points-			Attac	chment points					
Local hull	Г.		Local	l hull		۳.			
4.8	-0.2*side_key 0.7	C	0.4	C	-0.2*side_	key 🖻	0.7		С
Road arm	r,		Road	d arm		<b>r</b> .,			
-0.35	. 0.15+dz_dam	iper 🗅	0.35	C	-	C	0.15+dz	_damp	er <mark>C</mark>
		2		5/-					

Fig. 24 Assignment of bodies and coordinates

Rename the element; assign bodies and coordinates of attachment points, Fig. 24 left. Note that the *side\_key* is used for the lateral coordinate to change the coordinate sign in case of the left and right tracks.

To add the rear shock absorber, copy the front on by the <sup>1</sup>/<sub>2</sub> button, rename it, change the second body and coordinates of attachment points as in Fig. 24 right.

![](_page_14_Figure_10.jpeg)

Fig. 25 Model of track with shock absorbers

To finish the process of adding the shock absorbers, close the subsystem by the Accept button, Fig. 25.

Save the ready mode of the left track to file.

**Remark**. We have developed a simplified track model. Several elements are not included in the model.

.....

# 1.9. Development of full TV model

To finish the model development, we must add a hull and the second track.

![](_page_16_Figure_5.jpeg)

Fig. 26 Hull image

# 1.9.1. Adding hull

1) Read an image of the hull from the UM database, Fig. 26 by the **Edit** | **Read from file** command, select the file

![](_page_16_Figure_9.jpeg)

	Name Hull Comments/Text a	ttribute C	<u>a tt -</u>
	Oriented points Parameters Go to element	Vectors Position	3D Contact Points
	Image: goHull	Visil	ble
<ul> <li>Gobject</li> <li>Curves</li> <li>F⊠ Variables</li> <li>abc Attributes</li> <li>Subsystems</li> <li>E Left track</li> <li>Right track</li> <li>Bodies</li> <li>Bodies</li> <li>Ground</li> <li>Joints</li> </ul>	Inertia parameter Mass mHu	matically 's II	c
	Inertia tensor ixHull C	C	C
	<u>iy</u> t	Hull 🕒	izHull C
	Added mass ma Coordinates of ce xc C	trix enter of mass	(none) <u></u> s zc <u>c</u>

Fig. 27 Adding a body

- 2) Add a body to the model:
  - select the **Bodies** item of the element list, Fig.27;
  - create a new body by the 🗳 button in the inspector;
  - set a name, image and inertia parameters; mass, moments of inertia relative to central axes, coordinates of center of mass (gravity).

mhull	8000
ixhull	5000
iyhull	4.0000000E+4
izhull	4.0000000E+4
хс	2.605
zc	0.6

Fig. 28 Example of hull inertial parameters

It is recommended to parameterize the inertia parameters like in Fig. 27. An example of numeric values of inertia parameter is shown in Fig. 28.

![](_page_17_Figure_6.jpeg)

Fig. 29 Adding a joint for hull

3) Add a joint to the model. The joint introduces six degrees of freedom of the hull relative to Base0 (SC0):

- select the Joints item in the list of elements, Fig. 29;
- create a new joint by the 📑 button;
- set the joint type **6 d.o.f.**

**Remark 1**. Note that it is important which body in the joint description is the first one (Body1), and which is the second one (Body2). According to the UM rules, the joint introduces coordinates of the *second* body relative to the *first* one, i.e. coordinates of the hull relative to the inertial frame SCO.

**Remark 2**. As it is known, any three orientation angles have a singular position. For instance, the Euler angles are singular for zero values of coordinates, and these angles practically do not used in technical applications. We do not recommend the user to use the angles, which are singular at zeroes, i.e. angles corresponding to sequences of rotations in which the first and the third rotations axis are of the same name: are 3, 1, 3; 1, 2, 1 and so on. In the example in Fig. 29, we have assigned the Cardan angle with the sequence of rotations 1, 2, 3, which are singular for the second rotation angle (rotation about the Y-axes) equal to 90 degrees, i.e. in fact by the overturning of the TV. As well, it is recommended to use the angles 3, 1, 2 (yaw, pitch, and roll angles).

![](_page_18_Figure_0.jpeg)

Fig. 30 Uncoupled and coupled hull and track

So far, the track in the current model is not connected with the hull, Fig. 30 left.

To connect some elements of the track with the hull, it is necessary to fix the local hull of the track with the hull body. To do this, we introduce a joint with zero degrees of freedom between these bodies. There are several ways for adding such the joint: a 6 d.o.f. joint with disabled coordinates, a generalized joint with one elementary transformation of the **tc** type (translation on a constant vector).

Name	Hull_Local hull <u>- 앞 함</u> 앞 <u>- 문</u> ∓
Body1	Body2
Hull	📕 Left track.Local hul 🗲
Type 🗋	🖟 Generalized 🛛 💌
тсу	
🗹 Ena	abled <u>· : 한 · 1</u> · 그 · · · · · · · · · · · · · · · · ·
ET typ	e I↔I tc (translation constant) 🛛 🔽
Comr	ments/Text attribute C
Tran	slation vector
ex	
ey 🖸	gauge/2
ez	

Fig. 31 Joint rigidly connecting hull of TV and local hull of left track

- Add a joint.
- Assign connecting bodies (Hull and Left track.Local hull).
- Select the joint type **Generalized**.
- Add an elementary transformation be the lower  $\stackrel{1}{\rightarrow}$  button.
- Set the lateral shift of the track. In example in Fig. 31 the gauge is set by the identifier *gauge*=2.6 m.

As a result, we have rigidly connected the local hull of the track with the hull of TV, Fig. 30 right, and now all the joints and force elements connecting track bodies with the local (fictitious) hull are coupled with the real hull of TV.

#### 1.9.3. Adding the second track

Name Right tra	ack	
Type Cate Comments/T	erpillar ext attribute C	×
[	Edit subsystem	
Parameters	Position Ider	ntifiers
Identifier	Subs11	
Rollers	Sprocket	Idler
Structure	Track	Suspension
Sprocket po	O Fr	ont
C Left	ion	ght
Suspension	subsystems	<u>6</u>

Fig. 32 The right track

Open the left track subsystem and copy it by the  $\stackrel{\text{P},\text{P}}{=}$  button. Rename the subsystem and set the track position **Right**, Fig. 32.

NamejHu	II_Local hull_	1	-1-5	<u>\$</u> . <u></u>	
Body1		Bodya	2		
Hull	•	Right	track	Loca	l h 💌
Туре 浜	Generalized				~
ТСУ					
🗹 Enab	led	<u>-1-</u>	<u>-1</u> 2	<u> </u>	-1-5
ET type	l⇔l tc (trans	lation c	onsta	ant)	*
Comme	ints/Text attril	bute C-			
Transla	ation vector—				
ex					С
ey -ga	wge/2				С
ez					С

Fig. 33 Joint rigidly connecting the hull of TV with the local hull of the right track Similar to Sect. *Coupling hull and track* create a joint fixing he local hull of the right track with the hull of TV, Fig. 33. Note that in this case the lateral shift is negative.

#### **1.9.4.** Correction of vertical TV position

![](_page_20_Picture_4.jpeg)

Fig. 34 Links are under zero level

Note that track links are still located under the zero level in the vertical direction, in fact they are 'under the ground', Fig. 34. To avoid intensive transient processes by simulation, it is recommended to shift the TV model upwards on the link height.

![](_page_20_Picture_7.jpeg)

Fig. 35 Adding an identifier from subsystem

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At first note that by default the track link height is set by the identifier *htracklink*, which is defined in track subsystems, and not 'visible' in the head part of the TV model. It is recommended to add an identifier with the same name in the head part, Fig. 35:

- click by the right mouse button on the list of identifiers and select the **Add from subsystems** command;
- select the *htracklink* identifier in one of the track subsystems and click on it;
- make sure that the identifier appears in the list.

Vamej	Base	0_Hull	2	-1 <del>4</del> 4-1	<u>₽ -</u> = ∓
Body1			Bo	idy2	
Base0			🚽 Hu	all	-
Туре 🛛	🔎 6 c	d.o.f.			~
Geor	netry	Coor	dinates		
Body	1 E	lody 2	1		
2	Visua	ul assi	qnment		
Tran	Islatic	n	-		
× [					C
у [					C
z	ntrack	dink			C
	_	_			

Fig. 36 Vertical shift of TV model

To shift the model upwards, open the joint specifying coordinates of the TV hull relative to the SC0 and set the vertical coordinate in the **Geometry** | **Body1** tab, Fig. 36. The result is shown in Fig. 37.

![](_page_21_Picture_10.jpeg)

Fig. 37 Links are located on zero vertical level

Now we can start dynamic tests with the developed model of TV.

![](_page_22_Picture_3.jpeg)

# 2. Simulation of TV dynamics

#### 2.1. General remarks

Computer model of TV has usually a large number of degrees of freedom and requires of high performance computers. For instance, the developed model of TV has 1332 degrees of freedom. It is recommended to use computers with multi-core physical processors and apply the multithread solver realized in UM6.0.

As a rule, the model of TV is fully parameterized. It is important that some of the identifiers cannot be changed in the simulation module and requires regeneration of the track models in UMInput. These are identifiers, which influence the track chain and sprocket geometry:

- wheel radii;
- coordinates of wheel centers;
- track height.

Object simulation inspector					
XVA	Informa	tion	Tools	Tracked ve	hicle
Solver	Identifiers	Initi	al condition:	s Object vari	ables
🖻 🔒	😂 🖬 🖹 🍋 📴 gstv.Left track.				
Wh	ole list		Sprocket	Idler	
Tra	Track Ro		llers	Suspensio	1
Name	Expression	E	Value	Comment	~
wguide	0.02				
hguide	0.1				
Itracklin	0.11167				
wtracklin	0.3				
htracklin	0.03				
r_pin_in	r_pin_in 0.01				
wsproke	0				
	l lua*1 1		0.0275		>
Integ	ration	М	essage	Close	

Fig. 38 List of identifiers in UMSimul

Other parameters can be modified without regeneration of the track models. In particular, these are parameters used in the description of force elements (stiffness, damping constants etc.) and inertia parameters. To change values of these identifiers, the user must not come back to the UMInput. Usually, these changes are made on the **Identifiers** tab of the **Object simulation inspector**, Fig. 38. Modifications in parameter values are saved in special \*.par files and can be used in simulations.

The user can apply the preliminary prepared configurations for each of the tests described below. The list of configurations is available by the **File** | **Read configuration** | {**Test name**} command, Fig. 39.

💑 UM - Simulation - d	:\um60_work\tests\trackedvehicl
File Analysis Advanced	analysis Tools Windows Help
➢ Open F3 Reopen → Close Shift+F4	
Bead configuration     P     Save configuration     Exit     Alt+X	Desktop Ctrl+R Computation of velocities equilibrium
	Jump last Motion on sinusoidal irregularities Track tension Vertical harmonic loading

Fig. 39 List of configurations for tests

# 2.2. Auxiliary tests

The auxiliary tests are used for preparing the model to analysis of its dynamics. In particular, one of such the tests is used for getting a desired tension of track chains.

#### 2.2.1. Test: equilibrium

Consider an auxiliary test «Equilibrium» as the first dynamic test with the TV model. The objective of the test is to compute positions of bodies near the equilibrium state because the positions of bodies after the automatic generation of tracks do not correspond to the TV equilibrium.

Solver	Identifiers	Initial conditions	Object variab	le
🕞 🔒	e 🕨 🗗	gstv.Left track.Bog	ie1. 💽	-
Latest ide	entifier file:	Равн	новесие.par	
Whole li	st			
Name	Expression	Value	Comment	^
xbogie	0.775			
rear_arn	1		Rear(1) of fro	
wguide	0.04			
guide_ir	1			
hguide	0.1			
rroadwh	0.335		Radius of roa	
wroadwł	0.3		Width of road	
l_road_a	0.25			
l_road_a	0.36		(m) Length of	
f_dyn	110		(mm) Dynami	
p_stat	7000			
f_stat	70		(mm) Static m	
alaha a	20	2 <sup>1</sup>	(dea) Statica	

Fig. 40 Modification of parameters

Before start of the test, the user must verify numeric values of identifiers and their correspondence to the real values. In particular, one of the important parameters is the value static load on a road wheel, which is specified by the identifier *pstat*. Value of this parameter depends on the track tension. Let the design value of this parameter be 7 kN. Setting this value to the identifier can be done on the **Identifier** tab of the inspector. Note that the *pstat* identifier is defined in suspension subsystems. Open the list of identifiers for one of the suspension subsystem by the drop-down list, Fig. 38.

Solver	Identifiers	Initia	al cor	nditions	Obje	ct variables
XVA	Informat	ion Tools Tracke			ed vehicle	
Options	Resistance	e To	ols	Identifi	cation	Tests
Options	Resistance	e   To	ols	Identifi	cation	Tests
Equilibri	um test					*
Parame	ters Variat	oles				

#### Fig. 41 Equilibrium test

1) Load the model of TV in UMSimul. Open the Object simulation inspector by the **Analysis** | **Simulation** menu command. Open the **Tracked vehicle** | **Tests** tab. Select the **Equilibrium test** from the drop-down list, Fig. 41.

2) Open a graphic window by the 🖾 button on the tool panel. Drag the **Kinetic energy** variable prom the **Variables** tab into the graphic window.

![](_page_25_Figure_7.jpeg)

Fig. 42 Plot: kinetic energy vs. time

3) Run the simulation by the **Integration** button in the bottom of the inspector. In our test the energy value decreases to the value lower than 1 J after 7 seconds of simulation, Fig. 42, i.e. the TV is nearly the equilibrium.

4) Start the pause mode after 7 s of simulation by the 🔲 button in the window of integration process parameters or by the Esc button. Save the final values of coordinates in the \*.xv file with any name by the **Save** button in the bottom of the pause window. Break simulation by the **Interrupt** button.

![](_page_25_Picture_11.jpeg)

Fig. 43 Track before and after the equilibrium test

5) Read the saved file by the  $\stackrel{\frown}{\Rightarrow}$  button on the **Initial conditions** | **Coordinates** tab of the inspector. Set zero values for velocities by the  $\stackrel{\frown}{\otimes}$  button. It is recommended to save the found coordinates in a file by the  $\blacksquare$  button for the next tests. Positions of track bodies before and after the test are shown in Fig. 43. Remember that the necessary track tension is still not set.

#### 2.2.2. Track tension

Options Resist	tance To	ols Identifica	tion Tests			
Tension by joint preload						
Parameters Variables						
_Identifiers						
Name			Identifier	Value		
Elongation of te	Elongation of tension rod (Left track) Left track.track_tension 0					
Elongation of tension rod (Right track) Right track.track_tension 0						
-Numeric paran	neters					
Name	Value					
TStart (s)	0					
PStart (kN)	10					
PFinish (kN)	45					
PV (kN/s)	3					

Рис. 44 Parameters of the test

1) Select the '**Tension by joint preload**' test. In this test, a value of the preload force in bushings can be found, which gives the desired value of the track tension. Note that there exists a test 'Track tension' where the tension value is obtained by elongation of the tensions rod, but this method is usually used for track links with rigid joints.

Test parameters are presented in Fig. 44. First, identifiers of preload force in bushing models are specified in the **Identifiers** group. Increase of the value of these identifiers leads to the growth of the track tension. Note that these identifiers were found automatically because the standard name *track\_tension* was used.

2) Set numeric parameters of the test as in Fig. 44. A uniforms increase of the preload force in bushings starts from 10kN to 45 kN with the rate 3 kN/s.

Tension by joint preload					
Parameters Variables					
Joint preload Joint preload Average tens Average tens	(Left track) (Right trac ion (Left tra ion (Right t	k) ick) rack)			

Fig. 45 List of standard variables of the test

3) Open a new graphic window and drag two variables from the list by the mouse into the window: preload and tension, Fig. 45.

🗠 Plots			
Variables			
🔽 🔜 Joint preload (Lef	ttrack)		1
Average tension	Options		
	Edit		
Tension /N	Delete	Del	
- Crisiony Kiv	Copy to clipboard	Ctrl+C	
	Copy to active MS Excel book	Ctrl+E	
	Filter	Ctrl+F	
20	Copy as static variables	Ctrl+S	
	Save as text file	Ctrl+T	
	Sa∨e as *.tgr file	Ctrl+V	
	Read from text file		
10	Read from RSP file		
	Lav off variable as abscissa		
	Lay off "time" as abscissa		
	Clear	Ctrl+Del	

Fig. 46 Preload must be laid off as abscissa

Lay off the preload as abscissa: select the variable in the list of graphic window, call the context menu by the right mouse button and select the menu command, Fig. 46.

XVA Inform	ation				
010	uaon	Tools	Tracked vehicle		
Solver Identifiers	s Initi	al conditions	6 Object variables		
Simulation process	; paran	neters Solv	/er options		
Solver BDF ABM Park method Gear 2 Solver Type of solution O Null space method (NSM)					
© RK4 © Park Parallel		Range	space method (RS		
Simulation time 12.000			12.000 🏒		
Step size for anima	tion an	d data stora	ge 0.01		
Error tolerance 1E-0006			1E-0006		
Delay to real tim Computation of CG iterations	ne simu accele	Ilation rations and I	reaction forces		
CG error			0.1		
Use threads					
Number of threads			4		

Fig. 47 Setting simulation time

4) Set simulation time 12 s on the Solver | Simulation process parameters tab and run simulation by the Integration button.

![](_page_28_Figure_2.jpeg)

Let us discuss the main result of the test: dependence of the average track tension on the preload in bushings, Fig. 48. The plot has two straight sections: the first section (tension is lower 35 kN) when the load on the tension device is less than the tension spring preload and the second section when the tension spring compressed. In our model the preload of the tension spring is 50 kN.

![](_page_28_Figure_4.jpeg)

Fig. 49 Force in tension spring (left) and angle of the tension crank rotation (right) vs. bushing preload

These conclusions are confirmed by the plots in Fig. 49.

5) Now the preload in bushings can be evaluated from Fig. 48 by the desired track tension. Let the track tension must be 20 kN. The corresponding bushing preload is approximately 26.6 kN.

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Options Resistance Tools Identif	cation Tests
General Irregularities Macrogeome	try
-Sprocket rotation-	
-5.2262 5.2163	*/+
Hull Hull	*
Mass of TV (t) $12.38$ Mass of hull (	) 8.00
Elongation of tension rod (mm)	0
Preload in joint (kN)	26.6

Fig. 50 Setting joint preload for the further use

Break the pause mode and set the found preload value in the **Tracked vehicle** | **Options** | **General** for use in other tests.

6) Now we must solve the last problem. Positions of TV bodies for the given track tension must be computed and stored:

- set the Equilibrium test
- run test during 7 seconds
- save coordinates in the pause mode by the **Save** button;
- break simulation, read the saved coordinates on the **Initial conditions** tab, set zero values for velocities, and save the coordinates by the 🖬 button.

Use this coordinates any time when the test requires an equilibrium state of the TV by the given value of the track tension.

#### 2.2.3. Vertical harmonic loading

The test allows the user to get nonlinear vertical characteristics of the suspension by a slow harmonic excitation

![](_page_29_Picture_14.jpeg)

![](_page_29_Figure_15.jpeg)

1) Select the corresponding type of the test and set parameters of the harmonic vertical force, Fig. 51.

Parameters	Variables	
Vertical forc	e movement	
	Fig. 52 Test variables	

2) Open a graphic window and drag in it the test variables, Fig. 52. Lay off the suspension movement as abscissa.

![](_page_30_Figure_2.jpeg)

Fig. 53 Test result: Load vs. vertical movement

3) Run the test. The results are shown in Fig. 53. Increase of the suspension stiffness corresponds to the vertical movement exceeding the road wheel dynamic travel 110 mm parameterized by the identifier  $f_dyn$ , Fig. 40.

#### 2.2.4. Test: initial velocities

The test is necessary for automatic computation of initial velocities of TV bodies by the given value of the TV speed, when one of the main dynamic tests is executed. As a rule, it is enough to create a file of initial conditions corresponding to one speed, e.g. 5 m/s. With this file, the program computes start velocities for any speed of TV using a scale factor.

Options Resistance T	ools Ide	entification	Tests			
Computation of initial velocities						
Parameters Variables						
-Numeric parameters						
Name	Value					
Target vehicle speed	5					
Time of acceleration	5					

Fig. 54 Test parameters

1) Select the corresponding type of the test; assign the target speed and time interval for acceleration, Fig. 54.

Parameters	Variables
V sprocket	Left track)
V sprocket	Right track)

Fig. 55 Test variables

2) Open a graphic window and drag in it the test variables, which are circular velocities of sprockets, Fig. 55.

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![](_page_31_Figure_3.jpeg)

3) Run the test. The plot of circular sprocket velocities vs. time is shown in Fig. 56.

4) **Confirm saving the results** after finishing the test. The values of coordinates and velocities of all he bodies are saved in the 50.tvv file and will be used in any main dynamic test, in which the TV speed differs from zero.

# 2.3. Straight motion of TV

This is the main test for analysis of dynamics of a TV by straight motion without turn. Here we consider two examples of such the test.

#### 2.3.1. Motion on sinusoidal road profile

Options	Resis	stance	Tools	Identification	Tests
Straight r	notion	test			~
Parame	ters \	/ariabl	es		
-Mode o	f motic	on		-	
ORun	-off	۲	)v=const	: O∨(t)∧	√(s)
Numeri	c para	meters			
Name		Valu	e		
		1.5			

Fig. 57 Test parameter

1) Select the corresponding type of the test, Fig. 57. The test parameter is used in control of the speed history, which will be constant in our test. The amplifier is not used if the 'Run-off' speed mode is set.

Options	Resistance	Tools	Identification	Tests
General	Irregularitie	s Macro	geometry	
Type of	firregularities		offic of in	
File		0	) A sin(2*pi*x/L	)
Н	armonic irreg	ularities	A*sin (2*pi*(x-x	0)/L)
Amplitu	de A (m)	0.20		
Wave I	ength L (m)	20.00		
Phase s	shift x0 of wav	e for left t	rack	
		7.00		

Fig. 58 Parameters of sinusoidal road profile

2) Use the **Tracked vehicle** | **Options** | **Irregularities** tab to set parameters of sinusoidal irregularities, Fig. 58. By x0=0, the irregularities for the left and right tracks are equal, by x0>0 the left road curve passes ahead of the right one. Use the  $\square$  button to visualize the curves, Fig. 59.

![](_page_32_Figure_6.jpeg)

Рис. 59 Sinusoidal irregularities for the left (thick) and right tracks

![](_page_32_Figure_8.jpeg)

Fig. 60 Setting camera motion

3) Open an animation window and assign the camera motion mode to keep the TV within the window. Move the mouse cursor to the hull image, click the right mouse button, and select the **Camera follows Hull** command, Fig. 60.

![](_page_33_Picture_3.jpeg)

Fig. 61 TV speed

4) Set 10 m/s speed of the TV on the **Identifiers** tab of the inspector, Fig. 61.

5) Open a graphic window and create some variables, which could be useful for dynamic analysis of the TV, e.g. the longitudinal and vertical acceleration of the hull center of gravity.6) Run simulation.

# 2.3.2. Modeling of jump

![](_page_33_Figure_8.jpeg)

Fig. 62 Setting irregularity files

![](_page_33_Figure_10.jpeg)

1) Use the preliminary created road profile

 $Path to UM \bin\caterpillar\Irregularities\jump_25_1.irr.$ 

The file must be assigned by the 🖻 buttons to the left and right tracks on the **Options** | **Irregularities** tab, Fig. 62. Use the 🖾 button to visualize the road profile, Fig. 63.

2) Assign speed 10 m/s and run simulation.

#### References

1. Crawler transporters / Platonov W.F. (Ed.). Moscow: Mashinostroenie. 1972 (Rus).