



IPGKinematics 'Forces Off' Simulation Formula CarMaker 9.1

SOLUTIONS FOR VIRTUAL TEST DRIVING

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Introduction

IPGKinematics is a program designed to simulate a vehicle axle on an axle test bench and is used to calculate the kinematics, steering kinematics and elastokinematics of a variety of suspension types.

For the simulation of high-performance competitive vehicles, such as Formula Student cars, the effects of compliance and elastokinematics become less prevalent due to generally stiffer suspension components and bushings being implemented - as opposed to that of a consumer vehicle as comfort is of a lower priority.

For this reason, it may be more relevant for a team to negate the effects of spring forces and torsion to produce a pure kinematics simulation, allowing suspension linkages to move freely throughout their range of motion.

This document instructs the user on how to parameterize IPGKinematics to complete a '*Forces* <u>Off</u> simulation for a <u>Double Wishbone</u>, <u>Pull-/Pushrod actuated suspension system</u>. By ignoring such forces, certain inputs do not need accurate parametrization and therefore saving time during the modelling process. For ease of use, the following diagrams have been annotated using the following key:



= Requires Parameterization

All other inputs can be left as their default value. At the end of each section, suggested settings are provided.



Although not required, it may be useful to use accurate values for all inputs when possible if you wish to complete a 'Forces On' simulation in the future.



Before reading this document, it is highly advised that the user has a substantial level of familiarity with the software which can be gained by completing the exercises within the Formula CarMaker Tutorial. This document is intended to be supplementary to the list of help manuals provided with CarMaker and therefore explanations offered within are not extensive. Example input values can be within the Formula CarMaker Tutorial document.

Chapter 1 Simulation Control

The *Simulation Control* GUI allows the user to parameterize the way in which the kinematics results will be generated and stored via the *General, Kinematics, Compliance* and *MixedForce* tabs. It is within this GUI that the simulation can be configured to run with 'Forces Off'. More information regarding Simulation Control and the various settings can be found within the IPGKinematics User Guide.

Creating a New File

Before parameterizing simulation settings, the suspension configuration to be modelled must be specified first. This can be achieved by navigating to *File > New* upon the IPGKinematics GUI.

IPGKinematics - Simulation Models	×
IPG	
Leaf-spring rigid axle	H.
Steering stub axie	
Integral link	
Trailing arm rigid axle	
McPherson	
Swing axle rear	
Swing axle front	
Double wishbone	
Multi link	
Semi trailing arm	
Swing arm	
Twistbeam	-
	1
OK Cancel	

Figure 1.1 Defining the suspension configuration

Upon the resulting window the user can select from range of pre-defined suspension configurations. As it the case for most open-wheeled race cars, i.e., Formula Student vehicles, a Double Wishbone arrangement is often implemented.

It is then recommended to then save the file, ensuring that a name is chosen which differentiates from previous simulations - i.e., "DWB_Forces_OFF.kin".

Simulation Control GUI

This dialog controls the simulation parameters.

lucs Compliance	MixedForce	
S	Kinematics	_
	Forces On 4	_
	Storage of Tables	
	Log 4	_
	Storage of Results	
mo	CarMaker Interface (1)	_
	Save CarMaker files only	
	md	s Kinematics S Forces On Storage of Tables Log Md Storage of Results CarMaker Interface (1) Save CarMaker files only

Figure 1.2 The General tab of the Simulation Control GUI

General

Upon the *General* tab, the following settings should be implemented to run a 'Forces Off' simulation:

- **Kinematics** Forces <u>Off</u> should be selected from the *Kinematics* drop down menu. This ensures that neither inertial nor spring forces are considered, and only pure kinematics are calculated.
- **Storage of Tables** The options for the output of the calculated tables. <u>*Log*</u> should be selected which will display all results tables within the GUI and will also produce an output file.

Storage of Results To export the results to CarMaker you must choose one of the CarMaker Interface options:

- CarMaker Interface (1) provides linear compliance model.
- CarMaker Interface (2) provides a non-linear compliance model.

As a non-linear compliance model will lead to unnecessarily increased computation times, it is recommended to select <u>CarMaker Interface (1)</u>. If the Save CarMaker files only option is enabled, only the .kin and .skc files will be stored which will reduce memory usage.

Simulation Control - General

Within the General tab, set:

- Kinematics = Forces Off
- Storage of Tables = Log
- Storage of Results = CarMaker Interface (1)

Kinematics

Para	llel Kinematic	s	Steering k	Kinematics —	
	On			On (1)	
Com	pression (mn	ו]	Distance :	Steering Rack	[mm]
Minin	num	-30.0	Minimum		-70.0
Maxir	mum	30.0	Maximum		70.0
Step	size	5.0	Stepsize		10.0
Reci	procal Kinem	atics]		
	Off				
L			1		

This tab defines the procedure according to which the movement of the wheels is calculated.

Figure 1.2 The Kinematics tab of the Simulation Control GUI

Parallel Both wheels of an axle will move in the same direction upon compression when activated. This should be set to On. **Kinematics** Reciprocal This option will move the axle's wheels in opposite directions. This parameter will not affect the output of the .skc file but will produce additional files describing the vehicle's reciprocal **Kinematics** kinematics, however this may unnecessarily increase simulation time. Steering This is used only for the front axle to calculate steering parameters. On (1) should be selected **Kinematics** as it does not consider the interaction between steering and reciprocal wheel travel. The maximum/minimum values for Compression and Distance Steering Rack should be kept **Compression and** close to the designed range to not unnecessarily increase computation time. **Distance Steering**

Simulation Control - Kinematics

Within the Kinematics tab, set:

- Parallel Kinematics = "On".
- Steering Kinematics = "On".
- Reciprocal Kinematics = "Off".
- Compression = "+/- 30mm", Stepsize = "5.0".
- Distance Steering Rack = "+/- 70mm", Stepsize = "5.0".

Rack

Compliance and MixedForce

The last two tabs are used to apply external forces to the wheels in the longitudinal and lateral directions. These are used to determine the stresses upon individual suspension components for FEM analysis. For pure kinematics, external forces are deactivated and compliance is irrelevant which is why these options should be configured to <u>Off</u>.

MixedForce
Longitudinal Force
Off 🛁
Longitudinal Force Right [%]
100
0 25 50 75 100
Longitudinal Force [N]
Minimum -5000.0
Maximum 5000.0
Stepsize 500.0
Close

Figure 1.3 The Compliance tab of the Simulation Control GUI

Simulation Control - Compliance and MixedForce

- Within the Compliance and MixedForce tabs, configure all settings to Off.
- Leave numerical inputs as their default values.

Chapter 2 Vehicle Data

This chapter describes the parametrization of the *Vehicle Data* section of IPGKinematics, accessed via *Edit* > *Vehicle Data*. This process mainly involves the specification of various hardpoints to allow the software to calculate the various movements of the suspension mechanism, however, with 'forces off' the definition of some of these components becomes redundant as they will no longer have an effect upon the simulation's results.

This section will therefore identify which settings can be disregarded, and in some instances provide suggested values as to prevent the program from producing an error. If you do not have values specific to your vehicle, the FCM Tutorial provides representative values.



It may be of interest to enter representative vehicle data where possible for all values in case the need for a 'Forces On' simulation arises which may save time later, however this may not be necessary. In this case, the FCM Tutorial should be referenced when parameterizing.

Vehicle Data GUI

General

The General Tab contains miscellaneous vehicle settings.

70 Fleight Vehicle Center of Gravity 425.0 mm 0 25 50 75 100 Wheel Base 2715.0 mm 0 25 50 75 100 Design Position 0 0 min 0 25 50 75 100 Wheel Toe Angle 0.0 min 0 25 50 75 100 Elastic Mounting Steering Gearbox 6 Elastic Mounting Steering Gearbox 6 Elastic Mounting Steering Gearbox Off 6 Elastic Mounting Steering Gearbox Off 6 Elastic Mounting Steering Gearbox Off 6 Elastic Mounting Steering Gearbox On 6 Elastic Mountin	Brake Force Ratio [%]	Vehicle		
0 25 50 75 100 Intring Torque Ratio [%] 0 Design Position 0 25 50 75 100 Image: Static Mounting Steering Gearbox -5.0 deg Chassis Subframe Image: Static Mounting Steering Gearbox Image: Static Mounting Steering Gearbox Image: Chassis Subframe On Image: Static Mounting Steering Gearbox On	70	Height Vehicle Center of Gravity	425.0	mm
0 25 50 75 100 0 25 50 75 100 hassis Subframe Elastic Mounting Steering Gearbox • Elastic Mounting Steering Gearbox Off • Chassis Subframe Off • Elastic Mounting Steering Gearbox Off • • Chassis Subframe Off • Elastic Mounting Steering Gearbox Off • Chassis Subframe On • Elastic Mounting Steering Gearbox On	0 05 50 75 100	Wheel Base	2715.0	mm
Chassis Subframe Off Chassis Subframe On C Elastic Mounting Steering Gearbox Off C Elastic Mounting Steering Gearbox On	0 25 50 75 100	Wheel Camber Angle	-5.0	deg
Chassis Subirane On C Elastic Mounting Steering Gearbox On	Chassis Subframe	Elastic Mounting Steering Gearbox	ov 0#	
	Chassis Subframe On	C Elastic Mounting Steering Gearbo	ox On	

Figure 2.1 The General tab of the Input Data GUI

Axle	This option defines which axle will be defined. The <i>Front Axle</i> option will include the calculation of various steering quantities.
Brake Force Ratio	This parameter does not affect 'Forces Off' kinematics.
Driving Torque Ratio	This parameter does not affect 'Forces Off' kinematics.
Chassis Subframe	For a Formula Student car <i>Chassis Subframe off</i> should be selected as only the chassis supports the engine and lower suspension components (i.e. there is no subframe).
Tire	This field is used to define the vertical stiffness of the tire (in N/mm). As the tire is modeled as a linear spring, a tire spring coefficient must also be entered. To negate the effects of tire deflection, it is recommended to enter a high value such as 5000 N/mm.
Design Position	Here, the static wheel toe and camber angles are defined. The design position is the position of the car with only the axle load upon it. This corresponds to a wheel travel of 0 mm. Therefore, it must be established if the weight of the driver was included in the design position calculation or not. If not, attention must be paid to various settings such as the location of the center of gravity, camber and toe angles etc. All of these should be measured or calculated without the driver's weight.
Elastic Mounting Steering Gearbox	This offers the option to model the rack-and-pinion steering rack elastically. However, as compliance will not be considered with 'Forces Off' this feature should <u>not</u> be enabled.

Vehicle Data - General

Within the General tab, set:

- Axle to either Front or Rear depending upon what you are modelling.
- Brake Force Ratio and Driving Torque Ratio can be set to any values.
- Chassis Subframe = Chassis Subframe Off
- *Tire Rate* = '5000 N/mm'
- Vehicle and Design Position should be set to representative values.
- *Elastic Mounting Steering Gearbox* = Elastic Mounting Steering Gearbox Off.

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Springing

The Springing tab features settings for the pull/push-rod, springing and the stabilizer bar.

Spring Fixing	Stabilizer Bar Fixing	Pull-/Pushroo	d Fixing
None 🛁	Pull-/Pushrod	Lower W	ishbone 🖳
Spring	Parameters Spring		
🕫 Linear	Spring Rate	65.0	N/mm
Curve	Spring Curve	Edit	
Stabilizer Bar	Parameters Stabilizer Bar		
Linear	Spring Rate	25.0	Nm/deg
Curve	Spring Curve	Edit	
Pull-/Pushrod	Parameters Pull-/Pushrod —		
Linear	Spring Rate	5000.0	N/mm
C Curve	Spring Curve	Edit	
3. Spring Stabi Torsion Bar	Parameters 3. Spring Stabi T	orsion Bar	
Linear C None	Spring Rate	65.0	N/mm
C Curve	Spring Curve	Edit	

Figure 2.2 The Springing tab of the Input Data GUI

As 'Forces Off' does not consider inertial nor spring forces, many of the settings upon this tab merely require a non-zero value to prevent a computational error.

Spring Fixing Defines which component the spring is fastened to. It is assumed that the "Spring Fixing" is on the suspension side. The option <u>None</u> is chosen in the case of a pull-/pushrod.

- Stabilizer BarThis parameter does not affect 'Forces Off' kinematics, however you should select pull-
/pushrod.
- **Pull-/Pushrod** Defines how the push-/pull rod is connected to the wheel.

ParameterThese parameters do not affect 'Forces Off' kinematics, however non-zero values should be
input to prevent a computational error. These stiffness values are used to consider
compliance effects of various suspension compnents, which does not concern a pure
kinematics simulation./Pull-/Pushrod
/Torsion BarThese parameters do not affect 'Forces Off' kinematics, however non-zero values should be
input to prevent a computational error. These stiffness values are used to consider
compliance effects of various suspension compnents, which does not concern a pure
kinematics simulation.

Vehicle Data - Springing

Within the Springing tab, set:

- Spring Fixing = None
- Stabilizer Bar Fixing = Push-/Pullrod
- Pull-/Pushrod Fixing = Lower Wishbone
- All LHS settings = Linear
- Spring Rates = Default values

Fixing

Bushings

The drop-down menu upon the *Bushings* tab allows you to allocate properties to each of the bushings of the selected suspension system.

Chassis Subframe Front Chyperinematics/win32-3.5.9/emplate Iarameters Bushing Chassis Subframe Front Browse illename Bushing Center -200.0 -400.0 165.0 mm oint Bushing Center -200.0 -400.0 265.0 mm ngle about Bushing Axis 0.0 deg		mainpaur	hui-20.2.6.08-			
traneters Bushing Chassis Subframe Front illename Bushing //data/gum/ipg/lin50000.gum Browse voint Bushing Center -200.0 -400.0 165.0 mm voint on Bushing Axis -200.0 -400.0 265.0 mm ngle about Bushing Axis 0.0 deg	Chassis Subframe Front 😐	c.//pg/kinematics	/win32-3.0.9/te	mplate		
illename Bushing //data/gum/ipg/lin50000.gum Browse voint Bushing Center -200.0 -400.0 165.0 mm voint on Bushing Axis -200.0 -400.0 265.0 mm ngle about Bushing Axis 0.0 deg	Parameters Bushing Chassis Su	bframe Front				
voint Bushing Center -200.0 -400.0 165.0 mm voint on Bushing Axis -200.0 -400.0 265.0 mm ngle about Bushing Axis 0.0 deg	ilename Bushing	./data/gum/ipg/li	n50000.gum			Browse
oint on Bushing Axis -200.0 -400.0 265.0 mm ngle about Bushing Axis 0.0 deg	Point Bushing Center	-200.0	-400.0	165.0	mm	
ngle about Bushing Axis 0.0 deg	oint on Bushing Axis	-200.0	-400.0	265.0	mm	
	ngle about Bushing Axis	0.0			deg	

Figure 2.3 The Bushings tab of the Input Data GUI

Again, as compliance is not considering during a 'Forces Off' simulation, the specification of bushings has no effect upon the results and will therefore be modelled as rigid.

Vehicle Data - Bushings

Within the *Bushings* tab, leave all parameters as their default values - bushings only need to not be parallel to connected members for a 'Forces Off' simulation. I.e., the cross product of the connected member and bushing axis should not be zero. For a 'Forces On' simulation the Bushing axis should be aligned with the general axis of rotation of the connected member. I.e., the cross product of the connected member and bushing axis should be as large as possible.

Mass

The Mass tab is used to specify the weights of certain suspension system components.

Mass			
Load	0.0	kg	
Mass			
Axle Weight	500.0	kg	^
Chassis Subframe	50.0	kg	
Lower Wishbone	1.0	kg	
Wheel Carrier	1.0	kg	
Wheel	20	kg	
Upper Wishbone	1.0	kg	
Steering Rod	1.0	kg	
Steering Rack	1.0	kg	
Steering Gearbox	5.0	kg	
Stabilizer Bar	2.0	kg	
Stabilizer Link	1.0	kg	
Rocker Arm (Pull-/Pushrod)	1.0	kg	

Figure 2.4 The Mass tab of the Input Data GUI

As no mass forces will be considered during the kinematics calculations, these values can be left as their defaults. (Note: 'zero' values will result in a computational error)

Vehicle Data - Bushings

Within the *Mass* tab, leave all parameters as their default values - masses do not need to be defined for a 'Forces Off' simulation.

Geometry

The *Geometry* tab is used to define the hardpoints of various suspension components and its correct parametrization is critical to the accuracy of kinematics calculations.

Automobile Industry					
Coordinates	х	Y Z			_
Wheel Center	0.0	-777.0	309.0	mm	-
Center of Tire Contact	0.0	-801.0	0.0	mm	
Force Application Tire Forces	0.0	-801.0	0.0	mm	
Body - Chassis Subframe Front	-200.0	-400.0	165.0	mm	
Body - Chassis Subframe Rear	400.0	-400.0	215.0	mm	
Wheel Carrier - Lower Wishbone	-1.0	-752.0	130.0	mm	
Wheel Carrier - Upper Wishbone	65.0	-610.0	482.0	mm	
Wheel Carrier - Steering Rod	-175.0	-746.0	255.0	mm	
Chassis Subframe - Bushing Front Lower Wishbo	-24.0	-340.0	118.0	mm	
Chassis Subframe - Bushing Rear Lower Wishbo	300.0	-340.0	117.0	mm	
Body - Bushing Front Upper Wishbone	-29.0	-440.0	472.0	mm	
Body - Bushing Rear Upper Wishbone	196.0	-440.0	442.0	mm	-

Figure 2.5 The Geometry tab of the Input Data GUI

As the forces associated with the springs and anti-rollbar are not considered, some of the inputs merely require a non-zero value to calculate the vehicle's kinematic properties. These are summarized in the following table.

Ve	hicle Data - Geometry
-	Populate the Geometry tab according to the below table. All other inputs can be any non-
	zero value during the parametrization process.

····· ··· · · · · · · · · · · · · · ·	
Parameter	Comment
Wheel Centre	-
Centre of Tire Contact	-
Body - Chassis Subframe Front	Can be set same as Chassis Subframe - Bushing Front Lower Wishbone.
Body - Chassis Subframe Rear	Can be set same as Chassis Subframe - Bushing Rear Lower Wishbone.
Wheel Carrier - Lower Wishbone	-
Wheel Carrier - Upper Wishbone	-
Wheel Carrier - Steering Rod	Not used by rear axle - will still require a non- zero value e.g., coordinates of Wheel Centre.
Chassis Subframe - Bushing Front Lower Wishbone	As the subframe is deactivated this corresponds to the mounting points of the lower wishbones to the body.

Table 2.1: All Geometry inputs which require parameterizing

Parameter	Comment
Chassis Subframe - Bushing Rear Lower Wishbone	As the subframe is deactivated this corresponds to the mounting points of the lower wishbones to the body.
Body - Bushing Front Upper Wishbone	-
Body - Rear Upper Wishbone	-
Body - Rocker Arm	-
Rotation Axis - Rocker Arm	Can be any point upon the rotation axis of the rocker arm.
Pull-/Pushrod - Wheel Suspension	-
Pull-/Pushrod - Rocker Arm	-
Spring Element - Body	The point at which the spring assembly is connected to the vehicle body / chassis.
Spring Element - Rocker Arm	The point at which the spring assembly is connected to the rocker.

All other inputs can be a non-zero value.

Saving Results

Once the Simulation Control and Vehicle Data have been configured, the simulation can be initiated by clicking the *Start* button upon the IPGKinematics GUI.



Figure 2.6: Start button upon IPGKinemtics GUI

This button will momentarily turn grey whilst the simulation is running and will return to green once it has completed. The resulting files should then be saved via *File > Save*.

Amongst the numerous data files generated by the simulation, one will be called:

• NameOfResults front.skc (for a front axle)

or

• NameOfResults rear.skc (for a rear axle).

To use IPGKinematics results in CarMaker you must copy the skc-files and paste them into the "<yourProjectDirectory>/Data/Chassis" folder of your CarMaker project directory, for example:

"FormulaCarMaker_Release2021.1 /Data/Chassis"

This process is demonstrated in the Formula CarMaker Tutorial chapter 5, '*Preparing a Vehicle Dataset in CarMaker*' pg. 75.