SIEMENS DIGITAL INDUSTRIES SOFTWARE

Simcenter Tire MF-Tyre/MF-Swift 2412

Third Party Manual

SIEMENS

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Introduction

Simcenter Tire is the Siemens branding for the former TNO/TASS Delft-Tyre portfolio containing tire modeling software and services. Simcenter Tire enables engineers to precisely and efficiently model the highly non-linear tire perfromance throughout vehicle dynamic simulations.

This allows analysis of the vehicle behavior earlier in the development cycle, reducing development time and costs. Simcenter Tire includes the MF-Tyre/MF-Swift tire model, the MF-Tool tire model parametrization tool, tire testing and engineering services. By combining those elements, customized tire modeling methodologies can be delivered that provide the optimal balance between the simulation accuracy and cost-efficiency.

The manual belongs to the Simcenter Tire MF-Tyre/MF-Swift product. Based on the renowned Magic Formula and tire modeling theory developed by Professor Pacejka [1], MF-Tyre/MF-Swift has a range of methods to model tire behavior for vehicle dynamic simulations. MF-Tyre/MF-Swift provides an integral cost efficient and fast tire modeling for all simulation applications.

MF-Tyre/MF-Swift is a plug-in to a number of Vehicle Simulation Packages capable of representing the (dynamic) tire behavior. MF-Tyre/MF-Swift supports usage for both desktop applications as well as on Real-Time systems. The two types of applications require different licensing strategies. For more information, see License Manual.

MF-Tyre/MF-Swift 2412 supports the following real-time systems:

- dSpace DS1006
- dSpace SCALEXIO
- Concurrent iHAWK
- IPG Xpack4
- NI-PXI Phar Lap ETS

For information on using the tire model, see User Manual.

Release Notes

This document describes the contents of the current release: MF-Tyre/MF-Swift v2412.

The release notes of MF-Tyre/MF-Swift v2412 present the latest generic updates and bug fixes that apply for the usage of MF-Tyre/MF-Swift in combination with all vehicle simulation packages.

Generic Updates

- MF-Tyre/MF-Swift 2412 is now using version 2.6.2 of the SALT licensing toolkit. There is no requirement to upgrade existing SALT license servers.
- MF-Tyre/MF-Swift 2412 is successfully tested on dSpace SCALEXIO up to version 2024a.

Prototype Features

- MF-Tyre/MF-Swift 2412 is prepared to support interoperability with rFpro Terrain Server. This capability allows to use the high definition Terrain Server road data in combination with the road contact algorithms of MF-Tyre/MF-Swift.
- MF-Tyre/MF-Swift 2412 contains an implementation of the wet road tire model extension. This capability allows to model the tire behaviour on wet roads.

If you are interested in making use of prototype features, please reach out to your local Siemens representative.

Recent Release Highlights

2406

- MF-Tyre/MF-Swift 2406 uses version 2.5 of the SALT licensing toolkit. To use licensed features in 2406.
- Two new tire parameters were introduced for improved stability at low velocities: DAMP_LSG and VX_STBL. For more information, see Tire Property File Parameters.
- In MF-Tyre/MF-Swift 2406 it is possible to change the tire behavior in generated code by completely changing the contents of the associated tire property file. In earlier versions, the contents of the tire property file were encoded in the generated code and could therefore not be changed after generation.

2306

- The scaling parameters (e.g. *LMUX* and *LUMY*) and inflation pressure can vary as a function of time during simulation run-time.
- The tire model can be re-initialized at run-time. This enables functionality such as changing TIR files and use modes. This is mainly beneficial for Real-Time simulations. For more information, see Advanced Parameters.

v2212

- Enveloping performance increased significantly (~45%), enabling a broader range of high-fidelity Real-Time applications.

- Software version naming was changed from YYYY.X (e.g. 2022.1) to YYMM (e.g. 2212 — December 2022) to align with the broader Simcenter 3D portfolio.

v2022.1

- The licensing daemon was upgraded, from MADLIC to SALT (Siemens Advanced Licensing Technology) — all releases from v2022.1 will use SALT. For more information see License Manual.
- The non-linear transient model was updated to model the deflection of the contact patch (in addition to the already-considered carcass deflection), without the need for any additional measurements or parameters.

v2020.2

- Thermal effects of a tire are accounted for through the Temperature and Velocity ("T&V") module.

License Manual

To use MF-Tyre/MF-Swift on both desktop and real-time platforms, the licensing system must be set up.

For this, the following convention is used:

`<installationdir>`—The full path of the directory where the MF-Tyre/MF-Swift product is installed, including the version. For example `C:\simcenter_tire\mftyre_mfswift`.

New Siemens Licensing Mechanism for Simcenter Tire Products

The licensing mechanism for Simcenter Tire MF-Tyre/MF-Swift 2022.1 has been changed to the Siemens License Server. The Siemens License Server uses a new vendor DEAMON called SALT. For details for obtaining a license for MF-Tyre/MF-Swift 2412, see Obtaining a License.

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Obtaining a License

The licenses for MF-Tyre/MF-Swift products can be obtained from a Siemens Digital Industries Software representative or our channel partners.

For creating the license file, some mandatory information is required. This is used to identify the computer on which the license server is to be deployed:

- Composite HostID Values
- Host Name
- MAC Address

To obtain the Composite HostID Values:

1. On the machine which is designated as the license server for MF-Tyre/MF-Swift:
   - On Windows, launch `getcid.exe`.
   - On Linux, launch `getcid`.
2. Send the Composite HostID Values to your sales representative to generate the license file for MF-Tyre/MF-Swift.

   In case of NodeLock counted License, run the `getcid` executable on the local machine that is to be used for running MF-Tyre/MF-Swift. The `getcid` executable is provided as part of the zip file. If these executables are not available, contact your Siemens Digital Industries sales representative or channel partners.

   For information required to obtain a license for a specific real-time platform, see License Protection on RT Platforms.

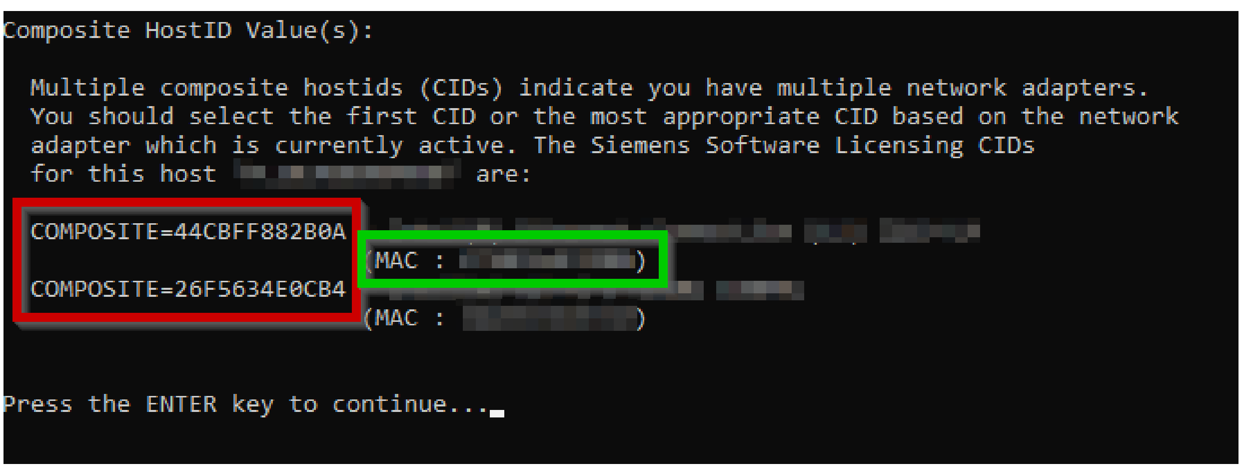

Figure 1: The Composite HostID Values after running the getcid executable

License Types and Features

The MF-Tyre/MF-Swift product is split in different functional modules:

- MF-Tyre—the base model for vehicle handling simulations.
- Turnslip—the add-on to MF-Tyre for parking and low-velocity maneuvering applications.
- Rigid Ring—the add on to MF-Tyre representing tire dynamics up to 100Hz.
- Enveloping—the add-on to MF-Tyre representing tire arbitrary road unevenness.
- Temperature and Velocity—the add-on to MF-Tyre to increase the accuracy by involving the temperature and velocity model calculations.

The combination of Rigid Ring and Enveloping allows for reliable uneven road simulations—for example, for ride comfort or road load calculations.

Siemens offers MF-Tyre/MF-Swift as both a desktop and Real-Time product. Within the desktop product, the MF-Tyre module is typically freeware functionality without license protection. The Turnslip, Rigid Ring, and Enveloping modules are combined in one product, which is license protected by one license feature. The Temperature and Velocity model is individually license protected. The desktop product is available in both a NodeLock Counted variant and a Floating Network variant.

Functional Module	License Feature
MF-Tyre	Freeware
Turnslip	sctire_mfswift_sw
Rigid Ring	
Enveloping	
Temperature and Velocity	sctire_mfswift_tv

In the Real-Time product, all functionality is license protected. The product comes with both a desktop license allowing setup of the simulation experiment as well as an entitlement file allowing the running of the simulation on the Real-Time target. For more information on entitlement files, see License Protection on RT Platforms.

In the Real-Time product, the MF-Tyre, Turnslip, Rigid Ring, Enveloping, and Temperature and Velocity models are individually available and hence individually license protected. The Real-Time product is available as NodeLock Counted only.

Functional Module	Desktop License Feature
MF-Tyre	-
Turnslip	sctire_mfwift_ts
Rigid Ring	sctire_mfswift_rr
Enveloping	sctire_mfswift_env
Temperature and Velocity	sctire_mfswift_tv

Note: The MF-Tyre part of MF-Tyre/MF-Swift Real-Time does not have a desktop license feature since it is available as a freeware license. However, it still requires an entitlement file to run on the Real-Time platform. For more information on obtaining an entitlement file for all supported platforms, see License Protection on RT Platforms.

License Protection on Desktop Platforms

To configure and manage the Siemens License Server, use the following procedure.

Note: The following steps to set up the Siemens License Server are executed after obtaining a valid license file for MF-Tyre/MF-Swift from your Siemens Digital Industries sales representative or channel partners.

The MF-Tyre/MF-Swift license is protected with Siemens License Server. The license tools can be installed with the main MF-Tyre/MF-Swift installer, which can be obtained from the product download area on the Siemens Support Center.

During the installation process, select the **License Tools** checkbox.

This automatically launches the Siemens License Server Installation tool. The Siemens License Server tool is installed in its own folder.

Licensing releases have version identifiers and release schedules that are different from Siemens Digital Industries Software products. For overall information about licensing, refer to the Siemens Digital Industries Software License Server Installation Instructions located in the Siemens Licence Server installation directory. The purpose of the license server manager is to:

- Start and maintain all the vendor daemons listed in the *VENDOR* lines of the license file.
- Refer application checkout (or other) requests to the correct vendor daemon, for example `saltd`.

The Siemens License Server, and henceforth the license server system, are automatically started during the installation process and also at system start-up after the installation.

Note: Start Siemens License Server only on the server machine specified on the *SERVER* line in the license file. If you are running a three-server redundant license server system, maintain an identical copy of the license file (as well as the Siemens License Server) locally on each server machine rather than on a file server.

If you do not do this, you lose all the advantages of having redundant servers, since the file server holding the file becomes a single point of failure.

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Starting the License Server Manager on Windows and LINUX Platforms

The license server manager must be started before MF-Tyre/MF-Swift can be used. The license tools can be installed with the main MF-Tyre/MF-Swift installer, which can be obtained from the product download area. In order to install the Siemens License Server, the *License tools* checkbox needs to be selected during the installation. This automatically launches the Siemens License Server installation tool.

The license file needs to be selected in the Siemens License Server installation wizard to install the licensing toolkit.

MF-Tyre/MF-Swift 2412 uses version 2.6.2 of the SALT licensing toolkit. To use licensed features in 2412, the SALT license server must correspond to version 2.1.0 or higher. The new server can be used with existing license files and, is compatible with all previous versions of MF-Tyre/MF-Swift using SALT licensing.

Note: Versions of Simcenter Tire MF-Tyre/MF-Swift older than 2022.1 are not compatible with the latest Siemens License Server. Refer to the user manuals of the respective version regarding licensing.

The license server manager can also be started via interactive install or non-interactive install on the command line.

Installing the License Server from the Command Line

Rather than using the Siemens License Server Installer wizard to install the license server, you can use the command line. This can be done either interactively (with prompts) or non-interactively (without prompt). The required tools are installed in the `license` subdirectory of the MF-Tyre/MF-Swift installation directory.

Note: Once the license server is started, set the environment variable `SALT_LICENSE_SERVER` on the corresponding machines that will use the MF-Tyre/MF-Swift tire model. The environment variable `SALT_LICENSE_SERVER` should be set to the `<portnumber>@<hostname>` specified in the license file.

Before you begin, refer to the Pre-installation Requirements and Considerations section of the Siemens Digital Industries Software License Server Installation Instructions. For complete command syntax, option descriptions, and examples, refer to the Siemens License Server Command section in the Siemens Digital Industries Software License Server Installation Instructions.

Interactive Install

An interactive install uses command prompts to guide you through the installation.

- On Windows, type the following in the command line:

```
SiemensLicenseServer_<version>_<platform>.exe -text
```

- On Linux, type the following in the terminal:

```
SiemensLicenseServer_<version>_<platform>.bin -text
```

Non-Interactive Install

A non-interactive install does not use command prompts because you enter a value for the arguments with the initial command. This install method is useful for system administrators who want to automate the installation with scripts.

- On Windows, type the following in the command line:

```
SiemensLicenseServer_<version>_<platform>.exe <arguements>
```

- On Linux, type the following in the terminal:

```
SiemensLicenseServer_<version>_<platform>.bin <arguements>
```

Note: It is important that both the license file and log files are readable and writable for the Windows Local System Account. Therefore, `C:\Program Files` and user-specified directories are not allowed.

The license server system starts and writes its debug log output to the defined *.log* file.

License Protection on RT Platforms

On Real-Time platforms (such as dSpace DS1006, SCALEXIO, NI-PXI, Concurrent iHAWK, or IPG Xpack4 platforms), applications of MF-Tyre/MF-Swift 2020.1 or higher do not communicate to a FlexLM license server. Simcenter Tire instead packages the purchased license features into an entitlement file, which can be obtained from your Siemens sales representative. The entitlement file is node-locked. It can only be used with a predefined set of machines or cores. Without a valid entitlement file, MF-Tyre/MF-Swift cannot be used on any Real-Time platform.

If you are using MF-Tyre/MF-Swift through a third party software package, then refer to the third party documentation on how to pass on the entitlement file and its location.

Obtaining the Serial Number(s) for dSpace Platforms

The entitlement file is node-locked to a predefined set of machines or cores based on the serial numbers. The serial number for dSpace DS1006 and SCALEXIO can be obtained from **dSPACE ControlDesk** > **Platforms** > **Manage Platforms** > **Manage Recent Platfomrm Configuration**. Alternatively for SCALEXIO, **dSPACE ConfigurationDesk** > **Platforms** > **Manage Platforms** > **Manage Recent Platform Configuration** can be used.

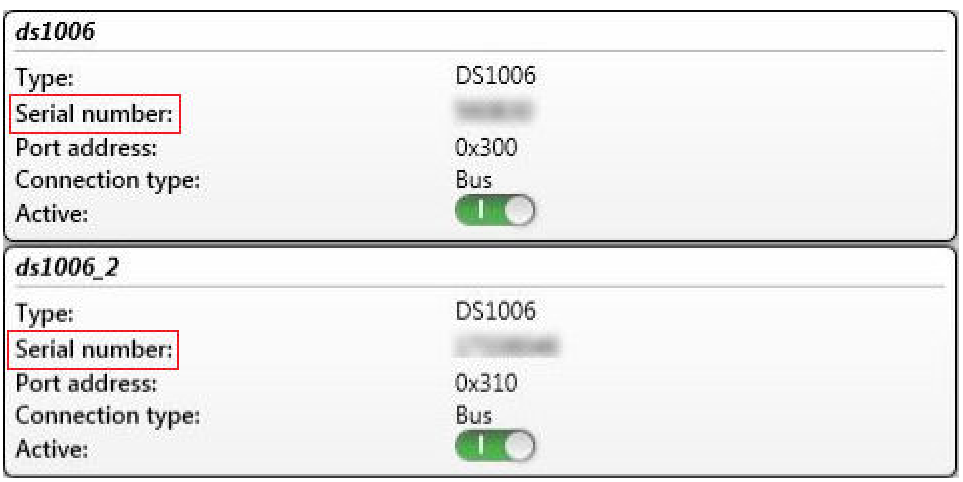


Figure 2: Control Desk

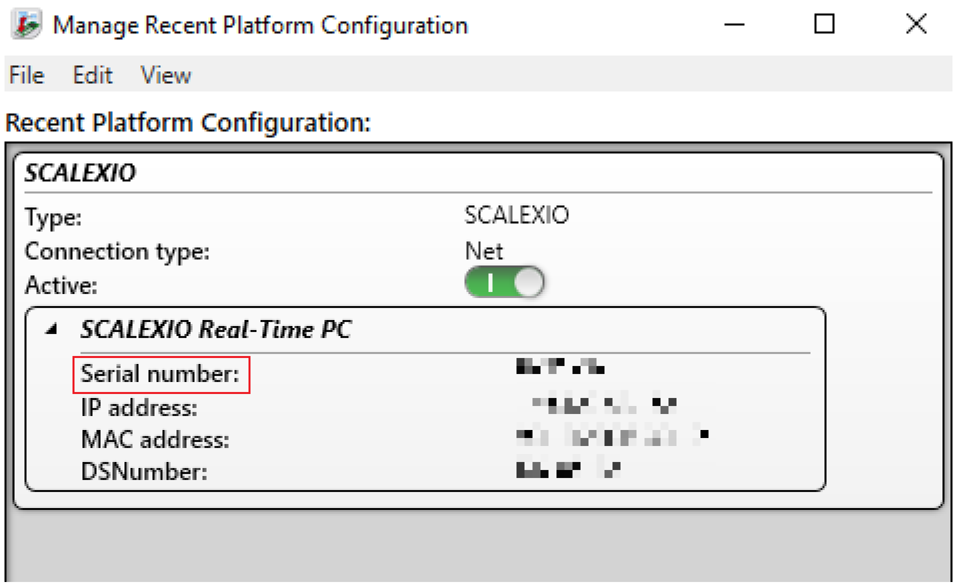


Figure 3: Configuration Desk

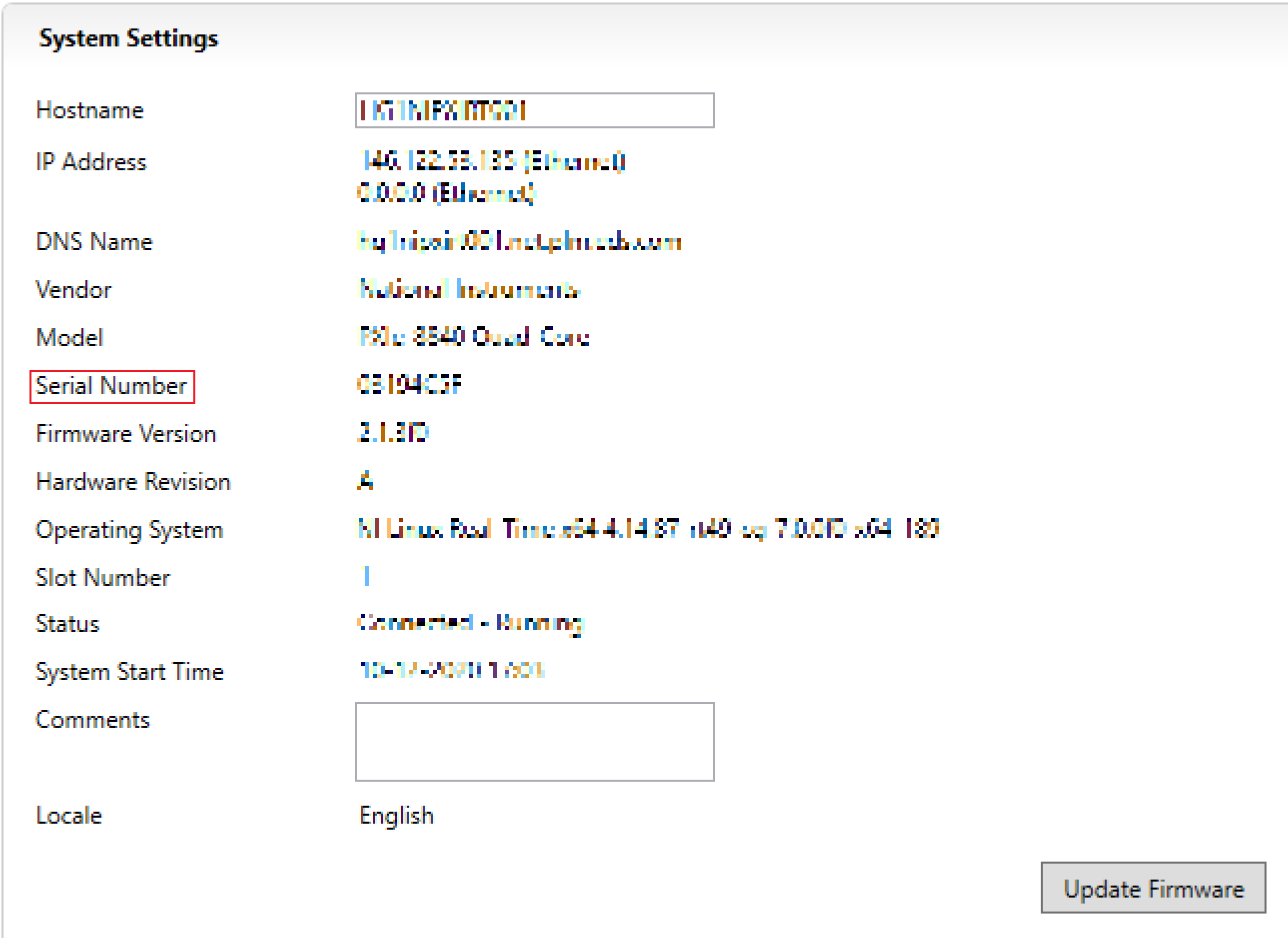
Obtaining the Serial Numbers for Concurrent iHAWK and IPG Xpack4 Platforms

To obtain the serial numbers for Concurrent iHAWK and IPG Xpack4 (Linux Real-Time) platforms, a hardware identification tool is required. This is supplied by Siemens and can be obtained by contacting your sales representative. To obtain the serial numbers, run the hardware identification tool on the Linux Real-Time platforms:

```
./mfswift_query_hardware_id
```

Obtaining the Serial Numbers for NI-PXI Platforms

The serial number of your Real-Time systems are shown in the NI-MAX application when clicking on *Remote Systems* behind the **Serial Number** label.



Set up Licensing for Simulink

Put the entitlement file, as supplied by Simcenter Tire upon purchasing Real-Time License Features, on the host machine of the Real-Time platform. Store the absolute path in the environment variable *MFSWIFT_ENTITLEMENT_FILE*.

For Windows, it is recommended you set the variable through **System Properties**. Typically, this can be done through **Control Panel** > **System and Security** > **System** > **Advanced System Settings** > **Environment Variables** > **New**.

License Troubleshooting Guide

Windows License Troubleshooting

1. Versions of MF-Tyre/MF-Swift older than 2022.1 are not compatible with the Siemens License Server. Refer to the user manuals of the respective versions regarding licensing.
2. The enviroment variable *SALT_LICENSE_SERVER* should be set to `<portnumber>@<hostname>`. The `<portnumber>` is the connection port number of the license server, and `<hostname>` is the name of the license server without the domain name. See the first line in the license file for these details.

   Note: The first hostname should be `<portnumber>@localhost`. This forces the system to check if it is detached from the network.

3. Considerable delays in start-up of the applications have been noticed if the license file contains license strings with expired start dates.
4. Considerable delays in start-up of the application have been noticed if non-existent servers are assigned to the *SALT_LICENSE_SERVER* environment variables or even in the registry.
5. For overall information about troubleshooting licensing, refer to the Siemens Digital Industries Software License Server Installation Instructions located in the Siemens License Server installation directory.

Real-Time License Troubleshooting

Any problem with the entitlement file makes an MF-Tyre/MF-Swift simulation fail at initialization.

- The message `ERROR - IO error: could not determine file size!` means that the entitlement file could not be opened. This is typically caused by the entitlement file not being in the expected location or having an incorrect name.
- The message `LICENSE could not be validated` indicates that the content of the entitlement file is not as required by the Real-Time application. Please contact you Siemens Digital Industries sales representative.

User Manual

Here you will find specific information regarding the usage of the MF-Tyre/MF-Swift product.

The contact interaction between tires and the road largely affects the driving performance of vehicles. Vehicle development engineers optimize the tire-road interaction so that the vehicle handles well and operates both safely and comfortably under any circumstances. To analyze the influence of tire properties on the dynamic behaviour of vehicles, the engineer requires an accurate description of the tire-road contact phenomena. Simcenter Tire provides a complete chain of tools and services for detailed assessment and modeling of vehicle-tire-road interaction.

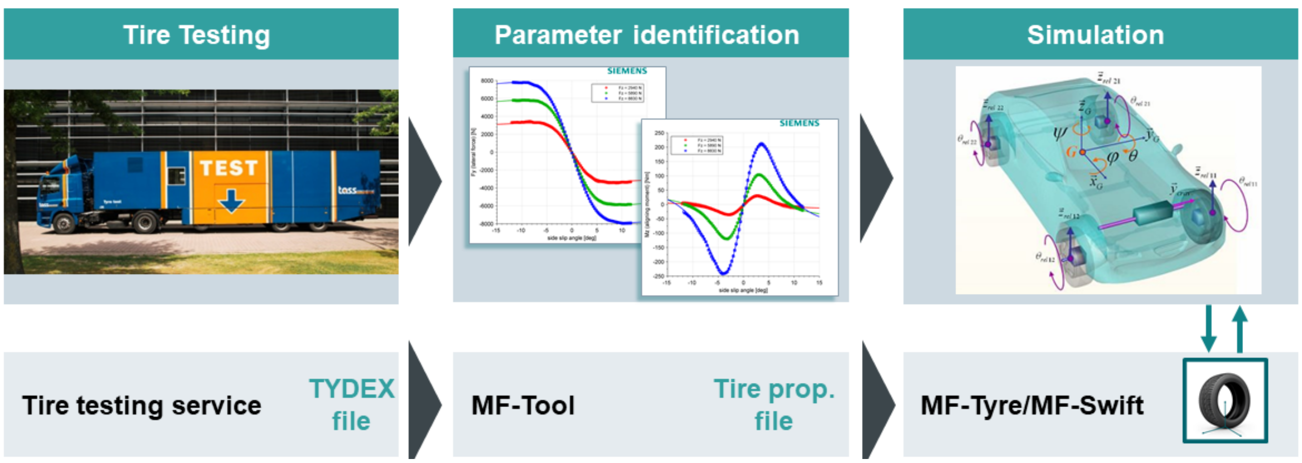


Figure 4: The Simcenter Tire tool chain

The tire model MF-Tyre/MF-Swift can be used in vehicle dynamics simulations with all major simulation packages. The model efficiently and accurately represents tire behaviour for applications ranging from steady-state to complex high-frequency dynamics. MF-Tyre/MF-Swift contains the latest implementation by Simcenter Tire of Pacejka's renowned 'Magic Formula' [1].

With MF-Tyre/MF-Swift, you can simulate steady-state and transient behaviour up to about 100Hz, which makes it a suitable tire model for:

- Vehicle Handling Simulations including Parking Maneuvers.
- Vehicle Control Prototyping (e.g. ABS/ESC)
- Rollover Analysis
- Ride Comfort Analysis.
- Durability Analysis
- Vibration Analysis

Contents:

MF-Tyre/MF-Swift

MF-Tyre/MF-Swift is Simcenter Tire implementation of the world standard Pacejka Magic Formula, including the latest developments.

MF-Tyre/MF-Swift semi-empirical approach enables fast and robust tire-road contact force and moment simulation for steady-state and transient tire behaviour. MF-Tyre/MF-Swift has been extensively validated using many experiments and conditions. For a given pneumatic tire and road conditions, the tire forces and moments due to slip follow a typical characteristic. These steady-state and transient characteristics can be accurately approximated by MF-Tyre/MF-Swift.

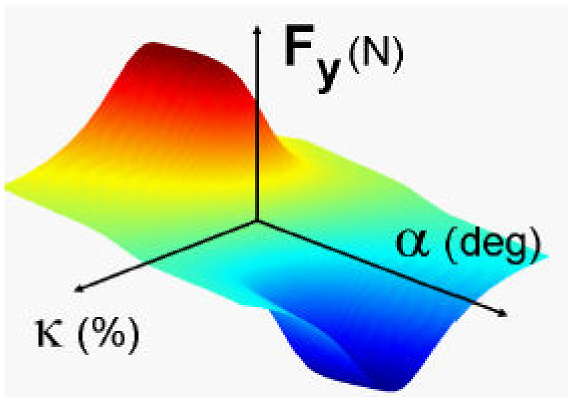


Figure 5: Steady-state tire lateral force as a function of longitudinal and lateral slip, calculated using MF-Tyre/MF-Swift

MF-Tyre/MF-Swift calculates the forces (F_x, F_y) and moments (M_x,M_y, M_z) acting on the tire for given:

- Pure or combined slip conditions
- Longitudinal, lateral and turn slip
- Wheel inclination angle (camber)
- The vertical force (F_z)

In addition to the Magic Formula description, MF-Tyre/MF-Swift uses a rigid ring model, which assumes the tire belt behaves like a rigid body. By accounting for inertial, centrifugal, and gyroscopic effects, the model is accurate in the frequency range where the bending modes of the tire belt can be neglected which, depending on the tire type, is us to 100Hz. A integrated thermodynamic model predicts the evolution of the temperature profile and propagates the effect of the tire temperatures into the Magic Formula. Both the rigid ring and thermodynamic model have been extensively validated using the measurements of a rolling tire.

Six main elements of the model structure can be distinguished. The first four elements, illustrated in Figure 6, are primarily based on Pacejka [1] and Besselink [3]. Several crucial changes and enhancements have been made in collaboration with Professor Pacejka to the model in order to improve functionality, robustness, calculation times, user-friendliness and compatibility between various operating modes.

1. Elastically suspended rigid ring (6 degrees of freedom)—represents the tire sidewalls and belt with its mass and inertia properties. The rigid ring describes the primary vibration modes of the tire belt.

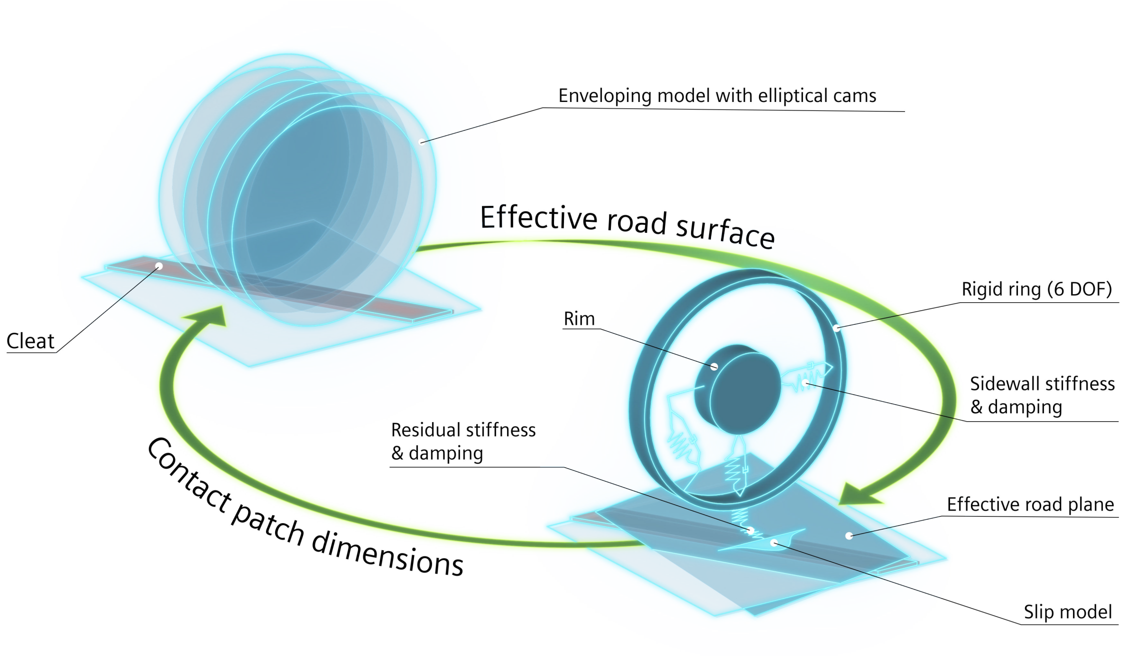


Figure 6: Schematic representation of MF-Tyre/MF-Swift.

2. Residual stiffness and damping—these have been introduced between the contact patch and the rigid ring to ensure that the total quasi-static tire stiffnesses in the vertical, longitudinal, lateral and yaw directions are modeled correctly. The total tire model compliance is made up of the carcass (ring suspension) compliance, the residual compliance (in reality a part of the total carcass compliance) and the tread compliance.
3. Contact patch model—features horizontal tread element compliance and partial sliding. Based on the model, the effects of the finite length and width of the footprint are approximately included.
4. Magic Formula steady-state slip model—describes the nonlinear slip force and moment properties. This enables an accurate response also for handling maneuvers.

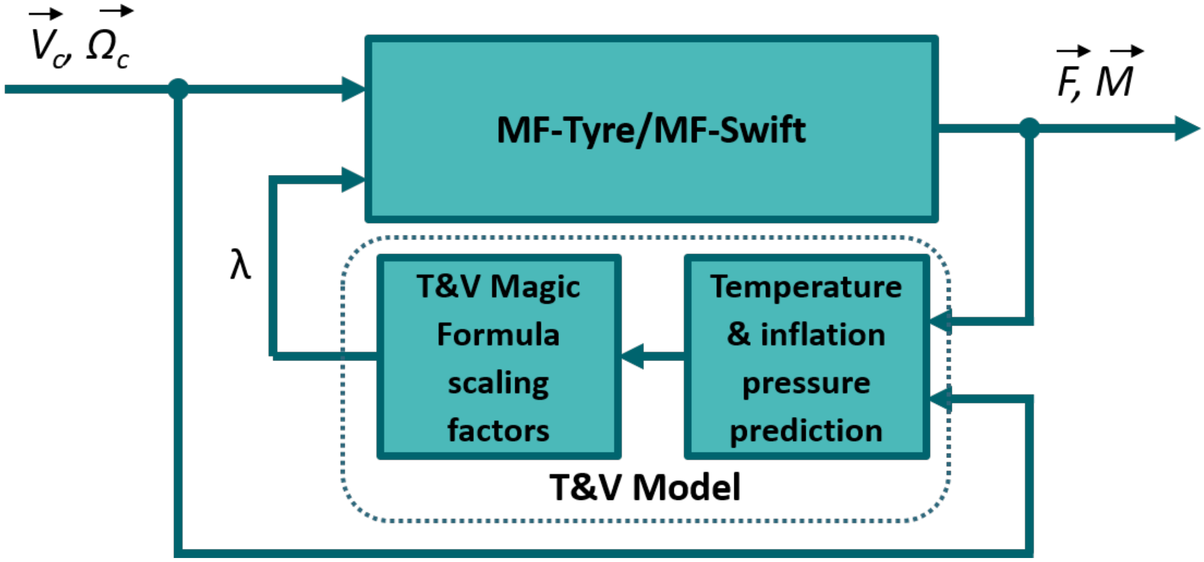


Figure 7: Illustration of Temperature & Velocity model in MF-Tyre/MF-Swift.

The fifth and sixth element make up the Temperature and Velocity model as developed by Iugaro et al ([4], [5]).

With reference to Figure 7:

5. The thermodynamic model—predicts the evolution of the temperature profile and inflation pressure.
6. The effect of tire temperature and rolling speed are then captured by appropriate Magic Formula scaling factors.

Model Usage and Computational Performance

MF-Tyre/MF-Swift is a plug in for Vehicle Dynamic Simulation (VDS) packages.

The VDS package communicates with the tire model through a dedicated API that is fundamentally based on the Standard Tire Interface format [2], and the tire model in turn communicates with the road model (for more information see Road Method). The VDS package and the tire model behaviour is configured through parameters stored in a Tire Property File (`*.TIR`). The VDS package specifies the operating model of the model. For more information see Tire Model Operating Modes.

The dynamic tire model can be integrated with its own (internal) solver. This internal solver runs at a fixed time step of one millisecond. As a result, any simulation that includes this tire model only obtains an update from the tire model at simulation times steps which are multiples of one millisecond. When calling the tire model at intervals less than one millisecond, the tire model returns the calculated forces and moments from the previous time point.

In order to provide guidelines, the computational performance of the MF-Tyre/MF-Swift has been checked on the Simcenter Tire Concurrent iHAWK Real-Time computer (SimWB 7.9-0, RedHawk Linux 6.5.3, Intel Xeon E5-1650 v3 @ 3.50GHz, 16Gb RAM). The computational performance is determined with specific MF-Tyre/MF-Swift operating modes and settings. For a detailed description of the operating modes and settings, see Tire Model Operating Modes. All results represent the turnaround time of a simulation including:

- A Matlab/Simulink model with one tire.
- MF-Tyre/MF-Swift 2412 in the form of a Matlab/Simulink s-function.
- Matlab/Simulink ODE-1 solver with one millisecond time-step.
- Default 205/60R15 TIR-file.
- OpenCRG road including a square 15x15 mm obstacle.

The following table provides an overview of the turnaround time (in microseconds) required to compute the tire model per millisecond time-step of the overall Matlab/Simulink simulation.

Operating Mode						**T&V**	**Enveloping Settings**			**Run Time (μ s)**
Contact Method		Dynamics		Slip Forces			Road_inc	Ellips_n_length	Ellips_n_width	
Smooth	Env.	N-L trans.	Rig. Ring	Comb.	Comb. Turnslip					
×		×		×		Disabled	-	-	-	19
×		×		×		Dyn. + IP	-	-	-	22
×		×			×	Disabled	-	-	-	21
×			×	×		Disabled	-	-	-	22
	×		×	×		Disabled	0.01	10	10	87
	×		×	×		Disabled	0.005	10	10	146

Operating Mode						**T&V**	**Enveloping Settings**			**Run Time (μs)**
	×		×	×		Disabled	0.01	5	5	53

Note: These figures are meant as a guideline and the computational performance may vary depending on a customer's specific system. No rights can be derived from this publication.

Conventions

The following axis system, Units and Mass and Inertia mode are available in MF-Tyre/MF-Swift.

Axis System

MF-Tyre/MF-Swift uses the ISO sign convention as shown in Figure 8. For a more comprehensive description of the sign convention and axis system, see Tire and Vehicle Dynamics [1].

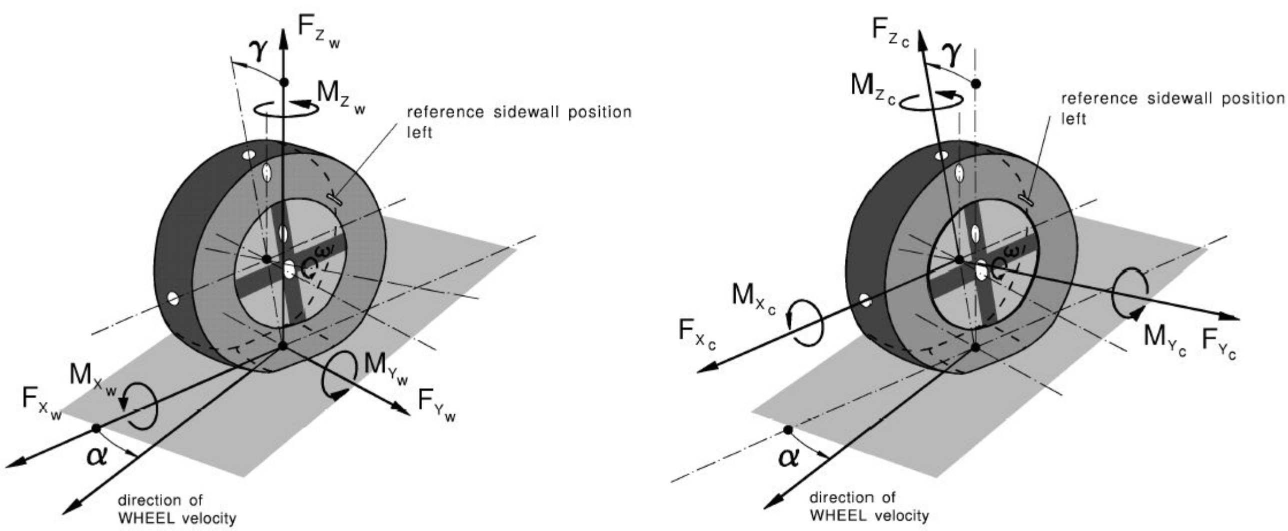


Figure 8: ISO sign conventions

The above defined sign convention corresponds with the following definition of the longitudinal slip and lateral slip angle α. The longitudinal slip is defined as:

$$\kappa = -\frac{V_{sx}}{V_x} \quad (1)$$

where $\kappa = -1$ means braking at wheel lock. The lateral slip angle is defined as:

$$\tan\left(\alpha\right) = \frac{V_{sy}}{|V_x|} \quad (2)$$

where V_x is equal to the x-component of velocity (in the wheel center plane) of the wheel contact center horizontal (i.e. parallel to the road) velocity V, and V_s is the wheel slip velocity (with components V_{sx} and V_{sy}), which is defined as the horizontal velocity of the slip point. The slip point is attached to the wheel at a distance that equals the effective rolling radius below the wheel center in the wheel center plane.

Units

The International System of Units (SI units) is used for the complete tire model. This implies that the tire model input (i.e. the Tire Property File) and the output use SI units by default. To define the system of units for the tire model, the Tire Property File contains a **[UNITS]** section. In the Tire Property File, the following symbols denote the SI units that are allowed:

Variable	Symbol
LENGTH	`'meter'`
FORCE	`'newton'`
ANGLE	`'radians'`
MASS	`'kg'`
TIME	`'second'`
TEMPERATURE	`'kelvin'`

Mass and Inertia

It is important to note that, for steady state, linear transient, and non-linear transient dynamic modes, MF-Tyre/MF-Swift does not have any mass. Hence, the definition of the mass and moments of inertia of the wheel in the simulation package should correspond to the mass and inertia moments of the tire (m_{tire}) and the rim (m_{rim}). However, when the rigid ring dynamics mode is selected, MF-Tyre/MF-Swift accounts for the mass of the belt internally. In this case, the belt mass (m_{belt}) and moments of inertia should be subtracted from the mass and inertia defined in the VDS package.

Note: Some VDS packages subtract m_{belt} automatically, while some require the user to account for the subtraction. Check the VDS package documentation for more details.

The mass definitions are summarized in the table below; the same holds for the inertia definitions:

Dynamics Mode	Tire Model Mass	VDS Mass
Steady State	-	$m_{tire} + m_{rim}$
Linear Transient		
Non-Linear Transient		
Rigid Ring	m_{belt}	$m_{tire} + m_{rim} - m_{belt}$

Tire Model Operating Modes

The behaviour of the tire model is defined by specifying the operating mode. The operating mode is set by defining the:

- Type of road the tire is to drive on. See Road Methods.
- Side on which the tire is mounted in the simulation model. See Tire Side.
- Tire-road contact evaluation method. See Contact Method.
- Tire dynamics model. See Dynamics Model.
- Components of the contact-point force and moment vector when evaluating the Magic Formula. See Slip-Force Method.
- Temperature model mode. See Temperature Mode.

Note: Some operating modes are restricted by the interface between the tire model and simulation package. For more information see Tutorials.

Contents:

Road Method

For the tire model to generate forces and moments, it requires information of the road it is travelling on.

In MF-Tyre/MF-Swift, this road surface information can originate from either an internal road (e.g. the default flat road or the OpenCRG road implementation in MF-Tyre/MF-Swift) or a road definition coming from the VDS package, the external road. To define the source of the road-surface information, the road method parameter needs to be set. The following values may be selected for the road method:

Value	Description
1	Default Flat Road
2	OpenCRG road
3	External Road

For a detailed description of the various road method definitions, see Road Surface Definition.

Note: MF-Tyre/MF-Swift supports road curvature with OpenCRG road files. The road curvature can be set in the OpenCRG road file by using the keyword `CURVTRSF` in the header section as a comment.

```
*CURVTRSF = 1.0
```

Comments in OpenCRG files are set using the `*` character. If the keyword `CURVTRSF` is not found in the header section, then the curvature is set to `0.0` as a default value.

Tire Side

Depending on the conicity or the ply-steer of the tire, a tire can have aysmmetric behavior. Due to this asymmetric behaviour, it is necessary, in a vehilce simulation model, to specify on which side of the vehicle a specific tire is mounted. Specifying the wrong tire-side can lead to unexpected simulation results.

The *tire-side* parameter can have the following values:

Value	Description
1	Tire is mounted on the left of the vehicle
2	Tire is mounted on the right side of the vehicle
3	Symmetric tire characteristics (asymmetric behavior is removed)
4	Mirror tire characteristics

In the Tire Property File, it should be specified how the tire measurement was executed: in other words, if a left or right tire was tested. In the Tire Property File **[Model]** section, the keyword `TYRESIDE` can be set to either `LEFT` or `Right`.

If `TYRESIDE` is `LEFT` and the tire is mounted on the right side of the vehicle (`Value = 2`), mirroring is applied on the tire characteristics. It is also possible to remove asymmetric behavior from an individual tire by specifying `Value = 3`.

Contact Method

To be able to determine the tire response, the tire model needs to be able to obtain information about the road surface. This information is obtained through the tire-road contact method. The following values may be selected for the tire-road contact method:

Value	Description
0/1	Smooth road contact
3	Moving road contact
5	Enveloping contact

The contact method uses global coordinates to obtain the road height. As already mentioned, the combination of road method and contact method determines the response of the tire model. The moving road method can be used for simulations of four poster test rigs.

Note: From MF-Tyre/MF-Swift v7.3, the motorcycle tire contact is supported. Contrary to the MF-Tyre/MF-Swift v6.2 implementation, this contact method is not supported by means of an explicit Tire Model Operating Mode. The motorcycle contact algorithm is automatically enabled when non-zero values for parameters `MC_CONTOUR_A` and `MC_CONTOUR_B` are present in the tire property file.

Only a limited number of combinations of road method and contact method are allowed by the tire model. The combination of road method and contact methods that are allowed is listed in the following table:

	Smooth Road	Enveloping	Moving Road
Default flat road	yes	yes	no
OpenCRG road	yes	yes	no
External road	yes[2]	no[1]	yes[2]

Note:

- The External road defined in Simulink generates just one road point. The External road is therefore not compatible with the Enveloping contact.
- The availability of this contact method depends on the selected VDS package that is used.

Contact Method Enveloping Settings

This 3D contact method is intended for when the road unevenness typically contains wavelengths smaller than two to three times the contact patch length. This occurs when modeling a cobblestone road or when it contains discrete obstacles, e.g. cleats, bumps or potholes. For a more detailed description of this contact model and its usage, see Pacejka [1].

This contact model requires a number of user-defined input parameters. These parameters can be set in the **[MODEL]** and **[CONTACT-PATCH]** sections of the tire property file as shown below:

Parameter	Model Section	Description
ROAD_INCREMENT	**[MODEL]**	Size of road increments. This parameter affects the number of points on the elliptic cam used in the contact calculation.
ELLIPS_MAX_STEP	**[CONTACT-PATCH]**	Threshold value indicating the largest obstacle height that can be encounter on this road. See Figure 9.
ELLIPS_NWIDTH	**[CONTACT-PATCH]**	Number of parallel ellipses covering the width of the contact patch. For sharp obstacles, the default value of 10 parallel ellipses generally is sufficient for an accurate simulation. See Figure 10. However, with smoother roads or with cleats oriented perpendicular to the X-axis, this value can be limited. For faster simulations, the number of parallel ellipses should be limited.
ELLIPS_NLENGTH	**[CONTACT-PATCH]**	Number of successive ellipses covering the length of the contact patch. For sharp obstacles, the default value of 10 successive ellipses generally is sufficient for an accurate simulation. See Figure 10. However, with smoother roads or with cleats oriented perpendicular to the X-axis, this value can be limited. For faster simulation the number of ellipses should be limited.

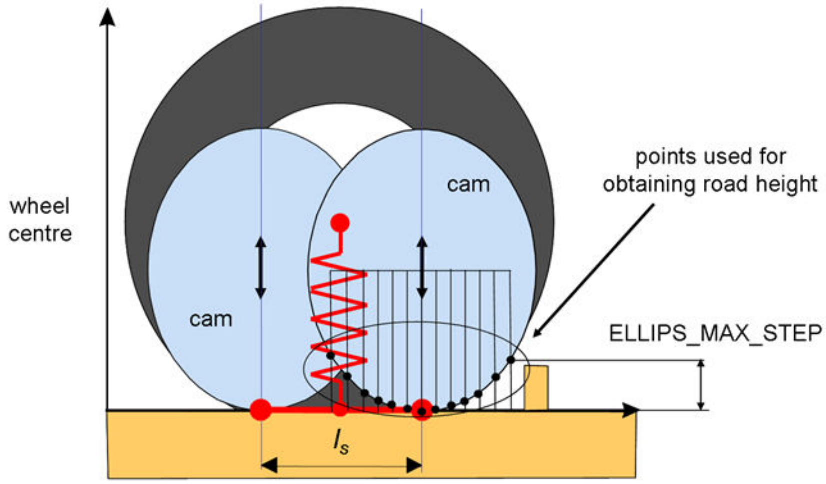


Figure 9: Graphical explanation of the ELLIPS_MAX_STEP parameter.

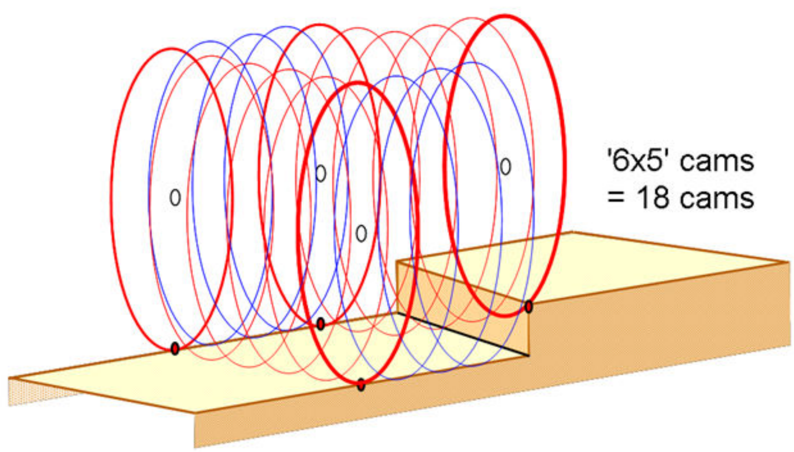


Figure 10: An example of 6 parallel cams in the front & rear row and 5 successive cams at both sides.

Dynamics Method

The flexibility of the tire carcass, the length of the contact patch, and the mass and inertia moments of the belt determine the transient response of the tire. Depending on the frequency under which the tire is excited, different dynamic modes can be selected:

Mode	Frequency Range	Description
0	< 1 Hz	Steady State
1	< 10 Hz	Transient (Linear)
2	< 10 Hz	Transient (Non-Linear)
3	<100 Hz[1]	Rigid Ring Dynamics[2]

Note:

1. The valid frequency range also depends on the size of tire.
2. Rigid ring dynamics plus initial statics can be enabled by setting the environement variable *MFS_RR_IS_ITERATIONS* to `5000`. "Initial Statics" refers to finding the static equilibrium of the tire belt (rigid ring/body) at the start of the simulation. Setting the environment variable *MFS_RR_IS_ITERATIONS* to `0.0` disables initial statics (default settings). Rigid ring dynamics plus initial statics is not available on HIL platforms. The setting is ignored when running on HIL setups.

The dynamic modes mentioned above distinguish themselves through the complexity of the dynamic model. In the case of Steady State, no dynamic or transient tire model behavior is included. The linear transient mode incorporates tire relaxation through the use of empirically determined models for the relaxation lengths. In the non-linear transient mode, a physical approach is used in which the compliance of the tire carcass is considered to determine the lag. This approach replicates the fact that, at high levels of slip, the lag diminishes in response to variation in wheel slip and vertical load. In the rigid ring mode, the belt as a rigid body is further introduced. The belt is connected to the rim by means of springs and dampers; its mass and inertia moments are also taken into account; this permits accurate modeling of the tire dynamic behavior also in a higher frequency range.

For more information on tire relaxation, see Pacejka [1].

Slip Forces Method

When using MF-Tyre/MF-Swift, you can select which components of the force and moment vector you want to use during a simulation.

The selection of the appropriate slip-force mode depends in part on the maneuver you try to simulate, e.g. for parking maneuvers, turn slip should be switched on. It is also possible to switch off parts of the calculation. This is useful when e.g. debugging a vehicle model, or if only in-plane tire behavior is required. This component selection is controlled through the slip-forces mode.

The following values for the slip-forces mode may be selected:

Mode	**Operating Mode**						**Description**
	F_{xw}	F_{yw}	F_{zw}	M_{xw}	M_{yw}	M_{zw}	
0			×				No Magic Formula evaluation
1	×		×		×		Longitudinal components only
2		×	×	×		×	Lateral components only
3	×	×	×	×	×	×	All components in *uncombined* mode
4	×	×	×	×	×	×	All components in *combined* mode
5	×	×	×	×	×	×	All components in *combined* mode, *turn slip* mode switched on.

Note: Turn slip functionality is only allowed in combination with Non-linear transient or rigid ring dynamic mode, Otherwise, an error message appears. For more information, see Dynamics Methods

For more information on the components, see Axis System.

ISWITCH Parameter

Although most packages use a Graphical User Interface (GUI) to select the operating mode for the tire model, in some cases the operating modes are combined into a single variable called *ISWITCH*.

The current *ISWITCH* parameter is composed by concatenating the integers defining the Road Method (E), Tire Side (A), Contact Method (B), Dynamics Method (C), and Slip-Force Mode (D). Hence given these integers, the `ISWITCH = EABCD`. For example, `ISWITCH = 31124` represents:

- `E = 3`—external road
- `A = 1`—left tire
- `B = 1`—smooth road contact
- `C = 2`—transient (non-linear)
- `D = 4`—combined slip forces or moments

For backward compatibility reasons, the current version also supports the v6.2 (4 digit) *ISWITCH* parameter formulation. In this case the road method is by default set to external road.

Note: The rules belonging to the correct combination of contact and road method still apply in this case.

Temperature Mode

The T&V model can be activated through the *TV_MODEL* parameter in the tire property file. If the VDS package provides a way to set the temperature mode, it overrides the *TV_MODEL* parameter.

Value	Mode	Description
0	Disabled	No temperature effects are modelled. This is the default, and the only value allowed for *FITTYP* earlier than 70.
1	Static	The temperature prediction model is deactivated. Throughout the simulation, the Magic Formula scaling factors are calculated based on the parameters defined in the TIR file; initial temperature (*INIT-TREAD*, *INITLINER*, *INITCOREAIR*, *TROAD*, and *TAMB*), longitudinal velocity (*LONGVL*) and inflation pressure (*INFLPRES*).
2	Dynamic without IP	The T&V model is updated continuously, but the inflation pressure remains constant throughout the simulation.
3	Dynamic with IP	The T&V model is updated continuously, as is the inflation pressure.

The T&V model only works with *FITTYP* ≥ 70.

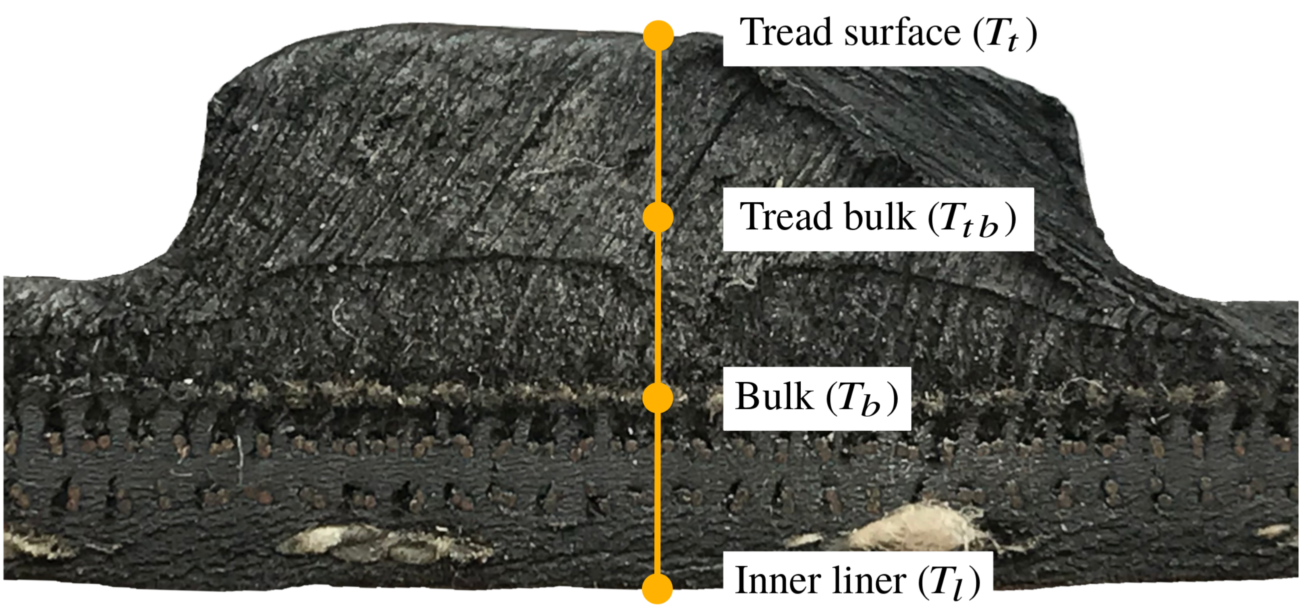


Figure 11: Illustration of Temperature & Velocity model in MF-Tyre/MF-Swift. This figure was first published in the SAE technical paper by Lugaro et al.

From Figure 11 (taken from the SAE technical paper by Lugaro et al [4]), the time-dependent temperature state of the tire is described by:

- T_t—tread surface temperature
- T_{tb}—tread bulk temperature at half-way between the surface and the belt positions
- T_b—tire bulk temperature at the interface between the tread and belt

- T_l—inner liner temperature
- T_i—core air temperature (not present in Figure 7)

Except for T_b, each of these temperature values is exported as a varinf signal. For a complete overview of all varinf signals, see Post Processing Signals.

The initial conditions for the temperature stat are specified by three parameters in the *[OPERATING _CONDITIONS]* section of the tire property file:

- *INITTREAD*—initial tread surface temperature
- *INITLINER*—initial inner liner temperature
- *INITCOREAIR*—initial core air temperature

These three parameters are required in case *TV_MODEL* is not equal to zero. The same is true for the *TROAD* and *TAMB* as well as all parameters in the *[TVX_COEFFICIENTS]* section.

Numberical Forgiveness at Low Velocities

From MF-Tyre/MF-Swift 2412 you can increase the numerical forgiveness of the tire model at low velocity operating conditions. This is accomplished by adding more damping to multiple states of the tire model when operating below a velocity threshold.

The numerical forgiveness at low velocities is considered experimental and therefore is disabled by default. To enable it:

1. Before launching the VDS package, set the *MFSWIFT_OPTIONS* environment variable to `switch-vx-damp=1`.

The numerical forgiveness can be tuned manually by adding the following parameters to the **[MODEL]** section of the Tire Property File:

Parameter	Description	Default Value
DAMP_LSG	Scaling factor on rigid ring damping for low velocity stability	`8` [-]
VX_STBL	Velocity threshold for low velocity stability solution	`5.5` [m/s]
DAMP_VLOW	Additional low speed damping	`0.001` [-]

Note: The parameters *DAMP_LSG* and *VX_STBL* are new to MF-Tyre/MF-Swift 2412. *DAMP_VLOW* is an existing parameter which is also used as a scaling factor on the damping in the Non-Linear Transient model.

Tire Property File

The MF-Tyre/MF-Swift tire model is a simulation model defined by a set of parameters. The parameters are typically stored in a Tire property File.

This file typically has the extension `.tir`, although this is not mandatory. The installation contains sample Tire Property Files for you to use, with the structure and content of the Tire Property File explained in the subsequent topics.

Note: If a required parameter is not specified, MF-Tyre/MF-Swift shows an error message indicating that this parameter is not specified.

Contents:

Obfuscated Tire Property Files

The MF-Tyre/MF-Swift product supports both human-readable and obfuscated TIR files. Obfuscated TIR files can be used to share tire model parameters that are confidential or guarantee that tire parameters are not altered after parameter identification.

In the obfuscated TIR files, the model parameters are defined in a binary blob in the *[OBFUSCATED]* section of the file. The following model parameters are not obfuscated:

- User settings
- Scaling factors
- The tire unloaded radius, masses, and inertias

Note: The tire unloaded radius, masses, and inertias are read-only parameters. All other visible parameters can be modified by the user.

TIR files can be obfuscated with the `mfswift_tir_obfuscator` tool, which is provided with the installer in the obfuscated subdirectory of the installation directory. A password can be optionally used in the obfuscation process, allowing de-obfuscation. The `mfswift_tir_obfuscator` tool is not required for MF-Tyre/MF-Swift to handle obfuscated data. For more detailed information, see the `help` of the `mfswift_tir_obfuscator`. This can be obtained by running `mfswift_tir_obfuscator.exe -h`.

Note: An obfuscated parameter cannot be overwritten by manually adding to the obfuscated TIR file, trying this results in an abort.

Parameter Sections Overview

The following section are available within the Tire Property File. Each of these sections contains a number of properties that need to be defined to define the tire.

General and Swift Parameters

[UNITS]

Unit system used for the definition of the parameters.

[MODEL]

Parameters on the usage of the tire model.

[DIMENSION]

Tire dimensions.

[OPERATING_CONDITIONS]

Tire operating conditions, e.g. inflation pressure.

[INERTIA]

Tire and tire belt mass/inertia properties

[VERTICAL]

Vertical stiffness; loaded and effecting rolling radius.

[STRUCTURAL]

Tire stiffness, Damping, and eigenfrequencies.

[CONTACT_PATCH]

Contact length, obstacle, and enveloping parameters.

Input Limitations (Magic Formula Inputs only)

[INFLATION_PRESSURE_RANGE]

Minimum and maximum allowed inflation pressures.

[VERTICAL_FORCE_RANGE]

Minimum and maximum allowed wheel loads.

[LONG_SLIP_RANGE]

Minimum and maximum valid longitudinal slips.

[SLIP_ANGLE_RANGE]

Minimum and maximum valid side slip angles.

[INCLINATION_ANGLE_RANGE]

Minimum and maximum valid inclination angles.

Magic Formula

[SCALING_COEFFICIENTS]

Magic Formula scaling factors.

[LONGITUDINAL_COEFFICIENTS]

Coefficients for the longitudinal force F_x .

[OVERTURNING_COEFFICIENTS]

Coefficients for the overturning moment M_x.

[LATERAL_COEFFICIENTS]

Coefficients for the lateral force F_y.

[ROLLING_COEFFICIENTS]

Coefficients for the rolling resistance moment M_y.

[ALIGNING_COEFFICIENTS]

Coefficients for the self aligning moment M_z.

[TURNSLIP_COEFFICIENTS]

Coefficients for turn slip (affects all forces and moments).

Temperature and Velocity Model

[TVX_COEFFICIENTS]

Coefficients for the temperature and velocity model.

Obfuscated Data

[OBFUSCATED]

Binary data that represents the obfuscated tire parameters.

Requirements for Reduced Input Data

If no (or limited) measurement data is available, it is also allowed to omit coefficients from the Tire Property File. Built-in procedures are used to provide a reasonable estimate for the missing data and only require a small number of coefficients.

The following table gives the minimum required coefficients:

Coefficient	Description
FITTYP	Magic Formula version number.
UNLOADED_RADIUS	Free tire radius.
WIDTH	Tire width.
RIM_RADIUS	Rim radius.
INFLPRES[1]	Tire inflation pressure.
FNOMIN	Nominal wheel load.
VERTICAL_STIFFNESS[1]	Tire vertical stiffness at nominal load and inflation pressure.
PDX1[1]	Longitudinal friction coefficient at nominal conditions.[2]
PKX1[1]	Provides the longitudinal slip stiffness at the nominal wheel load given by *PKX1*FNOMIN*.
PDY1[1]	Lateral friction coefficient at nominal conditions.[2]
PKY1[1]	Provides the maximum value of the cornering stiffness versus the vertical load characteristics given by *PKY1*FNOMIN*.
PKY2[1]	Provides the vertical load at which the cornering stiffness reaches its maximum value given by *PKY2*FNOMIN*.

1. Highly recommended parameter (when not specified the default will be used).
2. At nominal wheel load, nominal inflation pressure and zero camber angle.

When using a reduced parameter file, detailed effects such as combined slip, tire relaxation effects and enveloping behavior on short wave road obstacles are included, even when the related parameters are not explicitly specified.

Note:

1. Although not strictly required, it is recommended to add the enveloping settings discussed in Model Usage and Computational Performance to reduce tire property files, to adjust the behavior of the tire model. When omitted, default values for these settings are used.
2. *FNOMIN* may be set to `0.8*(Load Corresponding to Tire Load Index in N)`.
3. The reduced input method has been developed for passenger car tires; for other tire types (motorcycle, aircraft, etc.) estimated parameters may be less accurate.

Input Limitations

In the magic formula, MF-Tyre/MF-Swift enforces the limits specified in the sections **[*_RANGE]**.

A warning is issued when the calculated:

- Vertical load is limited to the interval [*FZMIN*, *FZMAX*].
- Inflation pressure is limited to the interval [*PRESMIN*,*PRESMAX*].
- Wheel slip is limited to the interval [*KPUMIN*,*KPUMAX*].
- Slip angle is limited to the interval [*ALPMIN*,*ALPMAX*].
- Inclination angle is limited to the interval [*CAMMIN*,*CAMMAX*].

A warning is triggered only the first time a limit is exceeded; repeated occurrences are ignored.

Scaling Factors

The force and moment testing is often done in a laboratory environment (e.g. using a MTS Flat Trac or a drum), so the artificial road surface on the tire test machine may be quite different from a real road surface.

Combined with other factors such as temperature, humidity, wear, inflation pressure, drum curvature, etc. the tire behavior under a vehicle may deviate significantly from the results obtained from a test machine. Differences of up to 20% in the friction coefficient and cornering stiffness have been reported in literature for a tire tested on different road surfaces compared to lab measurements.

For this purpose, scaling factors are included in the tire model, which allows for users to manipulate and tune the tire characteristics, for example to get a better match between full vehicle tests and simulation models. Another application of the scaling factors is that they may be used to eliminate some undesired offsets of shifts in the Magic Formula.

The most important scaling factors are:

- *LMUX*—longitudinal peak friction coefficient
- *LKX*—longitudinal slip stiffness
- *LMUY*—lateral peak friction coefficient
- *LKY*—cornering stiffness
- *LKYC*—camber stiffness
- *LTR*—pneumatic trail
- *LKZC*—camber moment stiffness
- *LMP*—parking moment at standstill

When processing the tire measurements, these scaling factors are normally set to 1, but when for a validation study on a full vehicle model, they can be adjusted to tune the tire behaviour. The scaling factors are defined in the **[SCALING_COEFFICIENTS]** section of the Tire Property File; see Parameter Sections Overview.

Tire Property File Parameters

The following table lists the required and optional parameters for each tire model version. For convenience, a comparison is made with the previous model version.

✓—Required Parameter

X—Optional Parameter

Name	Description	FITTYP				
		70	62	61	60	6
[UNITS]						
LENGTH		X	X	X	X	X
FORCE		X	X	X	X	X
ANGLE		X	X	X	X	X
MASS		X	X	X	X	X
TIME		X	X	X	X	X
TEMPERATURE		X				
[MODEL]						
FITTYP	Magic Formula version number	✓	✓	✓	✓	✓
TYRESIDE	Position of tire during measurements	X	X	X	X	X
USE_MODE	Tire use mode switch (Adams only)	X	X	X	X	X
LONGVL	Reference speed	X	X	X	X	X
VXLOW	Lower boundary velocity in slip calculation	X	X	X	X	X
ROAD_INCREMENT	Increment in road sampling	X	X	X	X	
TV_MODEL	Temperature and velocity model operation mode	✓				
DAMP_LSG	Scaling factor on rigid ring damping for low velocity stability	X	X	X	X	
VX_STBL	Velocity threshold for low velocity stability solution	X	X	X	X	
[DIMENSION]						
UNLOADED_RADIUS	Free tire radius	✓	✓	✓	✓	✓
WIDTH	Nominal section width of the tire	✓	✓	✓	✓	✓
RIM_RADIUS	Nominal rim radius	✓	✓	✓	✓	✓
RIM_WIDTH	Rim width	X	X	X	X	X

Name	Description	FITTYP				
		70	62	61	60	6
ASPECT_RATIO	Nominal aspect ratio	X	X	X	X	X
[OPERATING_CONDITIONS]						
INFLPRES	Tire inflation pressure	X	X	X		
NOMPRES	Nominal pressure used in (MF) equations	X	X	X		
INITTREAD	Initial treads surface temperature	X				
INITLINER	Initial inner liner temperature	X				
INITCOREAIR	Initial core air temperature	X				
TROAD	Road surface temperature	X				
TAMB	Ambient air temperature	X				
[INERTIA]						
MASS	Tire mass	X	X	X	X	
IXX	Tire diametral moment of inertia	X	X	X	X	
IYY	Tire polar moment of inertia	X	X	X	X	
BELT_MASS	Belt mass	X	X	X	X	
BELT_IXX	Belt diametral moment of inertia	X	X	X	X	
BELT_IYY	Belt polar moment of inertia	X	X	X	X	
GRAVITY	Gravity acting on belt in Z direction	X	X	X	X	
[VERTICAL]						
FNOMIN	Nominal wheel load	✓	✓	✓	✓	✓
VERTICAL_STIFFNESS	Tire vertical stiffness	X	X	X	X	X
VERTICAL_DAMPING	Tire vertical damping	X	X	X	X	X
MC_CONTOUR_A	Motorcycle contour ellipse A	X	X	X		
MC_CONTOUR_B	Motorcycle contour ellipse B	X	X	X		
BREFF	Low load stiffness of effective rolling radius	X	X	X	X	X
DREFF	Peak value of effective rolling radius	X	X	X	X	X
FREFF	High load stiffness of effective rolling radius	X	X	X	X	X
Q_RE0	Ratio of free tire radius with nominal tire radius	X	X	X	X	
Q_V1	Tire radius increase with speed	X	X	X	X	

Name	Description	FITTYP				
		70	62	61	60	6
Q_V2	Vertical stiffness increases with speed	X	X	X	X	
Q_FZ2	Quadratic term in load vs. deflection	X	X	X	X	
Q_FCX	Longitudinal force influence on vertical stiffness	X	X	X	X	
Q_FCY	Lateral force influence on vertical stiffness	X	X	X	X	
Q_FCY2	Explicit load dependency for including the lateral force influence on vertical stiffness	X	X			
Q_CAM	Stiffness reduction due to camber	X	X	X		
Q_CAM1	Linear load dependent camber angle influence on vertical stiffness	X	X			
Q_CAM2	Quadratic load dependent camber angle influence on vertical stiffness	X	X			
Q_CAM3	Linear load and camber angle dependent reduction on vertical stiffness	X	X			
Q_FYS1	Combined camber angle and side slip angle effect on vertical stiffness (constant)	X	X			
Q_FYS2	Combined camber angle and side slip angle linear effect on vertical stiffness	X	X			
Q_FYS3	Combined camber angle and side slip angle quadratic effect on vertical stiffness	X	X			
PFZ1	Pressure effect on vertical stiffness	X	X	X		
BOTTOM_OFFST	Distance to rim when bottoming starts to occur	X	X	X	X	
BOTTOM_STIFF	Vertical stiffness of bottomed tire	X	X	X	X	
[STRUCTURAL]						
LONGITUDINAL_STIFFNESS	Tire overall longitudinal stiffness	X	X	X	X	
LATERAL_STIFFNESS	Tire overall lateral stiffness	X	X	X	X	
YAW_STIFFNESS	Tire overall yaw stiffness	X	X	X	X	

Name	Description	FITTYP				
		70	62	61	60	6
FREQ_LONG	Undamped frequency fore/aft and vertical mode	X	X	X	X	
FREQ_LAT	Undamped frequency lateral mode	X	X	X	X	
FREQ_YAW	Undamped frequency yaw and camber mode	X	X	X	X	
FREQ_WINDUP	Undamped frequency wind-up mode	X	X	X	X	
DAMP_LONG	Dimensionless damping fore/aft and vertical mode	X	X	X	X	
DAMP_LAT	Dimensionless damping lateral mode	X	X	X	X	
DAMP_YAW	Dimensionless damping y aw and camber mode	X	X	X	X	
DAMP_WINDUP	Dimensionless damping wind-up mode	X	X	X	X	
DAMP_RESIDUAL	Residual damping (proportional to stiffness)	X	X	X	X	
DAMP_VLOW	Additional low speed damping (proportional to stiffness)	X	X	X	X	
Q_BVX	Load and speed influence on in-plane translation stiffness	X	X	X	X	
Q_BVT	Load and speed influence on in-plane rotation stiffness	X	X	X	X	
PCFX1	Tire overall longitudinal stiffness vertical deflection dependency linear term	X	X	X		
PCFX2	Tire overall longitudinal stiffness vertical deflection dependency quadratic term	X	X	X		
PCFX3	Tire overall longitudinal stiffness pressure dependency	X	X	X		
PCFY1	Tire overall lateral stiffness vertical deflection dependency linear term	X	X	X		
PCFY2	Tire overall lateral stiffness vertical deflection dependency quadratic term	X	X	X		
PCFY3	Tire overall lateral stiffness pressure dependency	X	X	X		

Name	Description	FITTYP				
		70	62	61	60	6
PCMZ1	Tire overall yaw stiffness pressure dependency	X	X	X		
[CONTACT_PATCH]						
Q_RA1	Square root term in contact length equation	X	X	X		
Q_RA2	Linear term in contact length equation	X	X	X		
Q_RB1	Root term in contact width equation	X	X	X		
Q_RB2	Linear term in contact width equation	X	X	X		
Q_A1	Square root load term in contact length				X	
Q_A2	Linear load term in contact length				X	
ELLIPS_SHIFT	Scaling of distance between front and rear ellipsoid	X	X	X	X	
ELLIPS_LENGTH	Semimajor axis of ellipsoid	X	X	X	X	
ELLIPS_HEIGHT	Semiminor axis of ellipsoid	X	X	X	X	
ELLIPS_ORDER	Order of ellipsoid	X	X	X	X	
ELLIPS_MAX_STEP	Maximum height of road step	X	X	X	X	
ELLIPS_NWIDTH	Number of parallel ellipsoids	X	X	X	X	
ELLIPS_NLENGTH	Number of ellipsoids at sides of contact patch	X	X	X	X	
ENV_C1	Effective height attenuation	X	X			
ENV_C2	Effective plane angle attenuation	X	X			
Q_CFG1	Variation of location of center of force with camber	X				
[SCALING_COEFFICIENTS]						
LFZO	Scale factor of nominal (rated) load	X	X	X	X	X
LCX	Scale factor of Fx shape factor	X	X	X	X	X
LMUX	Scale factor of Fx peak friction coefficient	X	X	X	X	X
LEX	Scale factor of Fx curvature factor	X	X	X	X	X
LKX	Scale factor of Fx slip stiffness	X	X	X	X	X

Name	Description	FITTYP				
		70	62	61	60	6
LHX	Scale factor of Fx horizontal shift	X	X	X	X	X
LVX	Scale factor of Fx vertical shift	X	X	X	X	X
LCY	Scale factor of Fy shape factor	X	X	X	X	X
LMUY	Scale factor of Fy peak friction coefficient	X	X	X	X	X
LEY	Scale factor of Fy curvature factor	X	X	X	X	X
LKY	Scale factor of Fy cornering stiffness	X	X	X	X	X
LKYC	Scale factor of Fy camber stiffness	X	X	X	X	
LKZC	Scale factor of Mz camber stiffness	X	X	X	X	
LHY	Scale factor of Fy horizontal shift	X	X	X	X	X
LVY	Scale factor of Fy vertical shift	X	X	X	X	X
LTR	Scale factor of Peak of pneumatic trail	X	X	X	X	X
LRES	Scale factor for offset of Mz residual torque	X	X	X	X	X
LXAL	Scale factor of alpha influence on Fx	X	X	X	X	X
LYKA	Scale factor of kappa influence on Fy	X	X	X	X	X
LVYKA	Scale factor of kappa induced Fy	X	X	X	X	X
LS	Scale factor of Moment arm of Fx	X	X	X	X	X
LMX	Scale factor of Mx overturning moment	X	X	X	X	X
LVMX	Scale factor of Mx vertical shift	X	X	X	X	X
LMY	Scale factor of rolling resistance torque	X	X	X	X	X
LMP	Scale factor of Mz parking torque	X	X	X	X	
LSGKP	Scale factor of Relaxation length of Fx					X
LSGAL	Scale factor of Relaxation length of Fy					X
LGYR	Scale factor gyroscopic moment					X

Name	Description	FITTYP				
		70	62	61	60	6
[INFLATION_PRESSURE_RANGE]						
PRESMIN	Minimum allowed inflation pressure	X	X	X		
PRESMAX	Maximum allowed inflation pressure	X	X	X		
[VERTICAL_FORCE_RANGE]						
FZMIN	Minimum allowed wheel load	X	X	X	X	X
FZMAX	Maximum allowed wheel load	X	X	X	X	X
[LONG_SLIP_RANGE]						
KPUMIN	Minimum valid wheel slip	X	X	X	X	X
KPUMAX	Maximum valid wheel slip	X	X	X	X	X
[SLIP_ANGLE_RANGE]						
ALPMIN	Minimum valid slip angle	X	X	X	X	X
ALPMAX	Maximum valid slip angle	X	X	X	X	X
[INCLINATION_ANGLE_RANGE]						
CAMMIN	Minimum valid camber angle	X	X	X	X	X
CAMMAX	Maximum valid camber angle	X	X	X	X	X
[LONGITUDINAL_COEFFICIENT]						
PCX1	Shape factor Cfx for longitudinal force	X	X	X	X	X
PDX1	Longitudinal friction Mux at Fznom	X	X	X	X	X
PDX2	Variation of friction Mux with load	X	X	X	X	X
PDX3	Variation of friction Mux with camber	X	X	X	X	X
PEX1	Longitudinal curvature Efx at Fznom	X	X	X	X	X
PEX2	Variation of curvature Efx with load	X	X	X	X	X
PEX3	Variation of curvature Efx with load squared	X	X	X	X	X
PEX4	Factor in curvature Efx while driving	X	X	X	X	X
PKX1	Longitudinal slip stiffness Kfx/Fz at Fznom	X	X	X	X	X
PKX2	Variation of slip stiffness Kfx/Fz with load	X	X	X	X	X

Name	Description	FITTYP				
		70	62	61	60	6
PKX3	Exponent in slip stiffness Kfx/Fz with load	X	X	X	X	X
PHX1	Horizontal shift Shx at Fznom	X	X	X	X	X
PHX2	Variation of shift Shx with load	X	X	X	X	X
PVX1	Vertical shift Svx/Fz at Fznom	X	X	X	X	X
PVX2	Variation of shift Svx/Fz with load	X	X	X	X	X
PPX1	Linear influence of inflation pressure on longitudinal slip stiffness	X	X	X		
PPX2	Quadratic influence of inflation pressure on longitudinal slip stiffness	X	X	X		
PPX3	Linear influence of inflation pressure on peak longitudinal friction	X	X	X		
PPX4	Quadratic influence of inflation pressure on peak longitudinal friction	X	X	X		
RBX1	Slope factor for combined slip Fx reduction	X	X	X	X	X
RBX2	Variation of slope Fx reduction with kappa	X	X	X	X	X
RBX3	Influence of camber on stiffness for Fx combined	X	X	X	X	
RCX1	Shape factor for combined slip Fx reduction	X	X	X	X	X
REX1	Curvature factor of combined Fx	X	X	X	X	X
REX2	Curvature factor of combined Fx with load	X	X	X	X	X
RHX1	Shift factor for combined slip Fx reduction	X	X	X	X	X
PTX1	Relaxation length SigKap0/Fz at Fznom					X
PTX2	Variation of SigKap0/Fz with load					X
PTX3	Variation of SigKap0/Fz with exponent of load					X
OVERTURNING_COEFFICIENTS]						

Name	Description	FITTYP				
		70	62	61	60	6
QSX1	Vertical shift of overturning moment	X	X	X	X	X
QSX2	Camber induced overturning couple	X	X	X	X	X
QSX3	Fy induced overturning couple	X	X	X	X	X
QSX4	Mixed load lateral force and camber on Mx	X	X	X	X	
QSX5	Load effect on Mx with lateral force and camber	X	X	X	X	
QSX6	B-factor of load with Mx	X	X	X	X	
QSX7	Camber with load on Mx	X	X	X	X	
QSX8	Lateral force with load on Mx	X	X	X	X	
QSX9	B-factor of lateral force with load on Mx	X	X	X	X	
QSX10	Vertical force with camber on Mx	X	X	X	X	
QSX11	B-factor of vertical force with camber on Mx	X	X	X	X	
QSX12	Camber squared induced overturning moment	X	X	X		
QSX13	Lateral force induced overturning moment	X	X	X		
QSX14	Lateral force induced overturning moment with camber	X	X	X		
PPMX1	Influence of inflation pressure on overturning moment	X	X	X		
[LATERAL_COEFFICIENT]						
PCY1	Shape factor Cfy for lateral forces	X	X	X	X	X
PDY1	Lateral friction Muy	X	X	X	X	X
PDY2	Variation of friction Muy with load	X	X	X	X	X
PDY3	Variation of friction Muy with squared camber	X	X	X	X	X
PEY1	Lateral curvature Efy at Fznom	X	X	X	X	X
PEY2	Variation of curvature Efy with load	X	X	X	X	X
PEY3	Zero order camber dependency of curvature Efy	X	X	X	X	X

Name	Description	FITTYP				
		70	62	61	60	6
PEY4	Variation of curvature Efy with camber	X	X	X	X	X
PEY5	Variation of curvature Efy with camber squared	X	X	X	X	
PKY1	Maximum value of stiffness Kfy/ Fznom	X	X	X	X	X
PKY2	Load at which Kfy reaches maximum value	X	X	X	X	X
PKY3	Variation of Kfy/Fznom with camber	X	X	X	X	X
PKY4	Curvature of stiffness Kfy	X	X	X	X	
PKY5	Peak stiffness variation with camber squared	X	X	X	X	
PKY6	Fy camber stiffness factor	X	X	X	X	
PKY7	Vertical load dependency of camber stiffness	X	X	X	X	
PHY1	Horizontal shift Shy at Fznom	X	X	X	X	X
PHY2	Variation of shift Shy with load	X	X	X	X	X
PHY3	Variation of shift Shy with camber					X
PVY1	Vertical shift in Svy/Fz at Fznom	X	X	X	X	X
PVY2	Variation of shift Svy/Fz with load	X	X	X	X	X
PVY3	Variation of shift Svy/Fz with camber	X	X	X	X	X
PVY4	Variation of shift Svy/Fz with camber and load	X	X	X	X	X
PPY1	influence of inflation pressure on cornering stiffness	X	X	X		
PPY2	influence of inflation pressure on dependency of nominal tire load on cornering stiffness	X	X	X		
PPY3	linear influence of inflation pressure on lateral peak friction	X	X	X		
PPY4	quadratic influence of inflation pressure on lateral peak friction	X	X	X		
PPY5	Influence of inflation pressure on camber stiffness	X	X	X		
PTY1	Peak value of relaxation length SigAlp0/R0					X

Name	Description	FITTYP				
		70	62	61	60	6
PTY2	Value of Fz/Fznom where SigAlp0 is extreme					X
RBY1	Slope factor for combined Fy reduction	X	X	X	X	X
RBY2	Variation of slope Fy reduction with alpha	X	X	X	X	X
RBY3	Shift term for alpha in slope Fy reduction	X	X	X	X	X
RBY4	Influence of camber on stiffness of Fy combined	X	X	X	X	
RCY1	Shape factor for combined Fy reduction	X	X	X	X	X
REY1	Curvature factor of combined Fy	X	X	X	X	X
REY2	Curvature factor of combined Fy with load	X	X	X	X	X
RHY1	Shift factor for combined Fy reduction	X	X	X	X	X
RHY2	Shift factor for combined Fy reduction with load	X	X	X	X	X
RVY1	Kappa induced side force Svyk/Muy*Fz at Fznom	X	X	X	X	X
RVY2	Variation of Svyk/Muy*Fz with load	X	X	X	X	X
RVY3	Variation of Svyk/Muy*Fz with camber	X	X	X	X	X
RVY4	Variation of Svyk/Muy*Fz with alpha	X	X	X	X	X
RVY5	Variation of Svyk/Muy*Fz with kappa	X	X	X	X	X
RVY6	Variation of Svyk/Muy*Fz with atan(kappa)	X	X	X	X	X
[ROLLING_COEFFICIENTS]						
QSY1	Rolling resistance torque coefficient	X	X	X	X	X
QSY2	Rolling resistance torque depending on Fx	X	X	X	X	X
QSY3	Rolling resistance torque depending on speed	X	X	X	X	X
QSY4	Rolling resistance torque depending on speed ^4	X	X	X	X	X

Name	Description	FITTYP				
		70	62	61	60	6
QSY5	Rolling resistance torque depending on camber squared	X	X	X		
QSY6	Rolling resistance torque depending on load and camber squared	X	X	X		
QSY7	Rolling resistance torque coefficient load dependency	X	X	X		
QSY8	Rolling resistance torque coefficient pressure dependency	X	X	X		
[ALIGNING_COEFFICIENTS]						
QBZ1	Trail slope factor for trail Bpt at Fznom	X	X	X	X	X
QBZ2	Variation of slope Bpt with load	X	X	X	X	X
QBZ3	Variation of slope Bpt with load squared	X	X	X	X	X
QBZ4	Variation of slope Bpt with camber	X	X	X	X	X
QBZ5	Variation of slope Bpt with absolute camber	X	X	X	X	X
QBZ9	Factor for scaling factors of slope factor Br of Mzr	X	X	X	X	X
QBZ10	Factor for dimensionless cornering stiffness of Br of Mzr	X	X	X	X	X
QCZ1	Shape factor Cpt for pneumatic trail	X	X	X	X	X
QDZ1	Peak trail Dpt = Dpt*(Fz/ Fznom*R0)	X	X	X	X	X
QDZ2	Variation of peak Dpt with load	X	X	X	X	X
QDZ3	Variation of peak Dpt with camber	X	X	X	X	X
QDZ4	Variation of peak Dpt with camber squared	X	X	X	X	X
QDZ6	Peak residual torque Dmr = Dmr/ (Fz*R0)	X	X	X	X	X
QDZ7	Variation of peak factor Dmr with load	X	X	X	X	X
QDZ8	Variation of peak factor Dmr with camber	X	X	X	X	X
QDZ9	Variation of peak factor Dmr with camber and load	X	X	X	X	X

Name	Description	FITTYP				
		70	62	61	60	6
QDZ10	Variation of peak factor Dmr with camber squared	X	X	X	X	
QDZ11	Variation of Dmr with camber squared and load	X	X	X	X	
QEZ1	Trail curvature Ept at Fznom	X	X	X	X	X
QEZ2	Variation of curvature Ept with load	X	X	X	X	X
QEZ3	Variation of curvature Ept with load squared	X	X	X	X	X
QEZ4	Variation of curvature Ept with sign of Alpha-t	X	X	X	X	X
QEZ5	Variation of Ept with camber and sign Alpha-t	X	X	X	X	X
QHZ1	Trail horizontal shift Sht at Fznom	X	X	X	X	X
QHZ2	Variation of shift Sht with load	X	X	X	X	X
QHZ3	Variation of shift Sht with camber	X	X	X	X	X
QHZ4	Variation of shift Sht with camber and load	X	X	X	X	X
PPZ1	Effect of inflation pressure on length of pneumatic trail	X	X	X		
PPZ2	Influence of inflation pressure on residual aligning torque	X	X	X		
SSZ1	Nominal value of s/R0: effect of Fx on Mz	X	X	X	X	X
SSZ2	Variation of distance s/R0 with Fy/Fznom	X	X	X	X	X
SSZ3	Variation of distance s/R0 with camber	X	X	X	X	X
SSZ4	Variation of distance s/R0 with load and camber	X	X	X	X	X
QTZ1	Gyroscopic torque constant					X
[TURNSLIP_COEFFIECIENTS]						
PDXP1	Peak Fx reduction due to spin parameter	X	X	X	X	
PDXP2	Peak Fx reduction due to spin with varying load parameter	X	X	X	X	
PDXP3	Peak Fx reduction due to spin with kappa parameter	X	X	X	X	

Name	Description	FITTYP				
		70	62	61	60	6
PDXP4	Peak Fx reduction due to longitudinal spin parameter	X				
PKYP1	Cornering stiffness reduction due to spin	X	X	X	X	
PDYP1	Peak Fy reduction due to spin parameter	X	X	X	X	
PDYP2	Peak Fy reduction due to spin with varying load parameter	X	X	X	X	
PDYP3	Peak Fy reduction due to spin with alpha parameter	X	X	X	X	
PDYP4	Peak Fy reduction due to square root of spin parameter	X	X	X	X	
PDYP5	Peak Fy reduction due to spin parameter	X				
PDYP6	Peak Fy reduction due to lateral spin parameter	X				
PHYP1	Fy-alpha curve lateral shift limitation	X	X	X	X	
PHYP2	Fy-alpha curve maximum lateral shift parameter	X	X	X	X	
PHYP3	Fy-alpha curve maximum lateral shift varying with load parameter	X	X	X	X	
PHYP4	Fy-alpha curve maximum lateral shift parameter	X	X	X	X	
PECP1	Camber w.r.t. spin reduction factor parameter in camber stiffness	X	X	X	X	
PECP2	Camber w.r.t. spin reduction factor varying with load parameter in camber stiffness	X	X	X	X	
QDTP1	Pneumatic trail reduction factor due to turn slip parameter	X	X	X	X	
QCRP1	Turning moment at constant turning and zero forward speed parameter	X	X	X	X	
QCRP2	Turn slip moment (at alpha=90deg) parameter for increase with spin	X	X	X	X	
QBRP1	Residual (spin) torque reduction factor parameter due to side slip	X	X	X	X	

Name	Description	FITTYP				
		70	62	61	60	6
QDRP1	Turn slip moment peak magnitude parameter	X	X	X	X	
QDRP3	Dependency of the turn slip transition curvature at zero forward speed on load	X				
QDRP4	Turn slip transition curvature at zero forward speed and Fznom	X				
FREQ_SVLP	Low pass filter cut off frequency for filtered steer rate and velocities	X				
QDRPA	Drop magnitude during steer hold	X				
QDRPR	Drop rate input during steer hold	X				
QDRPMIN	Gain limit for numerical stability during steer hold	X				
DPSIMIN	Steer rate threshold for noise filtering and steer hold	X				
VXYMIN	Velocity threshold for noise filtering and steer hold	X				
[TVX_COEFFICIENTS]						
PPT1	Nominal temperature for nominal inflation pressure	X				
PKXT1	Asymptotic scaling for CFk vs T at T infinite	X				
PKXT2	Exponential gain for CFk vs T	X				
PKXT3	Exponential gain for CFk vs T	linear dependency on Fz	X			
PKXT4	Exponential gain for CFk vs T	quadratic dependency on Fz	X			
PKXT5	Nominal tread bulk temperature at nominal load for CFk vs T	X				
PKXT6	Load dependency of nominal tread bulk temperature for CFk vs T	X				
PKXV1	Gain for CFk vs Vx	X				

Name	Description	FITTYP				
		70	62	61	60	6
PKXV2	CFk at Vx - > 0 and nominal load	X				
PKXV3	Load dependendy for CFk at Vx - > 0	X				
PKYT1	Asymptotic scaling for CFa vs T at T infinite	X				
PKYT2	Exponential gain for CFa vs T	X				
PKYT3	Exponential gain for CFa vs T	linear dependency on Fz	X			
PKYT4	Exponential gain for CFa vs T	quadratic dependency on Fz	X			
PKYT5	Nominal tread bulk temperature at nominal load for CFa vs T	X				
PKYT6	Load dependency of nominal tread bulk temperature for CFa vs T	X				
PKYV1	Gain for CFa vs Vx	X				
PKYV2	CFa at Vx - > 0 and nominal load	X				
PKYV3	Load dependendy for CFa at Vx - > 0	X				
PDXT1	Maximum mux(T)	X				
PDXT2	Temperature at which the mux(T) occurs	X				
PDXT3	Nominal flash temperature at nominal load for mux(T)	X				
PDXT4	Load dependency of nominal flash temperature for mux(T)	X				
PDXT5	Smoothness of the transient from the maximum the minimum mux(T)	X				
PDXV1	Dependency of the flash temperature for mux(T) on Vx	X				
PDYT1	Maximum muy(T)	X				
PDYT2	Temperature at which the muy(T) occurs	X				
PDYT3	Nominal flash temperature at nominal load for muy(T)	X				

Name	Description	FITTYP				
		70	62	61	60	6
PDYT4	Load dependency of nominal flash temperature for muy(T)	X				
PDYT5	Smoothness of the transient from the maximum the minimum muy(T)	X				
PDYV1	Dependency of the flash temperature for muy(T) on Vx	X				
PEXT1	Dependency of Ex on T for positive slip	X				
PEXT2	Load dependency of Ex on T for positive slip	X				
PEXT3	Dependency of Ex on T for negative slip	X				
PEXT4	Load dependency of Ex on T for negative slip	X				
PEXV1	Dependency of Ex on Vx	X				
PEYT1	Dependency of Ey on T for positive slip	X				
PEYT2	Load dependency of Ey on T for positive slip	X				
PEYT3	Dependency of Ey on T for negative slip	X				
PEYT4	Load dependency of Ey on T for negative slip	X				
PEYV1	Dependency of Ey on Vx	X				
QRR_EM	Tread rubber elasticity storage modulus	X				
QRR_EL	Tread rubber elasticity loss factor	X				
QRR_VX	Rolling resistance dependency on Vx	X				
CPRHO	Tire specific heat capacity per volume	X				
LAMBDA_TR	Heat conductivity treads	X				
LAMBDA_BL	Heat conductivity belt	X				
HCV_IA	Convection liner inner air	X				
HCV_RM	Convection rim inner air	X				
HCV_AA_NOM	Convection treads ambient air at V0	X				

Name	Description	FITTYP				
		70	62	61	60	6
HCV_AA_VX	Convection treads ambient air Vx dependency	X				
HCV_TR	Convection treads road	X				
ETATR1	Partition frictional power road and tread	X				
ETATR2	Partition frictional power dependency on Fz	X				
ETATR3	Partition frictional power dependency on Tt	X				
HCV_TR_VX	Convection treads road Vx dependency	X				
ALSL	Longitudinal slip correction	X				

MF-Tyre/MF-Swift Version History

To enable the use of old Tire Property Files, MF-Tyre/MF-Swift is backwards compatible with older versions.

Tire Property Files generated for these tire models work with MF-Tyre/MF-Swift 2412 and give the same simulation results as before. The version history is presented in Figure 12.

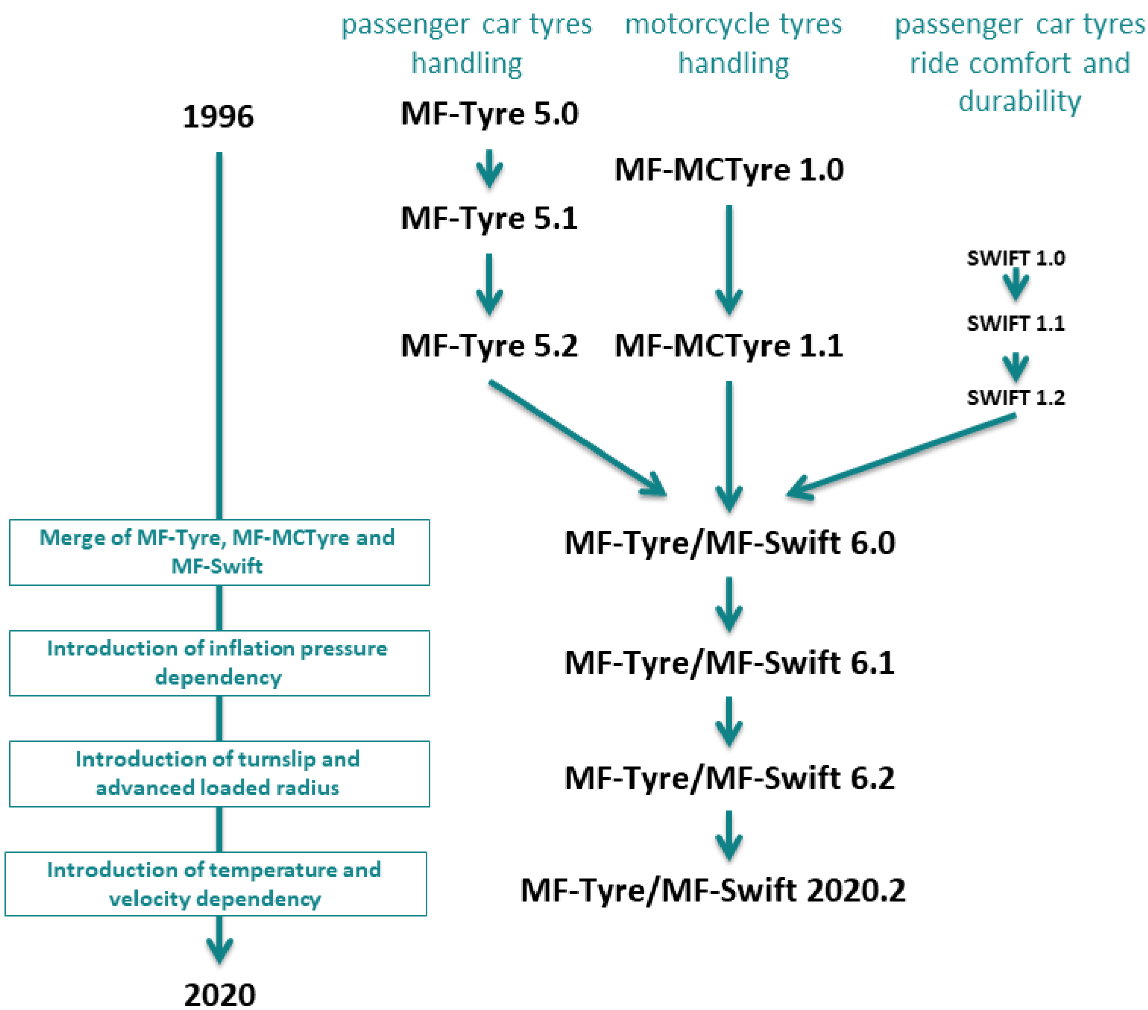


Figure 12: Version history of MF-Tyre/MF-Swift

The built-in estimation procedure (see Requirements for Reduced Input Data) allows the use of an existing MF-Tyre 5.2 Tire Property File for simulations including turn slip, rigid ring dynamics and tire enveloping behavior, thus already benefiting from the new functionality available in MF-Tyre/MF-Swift 2412.

FITTYP

The selection of the appropriate set of Magic Formula equations is based on the parameter *FITTYP* in the **[MODEL]** section of the Tire Property File. The following conventions apply:

- *FITTYP*=5—MF-Tyre 5.0, 5.1 Magic Formula equations.
- *FITTYP*=6—MF-Tyre 5.2 Magic Formula equations.
- *FITTYP*=21—MF-Swift 1.x Magic Formula equations (based on MF-Tyre 5.2).
- *FITTYP*=51—MF-MCTyre 1.0 Magic Formula equations.
- *FITTYP*=52—MF-MCTyre 1.1 Magic Formula equations.
- *FITTYP*=60—MF-Tyre 6.0 Magic Formula equations.
- *FITTYP*=61—MF-Tyre 6.1 Magic Formula equations.
- *FITTYP*=62—MF-Tyre 6.2 Magic Formula equations.
- *FITTYP*=70—MF-Tyre 6.2 Magic Formula equations plus Temperature and Velocity model.

Note: MF-Tyre/MF-Swift 2412 only accepts the following *FITTYP* values:

- *FITTYP*=6
- *FITTYP*=60
- *FITTYP*=61
- *FITTYP*=62
- *FITTYP*=70

It exits with an error for all other values of the *FITTYP* parameter.

Road Surface Definition

Besides the tire parameters, the tire model requires a road (surface) definition to be able to compute the tire output.

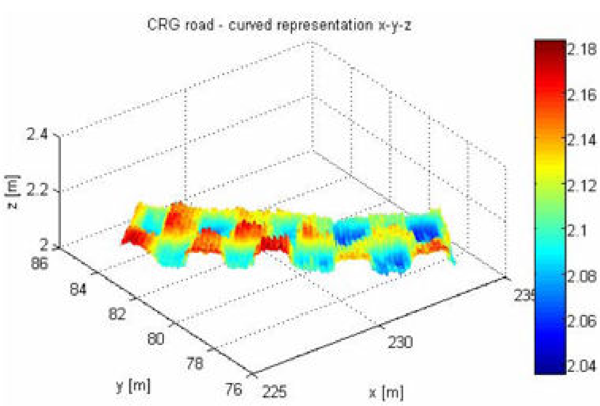
As described in Road Method, the tire model supports a number of ways to define the road (surface) definition.

Default Flat Road

The default flat road surface has a constant road height ($z = 0$ [m] in the global axis system) and constant surface conditions, i.e. friction coefficient of 1 in the x and y directions and zero road curvature. It is currently not possible to alter these conditions and hence there is no need to specify a road data file.

OpenCRG Road

The OpenCRG Road is the implementation of the interface between MF-Tyre/MF-Swift and OpenCRG, maintained by the Association of Standardization of Automation and Measuring Systems (ASAM), Germany.



OpenCRG

OpenCRG is an initiative to provide a unified approach to represent 3D road data in vehicle simulations. The motivation is that simulation applications of vehicle handling, ride comfort. and durability load profiles ask for a reliable and efficient road representation. OpenCRG is based on CRG, Curved Regular Grid, developed by Daimler, which is made available to everyone.

The provided free material includes an efficient C-API implementation to evaluate the recorded 3D surface information and some Matlab functions to handle the CRG road data files.

- Installation—The OpenCRG installation can be found under the Download section on the OpenCRG Website. This include links for the:
  - Documentation—User Manual
  - Source Code and Tools—OpenCRG tools (C-API and MATLAB)
- License—OpenCRG is licensed under the Apache License (version 2.0). The license conditions may be found in the MF-Tyre/MF-Swift installation folder.

- Invitation—you are invited, by the founders, to share ideas and supply contributions to complement and extend the intial work.

CRG

Curved Regular Grid represents road elevation data close to an arbitrary road center line. The road is represented as a curved reference line and a regular elevation grid. See Figure 13 for details.

This approach results in improved storage efficiency (smaller road data files), and faster elevation evaluation, with respect to other methods.

Note: The start of the CRG track is, by default, translated to the origin. This can be overruled by including an empty `$ROAD_CRG_MODS` block.

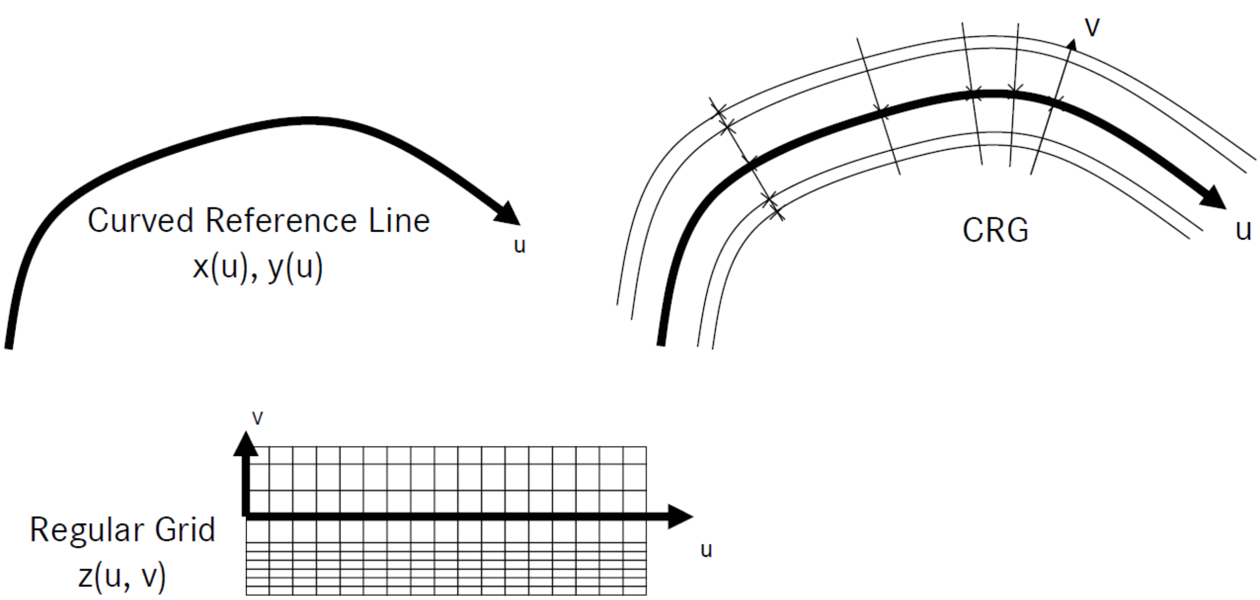


Figure 13: Curved Regular Grid

- Curved Reference Line—defined in the base place (usually x,y) by setting the direction (heading/yaw angle). Optionally, a pitch and bank angle can be defined to represent the hilliness and cross slope.
- Regular Elevation Grid—defines the elevation in the proximity of the reference line. The columns are longitudinal cuts that are parallel to the reference line. The rows are lateral cuts orthogonal to the reference line.

Creation

OpenCRG files (`*.crg`) can be easily created in Matlab with routines delivered with MF-Tyre/MF-Swift. Documentation about OpenCRG can be found in the installation at

```
simcenter_tire>mftyre_mfswift-simulink-2022.1>OpenCRG>doc
```

External Road

With the external road selector, the road surface is defined in the VDS package coupled to MF-Tyre/MF-Swift.

MF-Tyre/MF-Swift limits the user-defined road surface friction values in the interval [0,2].

See the VDS Package manuals for more information on how to define the road surface.

Road Model Numerical Limitations

While reading data from either OpenCRG or External Roads, the following limits are applied:

- Road longitudinal friction and lateral friction are limited to the interval [1e-5, 2.0].
- Road curvature is limited to the interval [-2.0, 2.0].

A warning is issued when road model data exceeds one of the above limits. Only the first time exceeding a limit triggers a warning; repeated occurrences are ignored.

Tire Model Output

MF-Tyre/MF-Swift is offered as a force element that can be connected to a simulation package.

Feedback to Simulation Packages

The primary feedback of the tire model to the simulation package consists of the tire force and moment vectors on the wheel. These primary feedback components are stored in the force and torque arrays which are returned by the library. They are expressed with respect to the fixed (non-rotating) wheel-carrier reference frame, with an origin at the wheel center.

- The x axis is in the wheel plane and parallel to the road plane and pointing forward.
- The y axis is perpendicular to the wheel plane.
- The z axis is perpendicular to the x and y axes and is pointing upwards.

For more information see Axis System.

These arrays contain the following data:

Force	Description	Unit
F_{xc}	Component of the tire force along the x axis of the wheel carrier reference frame.	[N]
F_{yc}	Component of the tire force along the y axis of the wheel carrier reference frame.	[N]
F_{zc}	Component of the tire force along the z axis of the wheel carrier reference frame.	[N]

Force	Description	Unit
M_{xc}	Component of the tire moment along the x axis of the wheel carrier reference frame.	[Nm]
M_{yc}	Component of the tire moment along the y axis of the wheel carrier reference frame.	[Nm]
M_{zc}	Component of the tire moment along the z axis of the wheel carrier reference frame.	[Nm]

Post-Processing Signals

Various signals are available for post-processing (these are stored in the VARINF array). The availability may be dependent on the implementation in the simulation package.

Depending on this implementation, the signals are selected by means of a key word, signal number, or by other methods. The available signals are listed below:

Array Index	Variable	Name	Description	Unit
		Tire Contact Forces and Moments in the Contact Point		
1	F_{xw}	Contact point force longitudinal	Longitudinal force in W axis system	[N]
2	F_{yw}	Contact point force lateral	Lateral force in W axis system	[N]
3	F_{zw}	Contact point force vertical	Vertical force in W axis system	[N]
4	M_{xw}	Contact point moment roll	Overturning moment in W axis system	[Nm]
5	M_{yw}	Contact point moment pitch	Rolling resistance moment in W axis system	[Nm]
6	M_{zw}	Contact point moment yaw	Self-aligning moment in W axis system	[Nm]
		Slip Quantities		
7	κ	Slip ratio longitudinal	Longitudinal slip	[-]
8	α	Slip angle lateral	Side slip angle	[rad]
9	γ	Inclination angle	Inclination angle	[rad]
10	ϕ	Turn slip	Turn slip	[1/m]
		Additional Tire Outputs		
11	V_x	Contact point velocity longitudinal	Wheel contact center	[m/s]
12	R_l	Loaded Radius	Loaded radius	[m]
13	R_e	Effective rolling radius	Effective rolling radius	[m]
14	ρ_z	Deflection vertical	Tire deflection	[m]
15	l_{cp}	Contact patch length	Tire contact length	[m]
16	t_p	Pneumatic trail	Pneumatic trail	[m]
17	μ_x	Peak friction longitudinal	Longitudinal friction coefficient	[-]
18	μ_y	Peak friction lateral	Lateral friction coeffiecient	[-]
19	σ_x	Relaxation length longitudinal	Longitudinal relaxation length[1]	[m]
20	σ_y	Relaxation length lateral	Lateral relaxation length[1]	[m]
21	V_{sx}	Slip velocity longitudinal	Longitudinal wheel slip velocity	[m/s]
22	V_{sy}	Slip velocity lateral	Lateral wheel slip velocity	[m/s]
23	V_z	Compression velocity vertical	Tire compression velocity	[m/s]
24	$\dot{\psi}$	Angular velocity yaw	Tire yaw velocity	[rad/s]
		Tire Contact Point		
31	x_{cp}	Contact point coordinate x	Global x coordinate contact point	[m]
32	y_{cp}	Contact point coordinate y	Global y coordinate contact point	[m]

Array Index	Variable	Name	Description	Unit
33	z_{cp}	Contact point coordinate z	Global z coordinate contact point	[m]
34	n_x	Road normal component x	Global x component road normal	[-]
35	n_y	Road normal component y	Global y component road normal	[-]
36	n_z	Road normal component z	Global z component road normal	[-]
37	h_{eff}	Effective road height	Effective road height	[m]
38	β_y	Effective road slope	Effective forward slope	[rad]
39	$curv$	Effective road curvature	Effective road curvature	[1/m]
40	β_x	Effective road banking	Effective road banking or road camber angle	[rad]
Temperature and Velocity Model				
51	T_t	Tread surface temperature	Figure 11	[K]
52	T_{tb}	Tread bulk temperature	Figure 11	[K]
53	T_l	Liner temperature	Figure 11	[K]
54	T_i	Core air pressure	-	[K]
55	P_{infl}	Inflation pressure	-	[N/m^2]

1. Contains a non-zero value if linear transient dynamics mode is selected and zero value otherwise.

Technical Support Details

Support is provided to those who have a support contract.

For support, please contact your local representative or create a ticket using the global Siemens Support Center platform via https://support.sw.siemens.com/.

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