

SIEMENS

Ingenuity for life

User Manual

Version 2212

Simcenter Tire

MF-Tyre/MF-Swift

Siemens Digital Industries Software

All rights reserved. No parts of this work may be reproduced in any form or by any means—graphic, electronic, or mechanical, including photocopying, recording, taping, or information storage and retrieval systems—without the written permission of the publisher.

Products that are referred to in this document may be either trademarks and/or registered trademarks of the respective owners. The publisher and the author make no claim to these trademarks.

While every precaution has been taken in the preparation of this document, the publisher and the author assume no responsibility for errors or omissions, or for damages resulting from the use of information contained in this document or from the use of programs and source code that may accompany it. In no event shall the publisher and the author be liable for any loss of profit or any other commercial damage caused or alleged to have been caused directly or indirectly by this document.

Unpublished work Copyright 2022 Siemens

Contents

| | | |
|----------|---|-----------|
| 1 | Introduction | 1 |
| 2 | Release Notes | 2 |
| 2.1 | MF-Tyre/MF-Swift generic | 2 |
| 2.1.1 | Enveloping runtime performance improvement | 2 |
| 2.1.2 | New Siemens Licensing mechanism for MF-Tyre/MF-Swift | 2 |
| 2.1.3 | Contact patch transient response improvement | 2 |
| 2.1.4 | Curvature support with OpenCRG files | 3 |
| 2.1.5 | Real-Time Platform Support | 3 |
| 2.1.6 | Bug fixes | 3 |
| 3 | License Manual | 4 |
| 3.1 | Obtaining a License | 4 |
| 3.2 | License Types and Features | 5 |
| 3.3 | License protection on desktop platforms | 6 |
| 3.3.1 | Starting the License Server Manager on Windows and LINUX Platforms | 7 |
| 3.4 | License protection on RT platforms | 8 |
| 3.4.1 | Obtain the serial number(s) for dSPACE platforms | 8 |
| 3.4.2 | Obtain the serial number(s) for Concurrent iHawk and IPG Xpack4 platforms | 9 |
| 3.4.3 | Obtain the serial number(s) for NI-PXI platforms | 9 |
| 3.4.4 | Set up Licensing for Simulink | 10 |
| 3.5 | License Troubleshooting Guide | 10 |
| 3.5.1 | Windows License Troubleshooting | 10 |
| 3.5.2 | Real Time License Troubleshooting | 10 |
| 4 | User Manual | 11 |
| 4.1 | Introduction | 11 |
| 4.1.1 | MF-Tyre/MF-Swift | 12 |
| 4.1.2 | Model Usage and computational performance | 14 |

| | | |
|-------|--|----|
| 4.1.3 | Conventions | 15 |
| 4.1.4 | Technical Support Details | 16 |
| 4.2 | Tire Model Operating Modes | 16 |
| 4.2.1 | Road method | 17 |
| 4.2.2 | Tire side | 17 |
| 4.2.3 | Contact method | 18 |
| 4.2.4 | Dynamics method | 20 |
| 4.2.5 | Slip Forces method | 20 |
| 4.2.6 | Definition of the ISWITCH parameter | 21 |
| 4.2.7 | Temperature mode | 21 |
| 4.3 | Tire Property File | 23 |
| 4.3.1 | Obfuscated Tire Property Files | 23 |
| 4.3.2 | Overview | 24 |
| 4.3.3 | Reduced Input Data Requirements | 24 |
| 4.3.4 | Input limitations | 25 |
| 4.3.5 | Scaling Factors | 26 |
| 4.3.6 | Parameters In The Tire Property File | 26 |
| 4.3.7 | Version History | 36 |
| 4.4 | Road Surface Definition | 37 |
| 4.4.1 | Default Flat Road | 37 |
| 4.4.2 | OpenCRG Road | 38 |
| 4.4.3 | External Road | 39 |
| 4.4.4 | Road model numerical limitations | 39 |
| 4.5 | Tire Model Output | 40 |
| 4.5.1 | Feedback to Simulation Package | 40 |
| 4.5.2 | Post Processing Signals | 40 |

1 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 performance 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 parameterization tool and tire testing and engineering services. By combining those elements, customized tire modeling methodologies can be delivered that provide the optimal balance between simulation accuracy and cost-efficiency.

This manual belongs to the Simcenter Tire MF-Tyre/MF-Swift product. Based on the renowned Magic Formula and tire modeling theory developed by prof. Pacejka, 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 application as well as on Real-Time systems. The two types of applications require different licensing strategies. Both are described in the section [License manual](#).

MF-Tyre/MF-Swift 2212 supports the following real-time systems:

1. dSPACE DS1006,
2. dSPACE SCALEXIO,
3. Concurrent iHawk,
4. IPG Xpack4, and
5. NI PXI Phar Lap ETS.

The usage of the tire model is described in the [User manual](#).

2 Release Notes

On September 1, 2017 Siemens has acquired TASS International, a global provider of automotive simulation software and engineering and test services. Under the umbrella of Siemens Digital Industries the MF-Tyre/MF-Swift product will be further developed in order to provide the most versatile and cost-efficient tire modeling product in the market. This document describes the contents of the current release; MF-Tyre/MF-Swift 2212.

MF-Tyre/MF-Swift 6.2 has been the default product for desktop simulations. A complete MF-Tyre/MF-Swift product renewal was initiated by TASS International in 2015, with a specific focus on Real-Time simulations. With MF-Tyre/MF-Swift version 2020.1 Siemens releases a product that can replace version 6.2 as well as support Real-Time simulations. This allows standardization to one single MF-Tyre/MF-Swift version throughout all simulation environments.

In this chapter the release notes of MF-Tyre/MF-Swift 2212 are presented. Section 2.1 contains the latest generic MF-Tyre/MF-Swift information which applies for usage in combination with all vehicle simulation packages.

2.1 MF-Tyre/MF-Swift generic

2.1.1 Enveloping runtime performance improvement

The Enveloping usemode's runtime performance has been improved for MF-Tyre/MF-Swift 2212, to ensure more complex full vehicle simulations capability on Real-time platforms. Kindly refer to the Introduction section for additional details.

2.1.2 New Siemens Licensing mechanism for MF-Tyre/MF-Swift

The licensing mechanism for Simcenter Tire MF-Tyre/MF-Swift 2212 is the Siemens License Server. The Siemens License Server uses a new vendor DEAMON called SALT, instead of MADLIC. Therefore, the versions of MF-Tyre/MF-Swift older than 2022.1 are not compatible with the Siemens License Server and will still use the previous mechanism for licensing. Refer to the user manuals of the respective version regarding Licensing.

The Siemens License Server is part of the MF-Tyre/MF-Swift 2212 installer and will require a new license file. Kindly contact our Siemens Digital Industries sales representative and/or our channel partners for further information.

2.1.3 Contact patch transient response improvement

The transient response of the contact patch, as a part of the non-linear transient mode (see section 4.2.4), is modeled by its relaxation length. This approach improves the accuracy of the tire dynamic

response, with the non-linear transient mode, in conditions of high levels of slip such as ABS braking.

2.1.4 Curvature support with OpenCRG files

MF-Tyre/MF-Swift 2212 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. For example: For a curvature of 1.0, the following needs to be added to the OpenCRG road file header:

```
*CURVTRSF = 1.0
```

If the keyword `CURVTRSF` is not found in the header section, then the curvature will be set to 0.0 as a default value.

2.1.5 Real-Time Platform Support

MF-Tyre/MF-Swift 2212 now supports:

- dSPACE DS1006 and SCALEXIO versions up until 2020-B
- SimWB up until 2020.2-0 (gold)

2.1.6 Bug fixes

- The parameter `Q_CAM` in the Tire property file is taken into consideration only when using FITTYP is 61. For newer FITTYP versions, this parameter is ignored.
- The parameters in the TIR file can be specified in the scientific notation for zero values as well. Previously, the scientific notation (E) was accepted only for non zero values
- Running unlicensed modes for longer than 10 minutes will not cause a license failure anymore.
- The parameters `Q_LIMP_3` and `Q_LIMP_4` are no longer supported for FITTYP 60 for MF-Tyre/MF-Swift 2212

3 License Manual

In this section the licensing system is described for usage of MF-Tyre/MF-Swift on both desktop and real-time platforms.

In the remainder of this document 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_tyre\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, instead of MADLIC. Kindly refer to the section [Obtaining a License](#) on the details for obtaining a license for MF-Tyre/MF-Swift 2212

3.1 Obtaining a License

The various licenses for MF-Tyre/MF-Swift products can be obtained from the Siemens Digital Industries sales representative and/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 shall be deployed:

- Composite HostID Value(s)
- Host Name
- MAC Address

In order to obtain the Composite HostID Value(s), run the **getcid** executable on the machine that is designated as the license server for MF-Tyre/MF-Swift. Send the Composite HostID Value(s) to the Sales representative to generate the license files for MF-Tyre/MF-Swift. On Windows platforms launch `getcid.exe` and on Linux platforms launch `getcid`.

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 the Siemens Digital Industries sales representative and/or our channel partners.

Section [License protection on RT platforms](#) describes the information required to obtain a license for a specific Real-time platform.

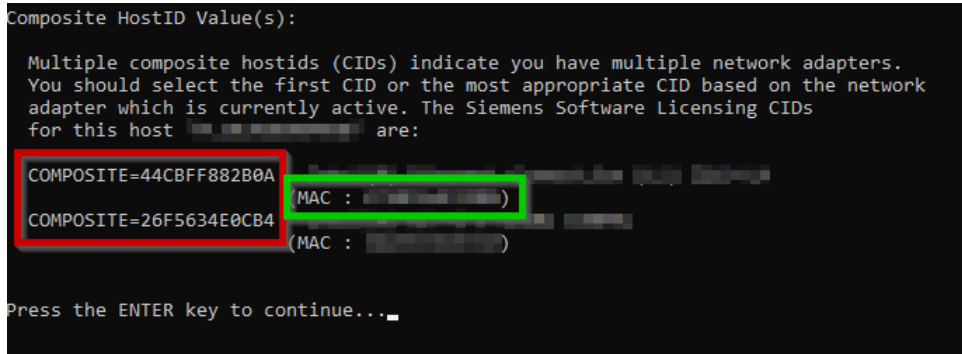


Figure 3.1: The Composite HostID Value(s) after running the getcid executable

3.2 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 & 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 and/or road load calculation purposes.

Siemens offers MF-Tyre/MF-Swift as both a desktop and a 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 and license is protected by one license feature. Temperature & 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 & Velocity | sctire_mfswift_tv |

Within the Real-Time product all functionality is license protected. The product comes with both a desktop license allowing to setup the simulation experiment as well as an entitlement file allowing to run the simulation on the Real-Time target (see section [License protection on RT platforms](#) for more information on entitlement files). In the Real-Time product the MF-Tyre, Turnslip, Rigid Ring Enveloping, and Temperature & 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_mfswift_ts |
| Rigid Ring | sctire_mfswift_rr |
| Enveloping | sctire_mswift_env |
| Temperature | 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. However it still requires an entitlement file to run on the Real-time platform. The section [License protection on RT platforms](#) describes the information required to obtain an entitlement file for all supported platforms.

3.3 License protection on desktop platforms

This chapter provides procedural information on how to configure and manage the Siemens License Server.

Note: This section describes the steps in setting up the Siemens License Server after obtaining a valid license file for MF-Tyre/MF-Swift from the Siemens Digital Industries sales representative and/or our 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 Siemens Support Center. In order to install the Siemens License Server, the `License tools` checkbox needs to be selected during the installation. This will automatically launch the Siemens License Server installation tool. The licensing tools are then installed in the `license` subdirectory of the MF-Tyre/MF-Swift installation directory.

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 `license` subdirectory of the MF-Tyre/MF-Swift 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, and
- Refer application checkout (or other) requests to the correct vendor daemon, for example `saltd`.

The Siemens License Server, and henceforth the license server system, will automatically be started during the installation process, and also at system startup 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 three-server redundant license server systems, 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 these files becomes a single point of failure.

3.3.1 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 will automatically launch the Siemens License Server installation tool.

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

Note: The versions of Simcenter Tire MF-Tyre/MF-Swift older than 2212 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. Both methods are discussed in the following sections.

Installing the License Server from the Command Line

Rather than using the Siemens License Server Installer wizard to install the license server, you can install from the command line either interactively (with prompts) or non-interactively (without prompts). 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 MF-Tyre/MF-Swift tire model. The environment variable `SALT_LICENSE_SERVER` should be set to `<portnumber>@<hostname>` specified in the license file

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

Interactive Install

An interactive install uses command prompts to guide you through the installation. Type the following on the command line:

On Windows

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

On Linux

```
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. Type the following on the command line:

On Windows

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

On Linux

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

Note: For complete command syntax, option descriptions and examples, refer to the “SiemensLicenseServerCommand” section in Siemens Digital Industries Software Licensing Manual.

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

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

3.4 License protection on RT platforms

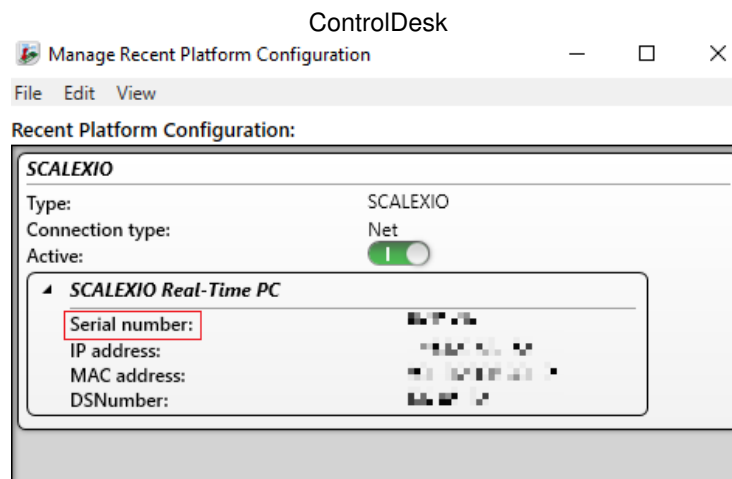
On Real-Time platforms (such as dSPACE ds1006, SCALEXIO, NI-PXI, Concurrent iHawk and IPG Xpack4 platforms), applications of MF-Tyre/MF-Swift 2020.1 or higher do not communicate to an FlexLM license server. Simcenter Tire instead packages the purchased license features into an entitlement file, which can be obtained from your Siemens sales representative. This entitlement file is node-locked; it can only be used with a predefined set of machine(s) and/or core(s). Without a (valid) entitlement file MF-Tyre/MF-Swift cannot be used on said platforms.

If you are using MF-Tyre/MF-Swift through software of a 3rd party, then refer to the 3rd party documentation on how to pass on the entitlement file and its location.

3.4.1 Obtain the serial number(s) for dSPACE platforms

The entitlement file is node-locked to a predefined set of machine(s) and/or core(s) based on the serial number(s). The serial number(s) for dSPACE DS1006 and SCALEXIO can be obtained from "dSPACE ControlDesk -> Platforms -> Manage Platforms -> Manage Recent Platform Configuration. Alternatively for SCALEXIO dSPACE ConfigurationDesk -> Platforms -> Manage Platforms -> Manage Recent Platform Configuration can be used.

| | |
|------------------|-------------------------------------|
| ds1006 | |
| Type: | DS1006 |
| Serial number: | |
| Port address: | 0x300 |
| Connection type: | Bus |
| Active: | <input checked="" type="checkbox"/> |
| ds1006_2 | |
| Type: | DS1006 |
| Serial number: | |
| Port address: | 0x310 |
| Connection type: | Bus |
| Active: | <input checked="" type="checkbox"/> |



ConfigurationDesk

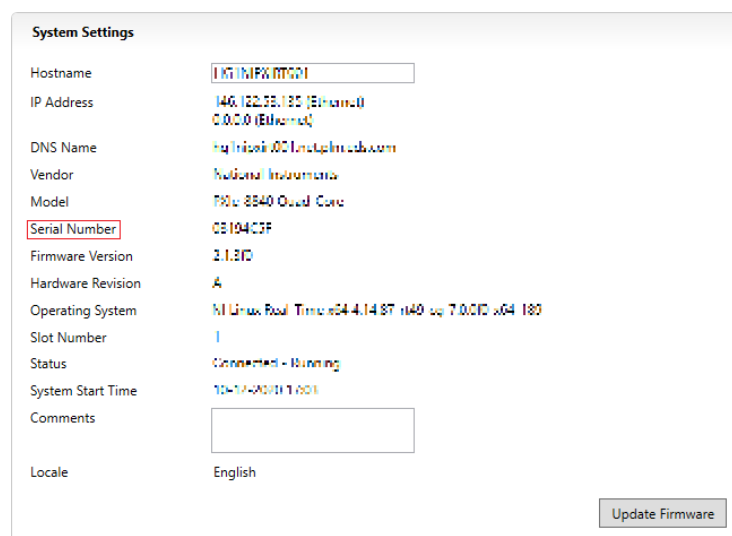
3.4.2 Obtain the serial number(s) for Concurrent iHawk and IPG Xpack4 platforms

To obtain the serial number(s) 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 the Sales representative. To obtain the serial number(s), run the Hardware identification tool on the Linux Real-Time platform(s):

```
./mfswift_query_hardware_id
```

3.4.3 Obtain the serial number(s) for NI-PXI platforms

The serial number of your real-time system(s) is shown in the NI-MAX application when clicking on 'Remote Systems' behind the 'Serial Number' label.



3.4.4 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 MFSWIFTRT_ENTITLEMENT_FILE.

For Windows OS, it is recommended to set the variable through "System Properties". Typically, this can be done through "Control Panel->System and Security->System->Advanced system settings->Environment Variables->New...".

3.5 License Troubleshooting Guide

3.5.1 Windows License Troubleshooting

1. The versions of MF-Tyre/MF-Swift older than 2212 are not compatible with the Siemens License Server. Refer to the user manuals of the respective version regarding Licensing.
2. The environment variable SALT_LICENSE_SERVER should be set to <portnumber>@<hostname>; portnumber is the connection port number of the license server, where hostname is the name of the license server without the domain name. See the first line in the license file for these details. Note that the first hostname should be <portnumber>@localhost. This will force the system to check if it is detached from the network.
3. Considerable delays in startup of the applications have been noticed if the license file contains license strings of which the end date has expired.
4. Considerable delays in startup of the applications have been noticed if nonexistent 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 license sub-directory of the MF-Tyre/MF-Swift installation directory.

3.5.2 Real Time License Troubleshooting

Any problem with the entitlement file will make an MF-Tyre/MF-Swift simulation fail at initialization. This section helps to identify and solve the problems.

- 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 your Siemens Digital Industries sales representative.

4 User Manual

4.1 Introduction

This chapter contains 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 circumstance. To analyze the influence of tire properties on the dynamic behavior 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.

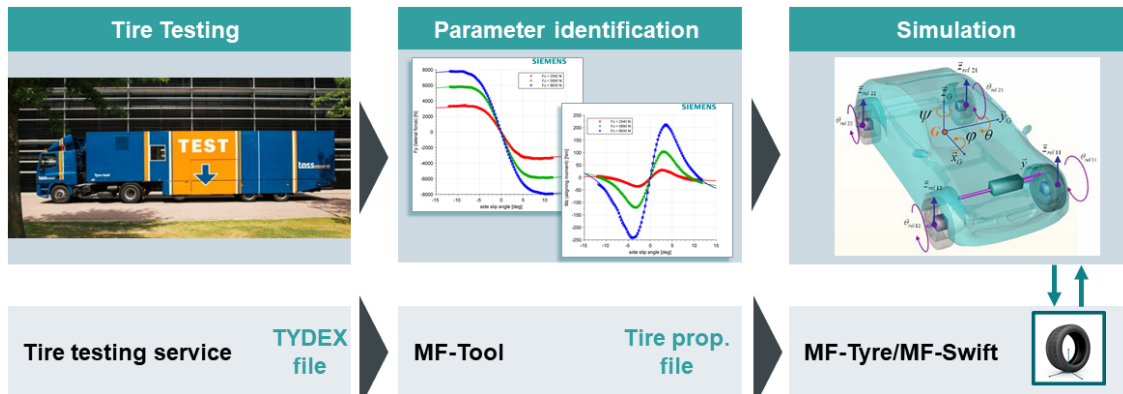


Figure 4.1: The Simcenter Tire tool chain

The tire model MF-Tyre/MF-Swift can be used in vehicle dynamics simulations with all major simulation packages. The model efficiently and accurately represent tire behavior 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'.

With MF-Tyre/MF-Swift you can simulate steady-state and transient behavior up to about 100 Hz, 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.

4.1.1 MF-Tyre/MF-Swift

MF-Tyre/MF-Swift is Simcenter Tire's implementation of the world-standard Pacejka Magic Formula, including the latest developments. MF-Tyre/MF-Swift's semi-empirical approach enables fast and robust tire-road contact force and moment simulation for steady-state and transient tire behavior. MF-Tyre/MF-Swift has been extensively validated using many experiments and conditions. For a given pneumatic tire and road condition, 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.

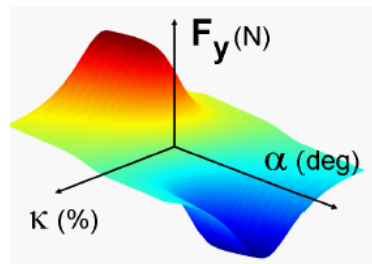


Figure 4.2: Steady-state tire lateral force as a function of longitudinal and lateral slip, calculated using MF-Tyre/MF-Swift

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') and
- 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 up to 100 Hz. An integrated thermodynamic model predicts the evolution of the temperature profile and propagates the effect of the tire temperature into the Magic Formula. Both the rigid ring and thermodynamic model have been extensively validated using measurements of a rolling tire.

Six main elements of the model structure can be distinguished. The first four elements, illustrated in figure 4.3, are primarily based on Pacejka [1] and Besselink [3]. The Simcenter Tire team has made several crucial changes and enhancements in cooperation with Prof. 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.

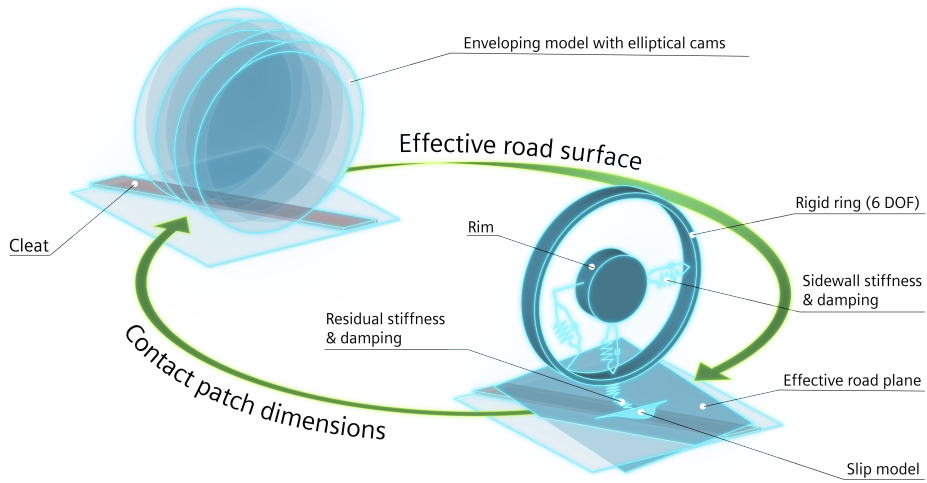


Figure 4.3: Schematic representation of MF-Tyre/MF-Swift.

2. Residual stiffness & damping: have been introduced between contact patch and rigid ring to ensure that the total quasi-static tire stiffnesses in 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 this 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.

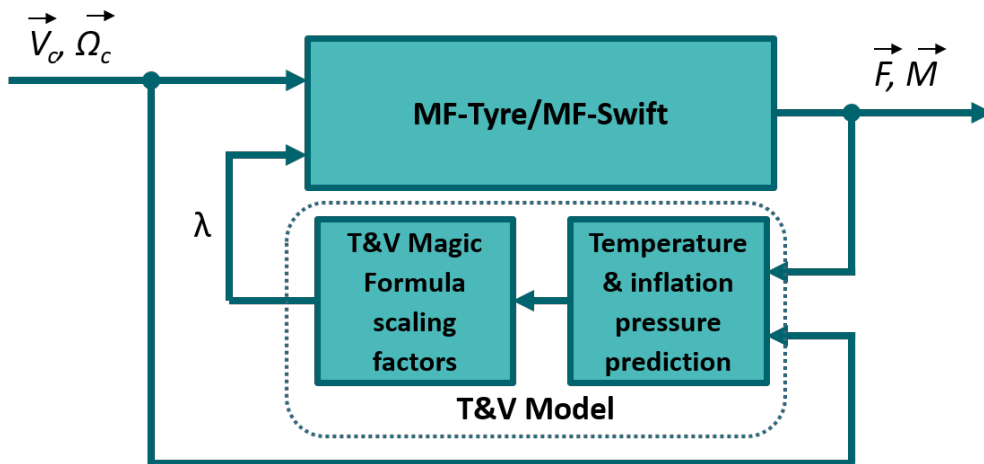


Figure 4.4: Illustration of Temperature & Velocity model in MF-Tyre/MF-Swift.

The fifth and sixth element make up the Temperature and Velocity model as developed by Lugaro et al [4, 5]. With reference to figure 4.4,

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

4.1.2 Model Usage and computational performance

MF-Tyre/MF-Swift is a plug-in to Vehicle Dynamic Simulation (VDS) packages. The VDS package communicates with the tire model following the Standard Tire Interface format, see Riedel [2] for details. The tire model in its turn is communicates with the road model (see Section 4.2.1). The VDS package and the tire model are fed by the Tire Property File (TPF). The VDS package specifies the operating mode of the model, see section 4.2.

The dynamical tire model can be integrated with its own (internal) solver. This internal solver runs at a fixed time step of 1 millisecond. As a result, any simulation that includes this tire model will only obtain an update from the tire model at simulation time steps which are a multiple of 1 millisecond. When calling the tire model at intervals less than 1 millisecond apart, the tire model will return 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 team's Concurrent iHawk Real-Time computer (SimWB 7.9-0, Red-Hawk 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 is referred to section 4.2 of this manual. All results represent the turnaround time of a simulation including:

- A Matlab Simulink model with one tire
- MF-Tyre/MF-Swift 2212 in the form of a Matlab Simulink s-function
- Matlab Simulink ODE-1 solver with 1 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 setting | | | 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 | | | | | |
| x | | x | | x | | disabled | - | - | - | 19 |
| x | | x | | x | | Dyn. + IP | - | - | - | 22 |
| x | | x | | | x | disabled | - | - | - | 21 |
| x | | | x | x | | disabled | - | - | - | 22 |
| | x | | x | x | | disabled | 0.01 | 10 | 10 | 87 |
| | x | | x | x | | disabled | 0.005 | 10 | 10 | 146 |
| | x | | x | x | | disabled | 0.01 | 5 | 5 | 53 |

Note that these figures are meant as a guideline and the computational performance may vary depending on customers specific systems. No rights can be derived from this publication.

4.1.3 Conventions

This section explains the axis system and units, used in MF-Tyre/MF-Swift.

Axis System

MF-Tyre/MF-Swift uses the ISO sign conventions as shown in figure 4.5 below. For a more comprehensive description of the sign convention and axis system, see [1].

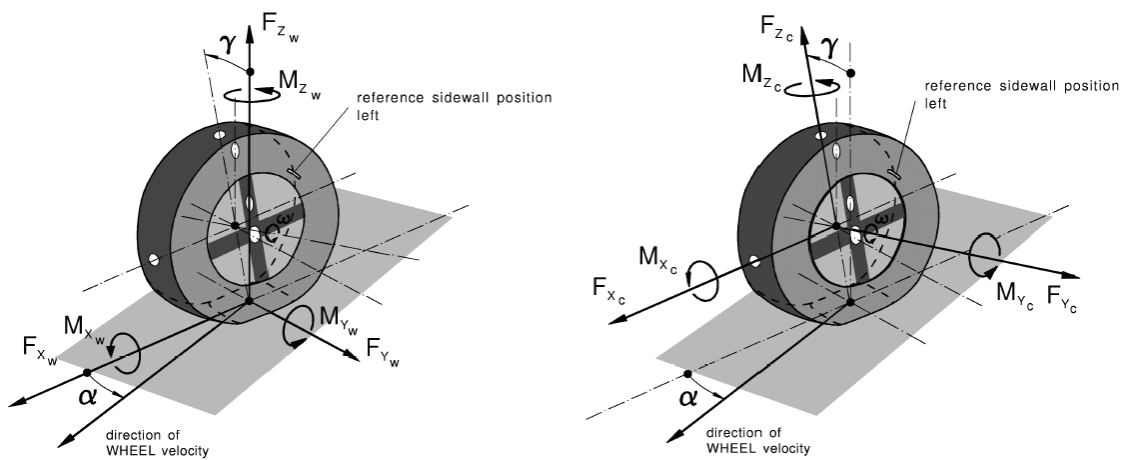


Figure 4.5: ISO sign conventions

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

$$\kappa = -\frac{V_{sx}}{V_x}; \quad (4.1)$$

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

$$\tan(\alpha) = \frac{V_{sy}}{|V_x|}. \quad (4.2)$$

The velocities used in equations (4.1) and (4.2) are

V_x : the x-component (in the wheel center plane) of the wheel contact center horizontal (i.e. parallel to road) velocity V .

V_s : 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. By specifying the appropriate symbol, as denoted in the tables below, for the variables in this section the system of units is set SI. In the [UNITS] section of 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 the steady-state, linear transient and non-linear transient dynamics 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, some require the user to account for the subtraction. Please check the VDS package documentation.

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 | | |
| Linear Transient | - | $m_{tire} + m_{rim}$ |
| Nonlinear Transient | | |
| Rigid Ring | m_{belt} | $m_{tire} + m_{rim} - m_{belt}$ |

4.1.4 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/>.

4.2 Tire Model Operating Modes

The behavior of the tire model is defined by specifying the so-called operating mode. The operating mode is set by defining the:

- type of road that the tire will be driving on (denoted by the road method, see section 4.2.1)
- side on which the tire is mounted in the simulation model (denoted by the tire side, see section 4.2.2)
- tire-road contact evaluation method (denoted by the contact method, see 4.2.3)
- tire dynamics model (denoted by the dynamics mode, see section 4.2.4)
- components of the contact-point force and moment vector when evaluating the Magic Formula (denoted by the slip-force mode, see section 4.2.5).
- which parts of the temperature model are active (denoted by the temperature mode, see section 4.2.7).

The operating mode will be provided to the library via the interface of the simulation package which is being used. Except for the temperature mode, this is done through the ISWITCH parameter as describe in section 4.2.6. How to set the temperature mode is explained in section 4.2.7.

Note: Some operating modes are restricted by the interface between the tire model and simulation package, see corresponding Tutorial for more information.

4.2.1 Road method

For the tire model to generate forces and moments it requires information of the road it is traveling 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 so-called 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 |

Section 4.4 gives a detailed description of the various road method definitions.

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 file are set using the * character. If the keyword CURVTRSF is not found in the header section, then the curvature will be set to 0.0 as a default value.

4.2.2 Tire side

Depending on the conicity and/or ply-steer of a tire, a tire can have asymmetric behavior. Due to this asymmetric behavior it is necessary, in a vehicle 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 to the following values:

| Value | Description |
|-------|---|
| 1 | Tire is mounted on the <i>left</i> side of the vehicle |
| 2 | Tire is mounted on the <i>right</i> 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” (the default is: “LEFT”).

If “TYRESIDE” is “LEFT” and the tire is mounted on the right side of the vehicle (Value = 2), mirroring will be applied on the tire characteristics.

It is also possible to remove asymmetrical behavior from an individual tire by specifying Value = 3.

4.2.3 Contact method

To be able to determine the tire response, the tire model needs to be able to obtain information about the road surface, again see section 4.4. This information is obtained through the tire-road contact method. The following value(s) 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 method that are allowed is listed in the table below:

| | Smooth-road | Enveloping | Moving road |
|-------------------|------------------|-----------------|------------------|
| Default flat road | yes | yes | no |
| OpenCRG road | yes | yes | no |
| External road | yes ² | no ¹ | yes ² |

Notes:

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

Contact Method Enveloping settings This 3D contact method is to be selected 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. See Pacejka [1] for a more detailed description of this contact model and its usage.

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, see table below.

| Parameter | Model section | Description |
|-----------------|-----------------|--|
| ROAD_INCREMENT | [MODEL] | Size of the 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 encountered on this road. (see figure 4.6.) |
| 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 4.7.) However, with more smooth roads or with cleats oriented perpendicular to the X-axis this value can be limited. For faster simulation 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 4.7.) However, with more smooth 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. |

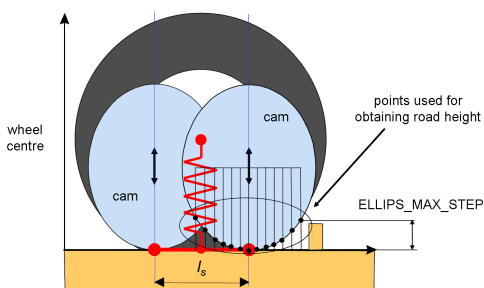


Figure 4.6: graphical explanation of the ELLIPS_MAX_STEP parameter.

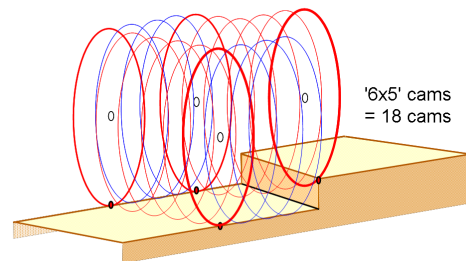


Figure 4.7: an example of 6 parallel cams in the front & rear row and 5 successive cams at both sides.

4.2.4 Dynamics method

The flexibility of the tire carcass, the length of the contact patch, 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 |

The dynamics modes mentioned above distinguish themselves through the complexity of the dynamical model. In the case of Steady-state, no dynamic/transient tire model behavior is included. The linear transient mode incorporates tire relaxation through the usage 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 variations 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 to accurately model the tire dynamic behavior also in a higher frequency range.

Notes:

1. The valid frequency range also depends on the tire type.
2. Rigid ring dynamics + initial statics can be enabled by setting the environment 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 zero will disable initial statics (default setting). Rigid ring dynamics + initial statics is not available on HIL platforms. The setting will be ignored when running on HIL setups.

For a more comprehensive explanation of the tire relaxation, see Pacejka [1].

4.2.5 Slip Forces method

When using MF-Tyre/MF-Swift one has the option to select which components of the force and moment vector one would like to use during the simulation.

The selection of the appropriate slip-forces mode depends in part on the maneuver one tries 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 | | | X | | | | No Magic Formula evaluation |
| 1 | X | | X | | X | | Longitudinal components only |
| 2 | | X | X | X | | X | Lateral components only |
| 3 | X | X | X | X | X | X | All components in uncombined mode |
| 4 | X | X | X | X | X | X | All components in combined mode |
| 5 | X | X | X | X | X | X | All components in combined mode turn slip mode switched on |

For the components see section 4.1.3.

Note: Turn slip functionality is only allowed in combination with Non-linear transient or Rigid ring dynamics mode, also see section 4.2.4. An error message will appear otherwise!

4.2.6 Definition of the ISWITCH parameter

Although most packages use a Graphical User Interface (GUI) to select the operating mode to the tire model, in some cases the operating modes are combined into a single variable called ISWITCH, see Riedel et al [2] for details.

The current ISWITCH parameter is composed by concatenating the integers defining the [road method](#) (E), the [tire side](#) (A), the [contact method](#) (B), the [dynamics mode](#) (C) and the [slip-forces 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/moments;

For backward compatibility reasons the current version 2212 also supports the version 6.2 (4-digit) ISWITCH parameter formulation. In this case the road method is by default set to external road. Note that the rules belonging to the correct combination of contact and road method still apply in this case.

4.2.7 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 will override 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 temperatures (INIT-TREAD, INITLINER, INITCOREAIR, TROAD and TAMB), longitudinal velocity (LONGVVL) 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 onwards.

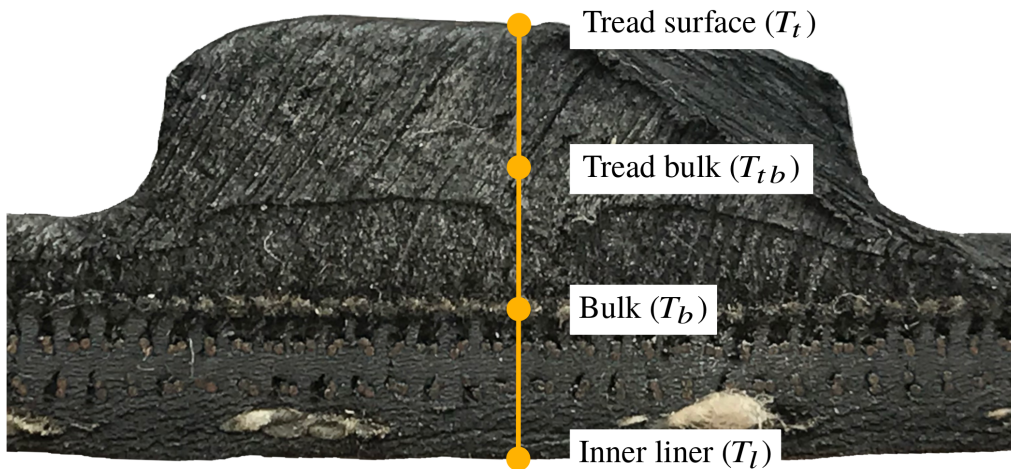


Figure 4.8: Illustration of Temperature & Velocity model in MF-Tyre/MF-Swift. This figure was first published in the SAE technical paper by Lugaro et al [4].

With reference to figure 4.8 (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 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 4.4).

Except for T_b , each of these temperature values is exported as a varinf signal. Section 4.5.2 gives a complete overview of all varinf signals.

The initial condition for the temperature state is 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, TAMB in the same section and all parameters in the [TVX_COEFFICIENTS]-section.

4.3 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 file, called Tire Property File. This file typically has the extension ".tir", although this is not mandatory. The structure and content of the Tire Property File is the subject of this section. Sample Tire property files are included in the installation.

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

4.3.1 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 which are confidential and/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. Model parameters, described in more detail below, 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 user.

TIR-files can be obfuscated with the `mfsswift_tir_obfuscator` tool which is provided with the installer in the obfuscation subdirectory of the installation directory. A password can be optionally used in the obfuscation process, allowing de-obfuscation. The `mfsswift_tir_obfuscator` tool is not required for MF-Tyre/MF-Swift to handle obfuscated data. More detailed information is available in the 'help' of the `mfsswift_tir_obfuscator` which can be obtained by running `mfsswift_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.

4.3.2 Overview

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 effective rolling radius |
| [STRUCTURAL] | tire stiffness, damping and eigenfrequencies |
| [CONTACT_PATCH] | contact length, obstacle enveloping parameters |

Input limitations (only for Magic Formula inputs)

| | |
|----------------------------|---|
| [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 |
| [TURN_SLIP_COEFFICIENTS] | coefficients for turn slip, affects all forces/moments |

Temperature & Velocity Model

| | |
|--------------------|---|
| [TVX_COEFFICIENTS] | coefficients for the temperature and velocity model |
|--------------------|---|

Obfuscated data

| | |
|--------------|--|
| [OBFUSCATED] | Binary data that represents the obfuscated tire parameters |
|--------------|--|

4.3.3 Reduced Input Data Requirements

If no (or limited) measurement data is available, it is also allowed to omit coefficients from the Tire Property File. Built-in procedures will be used to provide a reasonable estimate for the missing data and only a small number of coefficients are needed. The next 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 ^{a)} | Tire inflation pressure |
| FNOMIN | Nominal wheel load |
| VERTICAL_STIFFNESS ^{a)} | Tire vertical stiffness at nominal load and inflation pressure |
| PDX1 ^{a)} | Longitudinal friction coefficient at nominal conditions ^{b)} |
| PKX1 ^{a)} | PKX1*FNOMIN is the longitudinal slip stiffness at the nominal wheel load |
| PDY1 ^{a)} | Lateral friction coefficient at nominal conditions ^{b)} |
| PKY1 ^{a)} | PKY1*FNOMIN is the maximum value of the cornering stiffness versus vertical load characteristic |
| PKY2 ^{a)} | PKY2*FNOMIN is the vertical load at which the cornering stiffness reaches its maximum value |

a) Highly recommended parameter (when not specified the default will be used).

b) 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 wavelength road obstacles are included, even when the related parameters are not explicitly specified.

Notes:

1. Although not strictly required it is recommended to add the enveloping settings discussed in section 4.1.2 to reduced 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 equal 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.

4.3.4 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

1. vertical load is limited to the interval [FZMIN, FZMAX],
2. inflation pressure is limited to the interval [PRESMIN, PRESMAX],
3. wheel slip is limited to the interval [KPUMIN, KPUMAX],
4. slip angle is limited to the interval [ALPMIN, ALPMAX],
5. inclination angle is limited to the interval [CAMMIN, CAMMAX].

Only the first time a limit is exceeded triggers a warning, repeated occurrences are ignored.

4.3.5 Scaling Factors

Tire force and moment testing is often done in a laboratory environment (e.g. using an MTS Flat Trac or a drum). The artificial road surface on the tire test machine may be quite different from a real road surface. Combined with other factors 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 allow the user to manipulate and tune the tire characteristics, for example to get a better match between full vehicle tests and simulation model. Another application of the scaling factors is that they may be used to eliminate some undesired offsets or 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 behavior. The scaling factors are defined in the [SCALING_COEFFICIENTS] section of the Tire Property File (see section 4.3.2).

4.3.6 Parameters In The Tire Property File

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

R: Required parameter

X: Optional parameter

Note: Q_CAM is accepted for FITTYP 61 and above but only effective for FITTYP 61. For all other cases, setting a value to Q_CAM will not have an effect.

| 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 | | | | |

| NAME | DESCRIPTION | FITTYP | | | | |
|-------------------------------|--|--------|----|----|----|---|
| | | 70 | 62 | 61 | 60 | 6 |
| [MODEL] | | | | | | |
| FITTYP | Magic Formula version number | R | R | R | R | R |
| 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 | R | | | | |
| [DIMENSION] | | | | | | |
| UNLOADED_RADIUS | Free tire radius | R | R | R | R | R |
| WIDTH | Nominal section width of the tire | R | R | R | R | R |
| RIM_RADIUS | Nominal rim radius | R | R | R | R | R |
| RIM_WIDTH | Rim width | X | X | X | X | X |
| 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 | R | R | R | R | R |
| 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_REO | Ratio of free tire radius with nominal tire radius | X | X | X | X | |
| Q_V1 | Tire radius increase with speed | X | X | X | X | |
| 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 | |

| NAME | DESCRIPTION | FITYP | | | | |
|------------------------|--|-------|----|----|----|---|
| | | 70 | 62 | 61 | 60 | 6 |
| 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 | |
| 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 yaw 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 | | |

| NAME | DESCRIPTION | FIT TYP | | | | |
|-------------------------------|--|---------|----|----|----|---|
| | | 70 | 62 | 61 | 60 | 6 |
| PCFY3 | Tire overall lateral stiffness pressure dependency | X | X | X | | |
| 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 |
| 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 |
| LVIKA | 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 |

| NAME | DESCRIPTION | FIT TYP | | | | |
|------------------------------------|--|---------|----|----|----|---|
| | | 70 | 62 | 61 | 60 | 6 |
| LSGAL | Scale factor of Relaxation length of Fy | | | | | X |
| LGYR | Scale factor gyroscopic moment | | | | | X |
| [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_COEFFICIENTS] | | | | | | |
| 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 |
| 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 Svz/Fz at Fznom | X | X | X | X | X |
| PVX2 | Variation of shift Svz/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 | |

| NAME | DESCRIPTION | FITYP | | | | |
|-----------------------------------|--|-------|----|----|----|---|
| | | 70 | 62 | 61 | 60 | 6 |
| 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] | | | | | | |
| Q SX1 | Vertical shift of overturning moment | X | X | X | X | X |
| Q SX2 | Camber induced overturning couple | X | X | X | X | X |
| Q SX3 | Fy induced overturning couple | X | X | X | X | X |
| Q SX4 | Mixed load lateral force and camber on Mx | X | X | X | X | |
| Q SX5 | Load effect on Mx with lateral force and camber | X | X | X | X | |
| Q SX6 | B-factor of load with Mx | X | X | X | X | |
| Q SX7 | Camber with load on Mx | X | X | X | X | |
| Q SX8 | Lateral force with load on Mx | X | X | X | X | |
| Q SX9 | B-factor of lateral force with load on Mx | X | X | X | X | |
| Q SX10 | Vertical force with camber on Mx | X | X | X | X | |
| Q SX11 | B-factor of vertical force with camber on Mx | X | X | X | X | |
| Q SX12 | Camber squared induced overturning moment | X | X | X | | |
| Q SX13 | Lateral force induced overturning moment | X | X | X | | |
| Q SX14 | Lateral force induced overturning moment with camber | X | X | X | | |
| PPMX1 | Influence of inflation pressure on overturning moment | X | X | X | | |
| [LATERAL_COEFFICIENTS] | | | | | | |
| PCY1 | Shape factor Cfy for lateral forces | X | X | X | X | X |
| PDY1 | Lateral friction M _{uy} | X | X | X | X | X |
| PDY2 | Variation of friction M _{uy} with load | X | X | X | X | X |
| PDY3 | Variation of friction M _{uy} with squared camber | X | X | X | X | X |
| PEY1 | Lateral curvature E _{fy} at Fznom | X | X | X | X | X |
| PEY2 | Variation of curvature E _{fy} with load | X | X | X | X | X |
| PEY3 | Zero order camber dependency of curvature E _{fy} | X | X | X | X | X |
| PEY4 | Variation of curvature E _{fy} with camber | X | X | X | X | X |
| PEY5 | Variation of curvature E _{fy} with camber squared | X | X | X | X | |
| PKY1 | Maximum value of stiffness K _{fy} /Fznom | X | X | X | X | X |
| PKY2 | Load at which K _{fy} reaches maximum value | X | X | X | X | X |
| PKY3 | Variation of K _{fy} /Fznom with camber | X | X | X | X | X |
| PKY4 | Curvature of stiffness K _{fy} | 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 S _{hy} at Fznom | X | X | X | X | X |
| PHY2 | Variation of shift S _{hy} with load | X | X | X | X | X |
| PHY3 | Variation of shift S _{hy} with camber | | | | | X |
| PVY1 | Vertical shift in S _{vy} /Fz at Fznom | X | X | X | X | X |
| PVY2 | Variation of shift S _{vy} /Fz with load | X | X | X | X | X |
| PVY3 | Variation of shift S _{vy} /Fz with camber | X | X | X | X | X |

| NAME | DESCRIPTION | FITYP | | | | |
|--------------------------------|---|-------|----|----|----|---|
| | | 70 | 62 | 61 | 60 | 6 |
| 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 |
| 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 $\dot{\phi}$ | X | X | X | X | X |
| 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 |

| NAME | DESCRIPTION | FIT TYP | | | | |
|---------------------------------|---|---------|----|----|----|---|
| | | 70 | 62 | 61 | 60 | 6 |
| 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 |
| 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 |
| [TURN SLIP COEFFICIENTS] | | | | | | |
| 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 | |
| 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 | |

| NAME | DESCRIPTION | FITYP | | | | |
|---------------------------|---|-------|----|----|----|---|
| | | 70 | 62 | 61 | 60 | 6 |
| 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 | |
| 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 | | | | |

| NAME | DESCRIPTION | FITYP | | | | |
|--------|---|-------|----|----|----|---|
| | | 70 | 62 | 61 | 60 | 6 |
| PKXT6 | Load dependency of nominal tread bulk temperature for CFk vs T | X | | | | |
| PKXV1 | Gain for CFk vs Vx | X | | | | |
| PKXV2 | CFk at Vx - > 0 and nominal load | X | | | | |
| PKXV3 | Load dependency 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 dependency 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 | | | | |
| 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 | | | | |

| NAME | DESCRIPTION | FITTP | | | | |
|------------|---|-------|----|----|----|---|
| | | 70 | 62 | 61 | 60 | 6 |
| 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 | | | | |
| 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 | | | | |

4.3.7 Version History

To enable the use of old Tire Property Files, MF-Tyre/MF-Swift is backward compatible with older versions. Tire Property Files generated for these tire models will work with MF-Tyre/MF-Swift 2212 and will give the same simulation results as before. The version history is presented in figure 4.9 below.

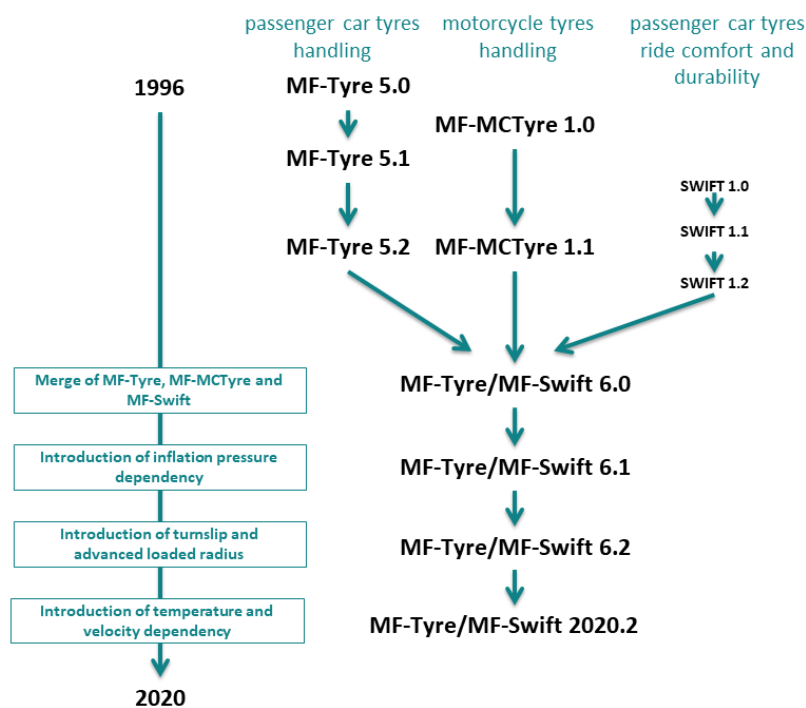


Figure 4.9: Version history of MF-Tyre/MF-Swift

The built-in estimation procedure (recall section 4.3.3), 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 2212.

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 + Temperature & Velocity model |

Note: MF-Tyre/MF-Swift 2212 only accepts the following FITTYP values:

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

It will exit with an error for all other values of the FITTYP parameter.

4.4 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 the Road method section 4.2.1, the tire model supports a number of ways to define the road (surface) definition. These methods are the topic of this chapter and are explained in more detail in each section.

4.4.1 Default Flat Road

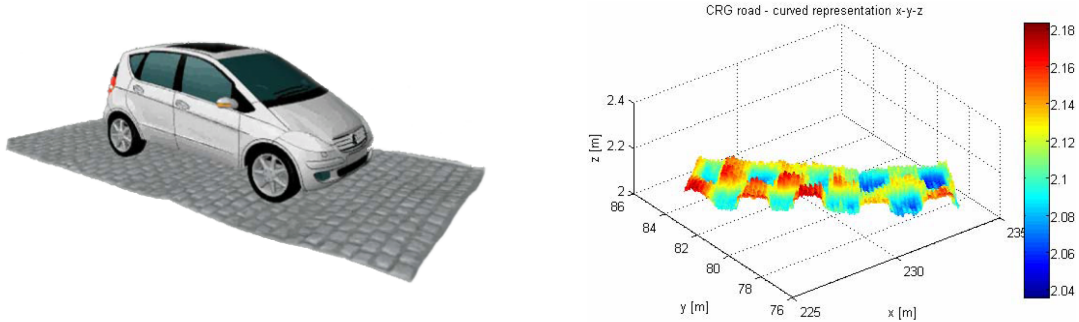
The default flat road surface has a constant road height ($z = 0$ [m] in the global axis system) and constant surface conditions, i.e. friction coefficients of 1 in x- and y-direction and zero road curvature.

Hence it is currently not possible to alter these conditions.

There is no need to specify a road data file.

4.4.2 OpenCRG Road

The OpenCRG Road is the implementation of the interface between MF-Tyre/MF-Swift and [OpenCRG](#), maintained by [Association for Standardization of Automation and Measuring Systems](#), 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 everybody.

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.

Documentation The material for OpenCRG, including documentation, source code and tools, can be found on the [OpenCRG website](#), in the section Download, using the links:

- User Manual
- 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 in MF-Tyre/MF-Swift installation folder.

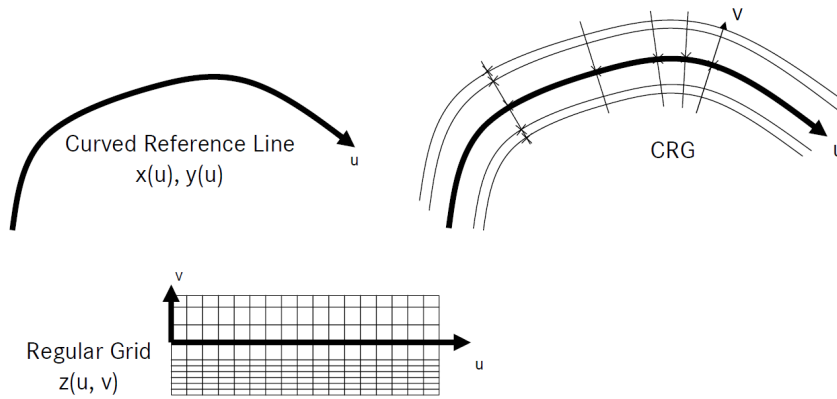
Invitation The founders invite the community to share experiences and would be pleased to have further contributions to complement and extend their initial work.

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 4.10 below.

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 4.10: Curved Regular Grid

Curved Reference Line The Curved Reference Line is defined in the base plane (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 The Regular Elevation Grid, which is locally orthogonal, is a special form of Regular Grid, or Curvilinear or Structured Grid. It 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-2212 > OpenCRG > doc
```

4.4.3 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 will limit the user-defined road surface friction values to the interval (0,2].

See the manuals of the specific VDS package on how to define the road surface.

4.4.4 Road model numerical limitations

While reading data from either [OpenCRG](#) or [External](#) roads, the following limits are applied.

1. Road longitudinal friction and
2. lateral friction are limited to the interval [1e-5, 2.0].
3. 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 a limit is exceeded events triggers a warning, repeated occurrences are ignored.

4.5 Tire Model Output

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

4.5.1 Feedback to Simulation Package

The primary feedback of the tire model to the simulation package consists of the tire force and moment vector 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 (i.e. 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;

y-axis is perpendicular to the wheel plane;

z-axis is perpendicular to the x- and y-axis and pointing upwards (see section 4.1.3).

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] |

| MOMENT | 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] |

4.5.2 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 keyword, signal number or by other methods. In the tables below the available signals are listed.

| Array Index | Variable | Long name | Description | Unit |
|---|--------------|-------------------------------------|---|---------|
| Tire contact forces/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 forward velocity | [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 coefficient | [-] |
| 19 | σ_x | relaxation length longitudinal | longitudinal relaxation length ^(a) | [m] |
| 20 | σ_y | relaxation length lateral | lateral relaxation length ^(a) | [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_{xp} | contact point coordinate y | global y coordinate contact point | [m] |

| Array Index | Variable | Long 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/road camber angle | [rad] |
| Temperature and Velocity model | | | | |
| 51 | T_t | tread surface temperature | see figure 4.8 | [K] |
| 52 | T_{tb} | tread bulk temperature | see figure 4.8 | [K] |
| 53 | T_l | liner temperature | see figure 4.8 | [K] |
| 54 | T_i | core air temperature | - | [K] |
| 55 | P_{infl} | inflation pressure | - | [N/m ²] |

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

Bibliography

- [1] H.B. Pacejka, *Tire and Vehicle Dynamics*, 3rd edition, Butterworth-Heinemann, Oxford 2012.
- [2] A. Riedel, J.J.M. van Oosten, *Standard Tyre Interface, Release 1.4*, Presented at 2nd International Colloquium on Tyre Models for Vehicle Dynamics Analysis, February 20-21 1997, Issued by the TYDEX - Working group.
- [3] I.J.M. Besselink, H.B. Pacejka, A.J.C. Schmeitz, S.T.H. Jansen, *The SWIFT tyre model: overview and applications*, Presented at the AVEC 2004: 7th International Symposium on Advanced Vehicle Control, 23-27 August 2004.
- [4] Lugaro, C., Alirezaei, M., Konstantinou, I., and Behera, A., *A Study on the Effect of Tire Temperature and Rolling Speed on the Vehicle Handling Response*, SAE Technical Paper 2020-01-1235, 2020, doi:10.4271/2020-01-1235
- [5] C. Lugaro, I. Konstantinou, M. Mazzeo, *A Tire model extension for Predicting Temperature and Rolling Speed Influences on Tire performance*, 2020 JSAE Annual Congress Proceedings, 20205081

About Siemens Digital Industries Software

Siemens Digital Industries Software is driving transformation to enable a digital enterprise where engineering, manufacturing and electronics design meets tomorrow. Our solutions help companies of all sizes create and leverage digital twins that provide organizations with new insights opportunities and levels of automation to drive automation For more information on Siemens Digital Industries products and services, visit [siemens.com/software](https://www.siemens.com/software) or follow us on [LinkedIn](#), [Twitter](#), [Facebook](#) and [Instagram](#). Siemens Digital Industries Software - Where today's meets tomorrow

Headquarters: +1 972 987 3000
Americas: +1 314 264 8499
Europe: +44 (0) 1276 413200
Asia-Pacific: +852 2230 3333

Unpublished work Copyright 2022 Siemens. A list of relevant Siemens trademarks can be found [here](#). Other trademarks belong to their respective owners.