SIEMENS

Ingenuity for life

User Manual

Version 2020.2

Simcenter Tire

MF-Tyre/MF-Swift

Siemens Digital Industries Software

Contents

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 2020.2 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 2020.2.

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 2020.2 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 Temperature and Velocity model

The tire model in MF-Tyre/MF-Swift 2020.2 allows for the effects of temperature and velocity to be incorporated in tire behaviour. The underlying model has been developed by and is described by Lugaro et al [4, 5]. This model captures the effect of the tire temperature and rolling speed into appropriate Magic Formula scaling factors. The tire temperature distribution can be:

static : constant tire temperature throughout the complete simulation,

dynamic : tire temperature continuously predicted throughout a simulation.

The T&V (Temperature and Velocity) model comes with a new Magic Formula version, v7.0. This version is indicated in the Tire Property files by means of the `FITTYP` 70. For `FITTYP`$\leq$62 the model will be inactive. Furthermore, the T&V model requires a separate license and 63 temperature-specific tire parameters.

2.1.2 Additional warnings when boundaries are enforced

MF-Tyre/MF-Swift limits input quantities to the Magic Formula and inputs quantities coming from the road model. As of version 2020.2 warnings are issued when these limitations are applied, details are described in 4.3.3 and 4.4.4.

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.

3.1 License Types and Features

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

- MF-Tyre: base model for vehicle handling simulations
- Turnslip: add-on to MF-Tyre for parking and low velocity maneuvering applications
- Rigid Ring: add-on to MF-Tyre representing tire dynamics up to 100Hz
- Enveloping: add-on to MF-Tyre representing tire arbitrary road unevenness passing
- Temperature & Velocity: 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 Rigid Ring Enveloping	MFSwiftTyreModel
Temperature & Velocity	MFSwiftTV

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	MF_SwiftBasic
Turnslip	MF_SwiftTurnslip
Rigid Ring	MF_SwiftRigidRing
Enveloping	MF_SwiftEnveloping
Temperature	MF_SwiftTV

3.2 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 desktop simulations the license file will be locked to a specific computer (a stand-alone machine or license server). Therefore, some information is necessary to identify this computer:

- Host Name
- MAC Address

Section License protection on RT platforms describes the information required to obtain a license for a specific platform.

3.3 License protection on desktop platforms

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

The MF-Tyre/MF-Swift license is protected with Flexera. For Windows, all the required applications are distributed via the license package `mftyre_mfswift-license-2020.2-win64.zip`. This package can be obtained from the product download area. After unzipping in `<installationdir>`, the tools, applications, and libraries needed for the license server manager are part of this package and can be found, in the directory `<installationdir>`/flexlm/bin.

Note: For the license tools for Linux, please contact the sales representative.

The *license server manager*, `lmgrd`, is one of two FLEXnet Licensing components that make up a license server system (the other being the vendor daemon). It handles the initial contact with a MF-Tyre/MF-Swift application, passing the connection on to the appropriate vendor daemon. 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 `madlic`.

A newer `lmgrd` can be used with an older vendor daemon, but a newer vendor daemon might not work properly with an older `lmgrd`. Always use the newest possible version of `lmgrd`, which is available for download from Flexera.

The license server manager, and hence the license server system, must be started before the application can be used.

The license server manager is started either manually on the command line or automatically at system startup. Both methods will be discussed separately for Linux and Windows platforms.

Note: Start `lmgrd` 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 `lmgrd` and the vendor daemons binaries) 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 LINUX Platforms

The license server manager, and hence the license server system, must be started before MF-Tyre/MF-Swift can be used.

The license server manager, `lmgrd`, is started either manually on the command line or automatically at system startup. Both methods are discussed in the following sections.

Manual start

Start `lmgrd` from the LINUX command line using the following syntax:

```
lmgrd -c <license_file_list> -L [+]<debug_log_path>
```

where <license_file_list> is one or more of the following:

- the full path to a single license file,
- a directory, where all files named `*.lic` in that directory are used

and <debug_log_path> is the full path to the debug log file. Prepending <debug_log_path> with the + character appends logging entries.

Start `lmgrd` by a user other than root; recall that processes started by root can introduce security risks. If `lmgrd` must be started by the root user, then use the su command to run lmgrd as a nonprivileged user:

```
su <username> -c "lmgrd -c <license_file_list> -l <debug_log_path>"
```

where <username> is a non-privileged user. You must ensure that the vendor daemons listed in the license file have execute permissions for <username>. The paths to all the vendor daemons in the license file are listed on each VENDOR line.

Automatic start

On LINUX, edit the appropriate boot script, which may be

- `/etc/rc.boot`,

- /etc/rc.local,
- /etc/rc2.d/Sxxx, or
- /sbin/rc2.d/Sxxxx.

Include commands similar to the following. See the following notes for a full explanation.

```
/bin/su daniel -c 'echo starting lmgrd > \
/home/flexlm/v5.12/hp700\_u9/boot.log'

/bin/nohup /bin/su daniel -c 'umask 022; \
/home/flexlm/v5.12/hp700\_u9/lmgrd -c \
/home/flexlm/v5.12/hp700\_u9/license.dat >> \
/home/flexlm/v5.12/hp700\_u9/boot.log' \

/bin/su daniel -c 'echo sleep 5 >>  \
/home/flexlm/v5.12/hp700\_u9/boot.log'

/bin/sleep 5

/bin/su daniel -c 'echo lmdiag >> \
/home/flexlm/v5.12/hp700\_u9/boot.log'
/bin/su daniel -c '/home/flexlm/v5.12/hp700\_u9/lmdiag -n -c\
/home/flexlm/v5.12/hp700\_u9/license.dat >> \
/home/flexlm/v5.12/hp700\_u9/boot.log'

/bin/su daniel -c 'echo exiting >> \
/home/flexlm/v5.12/hp700\_u9/boot.log'
```

Please note the following about how this script was written:

- All paths are specified in full because no paths are assumed at boot time.
- Because no paths are assumed, the vendor daemon must be in the same directory as lmgrd, or the VENDOR lines in the license file must be edited to include the full path to the vendor daemon.
- The su command is used to run lmgrd as a non-root user, **daniel**. It is recommended that lmgrd not be run as root since it is a security risk to run any program as root that does not require root permissions. lmgrd does not require root permissions.
- **daniel** has a csh login, so all commands executed as **daniel** must be in csh syntax. All commands not executed as **daniel** must be in /bin/sh syntax since that is what is used by the boot scripts.

3.3.2 Starting the License Server Manager on Windows

The license server manager, and hence the license server system, must be started before the MF-Tyre/MF-Swift application can be used.

The license server manager, lmgrd, is started either manually on the command line or automatically at system startup. Both methods are discussed in the following sections.

Manual start

This section provides procedural information on manual starts from the command line and how to configure the license server manager as a service.

Start `lmgrd` as an application from a Windows command shell using the following syntax:

```
lmgrd -c <license_file_list> -L [+]<debug_log_path>
```

where <license_file_list> is one or more of the following:

- the full path to a single license file, for example `mfswift.lic`
- a directory, where all files named `*.lic` in that directory are used

and `<debug_log_path>` is the full path to the debug log file. Prepending `<debug_log_path>` with the + character appends logging entries.

Spaces in path-names require double quotes around the path.

On Windows, `lmgrd` can be installed as a service to allow it to be started and stopped through a user interface and run in the background.

Automatic start : Configuring the License Server Manager as a Windows Service

To configure a license server system such that it automatically starts, the license server has to be configured as a service. To set up this service you need to have Administrator privileges on the system.

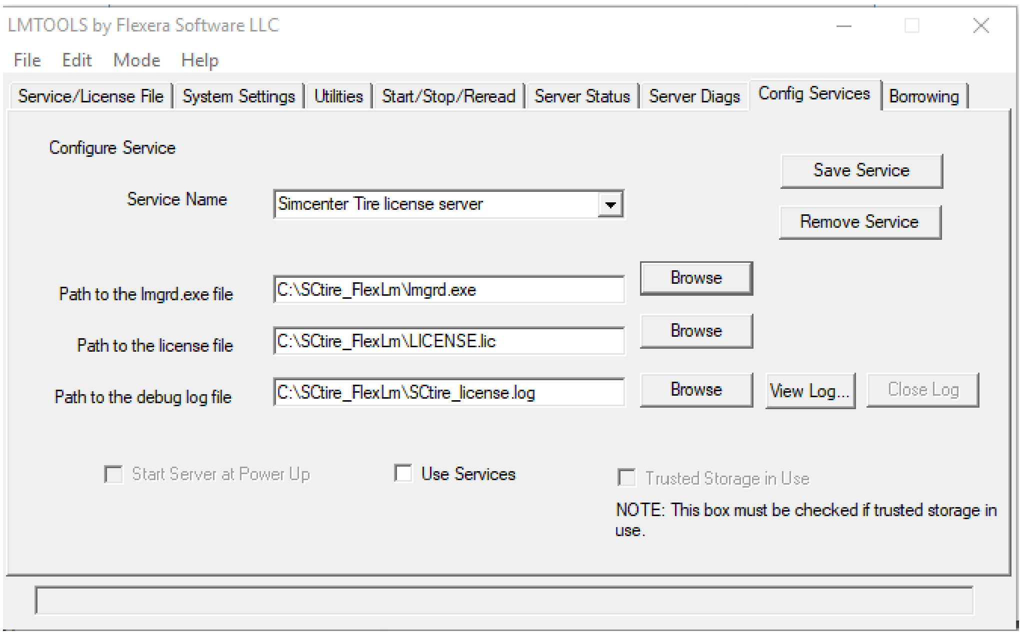
The configuration can be done through the graphical user interface `lmtools`. Some of the functions `lmtools` performs are:

- starting, stopping, and configuring FLEXnet license server systems
- getting system information, including hostids
- getting server status

The detailed steps for configuring `lmgrd` through `lmtools` are:

a) Launch the `lmtools` application, located in the folder `<installationdir>\flexlm\bin`

b) Click the **Configuration using Services** button, and then click the **Config Services** tab.



c) In the **Service Name**, type the name of the service that you want to define, for example, **Simcenter Tire license server**.

d) In the **Path to the lmgrd.exe file** field, enter or browse to lmgrd.exe for this license server system.

e) In the **Path to the license file** field, enter or browse to the license file for this license server system.

> **Note:** The licenses are provided via the local sales representative.

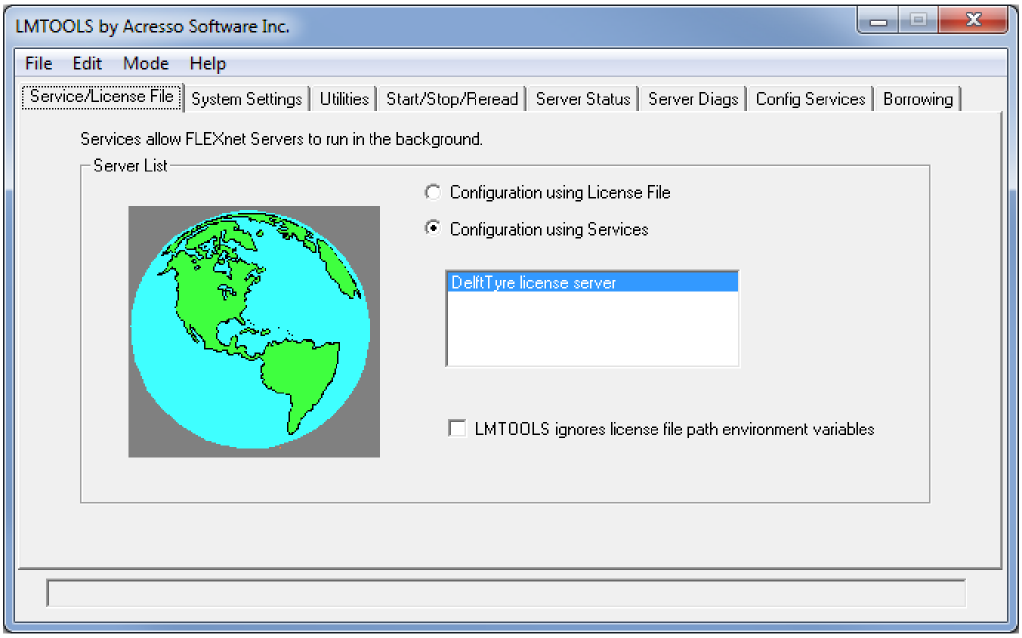
f) In the **Path to the debug log file**, enter or browse to the debug log file that this license server system writes. Prepending the debug log file name with the + character appends logging entries. The default location for the debug log file is the `C:\ProgramData\FNP_DIR folder`. To specify a different location, make sure you specify a fully qualified path. Note that the log file is not automatically created by default. It needs to be created by hand.

g) To save the new service to host the **Simcenter Tire license server**, click Save Service.

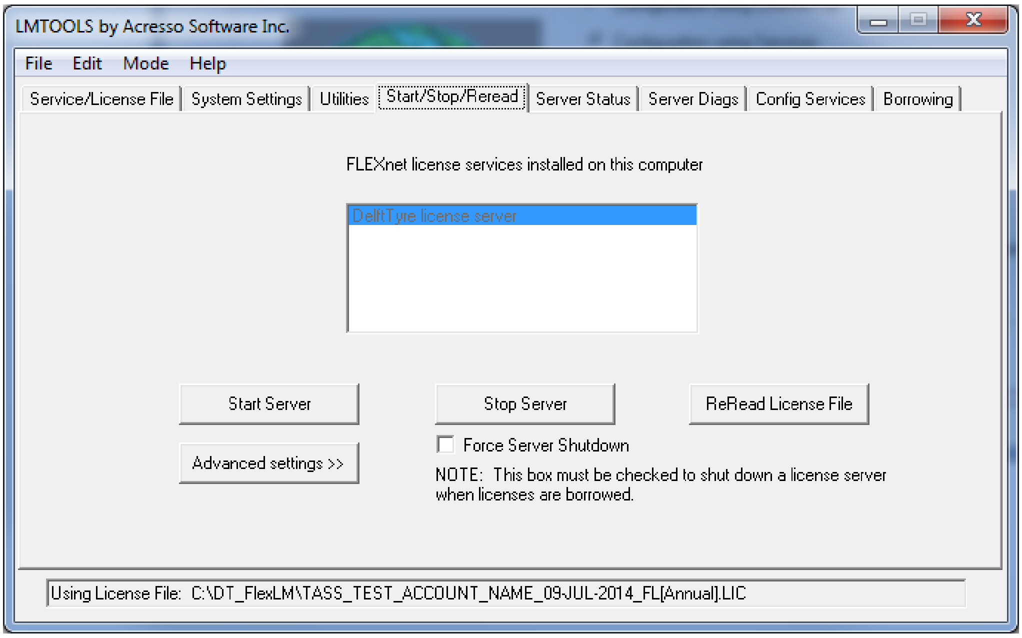
> **Note:** : It is important that both the license file and the log file are accessible, readable and writable for the Windows Local System account. Therefore, `C:\Program Files` and user specific directories are not allowed.

Once the license server manager service is configured, the service, (or rather `lmgrd`) can be started by the following steps:

1. Click **Configuration using Services** button on the **Service/License File** tab.



2. Select the service name from the list presented in the selection box. In this example, the service name is Simcenter license server.
3. Click the **Start**/**Stop**/**Reread** tab.



4. Start license server by clicking the **Start Server** button.
   The license server system starts and writes its debug log output to the defined log-file.
5. Once the license server is started. Set the environment variable MADLIC_LICENSE_FILE on the corresponding machines that will use MF-Tyre/MF-Swift tire model. The environment variable MADLIC_LICENSE_FILE should be set to <portnumber>@<hostname>

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

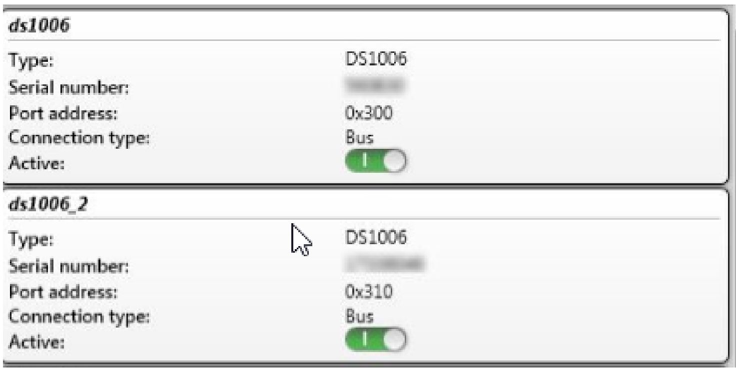
3.4 License protection on RT platforms

On Real-Time platforms (such as dSPACE ds1006, SCALEXIO, 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.



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 Set up Licensing

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. Make sure that your FLEXlm license server is the latest available version
2. The environment variable MADLIC_LICENSE_FILE 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 MADLIC_LICENSE_FILE environment variables or even in the registry.
5. The questions below have been taken from the FLEXlm user guide and are important when you have questions for Simcenter Tire support:
    - What kind of machine is your license server running on?
    - What version of the operating system?
    - What combination of machine and operating system is the application running on?
    - What version of FLEXlm does the FLEXlm-licensed application use? Use the lmutil lmver program. Alternatively, lmgrd -v gives the lmgrd version, and this works with the vendor daemon also.
    - What error or warning messages appear in the log file?
    - Did the server start correctly? Look for a message such as: server xyz started for: feature1 feature2.
    - What is the output from running lmutil lmstat -a?
    - What is the output from running serveractutil –view?
    - Are you running other products which are also licensed by FLEXlm?
    - Are you using a combined license file or separate license files?

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.

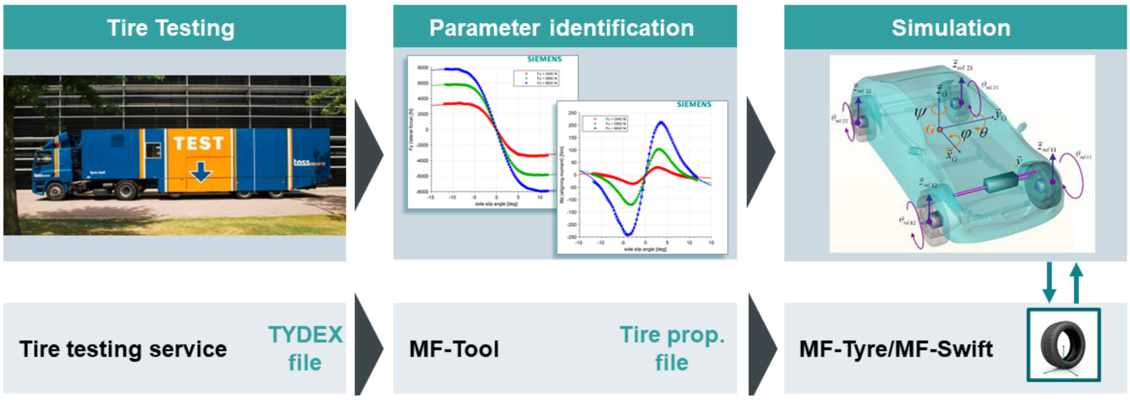


Figure 4.1: The Simcenter Tire tool chain

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.

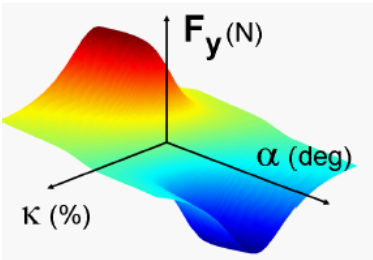


Figure 4.2: Steady-state tire lateral force as a function of longitudinal and lateral slip, calculated using MF-Tyre/MF-Swift

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. A 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.

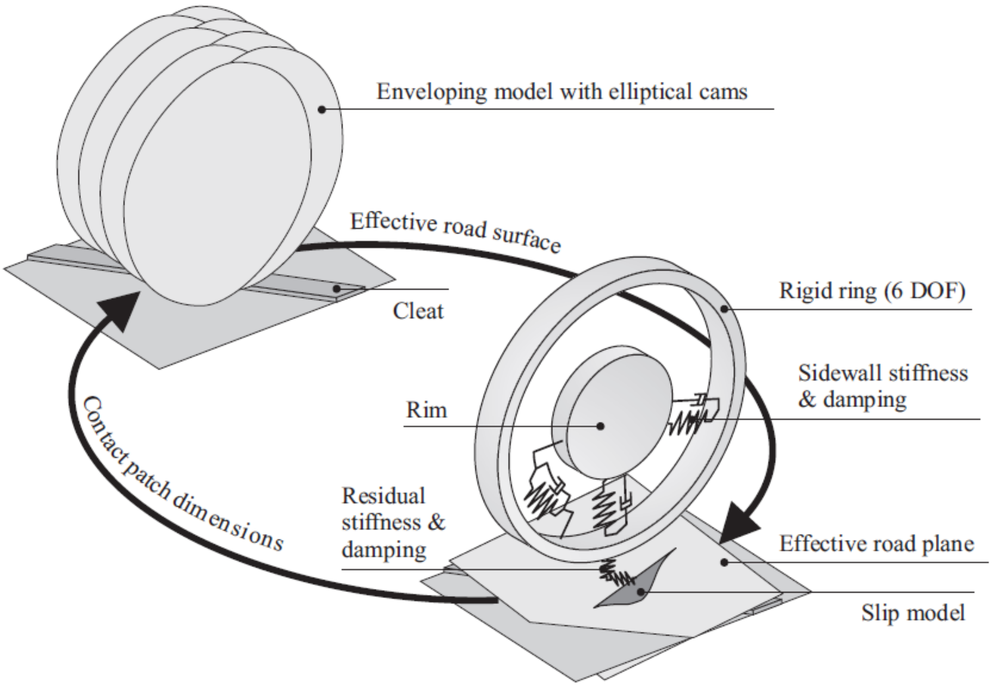


Figure 4.3: Schematic representation of MF-Tyre/MF-Swift.

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.

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.

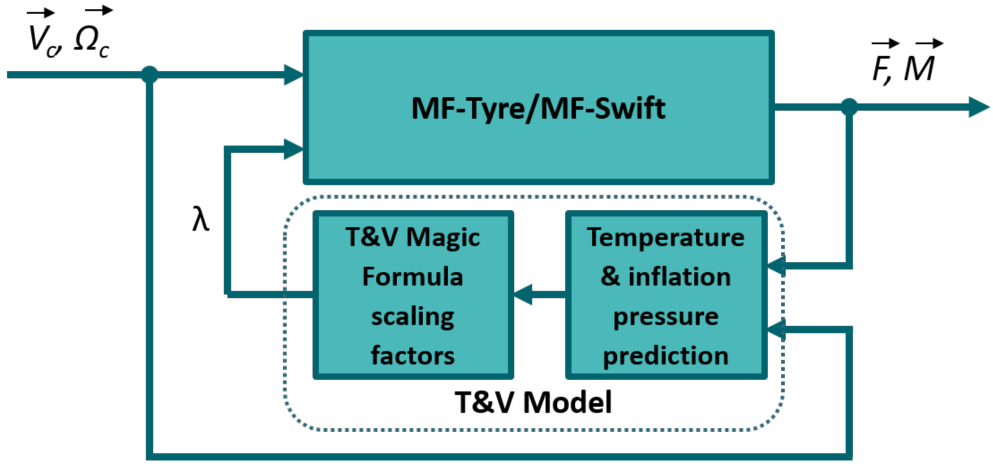


Figure 4.4: Illustration of Temperature & Velocity model in MF-Tyre/MF-Swift.

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 2020.2 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 (μs)
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	155
	x		x	x		disabled	0.005	10	10	274
	x		x	x		disabled	0.01	5	5	91

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].

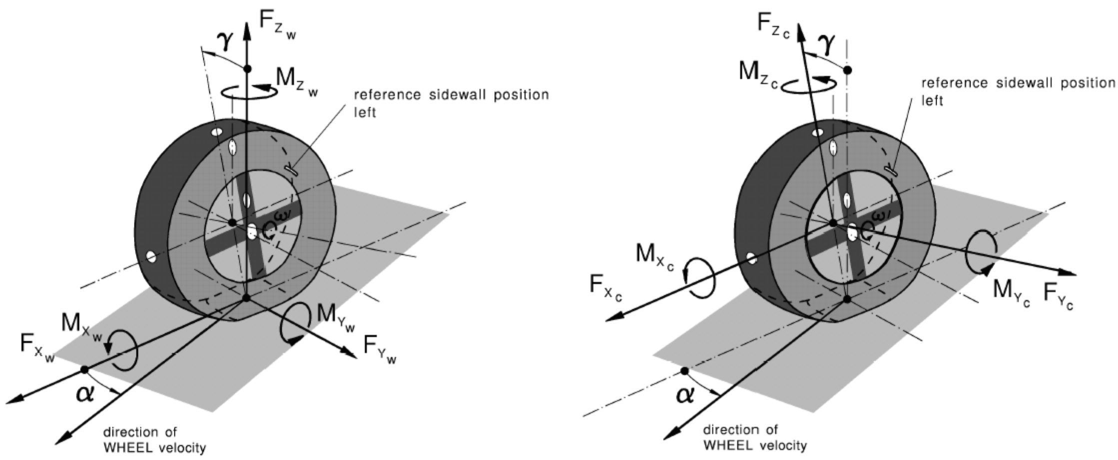


Figure 4.5: ISO sign conventions

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

$$\kappa = -\frac{V_{sx}}{V_x}; \tag{4.1}$$

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 Nonlinear Transient	-	$m_{tire} + m_{rim}$
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 and/or contact via the global Siemens support center platform https://www.plm.automation.siemens.com/global/en/support/.

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.

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

In the Tire Property File, it should be specified how the tire measurement was executed: in other words, if a left or right tire was tested.

In the Tire Property File [MODEL]-section, the keyword TYRESIDE can be set to either "LEFT" or "RIGHT" (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.

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:

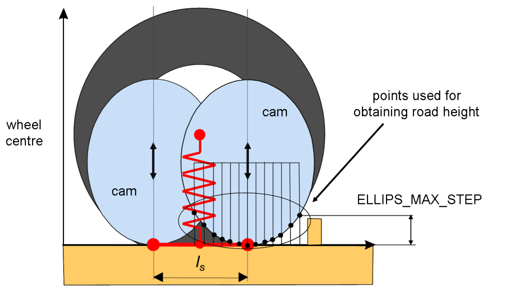


Figure 4.6: graphical explanation of the ELLIPS_MAX_STEP parameter.

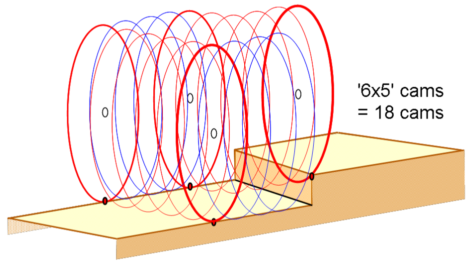


Figure 4.7: an example of 6 parallel cams in the front & rear row and 5 successive cams at both sides.

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 2020.2 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 with the initial temperature values (see below).
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 $\geq$ 70 onwards.

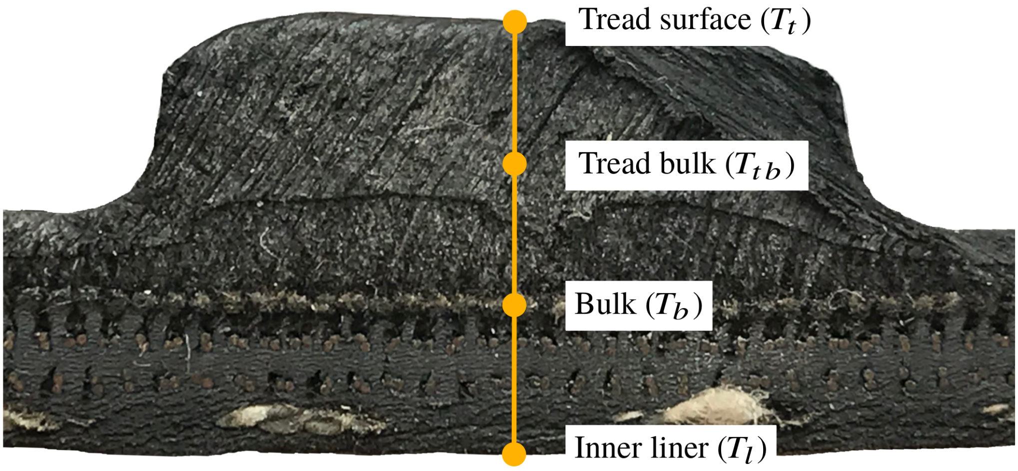


Figure 4.8: Illustration of Temperature & Velocity model in MF-Tyre/MF-Swift. This figure was first published in the SAE technical paper by Lugaro et al [4].

With reference to figure 4.8 (taken from the SAE technical paper by Lugaro et al [4]) the 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).

The initial condition for the temperature state is specified by the three parameters:

INITTREAD	Initial tread surface temperature
INITLINER	Initial inner liner temperature
INITCOREAIR	Initial core air temperature

The evolution of the model is exported as four varinf signals listed in section 4.5.2.

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 or has no default value, MF-Tyre/MF-Swift will show an error message indicating that this parameter is not specified.

4.3.1 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 Fx
[OVERTURNING_COEFFICIENTS]	coefficients for the overturning moment Mx
[LATERAL_COEFFICIENTS]	coefficients for the lateral force Fy
[ROLLING_COEFFICIENTS]	coefficients for the rolling resistance moment My
[ALIGNING_COEFFICIENTS]	coefficients for the self aligning moment Mz
[TURNSLIP_COEFFICIENTS]	coefficients for turn slip, affects all forces/moments

Temperature & Velocity Model

[TEMPERATURE_COEFFICIENTS]	coefficients for the temperature and velocity model

4.3.2 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.

4.3.3 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 occurences are ignored.

4.3.4 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 4.3.1).

4.3.5 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

NAME	DESCRIPTION	FITTYP 70	62	61	60	6
	[UNITS]					
`LENGTH`		X	X	X	X	X
`FORCE`		X	X	X	X	X
`ANGLE`		X	X	X	X	X
`MASS`		X	X	X	X	X
`TIME`		X	X	X	X	X
`TEMPERATURE`		X				
	[MODEL]					
`FITTYP`	Magic Formula version number	R	R	R	R	R
`TYRESIDE`	Position of tire during measurements	X	X	X	X	X

NAME	DESCRIPTION	FITTYP 70	62	61	60	6
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	R				
INITLINER	Initial inner liner temperature	R				
INITCOREAIR	Initial core air temperature	R				
TROAD	Road surface temperature	R				
TAMB	Ambient air temperature	R				
	[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_RE0	Ratio of free tire radius with nominal tire radius	X	X	X	X	
Q_V1	Tire radius increase with speed	X	X	X	X	
Q_V2	Vertical stiffness increases with speed	X	X	X	X	
Q_FZ2	Quadratic term in load vs. deflection	X	X	X	X	
Q_FCX	Longitudinal force influence on vertical stiffness	X	X	X	X	
Q_FCY	Lateral force influence on vertical stiffness	X	X	X	X	
Q_FCY2	Explicit load dependency for including the lateral force influence on vertical stiffness	X	X			
Q_CAM	Stiffness reduction due to camber	X	X	X		

NAME	DESCRIPTION	FITTYP				
		70	62	61	60	6
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 y aw and camber mode	X	X	X	X	
DAMP_WINDUP	Dimensionless damping wind-up mode	X	X	X	X	
DAMP_RESIDUAL	Residual damping (proportional to stiffness)	X	X	X	X	
DAMP_VLOW	Additional low speed damping (proportional to stiffness)	X	X	X	X	
Q_BVX	Load and speed influence on in-plane translation stiffness	X	X	X	X	
Q_BVT	Load and speed influence on in-plane rotation stiffness	X	X	X	X	
PCFX1	Tire overall longitudinal stiffness vertical deflection dependency linear term	X	X	X		
PCFX2	Tire overall longitudinal stiffness vertical deflection dependency quadratic term	X	X	X		
PCFX3	Tire overall longitudinal stiffness pressure dependency	X	X	X		
PCFY1	Tire overall lateral stiffness vertical deflection dependency linear term	X	X	X		
PCFY2	Tire overall lateral stiffness vertical deflection dependency quadratic term	X	X	X		
PCFY3	Tire overall lateral stiffness pressure dependency	X	X	X		
PCMZ1	Tire overall yaw stiffness pressure dependency	X	X	X		

NAME	DESCRIPTION	FITTYP 70	62	61	60	6
	[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			
	[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
LVYKA	Scale factor of kappa induced Fy	X	X	X	X	X
LS	Scale factor of Moment arm of Fx	X	X	X	X	X
LMX	Scale factor of Mx overturning moment	X	X	X	X	X
LVMX	Scale factor of Mx vertical shift	X	X	X	X	X
LMY	Scale factor of rolling resistance torque	X	X	X	X	X
LMP	Scale factor of Mz parking torque	X	X	X	X	
LSGKP	Scale factor of Relaxation length of Fx					X
LSGAL	Scale factor of Relaxation length of Fy					X
LGYR	Scale factor gyroscopic moment					X
	[INFLATION_PRESSURE_RANGE]					
PRESMIN	Minimum allowed inflation pressure	X	X	X		

NAME	DESCRIPTION	FITTYP 70	62	61	60	6
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 Svx/Fz at Fznom	X	X	X	X	X
PVX2	Variation of shift Svx/Fz with load	X	X	X	X	X
PPX1	Linear influence of inflation pressure on longitudinal slip stiffness	X	X	X		
PPX2	Quadratic influence of inflation pressure on longitudinal slip stiffness	X	X	X		
PPX3	Linear influence of inflation pressure on peak longitudinal friction	X	X	X		
PPX4	Quadratic influence of inflation pressure on peak longitudinal friction	X	X	X		
RBX1	Slope factor for combined slip Fx reduction	X	X	X	X	X
RBX2	Variation of slope Fx reduction with kappa	X	X	X	X	X
RBX3	Influence of camber on stiffness for Fx combined	X	X	X	X	
RCX1	Shape factor for combined slip Fx reduction	X	X	X	X	X
REX1	Curvature factor of combined Fx	X	X	X	X	X
REX2	Curvature factor of combined Fx with load	X	X	X	X	X
RHX1	Shift factor for combined slip Fx reduction	X	X	X	X	X
PTX1	Relaxation length SigKap0/Fz at Fznom					X

NAME	DESCRIPTION	FITTYP 70	62	61	60	6
PTX2	Variation of SigKap0/Fz with load					X
PTX3	Variation of SigKap0/Fz with exponent of load					X
	[OVERTURNING_COEFFICIENTS]					
QSX1	Vertical shift of overturning moment	X	X	X	X	X
QSX2	Camber induced overturning couple	X	X	X	X	X
QSX3	Fy induced overturning couple	X	X	X	X	X
QSX4	Mixed load lateral force and camber on Mx	X	X	X	X	
QSX5	Load effect on Mx with lateral force and camber	X	X	X	X	
QSX6	B-factor of load with Mx	X	X	X	X	
QSX7	Camber with load on Mx	X	X	X	X	
QSX8	Lateral force with load on Mx	X	X	X	X	
QSX9	B-factor of lateral force with load on Mx	X	X	X	X	
QSX10	Vertical force with camber on Mx	X	X	X	X	
QSX11	B-factor of vertical force with camber on Mx	X	X	X	X	
QSX12	Camber squared induced overturning moment	X	X	X		
QSX13	Lateral force induced overturning moment	X	X	X		
QSX14	Lateral force induced overturning moment with camber	X	X	X		
PPMX1	Influence of inflation pressure on overturning moment	X	X	X		
	[LATERAL_COEFFICIENTS]					
PCY1	Shape factor Cfy for lateral forces	X	X	X	X	X
PCY2	Shape factor Cfc for camber forces					
PDY1	Lateral friction Muy	X	X	X	X	X
PDY2	Variation of friction Muy with load	X	X	X	X	X
PDY3	Variation of friction Muy with squared camber	X	X	X	X	X
PEY1	Lateral curvature Efy at Fznom	X	X	X	X	X
PEY2	Variation of curvature Efy with load	X	X	X	X	X
PEY3	Zero order camber dependency of curvature Efy	X	X	X	X	X
PEY4	Variation of curvature Efy with camber	X	X	X	X	X
PEY5	Variation of curvature Efy with camber squared	X	X	X	X	
PKY1	Maximum value of stiffness Kfy/Fznom	X	X	X	X	X
PKY2	Load at which Kfy reaches maximum value	X	X	X	X	X
PKY3	Variation of Kfy/Fznom with camber	X	X	X	X	X
PKY4	Curvature of stiffness Kfy	X	X	X	X	
PKY5	Peak stiffness variation with camber squared	X	X	X	X	
PKY6	Fy camber stiffness factor	X	X	X	X	
PKY7	Vertical load dependency of camber stiffness	X	X	X	X	
PHY1	Horizontal shift Shy at Fznom	X	X	X	X	X
PHY2	Variation of shift Shy with load	X	X	X	X	X
PHY3	Variation of shift Shy with camber					X
PVY1	Vertical shift in Svy/Fz at Fznom	X	X	X	X	X
PVY2	Variation of shift Svy/Fz with load	X	X	X	X	X
PVY3	Variation of shift Svy/Fz with camber	X	X	X	X	X
PVY4	Variation of shift Svy/Fz with camber and load	X	X	X	X	X
PPY1	influence of inflation pressure on cornering stiffness	X	X	X		

NAME	DESCRIPTION	FITTYP				
		70	62	61	60	6
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
PTY3	Value of Fz/Fznom where Sig_alpha is maximum					
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 $\hat{4}$	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
QBZ5	Variation of slope Bpt with absolute camber	X	X	X	X	X

NAME	DESCRIPTION	FITTYP 70	62	61	60	6
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
	[TURNSLIP_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	
PKYP1	Cornering stiffness reduction due to spin	X	X	X	X	
PDYP1	Peak Fy reduction due to spin parameter	X	X	X	X	
PDYP2	Peak Fy reduction due to spin with varying load parameter	X	X	X	X	
PDYP3	Peak Fy reduction due to spin with alpha parameter	X	X	X	X	
PDYP4	Peak Fy reduction due to square root of spin parameter	X	X	X	X	
PHYP1	Fy-alpha curve lateral shift limitation	X	X	X	X	

NAME	DESCRIPTION	FITTYP				
		70	62	61	60	6
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	
	[TVX_COEFFICIENTS]					
PPT1	Nominal temperature for nominal inflation pressure	R				
PKXT1	Asymptotic scaling for CFk vs T at T infinite	R				
PKXT2	Exponential gain for CFk vs T	R				
PKXT3	Exponential gain for CFk vs T, linear dependency on Fz	R				
PKXT4	Exponential gain for CFk vs T, quadratic dependency on Fz	R				
PKXT5	Nominal tread bulk temperature at nominal load for CFk vs T	R				
PKXT6	Load dependency of nominal tread bulk temperature for CFk vs T	R				
PKXV1	Gain for CFk vs Vx	R				
PKXV2	CFk at Vx - > 0 and nominal load	R				
PKXV3	Load dependendy for CFk at Vx - > 0	R				
PKYT1	Asymptotic scaling for CFa vs T at T infinite	R				
PKYT2	Exponential gain for CFa vs T	R				
PKYT3	Exponential gain for CFa vs T, linear dependency on Fz	R				
PKYT4	Exponential gain for CFa vs T, quadratic dependency on Fz	R				
PKYT5	Nominal tread bulk temperature at nominal load for CFa vs T	R				
PKYT6	Load dependency of nominal tread bulk temperature for CFa vs T	R				
PKYV1	Gain for CFa vs Vx	R				
PKYV2	CFa at Vx - > 0 and nominal load	R				
PKYV3	Load dependendy for CFa at Vx - > 0	R				
PDXT1	Maximum mux(T)	R				
PDXT2	Temperature at which the mux(T) occurs	R				

NAME	DESCRIPTION	FITTYP				
		70	62	61	60	6
PDXT3	Nominal flash temperature at nominal load for mux(T)	R				
PDXT4	Load dependency of nominal flash temperature for mux(T)	R				
PDXT5	Smoothness of the transient from the maximum the minimum mux(T)	R				
PDXV1	Dependency of the flash temperature for mux(T) on Vx	R				
PDYT1	Maximum muy(T)	R				
PDYT2	Temperature at which the muy(T) occurs	R				
PDYT3	Nominal flash temperature at nominal load for muy(T)	R				
PDYT4	Load dependency of nominal flash temperature for muy(T)	R				
PDYT5	Smoothness of the transient from the maximum the minimum muy(T)	R				
PDYV1	Dependency of the flash temperature for muy(T) on Vx	R				
PEXT1	Dependency of Ex on T for positive slip	R				
PEXT2	Load dependency of Ex on T for positive slip	R				
PEXT3	Dependency of Ex on T for negative slip	R				
PEXT4	Load dependency of Ex on T for negative slip	R				
PEXV1	Dependency of Ex on Vx	R				
PEYT1	Dependency of Ey on T for positive slip	R				
PEYT2	Load dependency of Ey on T for positive slip	R				
PEYT3	Dependency of Ey on T for negative slip	R				
PEYT4	Load dependency of Ey on T for negative slip	R				
PEYV1	Dependency of Ey on Vx	R				
QRR_EM	Tread rubber elasticity storage modulus	R				
QRR_EL	Tread rubber elasticity loss factor	R				
QRR_VX	Rolling resistance dependency on Vx	R				
CPRHO	Tire specific heat capacity per volume	R				
LAMBDA_TR	Heat conductivity treads	R				
LAMBDA_BL	Heat conductivity belt	R				
HCV_IA	Convection liner inner air	R				
HCV_RM	Convection rim inner air	R				
HCV_AA_NOM	Convection treads ambient air at V0	R				
HCV_AA_VX	Convection treads ambient air Vx dependency	R				
HCV_TR	Convection treads road	R				
ETATR1	Partition frictional power road and tread	R				
ETATR2	Partition frictional power dependency on Fz	R				
ETATR3	Partition frictional power dependency on Tt	R				
HCV_TR_VX	Convection treads road Vx dependency	R				
ALSL	Longitudinal slip correction	R				

4.3.6 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 2020.2 and will give the same simulation results as before. The version history is presented in figure 4.9 below.

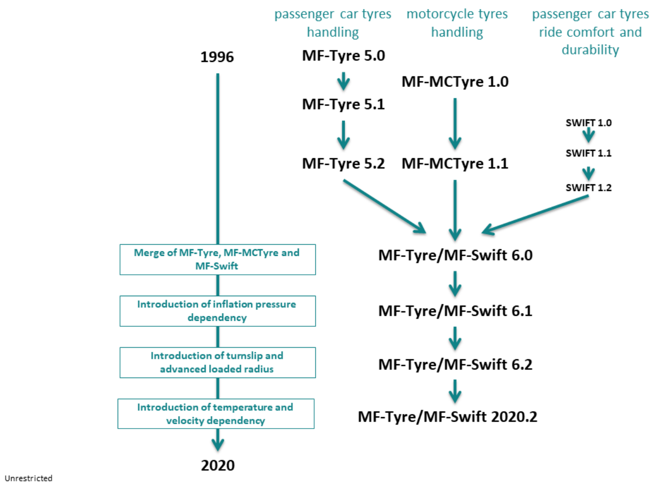


Figure 4.9: Version history of MF-Tyre/MF-Swift

The built-in estimation procedure (recall section 4.3.2), 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 2020.2.

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 2020.2 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

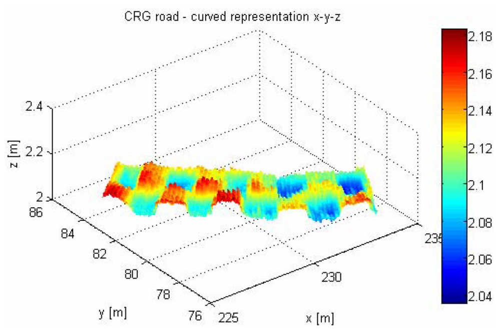
The default flat road surface has a constant road height (z = 0 [m] in the global axis system) and constant surface conditions, i.e. friction coefficients of 1 in x- and y-direction and zero road curvature.

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.

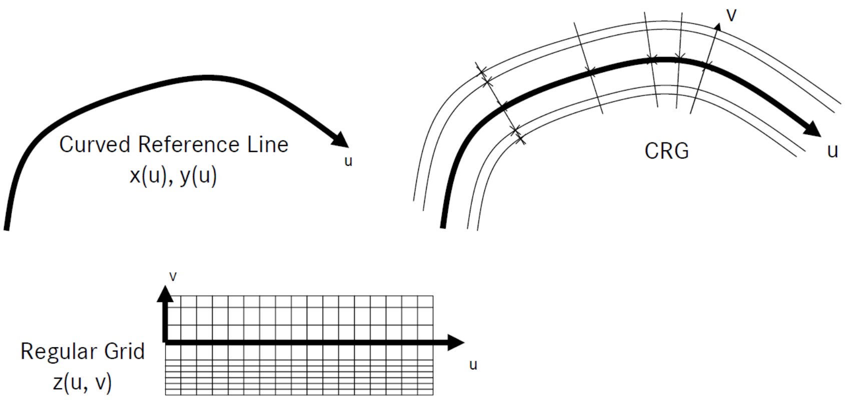


Figure 4.10: Curved Regular Grid

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.

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.

Friction

Friction, or variation of friction over the road surface, is a major issue in handling simulations. In the CRG Road implementation the friction can be modeled in the same way as the road elevation. The data in the CRG file now does not represent elevation anymore, but friction value, or better described the Road Friction Correction Factor, which is multiplied with the other friction (scaling) factors defined elsewhere. This way e.g. mu-split situations can be modeled.

As friction and elevation data are stored in separate files, see below, both files do not need to have the same grid size. Typically, one needs a much higher grid accuracy for the elevation data, than for the friction data. Although not required, mind that the friction and elevation data represent the same road surface.

Note: The start of the friction file is, by default, translated to the origin. This can be overruled by including an (empty) "$ROAD_CRG_MODS" block. In most cases this is required for friction to simulate correctly.

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-2020.2 > 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 occurences 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

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]
33	z_{cp}	contact point coordinate z	global z coordinate	[m]

Array Index	Variable	Long name	Description	Unit
34	n_x	road normal component x	contact point 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 4.4	[K]
52	T_{tb}	tread bulk temperature	see figure 4.4	[K]
53	T_l	liner temperature	see figure 4.4	[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.

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