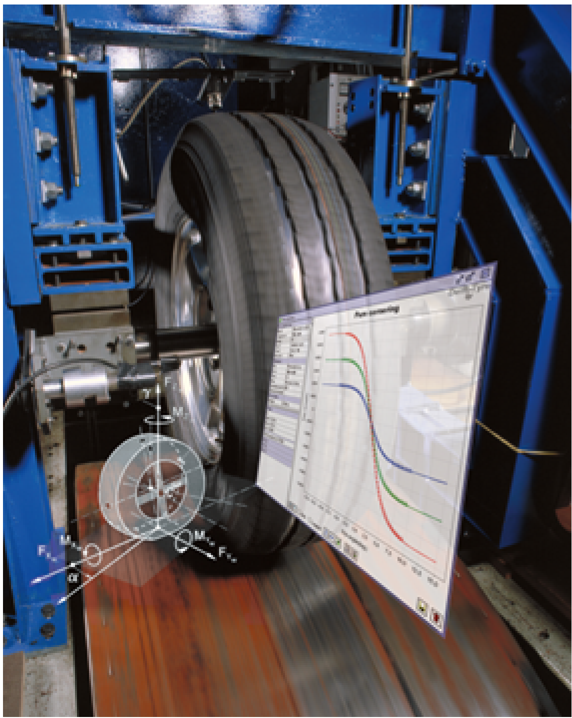
MF-Tyre/MF-Swift 6.2

Help Manual

TNO
The Netherlands
http://www.delft-tyre.nl

Document revision: 10/17/2013



The terms and conditions governing the licensing of MF-Tyre consist solely of those set forth in the document titled ‘License conditions of MF-Tyre software’. The terms and conditions governing the licensing of MF-Swift and MF-Tool consist solely of those set forth in the written contracts between TNO and its customers.

MF-Tool, MF-Tyre and MF-Swift are part of the Delft-Tyre product line, developed at TNO, The Netherlands.

Printed: June, 2013, The Netherlands

delfttyre

Publisher

TNO
PO Box 756
5700 AT Helmond
The Netherlands

Table of Contents

1 Release Notes

1.1 Contents of the 6.2 Release

This chapter describes the most important **changes** between the 6.1.2 and the 6.2 Release of MF-Tyre/MF-Swift.

New Features

- **Loaded radius modelling**
  The loaded radius model is enhanced for situations in which large side slip and large inclination angles occur, such that increased accuracy for these situations is obtained.

- **MF-Swift for motorcycle tyres**
  It is now possible to apply the MF-Swift functionality for motorcycle tyres. More specifically the rigid ring modelling has been validated for motorcycle tyres and the Contact Method for 2D and 3D roads has been extended. This functionality is activated if the motorcycle contour parameters (MC_CONTOUR_A and MC_CONTOUR_B) are defined and nonzero in a MF-Swift 6.2tyre property file (FITTYP = 62). In these cases first the enveloping model is used to determine the effective road plane. Next the motorcycle contact is applied on this effective road plane.
  Additionally, when using the 'smooth road contact, circular cross section (motorcycle tyres)' Contact Method, now also (smooth) uneven road surfaces are supported when using the motorcycle contour parameters (MC_CONTOUR_A and MC_CONTOUR_B).

- **Compatibility on WINDOWS**
  MF-Tyre/MF-Swift is now compatible with the latest versions of **Adams** (**2013**) and **MATLAB** (**R2013a**). For ADAMS 2010 onwards, there is an important **notice**: the default solver has changed from Fortran to C. As there are slight differences between these solvers, extra care should be taken to set the **time-step** and **error** criterion **sufficiently small** when using the C solver.

- **Compatibility with ADAMS road surface modelling**
  MF-Tyre/MF-Swift is now compatible with ADAMS road formats. The 2D and 3D_spline roads can be used with all ADAMS versions. The 3D shell roads can only be used in ADAMS2013. For a complete overview of the compatibility of MF-Tyre/MF-Swift with the different ADAMS road types is referred to the compatibility table in the Adams road formats section.

> **Note**: It is required to add the keyword ROAD_SOURCE = 'MBS' in the tyre property file to select the ADAMS road formats.

- **Tyre property input using a structure (MATLAB only)**
  In MATLAB (R2008a and up) it is now possible to use a MATLAB structure to provide tyre properties to the tyre model. This functionality is available for both the Simulink STI interface and the SimMechanics interface.

- **Flexera FlexLM licensing** 10
  In the MF-Tyre/MF-Swift 6.2 release a different license protection mechanism is used. From release 6.2 onwards the Flexera FlexLM licensing is included instead of Safenet Sentinel RMS.

Enhancements

- **Turn slip modelling**
  In cooperation with Prof. Pacejka the turn slip implementation has been reviewed and updated. The theory can be found in the latest version of the book: Hans Pacejka, "Tyre and Vehicle Dynamics", third edition, SAE International, 2012. With the updated model, several issues are solved concerning:
  - driving from and to standstill while steering;

- driving forward and backward while steering and/or cambering;
- steering at standstill for non centre-point steering conditions.

Note that for turn slip modelling only Dynamics Modes 24 "non-linear transient" and "rigid-ring" are supported. When using a Dynamics Mode 24 "steady-state" or "linear transient" in combination with turn slip the Dynamics Mode 24 is automatically reset to "non-linear transient".

- **Estimation methods**
  The estimation methods for determining the MF-Swift parameters have been strongly updated. The new sophisticated estimation methods make use of a combination of a model of the physical tyre structure and ermperical knowledge.

- **ADAMS interface**
  The interface with ADAMS is updated in order to comply with the latest standards. By means of this enhancement it is no longer required to work with dedicated ADAMS solvers that include the MF-Tyre/MF-Swift interface. Moreover the SmartDriver functionality in ADAMS 2011 and upward is now supported. The ADAMS documentation explains in detail how to work with the new interfacing method.

Note: The updated interface with ADAMS requires an update of all MF-Tyre/MF-Swift tyre property files.
The lines:

```
USER_SUB_ID              = 815
N_TIRE_STATES            = 4
```

must be replaced by:

```
FUNCTION_NAME            = 'TNO_DelftTyre_Adams_interface::TYR815'
N_TIRE_STATES            = 5
```

- **MATLAB interface**
  The interfaces with MATLAB Simulink and SimMechanics have been extended in order to support the MF-Tyre/MF-Swift release 6.2 model extensions and enhancements.

- **OpenCRG**
  MF-Tyre/MF-Swift 6.2 supports **OpenCRG** release 1.0.5. For details about changes please check the website www.OpenCRG.org.

Bug Fixes

- **ADAMS quasi-statics initialisation**
  The robustness of MF-Tyre/MF-Swift during a quasi-statics initialisation in ADAMS is improved.

- **Visual C++ 2008 redistribution packages** are now shipped with the MF-Tyre/MF-Swift for users without (implicit) C++ libraries installed.

- For release 6.2 the `OFFSET` parameter (vertical offset of the ground w.r.t. the inertial frame) will be taken into account for a Poly_line road with [UNITS] LENGTH = 'meter'.

- Help button in MATLAB Simulink and SimMechanics mask working for Matlab 2011a and up.

Discontinued

From MF-Tyre/MF-Swift release 6.2 the compatibility with the following simulation packages be discontinued:
- DADS; all versions
- ADAMS; versions 2005r2 and lower
- MATLAB; versions 2007b and lower

From MF-Tyre/MF-Swift release 6.2 the compatibility with the following operating systems be discontinued:
- WINDOWS; versions 2000 and Vista

Known Issues

- When using a fixed-step solver for the Dynamics Mode 24 **tyre relaxation behaviour (< 10 Hz, nonlinear)**, the time-step of the simulation should be chosen small enough for the simulation to produce correct results. A variable-step solver will automatically reduced the time-step when required.

- The moving road functionality is not supported in ADAMS

2 Compatibility Table

The MF-Tyre/MF-Swift models are available for a wide variety of multi-body simulation packages. We may distinguish between:

Coupling with MBS package done by TNO

Adams (MSC software)
MATLAB/Simulink (MathWorks)

Coupling with MBS package done by MBS package supplier

Recurdyn (FunctionBay)
CarSim/TruckSim/BikeSim (Mechanical Simulation Corporation)
Dymola (Modelon) (NOTE: Modelon delivers a general Modellica interface)
AVL software (AVL)
SAMCEF (LMS Samtech)
MotionSolve (Altair)
DAFUL (VirtualMotion)
VI-CarRealTime (VI-Grade)
Virtual.Lab (LMS)
SIMPACK (SIMPACK AG)
MADYMO (TASS)

The corresponding compatibility table is shown below.

Multi-body package	Version	Win32 **	Win64 ***
Adams	2008r1	x	x
	2010	x	x
	2011	x	x
	2012	x	x
	2013	x	x
MATLAB/Simulink	2008a and up	x	x
Recurdyn	*	*	*
CarSim/TruckSim/BikeSim	*	*	*
Dymola	*	*	*
AVL software	*	*	*
SAMCEF	*	*	*
MotionSolve	*	*	*
DAFUL	*	*	*
VI-CarRealTime	*	*	*
Virtual.Lab	*	*	*
SIMPACK	*	*	*
MADYMO	*	*	*

*: Availability depends on the implementation in the respective multi-body packages.
**: Win32 includes Windows XP, Windows 7
***: Win64 includes Windows XP Professional x64 Edition, and Windows 7 (64-bit)

3 License Manual

This chapter contains information regarding the license system necessary to run the Delft-Tyre products. Licensing is used in two ways in this chapter: licensing regarding terms and conditions, and licensing as a mechanism to protect the software from unauthorized use. The context will reveal the meaning.

The terms and conditions governing the licensing of **MF-Tyre** consist solely of those set forth in the document titled 'License conditions of MF-Tyre software'. The terms and conditions governing the licensing of **MF-Swift**, **MF-Tool** and other Delft-Tyre software consist solely of those set forth in the **written contracts** between TNO and its customers.

MF-Tyre/MF-Swift includes OpenCRG, licensed under the Apache License, Version 2.0.

The software is protected / licensed with Flexera. Licensed products include:

- MF-Swift
- MF-Tool

Note: For MF-Tyre no license is required.

Note that the license information described holds for Delft-Tyre Release 6.2 products. The licensing tools are distributed via the installer.

In the remainder of this document the following convention is used:
- `installationdir`: The full path of the directory where the Delft-Tyre product is installed, including the version, for example: C:\TNO Delft-Tyre\MF-Tyre MF-Swift 6.2.

3.1 Licensing Set Up

Available License type

Delft-Tyre is licensed by the feature licenses which allows a specific Delft-Tyre module to run. A single license for the given feature name is checked out when feature based licenses are used. The licensing mechanism supports floating and node-locked licenses. No uncounted node-locked licenses are offered for native Delft-Tyre licensing.

Obtaining a license

The various licenses for Delft-Tyre products can be retrieved via your Delft-Tyre sales representative. The Delft-Tyre license will be locked to a specific computer (a stand-alone machine or license server). Therefore some information is necessary to identify this computer, which is the host name and MAC address.
On Windows this can be obtained by typing: "ipconfig /all" in a command window.
On Linux the host name can be obtained by typing: "cat etc/hostname" in a terminal and for the MAC address type: "ifconfig".

Install clients

The Delft-Tyre license server(s) has(have) to be specified by the **MADLIC_LICENSE_FILE** environment variable. This environment variable is used by the applications to find the license server. When no license server is specified via the environment variable, the license server defaults to port 26000 on the local machine (26000@localhost). This is valid for both multiple stack and single stack licenses.
The environment variable can be modified by opening the “Environment Variables” menu of your Windows installation (right click “My Computer”, select “Properties” (and "Advanced System Settings" if using Windows 7), and select the “Advanced” tab. Press the “Environment Variables” button and edit the **MADLIC_LICENSE_FILE** environment variable.

The environment variable **MADLIC_QUEUE_MAX_MINUTES** determines the time an application stays queued if no licenses are available in batch mode. The variable has the following meaning:

- If set to 0, no queuing takes place, the application will terminate
- If not set, the application is queued for 60 minutes where each minute a check is done if licenses have become available.
- If set to any x >0, the application will queue for x minutes where each minute a check is done if licenses have become available

License server

The tools, applications, and libraries needed for the license server manager are part of the distribution and packaged in a separate subdirectory. The directory is named `installationdir/FlexLM`.

3.2 The License Server Manager

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 Delft-Tyre application, passing the connection on to the appropriate vendor daemon. The purpose of the license server manager, `lmgrd`, is to:

- Start and maintain all the vendor daemons listed in the VENDOR lines of the license file.
- Refer application checkout (or other) requests to the correct vendor daemon, for example `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 version of `lmgrd` as possible, which is available for download from Flexera.

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

lmgrd Command-Line Syntax

`lmgrd` is the main daemon for FLEXnet Licensing. When you invoke `lmgrd`, it looks for a license file that contains information about vendors and features and starts those vendor daemons.

3.2.1 Starting the License Server Manager on UNIX Platforms

The license server manager, and hence the license server system, must be started before the Delft-Tyre 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.

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 loose all the advantages of having redundant servers, since the file server holding these files becomes a single point of failure.*

3.2.1.1 Manual Start

Start `lmgrd` from the UNIX 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
- `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 since processes started by root can introduce security risks. If `lmgrd` must be started by the root user, 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.

3.2.1.2 Automatic Start

On UNIX, edit the appropriate boot script, which may be `/etc/rc.boot, /etc/rc.local, /etc/rc2.d/Sxxx, /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.

Note: *This does not start the daemon until you reboot your license server machine.*

3.2.2 Starting the License Server Manager on Windows

The license server manager, and hence the license server system, must be started before the Delft-Tyre 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.

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 loose all the advantages of having redundant servers, since the file server holding these files becomes a single point of failure.*

3.2.2.1 Manual Start

It is not uncommon for the License Server Manager to be started on a Windows platform. This section provides procedural information on manual starts from the command line and how to configure the License Server Manager as a service.
To start `lmgrd` from the command line:

1. Start `lmgrd` as an application from a Windows command shell using the following syntax:
   ```
   C:\TNO Delft-Tyre\MF-Tyre MF-Swift 6.2.0\FlexLM> 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
   - `debug_log_path` is the full path to the debug log file

   Prepending `debug_log_path` with the + character appends logging entries.

Spaces in pathnames 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.

3.2.2.2 Automatic Start

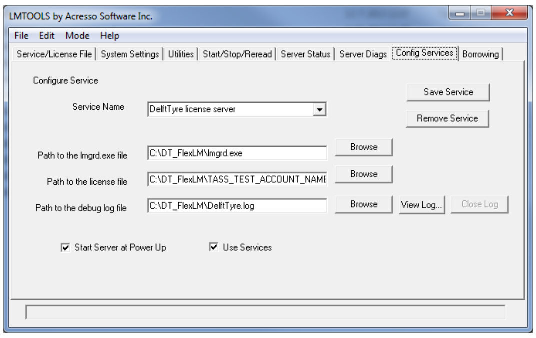
To configure a license server system such that it automatically starts, the license server has to be configured as a service, you must have Administrator privileges for this.

To configure a license server system as a service a graphical user interface to the license server manager tools is provided called LMTOOLS. Some of the functions LMTOOLS performs include:

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

In order to control the operation of `lmgrd`, and hence the license server system, from the LMTOOLS user interface, you first must configure it as a license server manager service like:

1. Run the file *lmtools.exe* which can be found in the folder `installationdir\FlexLM`.
2. Click the **Configuration using Services** button, and then click the **Config Services** tab.
3. In the **Service Name**, type the name of the service that you want to define, for example, **Delft-Tyre license server**.
4. In the **Path to the lmgrd.exe file** field, enter or browse to lmgrd.exe for this license server system.
5. 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.
6. 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:\winnt\System32` folder. To specify a different location, make sure you specify a fully qualified path. Note that the log file is not automatically created. It needs to be created by hand.
7. In order for the license server system to start up automatically at system start-up time:
   7.1. Make this license server manager a Windows service by selecting the **Use Services** check box (otherwise, it becomes a FLEXnet Licensing service).
   7.2. Configure it to start at system startup time by selecting the **Start Server at Power Up** check box.
   From now on, when the machine is rebooted, this license server manager starts automatically as a Windows service



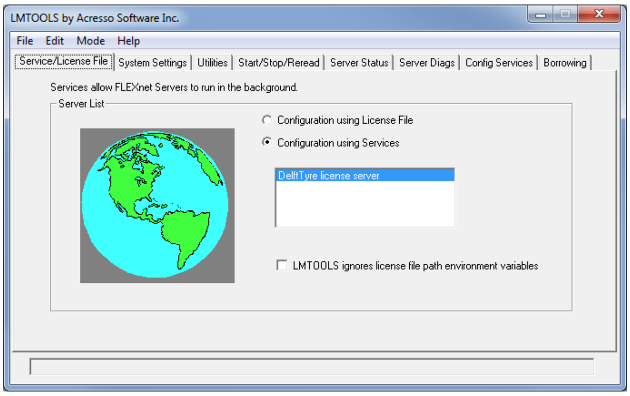
Service Name: DelftTyre license server
Path to the lmgrd.exe file: C:\DT_FlexLM\lmgrd.exe
Path to the license file: C:\DT_FlexLM\TASS_TEST_ACCOUNT_NAME
Path to the debug log file: C:\DT_FlexLM\DelftTyre.log
☑ Start Server at Power Up
☑ Use Services

8. To save the new **Delft-Tyre license server** service, click **Save Service**.

Once the license server manager service is configured, `lmgrd` is started by starting the service from the LMTOOLS interface.

To start the service from the LMTOOLS interface:

1. Click **Configuration using Services** button.



Services allow FLEXnet Servers to run in the background.

Server List

○ Configuration using License File

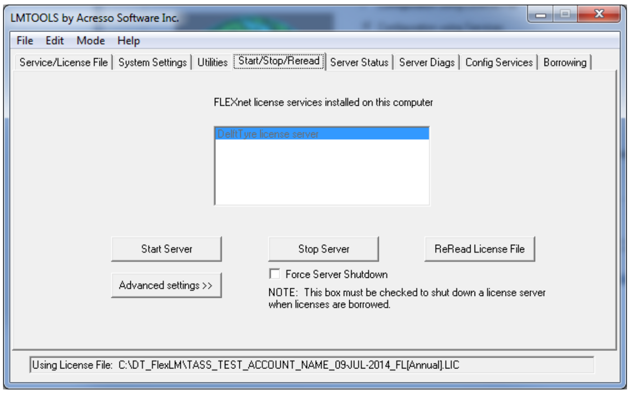
● Configuration using Services

DelftTyre license server

☐ LMTOOLS ignores license file path environment variables

2. Select the service name from the list presented in the selection box. In this example, the service name is **DelftTyre license server**.

3. Click the **Start/Stop/Reread** tab.



FLEXnet license services installed on this computer

DelftTyre license server

☐ Force Server Shutdown

NOTE: This box must be checked to shut down a license server when licenses are borrowed.

Using License File: C:\DT_FlexLM\TASS_TEST_ACCOUNT_NAME_09JUL-2014_FL[Annual].LIC

5. Start **DelftTyre license server** by clicking the **Start Server** button.

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

3.3 License Troubleshooting Guide

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 enforce to look locally on your system if the machine is detached from the network.

3. Considerable delays in start up of the applications have been noticed if the license file contains license strings of which the end date has expired.

4. Considerable delays in start up 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 Delft-Tyre Support:

   - What kind of machine is your license server running on?
   - What version of the operating system?
   - What machine and operating system is the application running on?
   - What version of FLEXlm does the FLEXlm-licensed application use? Use the lmver script, or, on Linux, execute the following command on your lmgrd, vendor daemon, and application: strings binary_name | grep

copy. 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?
- Are you using a three-server redundant license server (multiple SERVER lines in your license file)?

6. Set the environment variable FLEXLM_TIMEOUT to 10000000. Its value is in microseconds and corresponds to 10 seconds. As the name suggests it sets a timeout value of 10 seconds to contact the FLEXlm server. This should be considered to be a last resort in case of failing license checkouts.

4 Technical Support

Support is provided to those who have a support contract.

Categories

Support categories (among others):
- Bugs
- Request for enhancements / new features
- Installation help
- Application help

Supported multi-body packages

TNO provides (direct) support for the following multi-body packages
- Adams
- MATLAB / Simulink / SimMechanics

For other multi-body packages support can be requested at the respective multi-body package used. If required the multi-body package will contact TNO to solve the issue. Requests for enhancements and / or new features may also be asked directly.

Checklist

Before asking support, make sure you followed all steps as described in the Simulation Guidelines.Especially step 9), checking model messages, is encouraged to carry out.

Required information

To be able to provide you support, we need to be able to reproduce your issue. When asking support, please provide the following:
- MF-Tyre/MF-Swift and multi-body package release number
- Brief summary of the issue
- Reproduction path: what steps did you take for the issue to occur
- Error message: exact error message, preferably complete text or screenshot
- If allowed: Models* used for the issue to occur (don't forget the include files)

* **Note**: We understand your hesitation to share your models with us, since they may contain **property knowledge** or project / company **restricted information**. TNO will always treat your information as confidential unless otherwise stated.

Support

Finally, send your support request to the following mail address, or your current contact at the Delft-Tyre group:

Mail: Support-DelftTyre@tno.nl

4.1 Contact Information

Other contact information.

Sales

Contact information can be found on our website or may be reached by e-mail.
Website www.delft-tyre.nl
Mail DelftTyre@tno.nl

Support

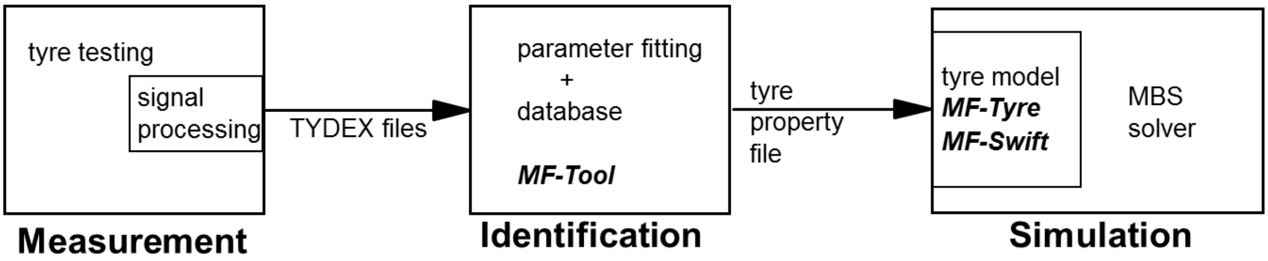
Support may be reached by e-mail:
Mail: Support-DelftTyre@tno.nl

5 User Manual

This chapter is the User Manual of MF-Tyre/MF-Swift.

5.1 Introduction

The contact interaction between tyres and the road largely affects the driving performance of vehicles. Automotive engineers are optimising the tyre-road interaction so that the vehicle handles well and operates both safely and comfortably under any circumstance. To analyse the influence of tyre properties on the dynamic behaviour of vehicles, the engineer requires an accurate description of the tyre-road contact phenomena. TNO Delft-Tyre provides a complete chain of tools and services for detailed assessment and modelling of vehicle-tyre-road interaction.



TNO Delft-Tyre chain of tools for tyre analyses.

The tyre models MF-Tyre 20 and MF-Swift 21 can be used in vehicle dynamics simulations in all major simulation packages to efficiently and accurately represent tyre behaviour for applications ranging from steady-state to complex high frequency dynamics. MF-Tyre and MF-Swift contain the latest implementation by Delft-Tyre of Pacejka's renowned 'Magic Formula' tyre model.

With MF-Tyre you can simulate steady-state and transient behaviour, making it a suitable tyre model for:
- vehicle handling,
- control prototyping,
- rollover analysis, or

With MF-Swift you can simulate tyre dynamic behaviour up to about 100 Hz, which is particularly useful for
- vehicle comfort,
- durability,
- vehicle control prototyping, or
- vibration analysis

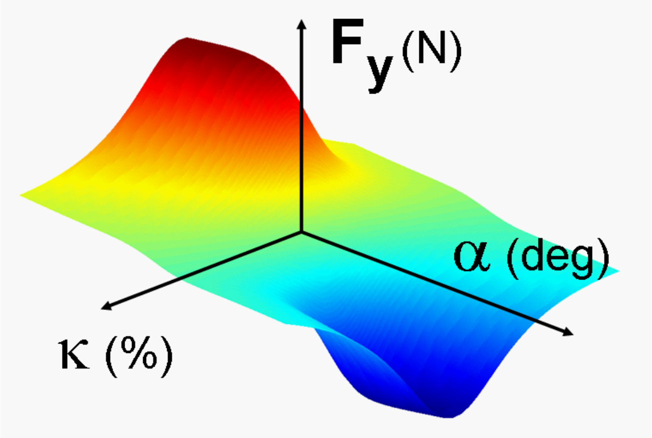
Further, the MF-Swift model can be used for simulating parking manoeuvres.

Special attention has been paid to include behaviour necessary for special applications such as motorcycles (regular and racing), motorsport (e.g. Formula 1) or aircraft tyres.

TNO Delft-Tyre's MF-Tyre and MF-Swift are available for all major simulation packages, see Compatibility Table. TNO Delft-Tyre makes sure that the tyre model implementation and simulation results are identical and that the same set of tyre model parameters can be used for all these packages. Further, MF-Tyre and MF-Swift are fully compatible with all previous 'official' TNO Delft-Tyre releases, see Backward compatibility 34.

5.1.1 MF-Tyre

MF-Tyre is TNO Delft-Tyre's implementation of the world-standard Pacejka Magic Formula tyre model, including the latest developments by TNO and Prof. Pacejka [1] and [2]. MF-Tyre's semi-empirical approach enables fast and robust tyre-road contact force and moment simulation for steady-state and transient tyre behaviour. MF-Tyre has been extensively validated using many experiments and conditions. For a given pneumatic tyre and road condition, the tyre forces and moments due to slip follow a typical characteristic. These steady-state and transient characteristics can be accurately approximated by MF-Tyre.



Steady –state tyre lateral force as function of longitudinal and lateral slip, calculated using MF-Tyre.

MF-Tyre calculates the forces (Fx, Fy) and moments (Mx, My, Mz) acting on the tyre under pure and combined slip conditions on arbitrary 3D roads, using longitudinal, lateral and turn slip, wheel inclination angle ('camber') and the vertical force (Fz) as input quantities.

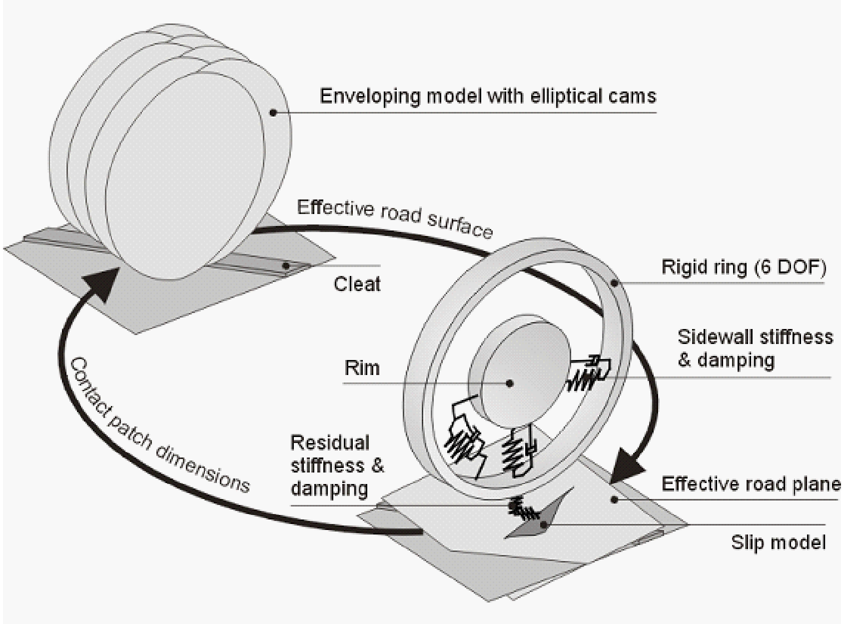
MF-Tyre is valid for large slip angles (typically over 30 degrees), longitudinal slip (+/- 100%), large load variations (including truck tyre loads) and large camber angles (including motorcycle camber angles; MF-Tyre 6.x includes the functionality of MF-MCTyre). It can handle road undulations that have a wavelength larger than the tyre circumference and is typically applied for vehicle handling simulation.

5.1.2 MF-Swift

In addition to the Magic Formula description in the MF-Tyre 20 part of the model, **MF-Swift** uses a rigid ring model in which the tyre **belt** is assumed to behave like a rigid body. This means that the model is accurate in the frequency range where the bending modes of the tyre belt can be neglected, which, depending on the tyre type, is up to 60 – 100 Hz. MF-Swift has been validated using measurements of a rolling tyre (7 to 40 m/s) containing frequencies up to 120 Hz. The model includes essential gyroscopic effects.

The tyre model functionality is primarily based on [1] to [6]. TNO has made several crucial changes and enhancements in cooperation with Prof. Pacejka to the models as described in [1] in order to improve functionality, robustness, calculation times, user-friendliness and compatibility between various operating modes.

MF-Swift uses an efficient single point contact for slip calculation which results in full compatibility with MF-Tyre. Due to the introduction of a so-called phase leading network for the pneumatic trail, MF-Swift is suitable for path curvature with a wavelength in the order of two times the contact length. For braking/traction applications, wavelengths as small as half the contact length are well described. The transient slip behaviour is well described up to full sliding, due to modelling of decrease in relaxation length for increased slip levels.



Graphical representation of the MF-Swift model.

Five main elements of the model structure can be distinguished:

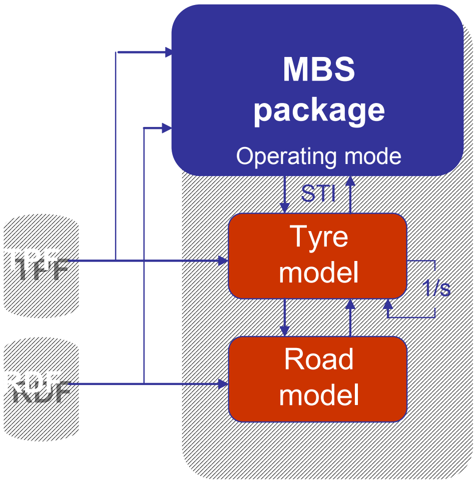
1. Elastically suspended **rigid ring** (6 degrees of freedom): represents the tyre sidewalls and belt with its mass and inertia properties. The rigid ring describes the primary vibration modes of the tyre belt.
2. Residual stiffness & damping: have been introduced between contact patch and rigid ring to ensure that the total quasi-static tyre stiffnesses in vertical, longitudinal, lateral and yaw directions are modelled correctly. The total tyre 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. On the basis of this model, the effects of the finite length and width of the footprint are approximately included.
4. Generic 3D obstacle enveloping model: calculates effective road inputs to enable the simulation of the tyre moving over an uneven road surface with the enveloping behaviour of the tyre properly represented. The actual three-dimensional profile of the road is replaced by a set of four effective inputs: the effective height, the effective forward and camber slopes of the road plane and the effective forward road curvature (that is largely responsible for the variation of the tyre effective rolling radius).
5. Magic Formula steady-state slip model (MF-Tyre): describes the nonlinear slip force and moment properties. This enables an accurate response also for handling manoeuvres.

For more details on the MF-Swift tyre model, please refer to [1] and [6].

5.2 Model Usage

Tyre Simulation

MF-Tyre/MF-Swift is a plug-in to Multi-body simulation packages (MBS). The communication between the MBS Package and the tyre model during simulation is presented below.



The MBS package is communicating with the tyre model following the Standard Tire Interface format [7]. The tyre model in its turn is communicating with the Road model. The multi-body simulation package, and the Tyre and Road model are fed by the Tyre Property File (TPF) 32 and Road Data File (RDF) 47. The MBS package specifies the Operating mode 25 of the tyre model.

To set up a simulation in a MBS package using MF-Tyre/MF-Swift, the user is advised to follow the Simulation Guidelines 23.

Note: It is assumed that a user of MF-Tyre/MF-Swift is familiar with the use of a Multi-body simulation package.

5.2.1 Simulation Guidelines

In this section a stepwise description is given of how to perform a simulation using the MF-Tyre/MF-Swift model, more details can be found in the rest of this document.

Steps

The following steps are recommended to take when setting up a vehicle dynamics simulation with MF-Tyre/MF-Swift:

1) Add the TNO Delft-Tyre model to your simulation model, see chapter Multi-Body Simulation Packages (MBS) for details.

2) Set Tyre Property File 32

3) Select road surface 47 (MBS, TNO, UserRoad)
   a) Set the Road Data File 47

4) Select the correct operating mode 25 (ISWITCH 28) for the tyre model
   a) Advised operating modes (format: ABCD):
      i) x104 for steady-state MF-Tyre simulations only (e.g. steady-state cornering)
      ii) x124 or x114 for general MF-Tyre simulations (e.g. slalom, ISO lane change, J-turn)
      iii) x134 or x144 for MF-Swift on flat or smooth road surfaces (e.g. shimmy or ABS braking)
      iv) x434 or x444 for MF-Swift on 2d road surfaces (e.g. ride comfort and durability simulations)

    v) x534 or x544 for MF-Swift on 3d road surfaces (e.g. ride comfort and durability simulations)
    vi) x125 or x145 for parking maneuvers on flat road surface
    vii) x224 or x214 for MF-Tyre motorcycle simulations (e.g. slalom, ISO lane change, J-turn)

5) Set the correct mounting side 26 of the tyre model, all left tyres must be specified as left and all right tyres must be specified as right in the MBS Packages. When using ISWITCH 28 set A.

6) Masses and inertia 30:
   a) MF-Tyre: tyre model is massless; mass and inertia of tyre have to be added to rotating wheel body in MBS program;
   b) MF-Swift: tyre model contains mass and inertia of tyre belt; mass and inertia of tyre except mass and inertia of belt have to be added to rotating wheel body in MBS program.

7) When using a short wavelength road contact method 26:
   a) 2d contact method (B =4):
      i) Set ROAD_INCREMENT properly. Typically use a road increment that corresponds with the sample interval of the measured road profile.
      ii) Set ROAD_DIRECTION properly.
   b) 3d contact method (B = 5):
      i) Set ROAD_INCREMENT 27 properly. Typically use a road increment that corresponds with the sample interval of the measured road profile.
      ii) Set the value of ELLIPS_MAX_STEP 27 sufficiently larger than the obstacle height for discrete obstacle impacts or larger than the difference in height of two neighbouring road points for arbitrary/measured road profiles. For arbitrary road surfaces always check for error and warning messages like:
         (1) 'Too many ellipse points, increase parameter ROAD_INCREMENT, or reduce ELLIPS_MAX_STEP'
         (2) 'Road data may require to extend ELLIPS_MAX_STEP'
      iii) If these messages occur please change the values of ROAD_INCREMENT and ELLIPS_MAX_STEP according to suggestion provided in the error or warning message till these messages disappear.
      iv) The number of elliptical cams in the contact can be specified with the parameters ELLIPS_NWIDTH and ELLIPS_NLENGTH. The default settings for ELLIPS_NWIDTH and ELLIPS_NLENGTH are respectively 10 and 10. This should be sufficient for sharp obstacles like oblique cleats. The number of ellipses can be increased or decreased depending on the simulation requirements (accuracy vs. computational effort).

> **Note**: The minimal distance between the contact points on the cams is 1 mm. Thus for highest accuracy, set the *ROAD_INCREMENT* to 1 mm for simulations on sharp obstacles.

8) Set the simulation time step.
   a) Variable-step solver: solver will determine correct time step itself
   b) Fixed-step solver: user needs to determine the time step so that the simulation (tyre and vehicle) stays stable. Typical values for each Dynamics mode 28 are:
      i) Steady-state, relaxation behaviour, linear: 10^{-2} - 10^{-4}
      ii) Relaxation behaviour, non-linear: 10^{-3} - 10^{-5}
      iii) Rigid Ring: 10^{-3} - 10^{-5}

9) Perform a short simulation and check the tyre model messages.
   a) Is the TNO tyre model used?
   b) Are indeed the correct tyre property file, road surface, use mode, etc. used?
   c) Are there any error or warning messages related to the tyre model?
   d) Was the vehicle positioned correctly on the road? Are the vertical tyre forces correct?

5.2.2 Dynamics Mode

Depending on the frequency range of interest, the **Dynamics Mode** of the Delft-Tyre model family may be chosen. With increasing frequency, more details in the dynamic behaviour of the tyre are included. Five modes exist for the

Delft-Tyre model, separated over the two components:

- MF-Tyre 20
- MF-Swift 21

Note: For MF-Swift a license is required. For MF-Tyre, it is not.

MF-Tyre/MF-Swift Operating Modes

The **Dynamics Modes** are:

Dynamics mode	Frequency range	Component
Steady-state	< 1 Hz	MF-Tyre
Relaxation behaviour, linear	< 10 Hz, linear	MF-Tyre
Relaxation behaviour, non-linear	< 10 Hz, non-linear	MF-Tyre
Rigid ring	< 100 Hz, non-linear	MF-Swift (requires license)
Rigid ring + initial statics	< 100 Hz, non-linear*	MF-Swift (requires license)

* Same as Rigid Ring, but with finding static equilibrium at the start of the simulation

Steady-State

In the case of a steady-state evaluation no dynamic behaviour is included.

Relaxation Behaviour, linear

“Linear transient effects” indicates that the tyre relaxation behaviour is included using empirical relations for the relaxation lengths.

Relaxation Behaviour, non-linear

In the “Nonlinear transient effects” mode, a physical approach is used in which the compliance of the tyre carcass is considered to determine the lag. This approach correctly accounts for the tyre property that the lag in the response to wheel slip and load changes diminishes at higher levels of slip. This approach is fully compatible with the MF-Swift theory.

Rigid Ring Dynamics

“Rigid ring dynamics” refers to a detailed dynamic model (MF-Swift), where the tyre belt is modelled as a separate rigid body.

Rigid Ring Dynamics with Initial Statics

Finally, “initial statics” refers to finding the static equilibrium of the tyre belt (rigid ring/body) at the start of the simulation.

Note: When selecting rigid ring dynamics the belt is not massless anymore. The mass and moments of inertia of the tyre belt have to be subtracted from the total wheel + tyre mass and moments of inertia.

5.2.3 Tyre model operating modes

The main operating modes of the MF-Tyre/MF-Swift model are described below. This information should always be provided by the Tyre Property File or by the MBS package.

MF-Tyre/MF-Swift is set up in a modular way and allows a user to independently set the operating mode of the Magic Formula, tyre dynamics and contact method.

A: Tyre side - Magic Formula mirroring

If a tyre has asymmetric behaviour, caused by e.g. conicity or plysteer, using the same characteristics on the left and right hand side of a vehicle will result in incorrect results. For this reason the side of the vehicle a tyre is mounted on should be specified.

We may select one of the following values for the tyre side in the **MBS Package**:

0/1	tyre is mounted on the left side of the car
2	tyre is mounted on the right side of the car
3	symmetric tyre characteristics (asymmetric behaviour is removed)

In the **Tyre Property File**, it should be specified how the tyre measurement was executed: in other words, if the left or right tyre was tested. In the Tyre Property File [MODEL]-section, the keyword TYRESIDE can be set to either “LEFT” or “RIGHT” (when missing: “LEFT” is assumed).

If “TYRESIDE” is “LEFT” and the tyre is mounted on the right side of the vehicle (A=2), mirroring will be applied on the tyre characteristics and the total vehicle will behave symmetrically. It is also possible to remove asymmetrical behaviour from an individual tyre (A=3).

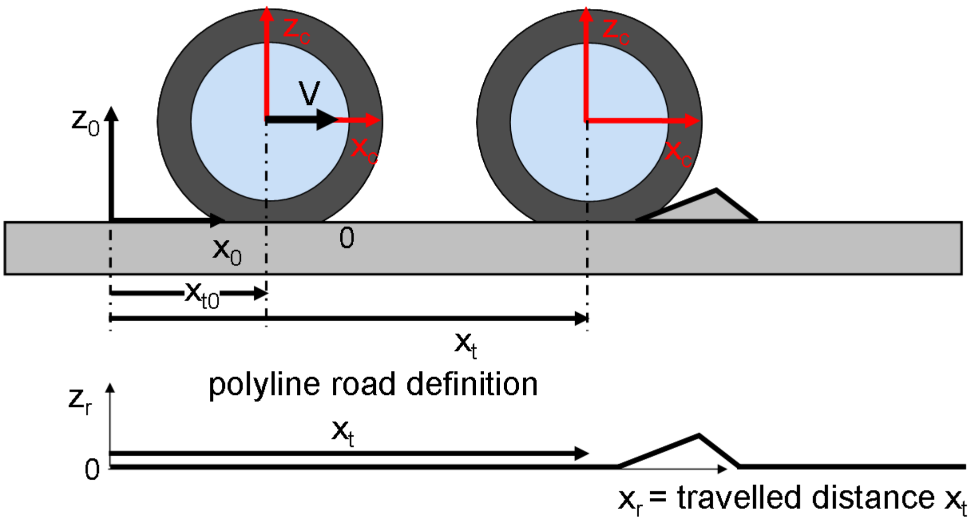
B: Contact Method

Various methods are available to calculate the tyre–road contact point. Smooth road contact should only be used on a smooth road surface profile containing a minimum wavelength larger than twice the tyre radius. For short obstacles (e.g. cleats/bumps, discrete steps, potholes) or road surfaces containing wavelength smaller than twice the tyre radius, either the road contact for 2D or 3D roads should be selected. The road contact for 3D roads works on both 2D and 3D road surfaces, but it is computationally more expensive than the road contact for 2D roads that works only with 2D road profiles. The moving road is to be used for simulation of a four poster test rig. It is available in a limited number of simulation packages (e.g. MATLAB/Simulink, SIMPACK 8.700 and up)

The following values may be selected for the contact method in the **MBS Package**:

0/1	smooth road contact, single contact point
2	smooth road contact, circular cross section (motorcycle tyres)
3	moving road contact, flat surface
4	road contact for 2D roads (using travelled distance)
5	road contact for 3D roads

All contact methods use global coordinates to obtain the road height. Exception is the road contact for 2D roads where the travelled distance is used to obtain the road height. The travelled distance is the distance the wheel centre has travelled with respect to the origin of the global axis system (x^0, y^0, z^0). By default, the travelled distance is positive in the direction of the x^c-coordinate system. The travelled distance changes sign when the origin of the global coordinate system is passed.



Road contact for 2D and 3D roads

There are two variables in the road contact that need some special attention:

- Increment of the road sampling: step size with which the contact algorithm is evaluating the road surface
- Maximum allowed discrete step in road height (3D contact only)

The increment of the road sampling is the step size with which the contact algorithm is evaluating the road surface. In general, a smaller road sampling increment will give more accurate results but a slower simulation as more contact points are evaluated. The contact algorithm will try to use at least 3 contact points of the elliptical cams in one road increment. But there are some limitations:

- The distance between the contact points on the cams is at least 1 mm;
- Due to the limited memory space reserved for the calculation of the effective road height and slope, the distance between the contact points may become larger. The tyre model will generate warning messages when a memory problem has occurred. For 2D contact the message “Road increment adjusted to minimum possible increment of: (value) m” appears and for 3D contact the message “Too many ellipse points, increase parameter ROAD_INCREMENT, or reduce ELLIPS_MAX_STEP” appears.

A typical value for ROAD_INCREMENT is 0.01 m, and should be defined in the `[MODEL]` section of the Tyre Property File 32.

```
ROAD_INCREMENT = 0.01
```

The maximum allowed discrete step in road height should be set by the user larger than the highest obstacle in the road surface. It should be set in the Tyre Property File 32 in the `[CONTACT_PATCH]`, e.g.:

```
ELLIPS_MAX_STEP = 0.025
```

For a detailed description of these parameters see the Tyre model settings 36 section.

Note:

- When motorcycle contour parameters MC_CONTOUR_A and MC_CONTOUR_B are defined and nonzero in a MF-Swift 6.2 tyre property file (FITTYP = 62), the motorcycle contact (contact method 2) is activated also in combination with the road contact for 2D and 3D roads. In these cases first the enveloping model is used to determine the effective road plane. Next the motorcycle contact is applied on this effective road plane. See also the Miscellaneous 39 section.

C: Dynamics

We may select one of the following values for the Dynamics Mode 24:

0 Steady-state evaluation (< 1 Hz)
1 Transient effects included, tyre relaxation behaviour (< 10 Hz, linear)
2 Transient effects included, tyre relaxation behaviour (< 10 Hz, nonlinear)
3 Rigid ring dynamics included (< 100 Hz, nonlinear) *(requires MF-Swift license)*
4 Rigid ring dynamics + initial statics (same as 3, but with finding static equilibrium) *(requires MF-Swift license)*

Known issue: When using a fixed-step solver for **tyre relaxation behaviour (< 10 Hz, nonlinear)**, the time-step of the simulation should be chosen small enough (typically 10^{-5}) for the simulation to produce correct results. A variable-step solver will automatically reduced the time-step when required.

D: Slip forces - Magic Formula evaluation

When evaluating the Magic Formula almost always combined slip is used (D = 4). In cases where turn slip is important, e.g. in parking maneuvers, D = 5 is recommended. 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 tyre behaviour is required. The following values may be selected for D:

0 no Magic Formula evaluation (Fz only)
1 longitudinal forces/moments only (Fx,My)
2 lateral forces/moment only (Fy,Mx,Mz)
3 uncombined forces/moment (Fx,Fy,Mx,My,Mz)
4 combined forces/moment (Fx,Fy,Mx,My,Mz)
5 combined forces/moment (Fx,Fy,Mx,My,Mz) + turnslip

Note 1: In principle all combinations are possible, although some make more sense than others. Typically you do not use road contact for 2D or 3D roads without activating rigid ring dynamics. On the other hand you may want to use rigid ring dynamics on a flat road surface e.g. in case of ABS/ESP or shimmy analysis. Obviously the choice of the operating mode will affect the calculation times.

Note 2: For turn slip simulation only Dynamics Modes 24 > 1 are supported ("non-linear transient" and "rigid ring"). When turn slip is selected in combination with "steady-state" or "linear transient" the dynamics mode is automatically reset to "non-linear transient".

Note 3: Don't forget to specify the mass of the wheel in the multi-body package.

5.2.3.1 ISWITCH

Although most packages use a Graphical User Interface (GUI) to supply the operating mode to the tyre model, on a lower level the operating modes are combined to a single variable called **ISWTCH**, see Standard Tyre Interface for details [7]. The following format is used: ISWTCH = ABCD. For example, ISWTCH = 1134 stands for:

- A = 1: left tyre;
- B = 1: smooth road contact, single contact point
- C = 3: Rigid ring dynamics
- D = 4: combined slip forces/moments

Note: In ADAMS the operating mode must be set using the parameter **USE_MODE** in the [MODEL] section of the Tyre Property File.

5.2.4 Supported operating modes

The next table lists the operating modes that are supported by MF-Tyre and MF-Swift licenses.

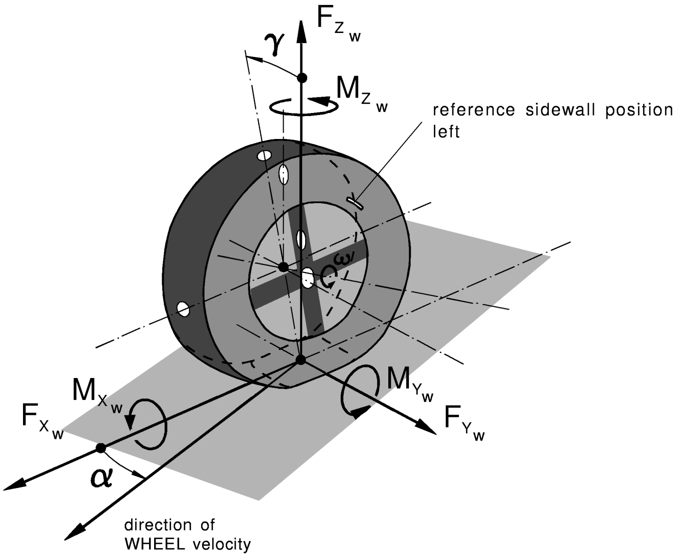
	MF-Tyre	MF-Swift
Slip forces - Magic Formula evaluation (number D)	0,1,2,3,4	0,1,2,3,4,5
Dynamics (number C)	0,1,2	0,1,2,3,4
Contact Method (number B)	0,1,2,3	0,1,2,3,4,5
Tyre side - Magic Formula mirroring (number A)	0,1,2,3	0,1,2,3

5.2.5 Conventions

In this section the axis system and units, used in MF-Tyre/MF-Swift, are explained.

Axis System

MF-Tyre/MF-Swift uses the ISO sign conventions as shown in the figure below.



ISO sign conventions.

The longitudinal slip κ and sideslip angle α are defined as:

$$\kappa = -\frac{V_{sx}}{V_x}$$

, (note: $\kappa = -1$ means braking at wheel lock),

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

In these equations:

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

Units

The output of the tyre model is always in SI units (m, N, rad, kg, s).

The Tyre Property File uses SI units by default (m, N, rad, kg, s); this is always the case when it is generated by TNO Automotive. It is allowed to use a different set of units (e.g. mm or inch for length). The specification in the `[UNITS]` section file applies to all parameters in the Tyre Property File.

The tyre model expects SI units to be passed via the interface between tyre model and the multi-body simulation program, as defined in the specification of the Standard Tyre Interface (STI) [8]. However many multi-body codes do not use units internally and leave the choice of a consistent set of units to the user. In many cases this implies that the vehicle model has to be defined using SI units to avoid unit conversion problems.

Mass

An MF-Tyre 20 model does **not** contain any mass, and an MF-Swift 21 model does **only** contain a mass for the belt 21. In the multi-body packages used, the mass should be defined as rim + tyre mass. For MF-Swift the belt mass should be subtracted from this mass. The mass definition is summarized in the table below.

Model	Tyre model mass	Mass definition in MBS Package
MF-Tyre	None	Rim + Tyre
MF-Swift	Belt mass	Rim + Tyre - Belt mass

Note: The Tyre Mass definition in the Tyre Property File is ignored in all multi-body packages, except by the “SimMechanics Wheel + tyre” block provided with MF-Tyre/MF-Swift, in which a complete wheel (including a tyre) is modelled.

5.2.6 Tyre model output

MF-Tyre/MF-Swift is offered as a force element which can be connected to a Multi-body simulation (MBS) package.

Various signals are available for post-processing (sometimes called varinf). The availability may be dependent on the implementation in the MBS package. Depending on the implementation they are selected by means of a keyword, signal number or other methods.

tyre contact forces/moments in the contact point:

# Variable	Description	Unit
1 Fx	longitudinal force Fx_w	[N]
2 Fy	lateral force Fy_w	[N]
3 Fz	vertical force Fz_w	[N]
4 Mx	overturning moment Mx_w	[Nm]
5 My	rolling resistance moment My_w	[Nm]
6 Mz	self aligning moment Mz_w	[Nm]

slip quantities:

7 kappa	longitudinal slip kappa	[-]
8 alpha	sideslip angle alpha	[rad]
9 gamma	inclination angle	[rad]
10 phi	turn slip	[1/m]

additional tyre outputs:

11 Vx	wheel contact centre forward velocity	[m/s]
13 Re	effective rolling radius	[m]

14 defl	tyre deflection	[m]
15 contact_length	tyre contact length	[m]
16 tp	pneumatic trail	[m]
17 mux	longitudinal friction coefficient	[-]
18 muy	lateral friction coefficient	[-]
19 sigma_x	longitudinal relaxation length	[m] (not always available)
20 sigma_y	lateral relaxation length	[m] (not always available)
21 Vsx	longitudinal wheel slip velocity	[m/s]
22 Vsy	lateral wheel slip velocity	[m/s]
23 Vz	tyre compression velocity	[m/s]
24 psidot	tyre yaw velocity	[rad/s]
28 s	travelled distance	[m] (not always available)

tyre contact point:

31 xcp	global x coordinate contact point	[m]
32 ycp	global y coordinate contact point	[m]
33 zcp	global z coordinate contact point	[m]
34 nx	global x component road normal	[-]
35 ny	global y component road normal	[-]
36 nz	global z component road normal	[-]
37 w	effective road height	[m] (not always available)
38 beta_y	effective forward slope	[rad] (not always available)
39	effective road curvature	[1/m] (not always available)
40 beta_x	effective road banking/road camber angle	[rad] (not always available)

Note: The wheel spindle forces and moments are in general obtained from the multibody package.

5.3 Tyre Property File

The **Tyre Property File** contains the parameters of the tyre model.

- The different **sections** of the Tyre Property File are described in Overview 32.
- If not all parameter are specified, MF-Tyre/MF-Swift has a built-in procedure 33 to estimate the missing parameters.
- Scaling factors 34 may be specified to manipulate and tune tyre characteristics.
- MF-Tyre/MF-Swift is backward compatible 34 for all commercially released versions of it.
- The full set of MF-Tyre/MF-Swift parameters is described in Parameters in the Tyre Property File 39.

- **Sample Tyre Property Files** are provided with the installation in the directory `<TNO Delft-Tyre>MF-Tyre MF-Swift 6.2\Tyre property files`.

5.3.1 Overview

The Tyre Property File (*.tir) is subdivided in various sections indicated with square brackets. Each section describes a certain aspect of the tyre behaviour. The next table gives an overview (a full description is given in Parameters in the Tyre Property File 39):

General and Swift parameters:

[UNITS]	units system used for the definition of the parameters
[MODEL]	parameters on the usage of the tyre model
[DIMENSION]	tyre dimensions
[OPERATING_CONDITIONS]	operating conditions like inflation pressure
[INERTIA]	tyre and tyre belt mass/inertia properties
[VERTICAL]	vertical stiffness; loaded and effective rolling radius
[STRUCTURAL]	tyre 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 sideslip angles
[INCLINATION_ANGLE_RANGE]	minimum and maximum valid inclination angles

Magic Formula:

[SCALING_COEFFICIENTS]	Magic Formula scaling factors 34
[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

Though at first sight the number of coefficients may seem extensive, Delft-Tyre has established two methods to significantly facilitate tyre model parameterisation:

1. **MF-Tool**: this is an automated parameter identification tool to determine the tyre model parameters and manipulate the resulting characteristics [8]. Fitting Magic Formula coefficients is a well established process within the vehicle industry.Furthermore, MF-Tool features a generic method for identifying MF-Swift parameters from standardised measurements such as loaded radius, contact length and cleat/drum tests.
2. Reduced Input Data Requirements 33

5.3.2 Reduced Input Data Requirements

If no (or limited) measurement data is available, it is also allowed to omit coefficients in the Tyre 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.

When using a reduced parameter file, detailed effects such as combined slip, tyre relaxation effects and enveloping behaviour on short wavelength road obstacles are included, although the related parameters are not explicitly specified (see for the location the Parameters in the Tyre Property File 39).

Coefficient	Description
FITTYP	Magic Formula version number
UNLOADED_RADIUS	Free tyre radius
WIDTH	Tyre width
RIM_RADIUS	Rim radius
INFLPRES*	Tyre inflation pressure
FNOMIN	Nominal wheel load
VERTICAL_STIFFNESS*	Tyre vertical stiffness at nominal load and inflation pressure
PDX1*	Longitudinal friction coefficient at nominal conditions**
PKX1*	PKX1*FNOMIN is the longitudinal slip stiffness at the nominal wheel load
PDY1*	Lateral friction coefficient at nominal conditions**
PKY1*	PKY1*FNOMIN is the maximum value of the cornering stiffness versus vertical load characteristic
PKY2*	PKY2*FNOMIN is the vertical load at which the cornering stiffness reaches its maximum value

Minimum set of parameters.

* highly recommended parameters (when not specified defaults are used)

** at nominal wheel load, nominal inflation pressure and zero camber angle

NOTE 1: Although not strictly required it is recommended to add the tyre model settings 36 in the reduced tyre property files to adjust the behaviour of the tyre model. When omitted default values for these settings are used.

NOTE 2: FNOMIN may be set equal to 0.8 * (load corresponding to tyre Load index in N).

NOTE 3: The reduced input method has been developed for passenger car tyres; for other tyre types (motorcycle, aircraft, etc.) estimated parameters may be less accurate.

Tip: When **extrapolating** to (very) low friction values, the use of “estimated combined slip” possibly improves the performance of the tyre model . “Estimated combined slip” can be turned on by setting the combined slip coefficients in the Tyre Property File to zero or by omitting them.

5.3.3 Scaling factors

Tyre force and moment testing is often done in a laboratory environment (e.g. using a MTS Flat Trac or a drum). The artificial road surface on the tyre 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 tyre behaviour 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 tyre tested on different road surfaces compared to lab measurements.

For this purpose scaling factors are included in the tyre model, which allow the user to manipulate and tune the tyre 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.

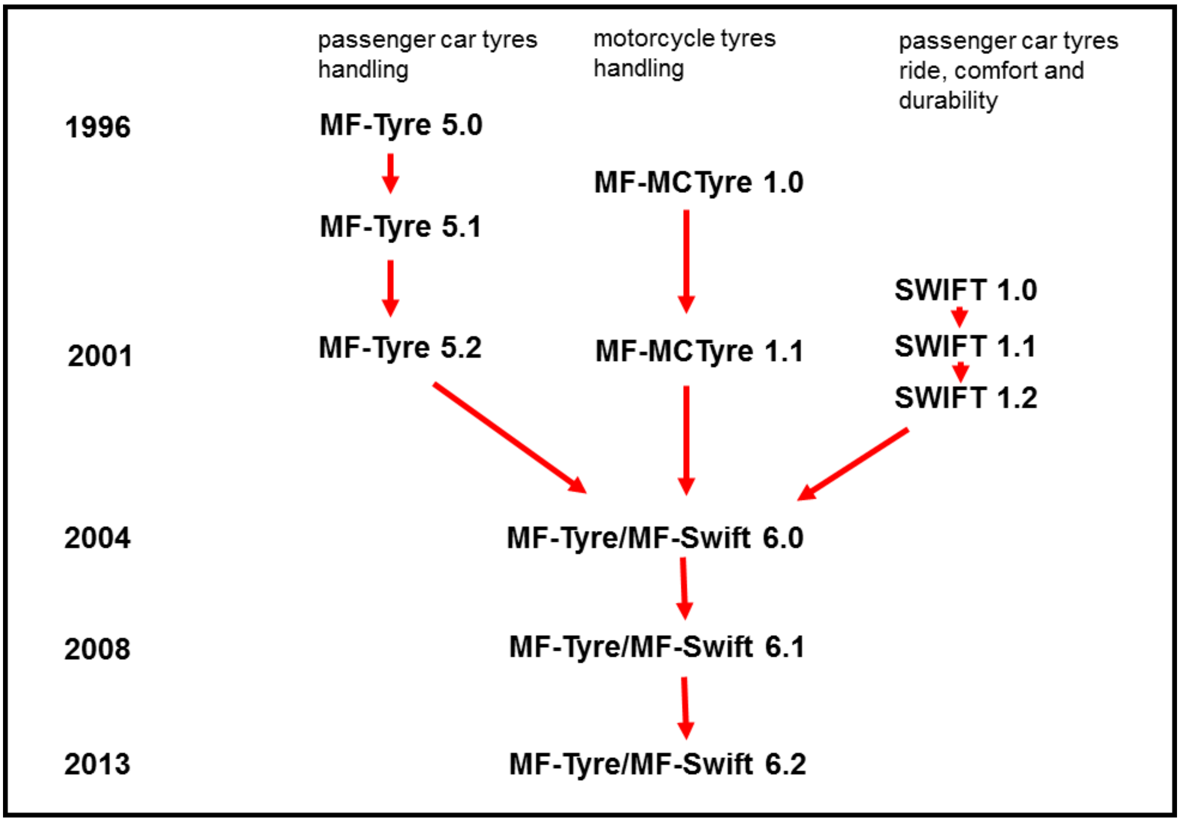
The most important scaling factors are:

LMUX	longitudinal peak friction coefficient (Fx)
LKX	longitudinal slip stiffness (Fx)
LMUY	lateral peak friction coefficient (Fy)
LKY	cornering stiffness (Fy)
LKYC	camber stiffness (Fy)
LTR	pneumatic trail (Mz)
LKZC	camber moment stiffness (Mz)
LMP	parking moment at standstill (Mz)

Normally when processing the tyre measurements these scaling factors are set to 1, but when doing a validation study on a full vehicle model they can be adjusted to tune the tyre behaviour. The scaling factors are defined in the [SCALING_COEFFICIENTS] section of the Tyre Property File (see section 4.3.1).

5.3.4 Backward compatibility

To be able to use old Tyre Property Files, and test data, MF-Tyre/MF-Swift is backward compatible with older versions (MF-Tyre 5.x, MF-MC-Tyre 1.x , SWIFT 1.x, MF-Tyre/MF-Swift 6.0.x and MF-Tyre/MF-Swift 6.1.x). Tyre Property Files generated for these tyre models will work with MF-Tyre/MF-Swift 6.1 and will give the same simulation results as before.



Backward compatibility of Tyre Property Files.

Due to the built-in estimation procedure 33 it is possible to use for example an existing MF-Tyre 5.2 Tyre Property File and perform simulations including turn slip, rigid ring dynamics and tyre enveloping behaviour, thus already benefiting from the new functionality available in MF-Tyre/MF-Swift 6.2.

FITTYP

The selection of the appropriate set of Magic Formula equations is based on the parameter FITTYP in the [MODEL] section of the Tyre 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-Tyre 5.2 Magic Formula equations
- 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

MF-Tyre/MF-Swift 6.2 accepts all these values for the parameter FITTYP. It is recommended not to change the value of the parameter FITTYP unless you are sure that the model parameters in the Tyre Property File are meant for that specific Magic Formula version!

Differences

However some differences may occur at very low speeds when relaxation behaviour is included combined with a forward velocity below the value specified with the parameter VXLOW in the [MODEL] section. Due to new formulations the tyre behaviour is much more realistic for these operating conditions.

In the case of MF-Swift minor differences may occur between the 1.x, 6.0.x, 6.1.x and 6.2 versions due to a different formulation of the contact patch dynamic behaviour. These differences can be observed in the tyre contact forces and slip values, whereas at wheel axle level the differences remain small.

Compatibility

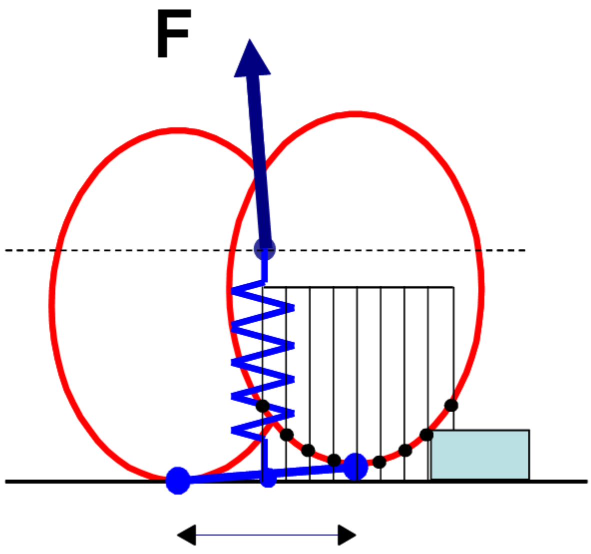
- Former MF-MCTyre users explicitly will have to select “smooth road contact, circular cross section” as Contact Method 26 to get the same results using MF-Tyre 6.2 with their MF-MCTyre datasets.
- Former SWIFT-Tyre 1.x users will have to select “road contact for 2D roads” as Contact Method 26 and “rigid ring dynamics” as Dynamics Mode 28 to get the same results as before.

Discontinued functionality

The camber angle scaling factors LGAX, LGAY and LGAZ are not supported anymore. The camber influence in MF-Tyre/MF-Swift 6.x can now be more conveniently controlled by the new parameters LKYC (Fy) and LKZC (Mz). These parameters allow explicit scaling of the camber stiffness and camber moment stiffness. These new parameters also have to be used in combination with MF-Tyre 5.x and MF-MCTyre 1.x datasets.

5.3.5 Tyre model settings

The MF-Swift model uses elliptical cams to determined the effective road profile, as is shown in the figure below. Each elliptical cam is discretised and each point is evaluated for the road height. Using the effective plane height and angle the direction and magnitude of the forces are determined. This paragraph discusses several setting, which have effect on this effective road profile.



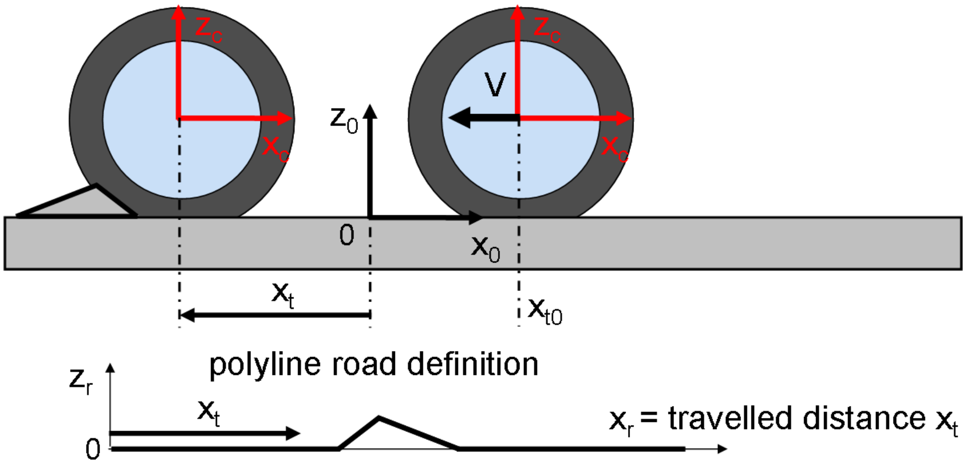
When using road contacts for 2D and 3D roads, the following points can be changed by the user and are explained below:

- When using the road contact for **2D roads**:
    - ROAD_DIRECTION 37 (direction of travelled distance, 1 (default) or -1 (reverse)).
    - ROAD_INCREMENT 37 (= increment in road sampling).
- When using the road contact for **3D roads**:
    - ROAD_INCREMENT 37 (= increment in road sampling).
    - ELLIPS_MAX_STEP 37 (= maximum allowed discrete step in road height).
    - ELLIPS_NWIDTH 38 (=number of parallel tandem ellipsoids)
    - ELLIPS_NLENGTH 38 (=number of successive cams at both sides)

In the following paragraphs more information about above tyre model settings are given:

ROAD_DIRECTION (only: road contact for 2D roads)

The travelled distance x_t is the distance the wheel centre has travelled with respect to the origin of the global coordinate system (x^0, y^0, z^0). By default, the travelled distance is positive in the direction of the x^c-coordinate system. However, the keyword *ROAD_DIRECTION* in the tyre property file can change the sign of the travelled distance for 2D road contact if it is set to -1.



In the figure above an example is given. When using the road contacts for 2D roads the cleat will only be seen if *ROAD_DIRECTION* = -1. Travelled distance x_t then is positive when moving to the left. Note that x_{t0} is negative, since the zero of the travelled distance measure is the origin of the global coordinate system Thus the travelled distance is initially negative and becomes positive when the origin of the global coordinate system is passed.

Note: If the carrier axis system is initially rotated 180° about z-axis (default in Adams/Car), the conversion is done automatically, thus then use *ROAD_DIRECTION* = 1.

Note: For Adams users the road reference marker must have to same position and orientation as the global reference marker.

ROAD_INCREMENT

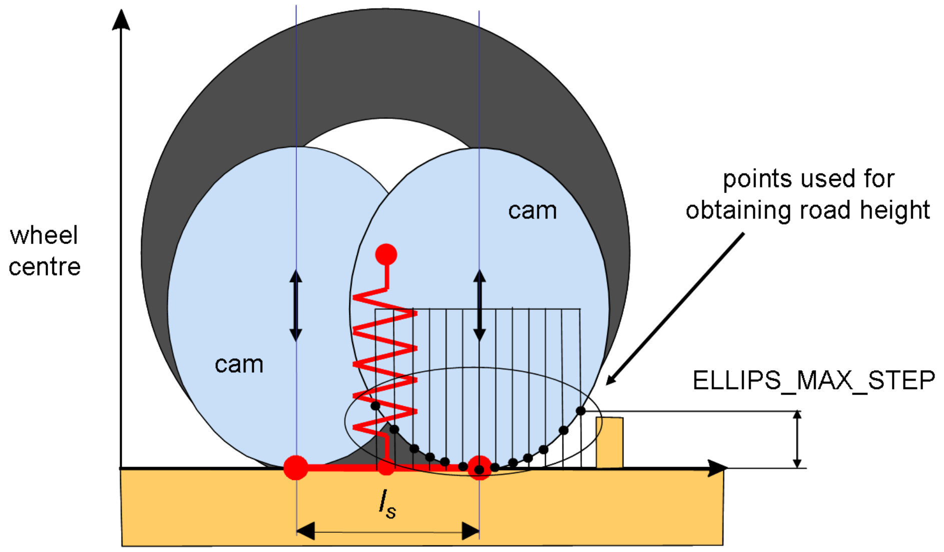
The *ROAD_INCREMENT* parameter is only used in combination with the enveloping model with elliptical cams. It affects the number of points used on the ellipse for calculation of the effective road height & slope. In general a smaller *ROAD_INCREMENT* will give more accurate results, because of more contact points, but more contact evaluations means slower simulation.

Note: Only a limited memory space is reserved for the calculation of the effective road height and slope. If the message “Too many ellipse points, increase parameter ROAD_INCREMENT, or reduce ELLIPS_MAX_STEP” appears when 3D contact method is used, a memory problem has occurred. If the message “Road increment adjusted to minimum possible increment of: (value) m” appears when 2D contact method is used, a memory problem has occurred.

Note: The minimal distance between the contact points on the cams is 1 mm. Thus for highest accuracy, set the *ROAD_INCREMENT* to 1 mm for simulations on sharp obstacles.

ELLIPS_MAX_STEP

For faster simulation the number of points on the elliptical cams should be limited. This can be controlled by the tyre property parameter *ELLIPS_MAX_STEP*. This parameter has to be larger than the obstacle height to prevent extreme slopes and high forces, see below.



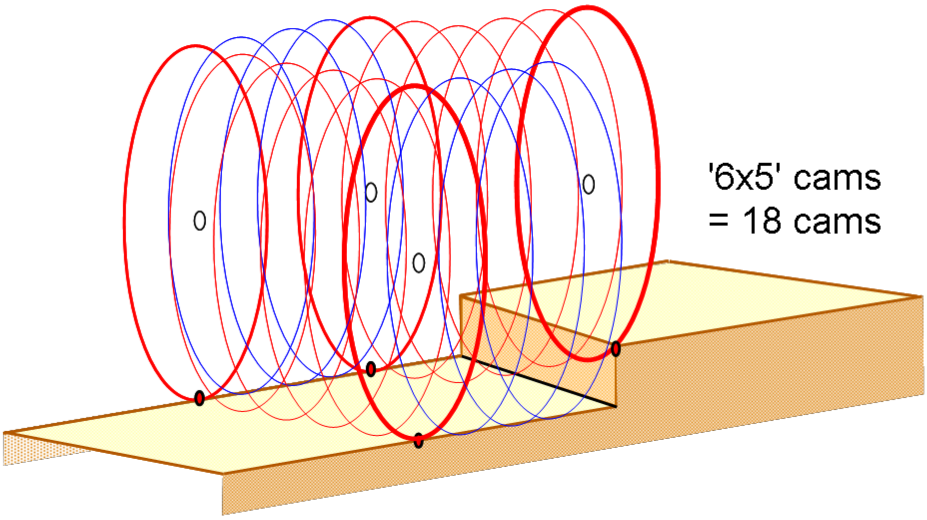
ELLIPS_NWIDTH

For faster simulation the number of parallel tandems (multi-track) should be limited. This can be controlled by the tyre property parameter *ELLIPS_NWIDTH*. For sharp obstacle the default value of 10 parallel ellipsoids generally is sufficient for an accurate simulation. However, with more smooth roads or with cleats oriented perpendicular to the X-axis this value can be limited.

ELLIPS_NLENGTH

For faster simulation the number of successive cams at both sides should be limited. This can be controlled by the tyre property parameter *ELLIPS_NLENGTH*. For sharp obstacle the default value of 10 successive ellipsoids generally is sufficient for an accurate simulation. However, with more smooth roads or with cleats oriented perpendicular to the X-axis this value can be limited.

In the figure below an example of 6 parallel cams in the **front** & **rear** row and 5 successive cams at **both** sides can be seen.



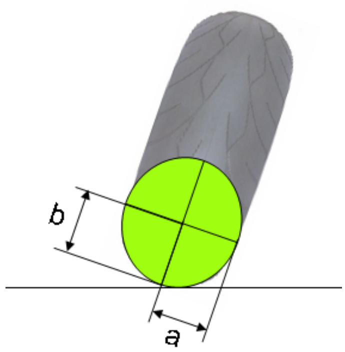
RIGID_RING_DYNAMICS

During dynamic simulation it is advised to select rigid ring dynamics of the model for the most realistic simulations. Then the tyre force element is not massless anymore! The mass and moments of inertia of the tyre belt have to be subtracted from the total wheel + tyre.

5.3.6 Miscellaneous

Motorcycle Contour Ellipse

The motorcycle contour ellipse is the contact ellipse of a motorcycle tyre. It is the ellipse over which the motorcycle tyre rolls, as explained in the figure below.



The dimension of the ellipse can be set using the dimensionless parameters 39 in the Tyre Property File MC_CONTOUR_A and MC_CONTOUR_B,in section [VERTICAL], according to the following formulas:

```
MC_CONTOUR_A = a / tyre width
MC_CONTOUR_B = b / tyre width
```

Note:
- When these parameters are nonzero in a MF-Swift 6.2 tyre property file (FITTYP = 62), the motorcycle contact is activated also in combination with the Contact Method 26 for 2D and 3D roads. In these cases first the enveloping model is used to determine the effective road plane. Next the motorcycle contact is applied on this effective road plane.
- In MF-Tyre 6.2 these parameters are used by the tyre model in the *smooth road contact, circular cross section (motorcycle tyres)* Contact Method 26. Uneven road surfaces are supported.
- In MF-Tyre 6.1 these parameters are used by the tyre model in the *smooth road contact, circular cross section (motorcycle tyres)* Contact Method 26. Only flat road surfaces are supported.
- If the parameters do not exist in a tyre property file, default values of zero are used in the tyre model.

5.3.7 Parameters in the Tyre Property File

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

x: required parameter
(x): optional parameter

Tyre Property File		**MF-Tyre 6.2**	**MF-Swift 6.2**	**MF-Tyre 6.1**	**MF-Swift 6.1**	**MF-Tyre 6.0**	**MF-Swift 6.0**	**MF-Tyre 5.2**	**SWIFT 1.2**	**MF-MCTyre 1.1**
[MODEL]										
FITTYP	Magic Formula version number	62	62	61	61	60	60	6	21	52
+	Moment representation 0=ground frame 1=wheel frame	x	x	x	x					
TYRESIDE	Position of tyre during measurements	x	x	x	x	x	x	x	x	x
LONGVL	Reference speed	x	x	x	x	x	x	x	x	x
VXLOW	Lower boundary velocity in slip calculation	x	x	x	x	x	x	x	x	x

Tyre Property File		MF-Tyre 6.2	MF-Swift 6.2	MF-Tyre 6.1	MF-Swift 6.1	MF-Tyre 6.0	MF-Swift 6.0	MF-Tyre 5.2	SWIFT 1.2	MF-MCTyre 1.1
ROAD_INCREMENT	Increment in road sampling		x		x		x		x	
ROAD_DIRECTION	Direction of travelled distance		x		x		x		x	
PROPERTY_FILE_FORMAT	Tyre model selection (Adams only)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)
USE_MODE	Tyre use mode switch (Adams only)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)
HMAX_LOCAL	Local integration time step (Adams only)		(x)		(x)		(x)		(x)	
TIME_SWITCH_INTEG	Time when local integrator is activated (Adams only)		(x)		(x)		(x)		(x)	
[DIMENSION]										
UNLOADED_RADIUS	Free tyre radius	x	x	x	x	x	x	x	x	x
WIDTH	Nominal section width of the tyre	x	x	x	x	x	x	x	x	x
RIM_RADIUS	Nominal rim radius	x	x	x	x	x	x	x	x	x
RIM_WIDTH	Rim width	x	x	x	x	x	x	x	x	x
ASPECT_RATIO	Nominal aspect ratio	x	x	x	x	x	x	x	x	x
[OPERATING_CONDITIONS]										
INFLPRES	Tyre inflation pressure	x	x	x	x					
NOMPRES	Nominal pressure used in (MF) equations	x	x	x	x					
[INERTIA]										
MASS	Tyre mass	x	x	x	x	x	x		x	
IXX	Tyre diametral moment of inertia	x	x	x	x	x	x			
IYY	Tyre polar moment of inertia	x	x	x	x	x	x			
BELT_MASS	Belt mass		x		x		x			
BELT_IXX	Belt diametral moment of inertia		x		x		x			
BELT_IYY	Belt polar moment of inertia		x		x		x			
GRAVITY	Gravity acting on belt in Z direction		x		x		x			
M_B	Portion of tyre mass of tyre belt part								x	
I_BY	Normalized moment of inertia about Y of tyre belt part								x	
I_BXZ	Normalized moment of inertia about XZ of tyre belt part								x	
C_GRV	Gravity constant								x	
[VERTICAL]										
FNOMIN	Nominal wheel load	x	x	x	x	x	x	x	x	x
VERTICAL_STIFFNESS	Tyre vertical stiffness	x	x	x	x	x	x	x	x	x
VERTICAL_DAMPING	Tyre vertical damping	x	x	x	x	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	x	x	x	x
DREFF	Peak value of effective rolling radius	x	x	x	x	x	x	x	x	x
FREFF	High load stiffness of effective rolling radius	x	x	x	x	x	x	x	x	x
Q_RE0	Ratio of free tyre radius with nominal tyre radius	x	x	x	x	x	x		x	
Q_V1	Tyre radius increase with speed	x	x	x	x	x	x		x	
Q_V2	Vertical stiffness increase with speed	x	x	x	x	x	x		x	
Q_FZ2	Quadratic term in load vs. deflection	x	x	x	x	x	x		x	
Q_FCX	Longitudinal force influence on vertical stiffness	x	x	x	x	x	x		x	
Q_FCY	Lateral force influence on vertical stiffness	x	x	x	x	x	x		x	
Q_FCY2	Explicit load dependency for including the lateral force influence on vertical stiffness	x	x							
Q_CAM	Stiffness reduction due to camber	x	x	x						
Q_CAM1	Linear load dependent camber angle influence on vertical stiffness	x	x							
Q_CAM2	Quadratic load dependent camber angle influence on vertical stiffness	x	x							
Q_CAM3	Linear load and camber angle dependent reduction on vertical stiffness	x	x							

Tyre Property File		MF-Tyre 6.2	MF-Swift 6.2	MF-Tyre 6.1	MF-Swift 6.1	MF-Tyre 6.0	MF-Swift 6.0	MF-Tyre 5.2	SWIFT 1.2	MF-MCTyre 1.1
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	x					
BOTTOM_OFFST	Distance to rim when bottoming starts to occur	x	x	x	x	x	x		x	
BOTTOM_STIFF	Vertical stiffness of bottomed tyre	x	x	x	x	x	x		x	
[STRUCTURAL]										
LONGITUDINAL_STIFFNESS	Tyre overall longitudinal stiffness	x	x	x	x	x	x			
LATERAL_STIFFNESS	Tyre overall lateral stiffness	x	x	x	x	x	x			
YAW_STIFFNESS	Tyre overall yaw stiffness	x	x	x	x	x	x			
FREQ_LONG	Undamped frequency fore/aft and vertical mode		x		x		x			
FREQ_LAT	Undamped frequency lateral mode		x		x		x			
FREQ_YAW	Undamped frequency yaw and camber mode		x		x		x			
FREQ_WINDUP	Undamped frequency wind-up mode		x		x		x			
DAMP_LONG	Dimensionless damping fore/aft and vertical mode		x		x		x			
DAMP_LAT	Dimensionless damping lateral mode		x		x		x			
DAMP_YAW	Dimensionless damping yaw and camber mode		x		x		x			
DAMP_WINDUP	Dimensionless damping wind-up mode		x		x		x			
DAMP_RESIDUAL	Residual damping (proportional to stiffness)	x	x	x	x	x	x			
DAMP_VLOW	Additional low speed damping (proportional to stiffness)	x	x	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	Tyre overall longitudinal stiffness vertical deflection dependency linear term	x	x	x	x					
PCFX2	Tyre overall longitudinal stiffness vertical deflection dependency quadratic term	x	x	x	x					
PCFX3	Tyre overall longitudinal stiffness pressure dependency	x	x	x	x					
PCFY1	Tyre overall lateral stiffness vertical deflection dependency linear term	x	x	x	x					
PCFY2	Tyre overall lateral stiffness vertical deflection dependency quadratic term	x	x	x	x					
PCFY3	Tyre overall lateral stiffness pressure dependency	x	x	x	x					
PCMZ1	Tyre overall yaw stiffness pressure dependency	x	x	x	x					
C_BX0	In-plane belt translation stiffness								x	
C_RX	Longitudinal residual stiffness								x	
C_BT0	In-plane belt rotation stiffness								x	
C_BY	Out-of-plane belt translation stiffness								x	
C_RY	Lateral residual stiffness								x	
C_BGAM	Out-of-plane belt rotation stiffness								x	
C_RP	Yaw residual stiffness								x	
K_BX	In-plane belt translation damping								x	
K_BT	In-plane belt rotation damping								x	
K_BY	Out-of-plane belt translation damping								x	
K_BGAM	Out-of-plane belt rotation damping								x	
[CONTACT_PATCH]										
Q_RA1	Square root term in contact length equation		x		x					
Q_RA2	Linear term in contact length equation		x		x					
Q_RB1	Root term in contact width equation		x		x					
Q_RB2	Linear term in contact width equation		x		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	

Tyre Property File		MF-Tyre 6.2	MF-Swift 6.2	MF-Tyre 6.1	MF-Swift 6.1	MF-Tyre 6.0	MF-Swift 6.0	MF-Tyre 5.2	SWIFT 1.2	MF-MCTyre 1.1
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							
ENV_C2	Effective plane angle attenuation		x							
Q_A2	Linear load term in contact length						x		x	
Q_A1	Square root load term in contact length						x		x	
Q_LBF	Length of basic function						x		x	
Q_LOS1	Basic function offset threshold						x		x	
Q_LOS2	Basic function offset scaling factor with basic function length						x		x	
Q_LIMP1	Linear contact length term in basic function shift						x		x	
Q_LIMP3	Scaling factor for quasi-static longitudinal enveloping force						x			
Q_LIMP4	Scaling factor for dynamic longitudinal enveloping force						x			
[INFLATION_PRESSURE_RANGE]										
PRESMIN	Minimum allowed inflation pressure	x	x	x	x					
PRESMAX	Maximum allowed inflation pressure	x	x	x	x					
[VERTICAL_FORCE_RANGE]										
FZMIN	Minimum allowed wheel load	x	x	x	x	x	x	x	x	x
FZMAX	Maximum allowed wheel load	x	x	x	x	x	x	x	x	x
[LONG_SLIP_RANGE]										
KPUMIN	Minimum valid wheel slip	x	x	x	x	x	x	x	x	x
KPUMAX	Maximum valid wheel slip	x	x	x	x	x	x	x	x	x
[SLIP_ANGLE_RANGE]										
ALPMIN	Minimum valid slip angle	x	x	x	x	x	x	x	x	x
ALPMAX	Maximum valid slip angle	x	x	x	x	x	x	x	x	x
[INCLINATION_ANGLE_RANGE]										
CAMMIN	Minimum valid camber angle	x	x	x	x	x	x	x	x	x
CAMMAX	Maximum valid camber angle	x	x	x	x	x	x	x	x	x
[SCALING_COEFFICIENTS]										
LFZO	Scale factor of nominal (rated) load	x	x	x	x	x	x	x	x	x
LCX	Scale factor of Fx shape factor	x	x	x	x	x	x	x	x	x
LMUX	Scale factor of Fx peak friction coefficient	x	x	x	x	x	x	x	x	x
LEX	Scale factor of Fx curvature factor	x	x	x	x	x	x	x	x	x
LKX	Scale factor of slip stiffness	x	x	x	x	x	x	x	x	x
LHX	Scale factor of Fx horizontal shift	x	x	x	x	x	x	x	x	
LVX	Scale factor of Fx vertical shift	x	x	x	x	x	x	x	x	x
LCY	Scale factor of Fy shape factor	x	x	x	x	x	x	x	x	x
LMUY	Scale factor of Fy peak friction coefficient	x	x	x	x	x	x	x	x	x
LEY	Scale factor of Fy curvature factor	x	x	x	x	x	x	x	x	x
LKY	Scale factor of cornering stiffness	x	x	x	x	x	x	x	x	x
LKYC	Scale factor of camber stiffness	x	x	x	x	x	x			
LKZC	Scale factor of camber moment stiffness	x	x	x	x	x	x			
LHY	Scale factor of Fy horizontal shift	x	x	x	x	x	x	x	x	x
LVY	Scale factor of Fy vertical shift	x	x	x	x	x	x	x	x	
LTR	Scale factor of Peak of pneumatic trail	x	x	x	x	x	x	x	x	x

Tyre Property File		**MF-Tyre 6.2**	**MF-Swift 6.2**	**MF-Tyre 6.1**	**MF-Swift 6.1**	**MF-Tyre 6.0**	**MF-Swift 6.0**	**MF-Tyre 5.2**	**SWIFT 1.2**	**MF-MCTyre 1.1**
LRES	Scale factor for offset of residual torque	x	x	x	x	x	x	x	x	x
LXAL	Scale factor of alpha influence on Fx	x	x	x	x	x	x	x	x	x
LYKA	Scale factor of alpha influence on Fx	x	x	x	x	x	x	x	x	x
LVYKA	Scale factor of kappa induced Fy	x	x	x	x	x	x	x	x	x
LS	Scale factor of Moment arm of Fx	x	x	x	x	x	x	x	x	x
LMX	Scale factor of overturning moment	x	x	x	x	x	x	x	x	x
LVMX	Scale factor of Mx vertical shift	x	x	x	x	x	x	x	x	x
LMY	Scale factor of rolling resistance torque	x	x	x	x	x	x	x	x	x
LMP	Scale factor of parking moment	x	x	x	x	x	x			
LKC	Scale factor of camber stiffness									x
LCC	Scale factor of camber shape factor									x
LEC	Scale factor of camber curvature factor									x
LSGKP	Scale factor of Relaxation length of Fx							x	x	x
LSGAL	Scale factor of Relaxation length of Fy							x	x	x
LGYR	Scale factor gyroscopic moment							x	x	x
[LONGITUDINAL_COEFFICIENTS]										
PCX1	Shape factor Cfx for longitudinal force	x	x	x	x	x	x	x	x	x
PDX1	Longitudinal friction Mux at Fznom	x	x	x	x	x	x	x	x	x
PDX2	Variation of friction Mux with load	x	x	x	x	x	x	x	x	x
PDX3	Variation of friction Mux with camber	x	x	x	x	x	x	x	x	x
PEX1	Longitudinal curvature Efx at Fznom	x	x	x	x	x	x	x	x	x
PEX2	Variation of curvature Efx with load	x	x	x	x	x	x	x	x	x
PEX3	Variation of curvature Efx with load squared	x	x	x	x	x	x	x	x	x
PEX4	Factor in curvature Efx while driving	x	x	x	x	x	x	x	x	x
PKX1	Longitudinal slip stiffness Kfx/Fz at Fznom	x	x	x	x	x	x	x	x	x
PKX2	Variation of slip stiffness Kfx/Fz with load	x	x	x	x	x	x	x	x	x
PKX3	Exponent in slip stiffness Kfx/Fz with load	x	x	x	x	x	x	x	x	x
PHX1	Horizontal shift Shx at Fznom	x	x	x	x	x	x	x	x	
PHX2	Variation of shift Shx with load	x	x	x	x	x	x	x	x	
PVX1	Vertical shift Svx/Fz at Fznom	x	x	x	x	x	x	x	x	x
PVX2	Variation of shift Svx/Fz with load	x	x	x	x	x	x	x	x	x
RBX1	Slope factor for combined slip Fx reduction	x	x	x	x	x	x	x	x	x
RBX2	Variation of slope Fx reduction with kappa	x	x	x	x	x	x	x	x	x
RBX3	Influence of camber on stiffness for Fx combined	x	x	x	x	x	x			x
RCX1	Shape factor for combined slip Fx reduction	x	x	x	x	x	x	x	x	x
REX1	Curvature factor of combined Fx	x	x	x	x	x	x	x	x	x
REX2	Curvature factor of combined Fx with load	x	x	x	x	x	x	x	x	x
RHX1	Shift factor for combined slip Fx reduction	x	x	x	x	x	x	x	x	x
PPX1	Linear pressure effect on slip stiffness	x	x	x	x					
PPX2	Quadratic pressure effect on slip stiffness	x	x	x	x					
PPX3	Linear pressure effect on longitudinal friction	x	x	x	x					
PPX4	Quadratic pressure effect on longitudinal friction	x	x	x	x					
PTX1	Relaxation length SigKap0/Fz at Fznom							x	x	x
PTX2	Variation of SigKap0/Fz with load							x	x	x
PTX3	Variation of SigKap0/Fz with exponent of load							x	x	x
[OVERTURNING_COEFFICIENTS]										
QSX1	Overturning moment offset	x	x	x	x	x	x	x	x	x
QSX2	Camber induced overturning couple	x	x	x	x	x	x	x	x	x
QSX3	Fy induced overturning couple	x	x	x	x	x	x	x	x	x
QSX4	Mixed load, lateral force and camber on Mx	x	x	x	x	x	x			
QSX5	Load effect on Mx with lateral force and camber	x	x	x	x	x	x			

Tyre Property File		MF-Tyre 6.2	MF-Swift 6.2	MF-Tyre 6.1	MF-Swift 6.1	MF-Tyre 6.0	MF-Swift 6.0	MF-Tyre 5.2	SWIFT 1.2	MF-MCTyre 1.1
QSX6	B-factor of load with Mx	x	x	x	x	x	x			
QSX7	Camber with load on Mx	x	x	x	x	x	x			
QSX8	Lateral force with load on Mx	x	x	x	x	x	x			
QSX9	B-factor of lateral force with load on Mx	x	x	x	x	x	x			
QSX10	Vertical force with camber on Mx	x	x	x	x	x	x			
QSX11	B-factor of vertical force with camber on Mx	x	x	x	x	x	x			
QSX12	Camber squared induced overturning moment	x	x	x	x					
QSX13	Lateral force induced overturning moment	x	x	x	x					
QSX14	Lateral force induced overturning moment with camber	x	x	x	x					
PPMX1	Influence of inflation pressure on overturning moment	x	x	x	x					
[LATERAL_COEFFICIENTS]										
PCY1	Shape factor Cfy for lateral forces	x	x	x	x	x	x	x	x	x
PDY1	Lateral friction Muy	x	x	x	x	x	x	x	x	x
PDY2	Variation of friction Muy with load	x	x	x	x	x	x	x	x	x
PDY3	Variation of friction Muy with squared camber	x	x	x	x	x	x	x	x	x
PEY1	Lateral curvature Efy at Fznom	x	x	x	x	x	x	x	x	x
PEY2	Variation of curvature Efy with load	x	x	x	x	x	x	x	x	x
PEY3	Zero order camber dependency of curvature Efy	x	x	x	x	x	x	x	x	x
PEY4	Variation of curvature Efy with camber	x	x	x	x	x	x	x	x	x
PEY5	Camber curvature Efc	x	x	x	x	x	x			x
PKY1	Maximum value of stiffness Kfy/Fznom	x	x	x	x	x	x	x	x	x
PKY2	Load at which Kfy reaches maximum value	x	x	x	x	x	x	x	x	x
PKY3	Variation of Kfy/Fznom with camber	x	x	x	x	x	x	x	x	x
PKY4	Curvature of stiffness Kfy	x	x	x	x	x	x			x
PKY5	Peak stiffness variation with camber squared	x	x	x	x	x	x			x
PKY6	Camber stiffness factor	x	x	x	x	x	x			x
PKY7	Load dependency of camber stiffness factor	x	x	x	x	x	x			x
PHY1	Horizontal shift Shy at Fznom	x	x	x	x	x	x	x	x	x
PHY2	Variation of shift Shy with load	x	x	x	x	x	x	x	x	
PVY1	Vertical shift in Svy/Fz at Fznom	x	x	x	x	x	x	x	x	
PVY2	Variation of shift Svy/Fz with load	x	x	x	x	x	x	x	x	
PVY3	Variation of shift Svy/Fz with camber	x	x	x	x	x	x	x	x	
PVY4	Variation of shift Svy/Fz with camber and load	x	x	x	x	x	x	x	x	
RBY1	Slope factor for combined Fy reduction	x	x	x	x	x	x	x	x	x
RBY2	Variation of slope Fy reduction with alpha	x	x	x	x	x	x	x	x	x
RBY3	Shift term for alpha in slope Fy reduction	x	x	x	x	x	x	x	x	x
RBY4	Influence of camber on stiffness of Fy combined	x	x	x	x	x	x			x
RCY1	Shape factor for combined Fy reduction	x	x	x	x	x	x	x	x	x
REY1	Curvature factor of combined Fy	x	x	x	x	x	x	x	x	x
REY2	Curvature factor of combined Fy with load	x	x	x	x	x	x	x	x	x
RHY1	Shift factor for combined Fy reduction	x	x	x	x	x	x	x	x	x
RHY2	Shift factor for combined Fy reduction with load	x	x	x	x	x	x	x	x	x
RVY1	Kappa induced side force Svyk/Muy*Fz at Fznom	x	x	x	x	x	x	x	x	x
RVY2	Variation of Svyk/Muy*Fz with load	x	x	x	x	x	x	x	x	x
RVY3	Variation of Svyk/Muy*Fz with camber	x	x	x	x	x	x	x	x	x
RVY4	Variation of Svyk/Muy*Fz with alpha	x	x	x	x	x	x	x	x	x
RVY5	Variation of Svyk/Muy*Fz with kappa	x	x	x	x	x	x	x	x	x
RVY6	Variation of Svyk/Muy*Fz with atan(kappa)	x	x	x	x	x	x	x	x	x
PPY1	Pressure effect on cornering stiffness magnitude	x	x	x	x					
PPY2	Pressure effect on location of cornering stiffness peak	x	x	x	x					
PPY3	Linear pressure effect on lateral friction	x	x	x	x					
PPY4	Quadratic pressure effect on lateral friction	x	x	x	x					

Tyre Property File		MF-Tyre 6.2	MF-Swift 6.2	MF-Tyre 6.1	MF-Swift 6.1	MF-Tyre 6.0	MF-Swift 6.0	MF-Tyre 5.2	SWIFT 1.2	MF-MCTyre 1.1
PPY5	Influence of inflation pressure on camber stiffness	x	x	x	x					
PCY2	Shape factor Cfc for camber forces									x
PHY3	Variation of shift Shy with camber							x	x	
PTY1	Peak value of relaxation length SigAlp0/R0							x	x	x
PTY2	Value of Fz/Fznom where SigAlp0 is extreme							x	x	x
PTY3	Value of Fz/Fznom where Sig_alpha is maximum									x
[ROLLING_COEFFICIENTS]										
QSY1	Rolling resistance torque coefficient	x	x	x	x	x	x	x	x	x
QSY2	Rolling resistance torque depending on Fx	x	x	x	x	x	x	x	x	x
QSY3	Rolling resistance torque depending on speed	x	x	x	x	x	x	x	x	x
QSY4	Rolling resistance torque depending on speed ^4	x	x	x	x	x	x	x	x	x
QSY5	Rolling resistance torque depending on camber squared	x	x	x	x					
QSY6	Rolling resistance torque depending on load and camber squared	x	x	x	x					
QSY7	Rolling resistance torque coefficient load dependency	x	x	x	x					
QSY8	Rolling resistance torque coefficient pressure dependency	x	x	x	x					
[ALIGNING_COEFFICIENTS]										
QBZ1	Trail slope factor for trail Bpt at Fznom	x	x	x	x	x	x	x	x	x
QBZ2	Variation of slope Bpt with load	x	x	x	x	x	x	x	x	x
QBZ3	Variation of slope Bpt with load squared	x	x	x	x	x	x	x	x	x
QBZ4	Variation of slope Bpt with camber	x	x	x	x	x	x	x	x	x
QBZ5	Variation of slope Bpt with absolute camber	x	x	x	x	x	x	x	x	x
QBZ9	Slope factor Br of residual torque Mzr	x	x	x	x	x	x	x	x	x
QBZ10	Slope factor Br of residual torque Mzr	x	x	x	x	x	x	x	x	x
QCZ1	Shape factor Cpt for pneumatic trail	x	x	x	x	x	x	x	x	x
QDZ1	Peak trail Dpt" = Dpt*(Fz/Fznom*R0)	x	x	x	x	x	x	x	x	x
QDZ2	Variation of peak Dpt with load	x	x	x	x	x	x	x	x	x
QDZ3	Variation of peak Dpt with camber	x	x	x	x	x	x	x	x	x
QDZ4	Variation of peak Dpt with camber squared	x	x	x	x	x	x	x	x	x
QDZ6	Peak residual torque Dmr = Dmr/(Fz*R0)	x	x	x	x	x	x	x	x	x
QDZ7	Variation of peak factor Dmr with load	x	x	x	x	x	x	x	x	x
QDZ8	Variation of peak factor Dmr with camber	x	x	x	x	x	x	x	x	x
QDZ9	Variation of peak factor Dmr with camber and load	x	x	x	x	x	x	x	x	x
QDZ10	Variation of peak factor Dmr with camber squared	x	x	x	x	x	x			x
QDZ11	Variation of Dmr with camber squared and load	x	x	x	x	x	x			x
QEZ1	Trail curvature Ept at Fznom	x	x	x	x	x	x	x	x	x
QEZ2	Variation of curvature Ept with load	x	x	x	x	x	x	x	x	x
QEZ3	Variation of curvature Ept with load squared	x	x	x	x	x	x	x	x	x
QEZ4	Variation of curvature Ept with sign of Alpha-t	x	x	x	x	x	x	x	x	x
QEZ5	Variation of Ept with camber and sign Alpha-t	x	x	x	x	x	x	x	x	x
QHZ1	Trail horizontal shift Sht at Fznom	x	x	x	x	x	x	x	x	x
QHZ2	Variation of shift Sht with load	x	x	x	x	x	x	x	x	x
QHZ3	Variation of shift Sht with camber	x	x	x	x	x	x	x	x	x
QHZ4	Variation of shift Sht with camber and load	x	x	x	x	x	x	x	x	x
SSZ1	Nominal value of s/R0: effect of Fx on Mz	x	x	x	x	x	x	x	x	x
SSZ2	Variation of distance s/R0 with Fy/Fznom	x	x	x	x	x	x	x	x	x
SSZ3	Variation of distance s/R0 with camber	x	x	x	x	x	x	x	x	x
SSZ4	Variation of distance s/R0 with load and camber	x	x	x	x	x	x	x	x	x
PPZ1	Linear pressure effect on pneumatic trail	x	x	x	x					
PPZ2	Influence of inflation pressure on residual aligning torque	x	x	x	x					
QTZ1	Gyroscopic torque constant							x	x	x

Tyre Property File		**MF-Tyre 6.2**	**MF-Swift 6.2**	**MF-Tyre 6.1**	**MF-Swift 6.1**	**MF-Tyre 6.0**	**MF-Swift 6.0**	**MF-Tyre 5.2**	**SWIFT 1.2**	**MF-MCTyre 1.1**
MBELT	Belt mass of the wheel							x	x	x
[TURNSLIP_COEFFICIENTS]										
PDXP1	Peak Fx reduction due to spin parameter	x	x	x	x	x	x			
PDXP2	Peak Fx reduction due to spin with varying load parameter	x	x	x	x	x	x			
PDXP3	Peak Fx reduction due to spin with kappa parameter	x	x	x	x	x	x			
PKYP1	Cornering stiffness reduction due to spin	x	x	x	x	x	x			
PDYP1	Peak Fy reduction due to spin parameter	x	x	x	x	x	x			
PDYP2	Peak Fy reduction due to spin with varying load parameter	x	x	x	x	x	x			
PDYP3	Peak Fy reduction due to spin with alpha parameter	x	x	x	x	x	x			
PDYP4	Peak Fy reduction due to square root of spin parameter	x	x	x	x	x	x			
PHYP1	Fy-alpha curve lateral shift limitation	x	x	x	x	x	x			
PHYP2	Fy-alpha curve maximum lateral shift parameter	x	x	x	x	x	x			
PHYP3	Fy-alpha curve maximum lateral shift varying with load parameter	x	x	x	x	x	x			
PHYP4	Fy-alpha curve maximum lateral shift parameter	x	x	x	x	x	x			
PECP1	Camber w.r.t. spin reduction factor parameter in camber stiffness	x	x	x	x	x	x			
PECP2	Camber w.r.t. spin reduction factor varying with load parameter in camber stiffness	x	x	x	x	x	x			
QDTP1	Pneumatic trail reduction factor due to turn slip parameter	x	x	x	x	x	x			
QCRP1	Turning moment at constant turning and zero forward speed parameter	x	x	x	x	x	x			
QCRP2	Turn slip moment (at alpha=90deg) parameter for increase with spin	x	x	x	x	x	x			
QBRP1	Residual (spin) torque reduction factor parameter due to side slip	x	x	x	x	x	x			
QDRP1	Turn slip moment peak magnitude parameter	x	x	x	x	x	x			

Obsolete parameters which may be in a Tyre Property File, but are ignored by MF-Tyre/MF-Swift 6.x

	description				**MF-Swift 6.0**	**MF-Tyre 5.2**	**SWIFT 1.2**	**MF-MCTyre 1.1**
[MODEL]								
TYPE		*1*				x	x	x
MFSAFE1		*1*				x	x	x
MFSAFE2		*1*				x	x	x
MFSAFE3		*1*				x	x	x
[SHAPE]	The complete shape section is obsolete	*2*				x		x
[INERTIA]								
M_A	Portion of tyre mass of tyre part fixed to rim	*3*					x	
I_AY	Normalized moment of inertia about Y of tyre part fixed to rim	*3*					x	
I_AXZ	Normalized moment of inertia about XZ of tyre part fixed to rim	*3*					x	
M_R	Normalized residual mass	*4*					x	
I_R	Normalized moment of inertia about Z of residual mass	*4*					x	
[STRUCTURAL]								
K_RX	Longitudinal residual damping	*5*					x	
K_RY	Lateral residual damping	*5*					x	
K_RP	Yaw residual damping	*5*					x	
[VERTICAL]								

BOTTOM_TRNSF	Transition range of bottoming	6					x		
[CONTACT_PATCH]									
FLT_A	Filter constant contact length	7					x		
Q_KC1	Low speed tread element damping coefficient	8					x		
Q_KC2	Low speed tread element damping coefficient	8					x		
ELLIPS_INC	Discretisation increment of ellipsoid contour	9			x		x		
Q_LIMP2	Quadratic contact length term in basic function shift	10					x		
[SCALING_COEFFICIENTS]									
LGAX	Scale factor of camber for Fx	11				x	x	x	
LGAY	Scale factor of camber for Fy	12				x	x	x	
LGAZ	Scale factor of camber for Mz	13				x	x	x	
1	*parameter was not used*								
2	*used in combination with Adams durability contact;*								
	replaced by motorcycle contact and basic functions/ellipsoid contact								
3	*replaced by new mass/inertia defintions*								
4	*in MF-Swift 6.0 and 6.1 a new formulation is used without residual mass*								
5	*replaced by parameter DAMP_RESIDUAL*								
6	*parameter deleted*								
7	*parameter set internally in the software*								
8	*replaced by parameter DAMP_VLOW*								
9	*parameter is set automatically based on specifiedROAD_INCREMENT*								
10	*parameter deleted*								
11	*parameter deleted, adjust PDX3 directly*								
12	*camber force stiffness is controlled by parameter LKYC*								
13	*camber moment stiffness is controlled by parameter LKZC*								

5.4 Road Data File

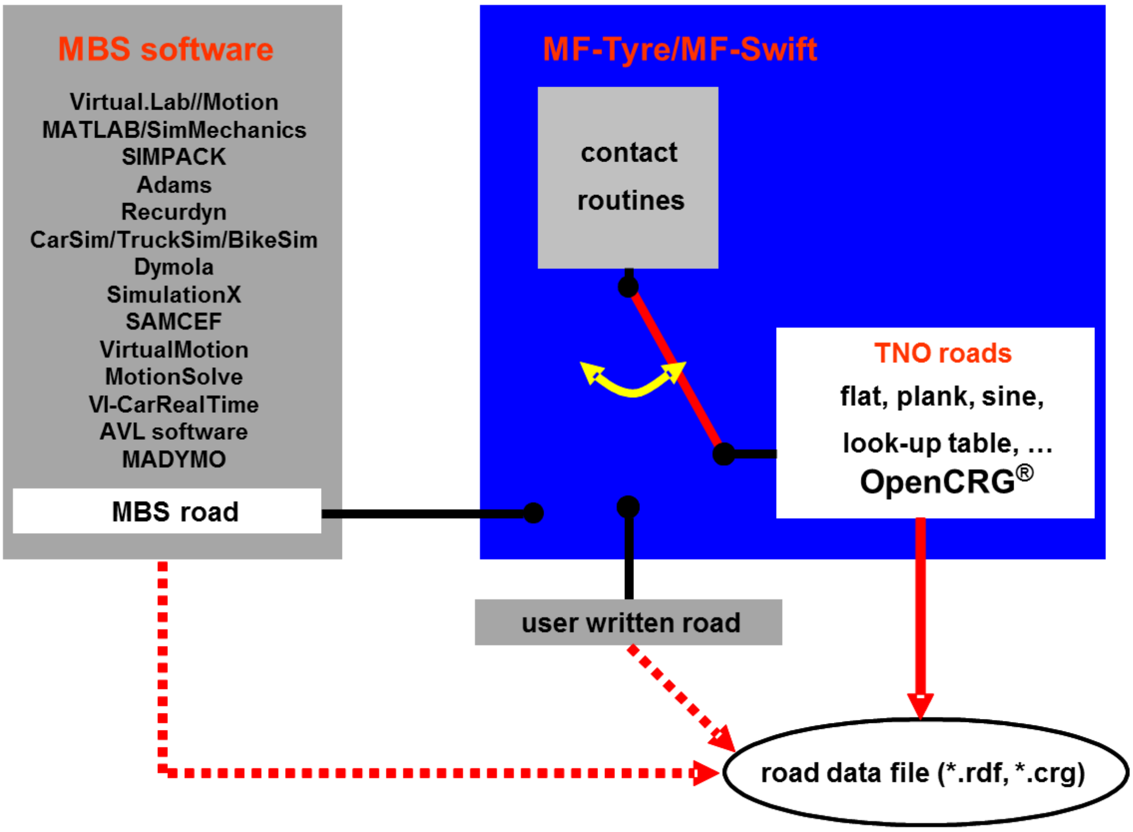
In general three ways exist to define a **road surface**:

- **Multi-body road** (default)
- TNO road 48 (including TNO OpenCRG Road 53)
- User-written subroutine

The default is using the road surfaces from the multi-body package MF-Tyre/MF-Swift is used in. Besides, TNO offers several relatively simple road surface types that can be used with the tyre model, e.g. with MATLAB/ SimMechanics.

Finally, for experienced MF-Tyre/MF-Swift users that have Fortran programming experience an option exists to write their own road routines. Please contact TNO for more information about the the user-written subroutine.

The various options are illustrated in the figure below:



Switching between these options is done based on the contents of the road data file. When the user specifies a road data file, MF-Tyre/MF-Swift analyses the file to see if the format is a TNO Road Type 48. If this is the case, the TNO road subroutine is used. If not the multi-body road will be called (default).

Overruling the switching mechanism

This switching mechanism can be overruled by the keyword `ROAD_SOURCE` in the `[MODEL]` section of the tyre property file. Only use this possibility if you are an experienced user. Three options exist:

- `ROAD_SOURCE = 'TNO'` use MF-Tyre/MF-Swift internal road definition
- `ROAD_SOURCE = 'MBS'` use road definition of the MBS package
- `ROAD_SOURCE = 'USER'` use the user written road

5.4.1 TNO Road Types

TNO offers the following road types:

- Flat Road 49
- Plank Road 50
- Polyline Road 50
- Sine Road 50
- Drum_Road 51
- OpenCRG Road 53

Note: The TNO Road Types are not available in all multi-body simulation packages.

TNO Road Definition

These road surfaces are defined in road data files (*.rdf). Like the Tyre Property File, the road data file consists of various sections indicated with square brackets:

```
! Comments section
$-----------------------------------------------------------UNITS
[UNITS]
LENGTH          = 'meter'
FORCE           = 'newton'
ANGLE           = 'degree'
MASS            = 'kg'
TIME            = 'sec'
$-----------------------------------------------------------MODEL
[MODEL]
ROAD_TYPE       = '...'
$------------------------------------------------------PARAMETERS
[PARAMETERS]
...
```

In the [UNITS] section, the units that are used in the road data file are set. The [MODEL] and [PARAMETERS] section are described below.

[Model] section

The [MODEL] section is used to specify the road type:

Road Type	**Coding**
Flat Road 49	`ROAD_TYPE = 'flat'`
Plank Road 50	`ROAD_TYPE = 'plank'`
Polyline Road 50	`ROAD_TYPE = 'poly_line'`
Sine Road 50	`ROAD_TYPE = 'sine'`
Drum Road 51	`ROAD_TYPE = 'drum'`
OpenCRG Road 53	`ROAD_TYPE = 'crg'`

[Parameters] section

The [PARAMETERS] section contains general and type specific parameters for the road surface.

General

The general parameters are valid for all Road types (except OpenCRG Road 53 for which only MU is valid) and are listed below:

MU	Road friction correction factor (not the friction value itself), to be multiplied with the LMU scaling factors of the tyre model. Default setting: MU = 1.0.
OFFSET	Vertical offset of the ground with respect to inertial frame.
ROTATION_ANGLE_XY_PLANE	Rotation angle of the XY-plane about the road Z-axis, i.e. definition of the positive X-axis of the road with respect to the inertial frame.
DRUM_RADIUS	Radius of the drum.

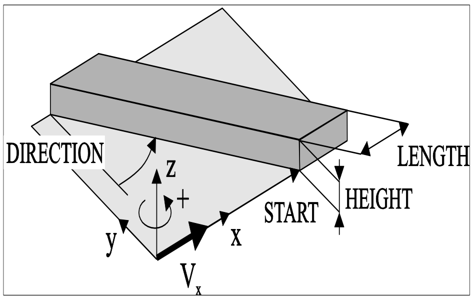
The road surface type specific parameters are explained in the next sections:

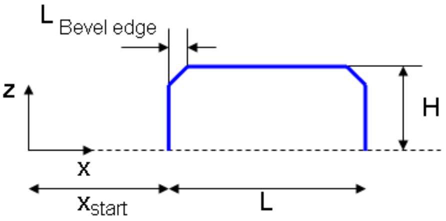
Flat Road

As the name already indicates this is a flat road surface. It has no parameters, except the General 49 parameters.

Plank Road

This is a single cleat or plank that is oriented perpendicular, or in oblique direction relative to the X-axis with or without bevel edges.





HEIGHT	Height of the cleat.
START	Distance along the X-axis of the road from the origin to the start of the cleat (i.e. travelling from the origin the tyre will hit the cleat at START).
LENGTH	Length of the cleat (including bevel) along X-axis of the road.
BEVEL_EDGE_LENGTH	Length of the 45 deg. bevel edge of the cleat.
DIRECTION	Rotation of the cleat about the Z-axis with respect to the Y-axis of the road. If the cleat is placed crosswise, DIRECTION = 0. If the cleat is along the X-axis, DIRECTION = 90.

Polyline

Road height as a function of travelled distance.

The [PARAMETERS] block must have a (XZ_DATA) sub-block. The sub-block consists of three columns of numerical data:

- Column one is a set of X-values in ascending order;
- Columns two and three are sets of respective Z-values for left and right track.

Example:

```
[PARAMETERS]
MU                         =  1.0 $ peak friction scaling
                                  $ coefficient
OFFSET                     =    0 $ vertical offset of the
                                  $ ground wrt inertial frame
ROTATION_ANGLE_XY_PLANE    =    0 $ definition of the positive
                                  $ X-axis of the road wrt
                                  $ inertial frame

$
$   X_road    Z_left   Z_right
(XZ_DATA)
-1.0e04        0      0
0              0      0
0.0500         0      0
...            ...    ...
```

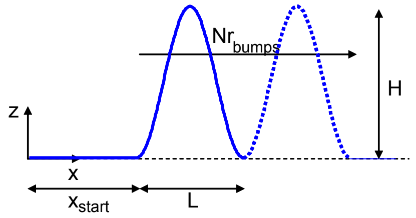
Sine Road

Road surface consisting of one or more sine waves with constant wavelength.

The TNO sine road is implemented as:

$$z(x) = \frac{H}{2}\left(1 - \cos\left(\frac{2\pi \cdot (x - x_{start})}{L}\right)\right)$$

With z: z-coordinate road; H; Height; x: current position; x_{start}: start of sine wave; L: Length



HEIGHT	Height of the sine wave.
START	Distance along the X-axis of the road to the start of the sine wave.
LENGTH	Wavelength of the sine wave along X-axis of the road.
DIRECTION	Rotation of the bump about the Z-axis with respect to the X-axis of the road. If the bump is placed crosswise, DIRECTION = 0. If the bump is along the X-axis, DIRECTION = 90.
N_BUMPS	Number of consecutive sine bumps.

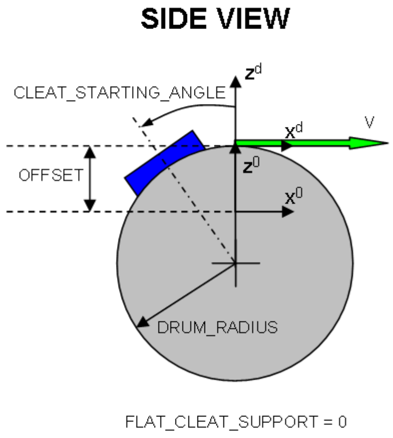
Note, the sine road in Adams is defined as follows:

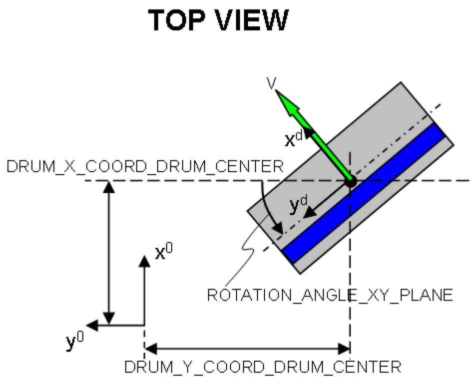
$$z(x) = \frac{H}{2}\sin\left(\frac{2\pi \cdot (x - x_{start})}{L}\right)$$

Drum Road

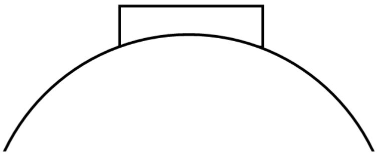
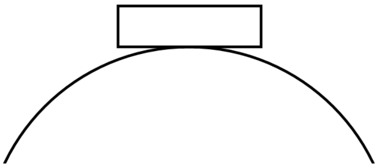
> **Note**: It is recommended to use the default road surfaces like e.g. Polyline Road or Plank Road and specify the DRUM_RADIUS as parameter, because it is computational more efficient. In case the mentioned approach is insufficient, e.g. in specific applications, a real DrumRoad can be used.

As the name already indicates this is a drum road surface. A single cleat that is oriented perpendicular to the local drum X,Z-plane can be mounted, which will be passed every revolution of the drum.





V	Tangential velocity of the drum in the local right handed drum coordinate

	system
CLEAT_STARTING_ANGLE	Drum angle coordinate of the centre of the first cleat (positive is a clockwise rotation). When undefined starting angle is 0.
DRUM_X_COORD_DRUM_CENTER	X-coordinate of drum centre in global coordinates, used for all wheels. When undefined x-coordinate drum centre is 0.
DRUM_Y_COORD_DRUM_CENTER	Y-coordinate of drum centre in global coordinates, used for all wheels. When undefined y-coordinate drum centre is 0.
DRUM_FLAT_CLEAT_SUPPORT	0: cleat is mounted on the drum such that its support on the drum surface is curved according to overall drum curvature.  1: cleat is mounted on the drum such that its support on the drum surface is flat.  When undefined cleat support is 0.

Note that the [PARAMETERS] block must have a (XZ_DATA) sub-block when an obstacle is mounted. The sub-block consists of two columns of numerical data:

- Column one is a set of X-values in ascending order;
- Column two is a set of Z-values.

These XZ_DATA are solely used to define the dimensions and shape of the obstacle.

Example:

```
! Comments section
$-----------------------------------------------------------UNITS
[UNITS]
LENGTH          = 'mm'
FORCE           = 'newton'
ANGLE           = 'degree'
MASS            = 'kg'
TIME            = 'sec'
$-----------------------------------------------------------MODEL
[MODEL]
ROAD_TYPE       = 'drum'
$------------------------------------------------------PARAMETERS

[PARAMETERS]
MU                           =  1.0 $ peak friction scaling
                                    $ coefficient
OFFSET                       =    0 $ vertical offset of the
                                    $ ground wrt inertial frame
ROTATION_ANGLE_XY_PLANE      =    0 $ definition of the positive
                                    $ X-axis of the road wrt
```

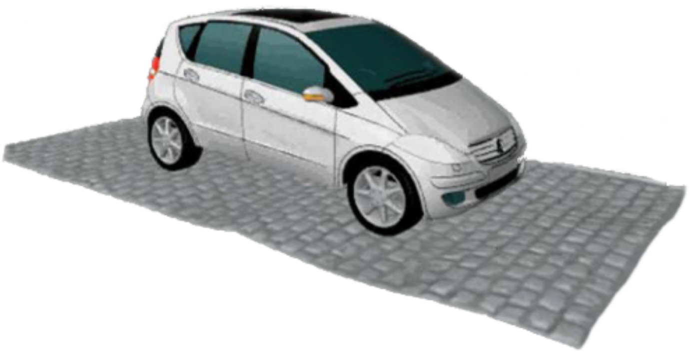
```
                                             $ inertial frame
$
DRUM_RADIUS                  =    2500 $ radius of the drum
V                            = -10000 $ velocity of the drum
CLEAT_SARTING_ANGLE          =       0 $ start angle of the centre
                                       $ of the cleat at the drum
DRUM_X_COORD_DRUM_CENTER     =       0 $ global displacement of
                                       $ the drum in x-direction
DRUM_Y_COORD_DRUM_CENTER     =       0 $ global displacement of
                                       $ the drum in y-direction
DRUM_FLAT_CLEAT_SUPPORT      =       0 $ the support of the cleat
$
(XZ_DATA)
-25       0
-15      10
 15      10
 25       0
```

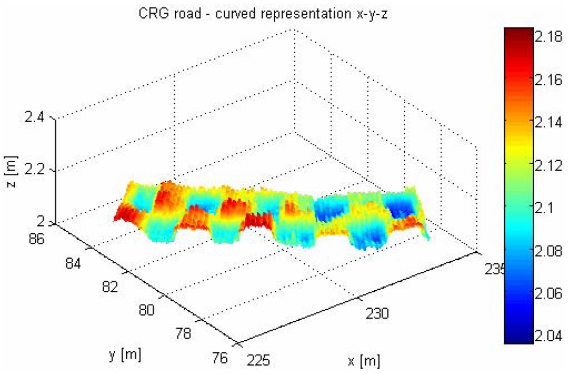
5.4.2 TNO OpenCRG Road

The TNO **OpenCRG** Road is the implementation of the interface between MF-Tyre/MF-Swift and OpenCRG, maintained by VIRES Simulationstechnologie GmbH, 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 representations. OpenCRG is based on CRG 54, 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 www.opencrg.org, 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.

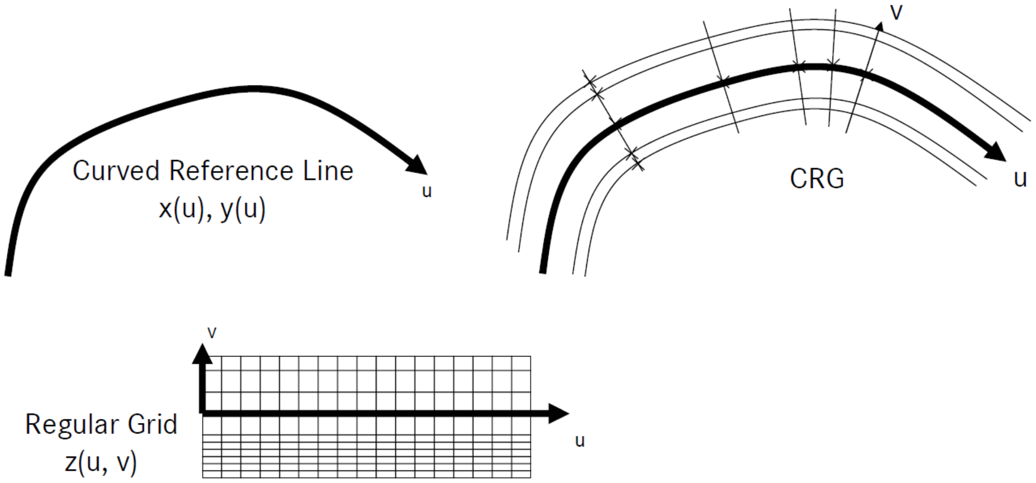
OpenCRG is a registered trademark of Daimler AG.

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

CRG, or 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 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.

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 TNO CRG Road implementation the friction can be modelled 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 modelled.

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.

Implementation

There are 2 ways to reference the CRG file(s):

- Reference from RDF file 55

- Direct reference to CRG file 55

Note that only the first method enables friction variation.

Reference from RDF file

The reference to CRG file(s) can be set in the Road Data File, RDF. This way **friction** of the road surface can be defined as well. When no friction file is set the value of MU will be used as Road Friction Correction Factor.

The references to the CRG file(s) need to be set in the [PARAMETERS] section 49 of an RDF. Standard, the specified CRG file(s) are taken from the same directory as the RDF. For referencing to CRG file(s) in a different directory, absolute and relative paths can be used. The following parameters can be set:

MU	Road Friction Correction Factor (not the friction value itself), to be multiplied with the LMU scaling factors of the tyre model. Default setting: MU = 1.0. Note, MU will be ignored if keyword CRG_FRICTIONFILE is specified, but must be specified.
CRG_ROADFILE	Reference to the crg file containing the **height** data of the road
CRG_FRICTIONFILE	(Optional) Reference to the crg file containing the **friction** data of the road. Note, if this keyword is used the value of MU will be ignored. However, MU must be specified.

Note: The `ROAD_TYPE` needs to be set to `'crg'` in the [Model] section 49 when using the reference from RDF.

Direct reference to CRG file

A CRG file can also be directly referenced by an MBS Package (except for Adams). MF-Tyre/MF-Swift will use this file to calculate the height of the road. Friction variation over the road surface is not possible with this method (because of limitations of the Standard Tyre Interface). The Road Friction Correction Factor (MU) will in this case be treated as being one.

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 start menu:

All Programs > TNO Delft-Tyre > MF-Tyre & MF-Swift 6.2 > OpenCRG > OpenCRG User manual

Note: How to add the routines to the MATLAB search path is described in the Installation Guide / .. / OpenCRG.

5.5 Multi-Body Simulation Packages

For more information about the use of the MF-Tyre/MF-Swift model with the supported Multi-body simulation (MBS) packages consult the MBS packages documentation.

Note: For MATLAB and Adams these instructions can be found in the manual in the installation of MF-Tyre/ MF-Swift.

5.6 References

[1] Pacejka, H.B.: “Tire and Vehicle Dynamics”, Third Edition, Butterworth-Heinemann, Oxford, 2012.
[2] Pacejka, H.B., I.J.M. Besselink: “Magic Formula Tyre model with Transient Properties”, Supplement to Vehicle System Dynamics, Vol. 27, pp. 234-249, 1997.
[3] Zegelaar, P.W.A., “The Dynamic Response of Tyres to Brake Torque Variations and Road Unevenesses”, dissertation, Delft University of Technology, The Netherlands, 1998.
[4] Maurice, J.P., “Short Wavelength and Dynamic Tyre Behaviour under Lateral and Combined Slip Conditions”, dissertation, Delft University of Technology, The Netherlands, 1999.
[5] Schmeitz, A.J.C., “A Semi-Empirical Three-Dimensional Model of the Pneumatic Tyre Rolling over Arbitrarily Uneven Road Surfaces”, dissertation, Delft University of Technology, Delft, The Netherlands, 2004.
[6] Besselink, I.J.M., 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.
[7] 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.
[8] TNO Automotive: “MF-Tool 6.1 Users Manual”, TNO Automotive, The Netherlands, 2008.

Index