MF-TYRE & MF-SWIFT 6.1

USER MANUAL 2008

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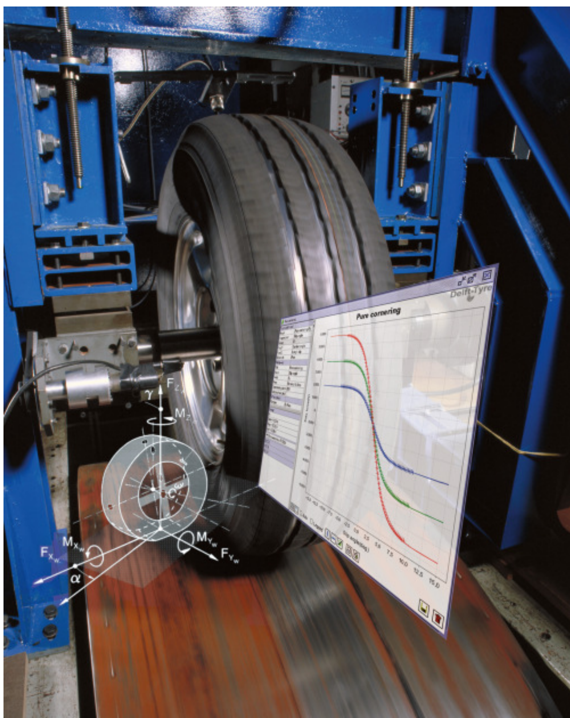

Delft-Tyre

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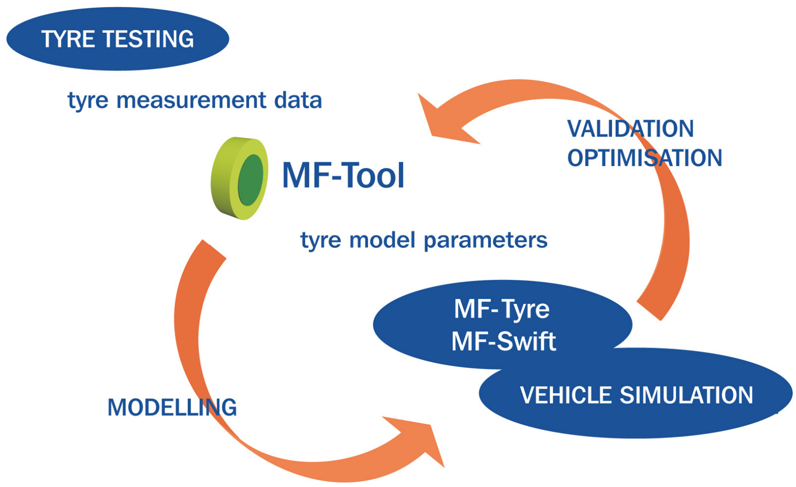
1 Overview

1.1 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 and MF-Swift 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.

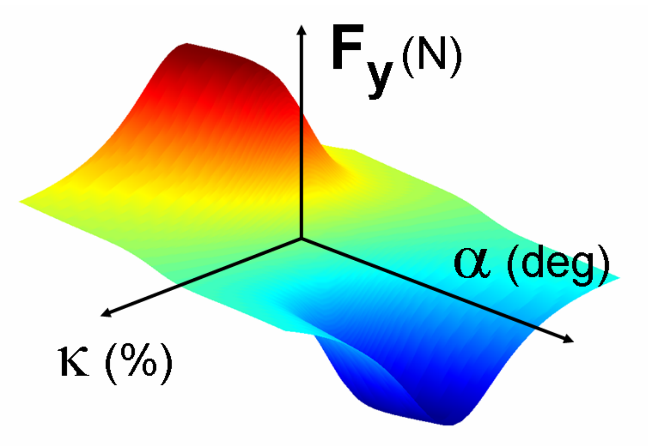
MF-Tyre and MF-Swift contain the latest implementation by Delft-Tyre of Pacejka's renowned 'Magic Formula' tyre model. With MF-Tyre you can simulate validated steady-state and transient behaviour, making it a very suitable tyre model for vehicle handling, control prototyping, or rollover analysis. With MF-Swift you can simulate tyre dynamic behaviour up to about 100 Hz, which is particularly useful for vehicle comfort, durability, dynamic vehicle control, or vibration analysis.

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. 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.

1.2 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.

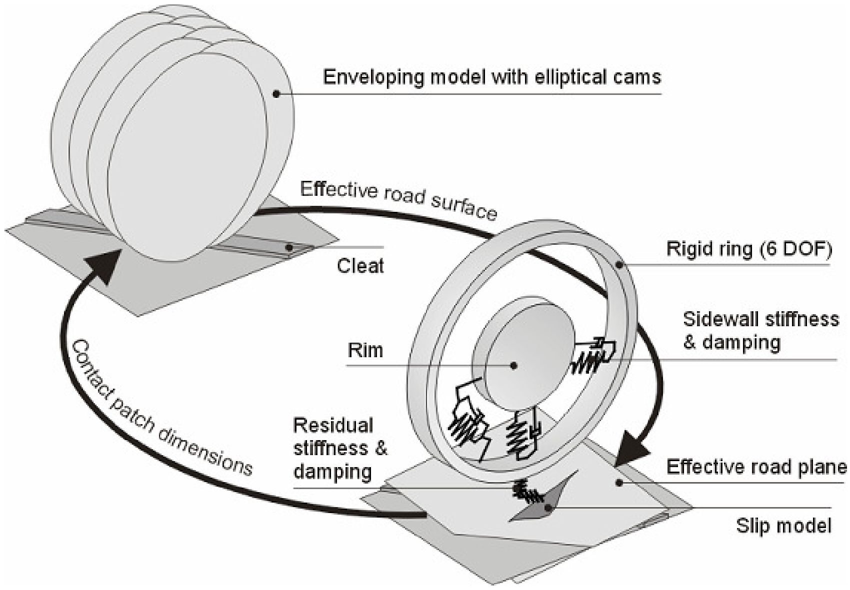
MF-Tyre is valid for large slip angles (typically over 30 degrees), longitudinal slip (100%), large load variations (including truck tyre loads) and large camber angles (including motorcycle camber angles; MF-Tyre 6.x includes the functionality of MF-MCTyre). It can handle road undulations that have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

1.3 MF-Swift

In addition to the Magic Formula description in the MF-Tyre 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] – [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. **Rigid ring with 6 degrees of freedom.** The primary vibration modes of the tyre belt are described by an elastically suspended rigid ring representing the tyre sidewalls and belt with its mass and inertia properties.
2. **Residual stiffness & damping.** These 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.** This part 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.** This part 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. This part (MF-Tyre 6.1) 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].

1.4 New features in MF-Tyre/MF-Swift 6.1

With respect to MF-Tyre/MF-Swift 6.0 the following changes have been made:

- Introduction of tyre pressure dependency on the tyre characteristics. This includes the Magic Formula, tyre stiffness, rolling resistance and other properties.
- Improved motorcycle tyre road contact.
- Replacement of the 2D road contact method using basic functions by the more robust and accurate ellipse contact method. The ellipse parameters can be used for both 2D and 3D road contact. Backward compatibility is maintained, so older tyre property files with basic function parameters will keep on working.
- A parameter DRUM_RADIUS has been added to the TNO road surfaces to allow simulations on a drum surface. The tyre model automatically adjusts tyre properties to account for the global road curvature.

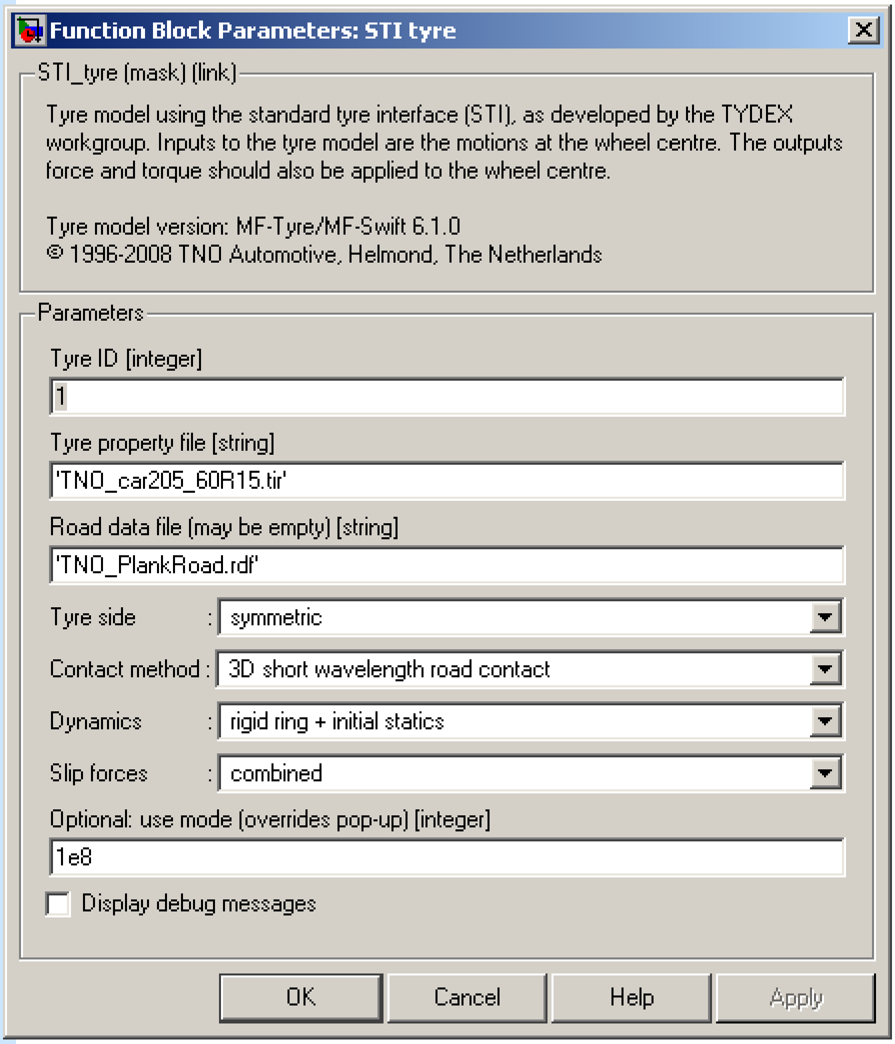
1.5 Licensing of MF-Tyre/MF-Swift 6.1

The licensing system of MF-Tyre and MF-Swift 6.1 depends on the multibody/simulation package in which it is used and the used operating system. Please read the license manual, license agreement and terms of use that are supplied with the Delft-Tyre and/or multibody/simulation software. If things are unclear please contact TNO Automotive (http://www.delft-tyre.nl/). The operating modes that are supported by MF-Tyre and MF-Swift licenses are discussed in section 2.1.

2 Model usage

2.1 Operating modes

MF-Tyre/MF-Swift 6.1 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. In some software packages this is done by defining a four digit value for the parameter ISWTCH in the GUI (DADS); for some other packages the selections can be made from a menu (e.g. SIMPACK, MATLAB/Simulink). In ADAMS changes to the operating mode can be made by setting the parameter USE_MODE in the [MODEL] section of the tyre property file. For details on various implementations see chapter 5.



Example operating mode selection: Simulink interface.

Basically USE_MODE (or ISWTCH) = ABCD (e.g. 1134); the following choices can be made:

Tyre side - Magic Formula mirroring (number A)

A Magic Formula tyre model may show offsets and asymmetric behaviour caused by conicity and/or plysteer. In the tyre property file [MODEL] -section there may be a keyword TYRESIDE, which can be either "LEFT" or "RIGHT" (when missing: "LEFT" is assumed). This indicates how the tyre measurement was executed. Using the same characteristics on the left and right hand side of a vehicle may result in undesired asymmetrical behaviour of the full vehicle. 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).

We may select one of the following values for A:

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

Contact Method (number B)

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 B:

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

Dynamics (number C)

Depending on the frequency range of interest more details on the dynamic behaviour of the tyre may be included. In the case of a steady-state evaluation no dynamic behaviour is included. "Linear transient effects" indicates that the tyre relaxation behaviour is included using empirical relations for the relaxation lengths. 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" refers to a detailed dynamic model (MF-Swift), where the tyre belt is modelled as a separate rigid body. Finally, "initial statics" refers to finding the static equilibrium of the tyre belt (rigid ring/body) at the start of the simulation.

We may select one of the following values for C:

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)
4	Rigid ring dynamics + initial statics (same as 3, but with finding static equilibrium)

Slip forces - Magic Formula evaluation (number D)

When evaluating the Magic Formula it is 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: 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.

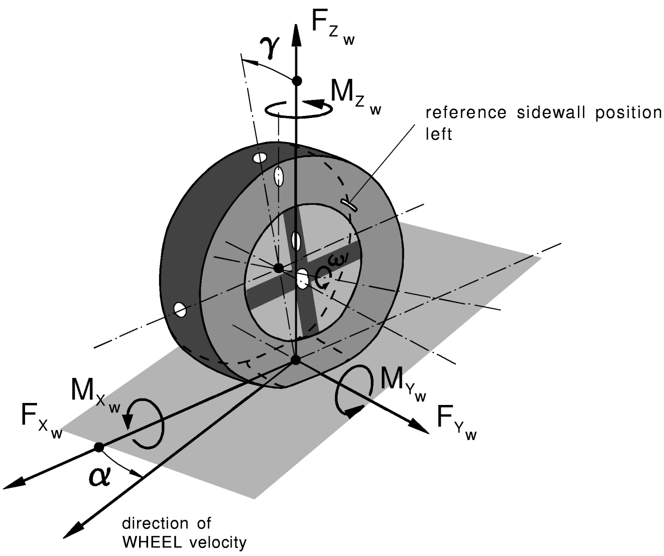
MF-Tyre and MF-Swift
The next table lists the operating modes that are supported by MF-Tyre and MF-Swift licenses.

	MF-Tyre 6.1	MF-Swift 6.1
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

2.2 Axis systems and units

Axis systems

MF-Tyre/MF-Swift 6.1 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:

$$\kappa = -\frac{V_{sx}}{V_x} \qquad \text{(note: } \kappa = -1 \text{ is braking at wheel lock),}$$

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

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 MF-Tool. 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 multibody simulation program, as defined in the specification of the Standard Tyre Interface (STI) [8]. However many multibody 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.

Please contact TNO if you have special, non-standard requirements with respect to units.

2.3 Tyre model output

Various signals are available for post-processing. 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:			
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)

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

3 The tyre property file

3.1 Overview

The tyre property file (*.tir) contains the parameters of the tyre model. Sample tyre property files are provided with the installation. The file 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:

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	
[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 camber angles
Magic Formula:	
[SCALING_COEFFICIENTS]	Magic Formula scaling factors, see also section 3.3
[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 fitting 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**: 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 this 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.

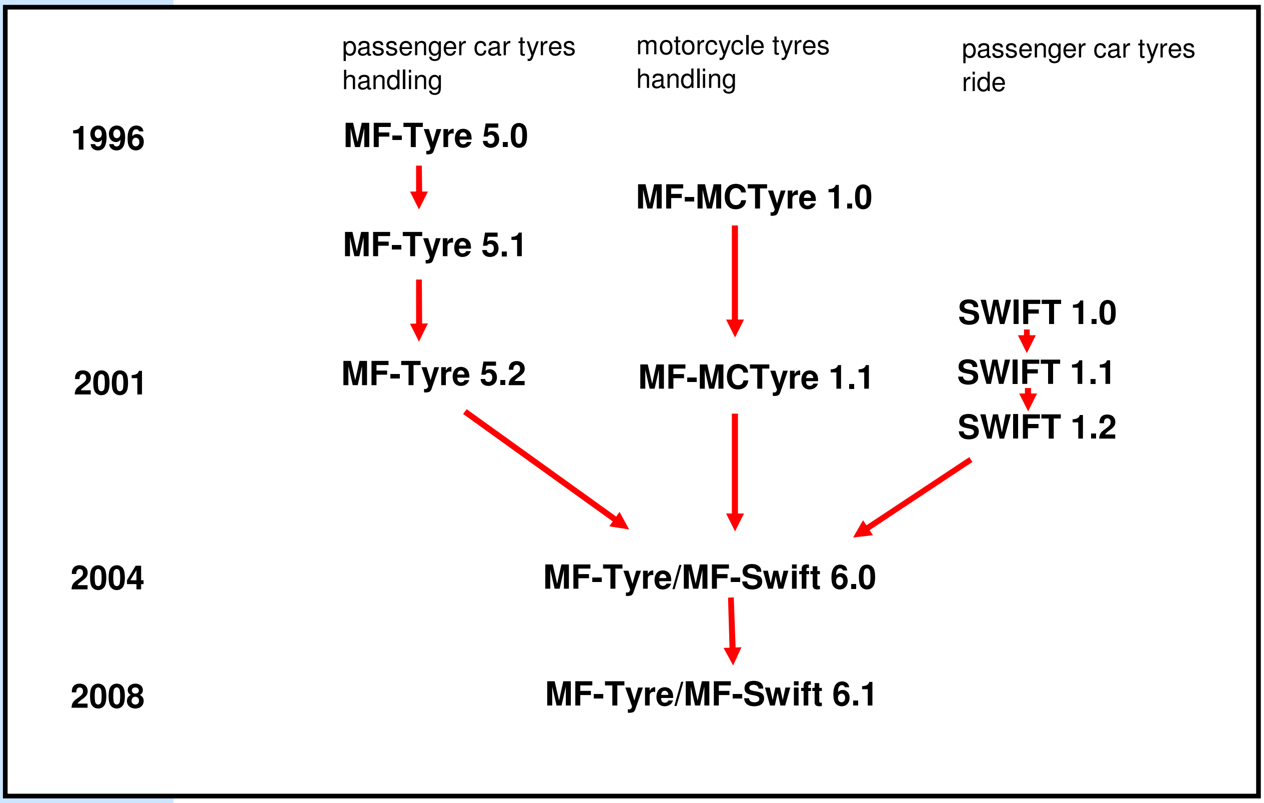
coefficient	**meaning**
FITTYP	Magic Formula version number
UNLOADED_RADIUS	Free tyre radius
MASS	Tyre mass
GRAVITY	Gravity acting on belt in Z direction
FNOMIN	Nominal wheel load
VERTICAL_STIFFNESS	Tyre vertical stiffness
VERTICAL_DAMPING	Tyre vertical damping
LONGITUDINAL_STIFFNESS	Tyre overall longitudinal stiffness
LATERAL_STIFFNESS	Tyre overall lateral stiffness
PDX1	Longitudinal friction Mux at Fznom
PKX1	Longitudinal slip stiffness Kfx/Fz at Fznom
PDY1	Lateral friction Muy
PKY1	Maximum value of stiffness Kfy/Fznom
PKY2	Load at which Kfy reaches maximum value

Tip:

The use of “estimated combined slip” possibly improves the performance of the tyre model when extrapolating to (very) low friction values. “Estimated combined slip” can be turned on by setting the combined slip coefficients in the tyre property file to zero or by omitting them.

3.2 Backward compatibility

MF-Tyre/MF-Swift 6.1 is backward compatible with MF-Tyre 5.x, MF-MC-Tyre 1.x , SWIFT 1.x and MF-Tyre/MF-Swift 6.0.x. Tyre property files generated for these tyre models will work with MF-Tyre/MF-Swift 6.1 and give the same simulation results as before.



Backward compatibility of tyre property files.

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 and 6.1 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.

Due to the built-in estimation procedure 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 6.1.

Note 1: 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

MF-Tyre/MF-Swift 6.1 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!

Note 2: As described in section 2.1, the modular approach of the tyre model allows a user to select various combinations of Magic Formula equations, contact methods and dynamics.

Former MF-MCTyre users explicitly will have to select "*smooth road contact with circular cross section*" (B=2) to get the same results using MF-Tyre 6.1 with their MF-MCTyre datasets.

Former SWIFT-Tyre 1.x users will have to select "*2D road contact using basic functions*" (B=4) and "*rigid ring dynamics*"(C=3) to get the same results as before.

Note 3: 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.

3.3 Scaling factors

Tyre force and moment testing is often done in a laboratory environment (e.g. using a flat track tyre tester 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 like 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.

3.4 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 6.1	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	61	61	60	60	6	21	52
TYRESIDE	Position of tyre during measurements	x	x	x	x	x	x	x
LONGVL	Reference speed	x	x	x	x	x	x	x
VXLOW	Lower boundary velocity in slip calculation	x	x	x	x	x	x	x
ROAD_INCREMENT	Increment in road sampling		x		x		x	
ROAD_DIRECTION	Direction of travelled distance		x		x		x	
PROPERTY_FILE_FORMAT	Tyre model selection (ADAMS only)	x	x	x	x	x	x	x
USE_MODE	Tyre use mode switch (ADAMS only)	x	x	x	x	x	x	x
HMAX_LOCAL	Local integration time step (ADAMS only)		x		x		x	
TIME_SWITCH_INTEG	Time when local integrator is activated (ADAMS only)		x		x		x	
[DIMENSION]								
UNLOADED_RADIUS	Free tyre radius	x	x	x	x	x	x	x
WIDTH	Nominal section width of the tyre	x	x	x	x	x	x	x
RIM_RADIUS	Nominal rim radius	x	x	x	x	x	x	x
RIM_WIDTH	Rim width	x	x	x	x	x	x	x
ASPECT_RATIO	Nominal aspect ratio	x	x	x	x	x	x	x
[OPERATING_CONDITIONS]								
INFLPRES	Tyre inflation pressure	x	x					
NOMPRES	Nominal pressure used in (MF) equations	x	x					
[INERTIA]								
MASS	Tyre mass	x	x	x	x		x	
IXX	Tyre diametral moment of inertia	x	x	x	x			
IYY	Tyre polar moment of inertia	x	x	x	x			
BELT_MASS	Belt mass		x		x			
BELT_IXX	Belt diametral moment of inertia		x		x			
BELT_IYY	Belt polar moment of inertia		x		x			
GRAVITY	Gravity acting on belt in Z direction		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

Tyre property file		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
VERTICAL_STIFFNESS	Tyre vertical stiffness	x	x	x	x	x	x	x
VERTICAL_DAMPING	Tyre vertical damping	x	x	x	x	x	x	x
MC_CONTOUR_A	Motorcycle contour ellipse A	x						
MC_CONTOUR_B	Motorcycle contour ellipse B	x						
BREFF	Low load stiffness of effective rolling radius	x	x	x	x	x	x	x
DREFF	Peak value of effective rolling radius	x	x	x	x	x	x	x
FREFF	High load stiffness of effective rolling radius	x	x	x	x	x	x	x
Q_RE0	Ratio of free tyre radius with nominal tyre radius	x	x	x	x		x	
Q_V1	Tyre radius increase with speed	x	x	x	x		x	
Q_V2	Vertical stiffness increase with speed	x	x	x	x		x	
Q_FZ2	Quadratic term in load vs. deflection	x	x	x	x		x	
Q_FCX	Longitudinal force influence on vertical stiffness	x	x	x	x		x	
Q_FCY	Lateral force influence on vertical stiffness	x	x	x	x		x	
Q_CAM	Stiffness reduction due to camber	x						
PFZ1	Pressure effect on vertical stiffness	x	x					
BOTTOM_OFFST	Distance to rim when bottoming starts to occur	x	x	x	x		x	
BOTTOM_STIFF	Vertical stiffness of bottomed tyre	x	x	x	x		x	
[STRUCTURAL]								
LONGITUDINAL_STIFFNESS	Tyre overall longitudinal stiffness	x	x	x	x			
LATERAL_STIFFNESS	Tyre overall lateral stiffness	x	x	x	x			
YAW_STIFFNESS	Tyre overall yaw stiffness	x	x	x	x			
FREQ_LONG	Undamped frequency fore/aft and vertical mode		x		x			
FREQ_LAT	Undamped frequency lateral mode		x		x			
FREQ_YAW	Undamped frequency yaw and camber mode		x		x			
FREQ_WINDUP	Undamped frequency wind-up mode		x		x			
DAMP_LONG	Dimensionless damping fore/aft and vertical mode		x		x			
DAMP_LAT	Dimensionless damping lateral mode		x		x			
DAMP_YAW	Dimensionless damping yaw and camber mode		x		x			
DAMP_WINDUP	Dimensionless damping wind-up mode		x		x			
DAMP_RESIDUAL	Residual damping (proportional to stiffness)	x	x	x	x			
DAMP_VLOW	Additional low speed damping (proportional to stiffness)	x	x	x	x			
Q_BVX	Load and speed influence on in-plane translation stiffness		x		x		x	
Q_BVT	Load and speed influence on in-plane rotation stiffness		x		x		x	
PCFX1	Tyre overall longitudinal stiffness vertical deflection dependency linear term	x	x					
PCFX2	Tyre overall longitudinal stiffness vertical deflection dependency quadratic term	x	x					
PCFX3	Tyre overall longitudinal stiffness pressure dependency	x	x					
PCFY1	Tyre overall lateral stiffness vertical deflection dependency linear term	x	x					
PCFY2	Tyre overall lateral stiffness vertical deflection dependency quadratic term	x	x					
PCFY3	Tyre overall lateral stiffness pressure dependency	x	x					
PCMZ1	Tyre overall yaw stiffness pressure dependency	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	

Tyre property file		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
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					
Q_RA2	Linear term in contact length equation		x					
Q_RB1	Root term in contact width equation		x					
Q_RB2	Linear term in contact width equation		x					
ELLIPS_SHIFT	Scaling of distance between front and rear ellipsoid		x		x		x	
ELLIPS_LENGTH	Semimajor axis of ellipsoid		x		x		x	
ELLIPS_HEIGHT	Semiminor axis of ellipsoid		x		x		x	
ELLIPS_ORDER	Order of ellipsoid		x		x		x	
ELLIPS_MAX_STEP	Maximum height of road step		x		x		x	
ELLIPS_NWIDTH	Number of parallel ellipsoids		x		x		x	
ELLIPS_NLENGTH	Number of ellipsoids at sides of contact patch		x		x		x	
Q_A2	Linear load term in contact length				x		x	
Q_A1	Square root load term in contact length				x		x	
ELLIPS_INC	Discretisation increment of ellipsoid contour				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			
Q_LIMP2	Quadratic contact length term in basic function shift						x	
[INFLATION_PRESSURE_RANGE]								
PRESMIN	Minimum allowed inflation pressure	x	x					
PRESMAX	Maximum allowed inflation pressure	x	x					
[VERTICAL_FORCE_RANGE]								
FZMIN	Minimum allowed wheel load	x	x	x	x	x	x	x
FZMAX	Maximum allowed wheel load	x	x	x	x	x	x	x
[LONG_SLIP_RANGE]								
KPUMIN	Minimum valid wheel slip	x	x	x	x	x	x	x
KPUMAX	Maximum valid wheel slip	x	x	x	x	x	x	x
[SLIP_ANGLE_RANGE]								
ALPMIN	Minimum valid slip angle	x	x	x	x	x	x	x
ALPMAX	Maximum valid slip angle	x	x	x	x	x	x	x
[INCLINATION_ANGLE_RANGE]								
CAMMIN	Minimum valid camber angle	x	x	x	x	x	x	x
CAMMAX	Maximum valid camber angle	x	x	x	x	x	x	x
[SCALING_COEFFICIENTS]								
LFZO	Scale factor of nominal (rated) load	x	x	x	x	x	x	x

Tyre property file		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
LCX	Scale factor of Fx shape factor	x	x	x	x	x	x	x
LMUX	Scale factor of Fx peak friction coefficient	x	x	x	x	x	x	x
LEX	Scale factor of Fx curvature factor	x	x	x	x	x	x	x
LKX	Scale factor of slip stiffness	x	x	x	x	x	x	x
LHX	Scale factor of Fx horizontal shift	x	x	x	x	x	x	
LVX	Scale factor of Fx vertical shift	x	x	x	x	x	x	x
LCY	Scale factor of Fy shape factor	x	x	x	x	x	x	x
LMUY	Scale factor of Fy peak friction coefficient	x	x	x	x	x	x	x
LEY	Scale factor of Fy curvature factor	x	x	x	x	x	x	x
LKY	Scale factor of cornering stiffness	x	x	x	x	x	x	x
LKYC	Scale factor of camber stiffness	x	x	x	x			
LKZC	Scale factor of camber moment stiffness	x	x	x	x			
LHY	Scale factor of Fy horizontal shift	x	x	x	x	x	x	x
LVY	Scale factor of Fy vertical shift	x	x	x	x	x	x	
LTR	Scale factor of Peak of pneumatic trail	x	x	x	x	x	x	x
LRES	Scale factor for offset of residual torque	x	x	x	x	x	x	x
LXAL	Scale factor of alpha influence on Fx	x	x	x	x	x	x	x
LYKA	Scale factor of alpha influence on Fx	x	x	x	x	x	x	x
LVYKA	Scale factor of kappa induced Fy	x	x	x	x	x	x	x
LS	Scale factor of Moment arm of Fx	x	x	x	x	x	x	x
LMX	Scale factor of overturning moment	x	x	x	x	x	x	x
LVMX	Scale factor of Mx vertical shift	x	x	x	x	x	x	x
LMY	Scale factor of rolling resistance torque	x	x	x	x	x	x	x
LMP	Scale factor of parking moment	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
PDX1	Longitudinal friction Mux at Fznom	x	x	x	x	x	x	x
PDX2	Variation of friction Mux with load	x	x	x	x	x	x	x
PDX3	Variation of friction Mux with camber	x	x	x	x	x	x	x
PEX1	Longitudinal curvature Efx at Fznom	x	x	x	x	x	x	x
PEX2	Variation of curvature Efx with load	x	x	x	x	x	x	x
PEX3	Variation of curvature Efx with load squared	x	x	x	x	x	x	x
PEX4	Factor in curvature Efx while driving	x	x	x	x	x	x	x
PKX1	Longitudinal slip stiffness Kfx/Fz at Fznom	x	x	x	x	x	x	x
PKX2	Variation of slip stiffness Kfx/Fz with load	x	x	x	x	x	x	x
PKX3	Exponent in slip stiffness Kfx/Fz with load	x	x	x	x	x	x	x
PHX1	Horizontal shift Shx at Fznom	x	x	x	x	x	x	
PHX2	Variation of shift Shx with load	x	x	x	x	x	x	
PVX1	Vertical shift Svx/Fz at Fznom	x	x	x	x	x	x	x
PVX2	Variation of shift Svx/Fz with load	x	x	x	x	x	x	x
RBX1	Slope factor for combined slip Fx reduction	x	x	x	x	x	x	x
RBX2	Variation of slope Fx reduction with kappa	x	x	x	x	x	x	x

Tyre property file		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
RBX3	Influence of camber on stiffness for Fx combined	x	x	x	x			x
RCX1	Shape factor for combined slip Fx reduction	x	x	x	x	x	x	x
REX1	Curvature factor of combined Fx	x	x	x	x	x	x	x
REX2	Curvature factor of combined Fx with load	x	x	x	x	x	x	x
RHX1	Shift factor for combined slip Fx reduction	x	x	x	x	x	x	x
PPX1	Linear pressure effect on slip stiffness	x	x					
PPX2	Quadratic pressure effect on slip stiffness	x	x					
PPX3	Linear pressure effect on longitudinal friction	x	x					
PPX4	Quadratic pressure effect on longitudinal friction	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
QSX2	Camber induced overturning couple	x	x	x	x	x	x	x
QSX3	Fy induced overturning couple	x	x	x	x	x	x	x
QSX4	Mixed load, lateral force and camber on Mx	x	x	x	x			
QSX5	Load effect on Mx with lateral force and camber	x	x	x	x			
QSX6	B-factor of load with Mx	x	x	x	x			
QSX7	Camber with load on Mx	x	x	x	x			
QSX8	Lateral force with load on Mx	x	x	x	x			
QSX9	B-factor of lateral force with load on Mx	x	x	x	x			
QSX10	Vertical force with camber on Mx	x	x	x	x			
QSX11	B-factor of vertical force with camber on Mx	x	x	x	x			
QSX12	Camber squared induced overturning moment	x	x					
QSX13	Lateral force induced overturning moment	x	x					
QSX14	Lateral force induced overturning moment with camber	x	x					
PPMX1	Influence of inflation pressure on overturning moment	x	x					
[LATERAL_COEFFICIENTS]								
PCY1	Shape factor Cfy for lateral forces	x	x	x	x	x	x	x
PDY1	Lateral friction Muy	x	x	x	x	x	x	x
PDY2	Variation of friction Muy with load	x	x	x	x	x	x	x
PDY3	Variation of friction Muy with squared camber	x	x	x	x	x	x	x
PEY1	Lateral curvature Efy at Fznom	x	x	x	x	x	x	x
PEY2	Variation of curvature Efy with load	x	x	x	x	x	x	x
PEY3	Zero order camber dependency of curvature Efy	x	x	x	x	x	x	x
PEY4	Variation of curvature Efy with camber	x	x	x	x	x	x	x
PEY5	Camber curvature Efc	x	x	x	x			x
PKY1	Maximum value of stiffness Kfy/Fznom	x	x	x	x	x	x	x
PKY2	Load at which Kfy reaches maximum value	x	x	x	x	x	x	x
PKY3	Variation of Kfy/Fznom with camber	x	x	x	x	x	x	x
PKY4	Peak stiffness variation with camber squared	x	x	x	x			x
PKY5	Lateral stiffness depedency with camber	x	x	x	x			x
PKY6	Camber stiffness factor	x	x	x	x			x
PKY7	Load dependency of camber stiffness factor	x	x	x	x			x
PHY1	Horizontal shift Shy at Fznom	x	x	x	x	x	x	x
PHY2	Variation of shift Shy with load	x	x	x	x	x	x	

Tyre property file		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
PVY1	Vertical shift in Svy/Fz at Fznom	x	x	x	x	x	x	
PVY2	Variation of shift Svy/Fz with load	x	x	x	x	x	x	
PVY3	Variation of shift Svy/Fz with camber	x	x	x	x	x	x	
PVY4	Variation of shift Svy/Fz with camber and load	x	x	x	x	x	x	
RBY1	Slope factor for combined Fy reduction	x	x	x	x	x	x	x
RBY2	Variation of slope Fy reduction with alpha	x	x	x	x	x	x	x
RBY3	Shift term for alpha in slope Fy reduction	x	x	x	x	x	x	x
RBY4	Influence of camber on stiffness of Fy combined	x	x	x	x			x
RCY1	Shape factor for combined Fy reduction	x	x	x	x	x	x	x
REY1	Curvature factor of combined Fy	x	x	x	x	x	x	x
REY2	Curvature factor of combined Fy with load	x	x	x	x	x	x	x
RHY1	Shift factor for combined Fy reduction	x	x	x	x	x	x	x
RHY2	Shift factor for combined Fy reduction with load	x	x	x	x	x	x	x
RVY1	Kappa induced side force Svyk/Muy*Fz at Fznom	x	x	x	x	x	x	x
RVY2	Variation of Svyk/Muy*Fz with load	x	x	x	x	x	x	x
RVY3	Variation of Svyk/Muy*Fz with camber	x	x	x	x	x	x	x
RVY4	Variation of Svyk/Muy*Fz with alpha	x	x	x	x	x	x	x
RVY5	Variation of Svyk/Muy*Fz with kappa	x	x	x	x	x	x	x
RVY6	Variation of Svyk/Muy*Fz with atan(kappa)	x	x	x	x	x	x	x
PPY1	Pressure effect on cornering stiffness magnitude	x	x					
PPY2	Pressure effect on location of cornering stiffness peak	x	x					
PPY3	Linear pressure effect on lateral friction	x	x					
PPY4	Quadratic pressure effect on lateral friction	x	x					
PPY5	Influence of inflation pressure on camber stiffness	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
QSY2	Rolling resistance torque depending on Fx	x	x	x	x	x	x	x
QSY3	Rolling resistance torque depending on speed	x	x	x	x	x	x	x
QSY4	Rolling resistance torque depending on speed ^4	x	x	x	x	x	x	x
QSY5	Rolling resistance torque depending on camber squared	x	x					
QSY6	Rolling resistance torque depending on load and camber squared	x	x					
QSY7	Rolling resistance torque coefficient load dependency	x	x					
QSY8	Rolling resistance torque coefficient pressure dependency	x	x					
[ALIGNING_COEFFICIENTS]								
QBZ1	Trail slope factor for trail Bpt at Fznom	x	x	x	x	x	x	x
QBZ2	Variation of slope Bpt with load	x	x	x	x	x	x	x
QBZ3	Variation of slope Bpt with load squared	x	x	x	x	x	x	x
QBZ4	Variation of slope Bpt with camber	x	x	x	x	x	x	x
QBZ5	Variation of slope Bpt with absolute camber	x	x	x	x	x	x	x
QBZ9	Slope factor Br of residual torque Mzr	x	x	x	x	x	x	x
QBZ10	Slope factor Br of residual torque Mzr	x	x	x	x	x	x	x
QCZ1	Shape factor Cpt for pneumatic trail	x	x	x	x	x	x	x

Tyre property file		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
QDZ1	Peak trail Dpt" = Dpt*(Fz/Fznom*R0)	x	x	x	x	x	x	x
QDZ2	Variation of peak Dpt with load	x	x	x	x	x	x	x
QDZ3	Variation of peak Dpt with camber	x	x	x	x	x	x	x
QDZ4	Variation of peak Dpt with camber squared	x	x	x	x	x	x	x
QDZ6	Peak residual torque Dmr = Dmr/(Fz*R0)	x	x	x	x	x	x	x
QDZ7	Variation of peak factor Dmr with load	x	x	x	x	x	x	x
QDZ8	Variation of peak factor Dmr with camber	x	x	x	x	x	x	x
QDZ9	Variation of peak factor Dmr with camber and load	x	x	x	x	x	x	x
QDZ10	Variation of peak factor Dmr with camber squared	x	x	x	x			x
QDZ11	Variation of Dmr with camber squared and load	x	x	x	x			x
QEZ1	Trail curvature Ept at Fznom	x	x	x	x	x	x	x
QEZ2	Variation of curvature Ept with load	x	x	x	x	x	x	x
QEZ3	Variation of curvature Ept with load squared	x	x	x	x	x	x	x
QEZ4	Variation of curvature Ept with sign of Alpha-t	x	x	x	x	x	x	x
QEZ5	Variation of Ept with camber and sign Alpha-t	x	x	x	x	x	x	x
QHZ1	Trail horizontal shift Sht at Fznom	x	x	x	x	x	x	x
QHZ2	Variation of shift Sht with load	x	x	x	x	x	x	x
QHZ3	Variation of shift Sht with camber	x	x	x	x	x	x	x
QHZ4	Variation of shift Sht with camber and load	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
SSZ2	Variation of distance s/R0 with Fy/Fznom	x	x	x	x	x	x	x
SSZ3	Variation of distance s/R0 with camber	x	x	x	x	x	x	x
SSZ4	Variation of distance s/R0 with load and camber	x	x	x	x	x	x	x
PPZ1	Linear pressure effect on pneumatic trail	x	x					
PPZ2	Influence of inflation pressure on residual aligning torque	x	x					
QTZ1	Gyroscopic torque constant					x	x	x
MBELT	Belt mass of the wheel					x	x	x
[TURNSLIP_COEFFICIENTS]								
PDXP1	Peak Fx reduction due to spin parameter	x	x	x	x			
PDXP2	Peak Fx reduction due to spin with varying load parameter	x	x	x	x			
PDXP3	Peak Fx reduction due to spin with kappa parameter	x	x	x	x			
PKYP1	Cornering stiffness reduction due to spin	x	x	x	x			
PDYP1	Peak Fy reduction due to spin parameter	x	x	x	x			
PDYP2	Peak Fy reduction due to spin with varying load parameter	x	x	x	x			
PDYP3	Peak Fy reduction due to spin with alpha parameter	x	x	x	x			
PDYP4	Peak Fy reduction due to square root of spin parameter	x	x	x	x			
PHYP1	Fy-alpha curve lateral shift limitation	x	x	x	x			
PHYP2	Fy-alpha curve maximum lateral shift parameter	x	x	x	x			
PHYP3	Fy-alpha curve maximum lateral shift varying with load parameter	x	x	x	x			
PHYP4	Fy-alpha curve maximum lateral shift parameter	x	x	x	x			
PECP1	Camber w.r.t. spin reduction factor parameter in camber stiffness	x	x	x	x			
PECP2	Camber w.r.t. spin reduction factor varying with load parameter in camber stiffness	x	x	x	x			
QDTP1	Pneumatic trail reduction factor due to turn slip parameter	x	x	x	x			
QCRP1	Turning moment at constant turning and zero forward speed parameter	x	x	x	x			
QCRP2	Turn slip moment (at alpha=90deg) parameter for increase with spin	x	x	x	x			
QBRP1	Residual (spin) torque reduction factor parameter due to side slip	x	x	x	x			
QDRP1	Turn slip moment peak magnitude parameter	x	x	x	x			

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

	description		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	
[SCALING_COEFFICIENTS]					
LGAX	Scale factor of camber for Fx	*9*	x	x	x
LGAY	Scale factor of camber for Fy	*10*	x	x	x
LGAZ	Scale factor of camber for Mz	*11*	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 deleted, adjust PDX3 directly*

10 *camber force stiffness is controlled by parameter LKYC*

11 *camber moment stiffness is controlled by parameter LKZC*

4 The road data file

Besides the road surfaces that are available to the tyre model when implemented in a multibody package, TNO offers several relatively simple road surface types that can be used with the tyre model:

- **Flat Road (ROAD_TYPE = 'flat')**
  As the name already indicates this is a flat road surface.

- **Plank Road (ROAD_TYPE = 'plank')**
  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.

- **Polyline Road (ROAD_TYPE = 'poly_line')**
  Road height as a function of travelled distance.

- **Sine Road (ROAD_TYPE = 'sine')**
  Road surface consisting of one or more sine waves with constant wavelength.

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] section is used to specify the road type, see listing above. The [PARAMETERS] section contains general parameters and road surface type specific parameters. The general parameters are listed below:

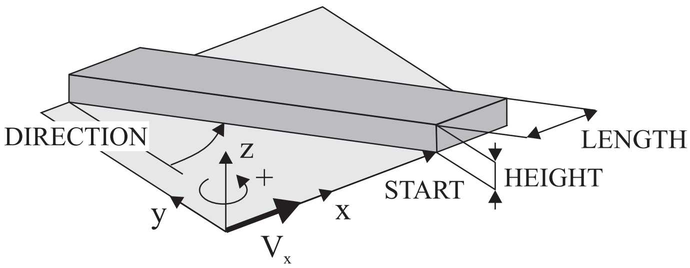
General

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:

Plank Road

HEIGHT	Height of the cleat.
START	Distance along the X-axis of the road to the start of the cleat.
LENGTH	Length of the cleat (excluding 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

The [PARAMETERS] block must have a (XZ_DATA) subblock. The subblock 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

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.

Finally, sample road data files are provided with the installation.

5 Application specific notes

5.1 ADAMS

MF-Tyre/MF-Swift 6.1 is offered as a user programmed tyre in ADAMS. To use the TNO tyre model you need a customised ADAMS solver. These are included in the delivery. The next table gives an overview of supported ADAMS versions and operating systems.

ADAMS	operating system		
version	Windows	Linux	HP-UX
2003	+	-	+
2005	+	+	-
2005r2	+	+	+
2007r1	under development	+	+

property file format

To use the tyre model in ADAMS make sure that the following statement is in the [MODEL] section of the tyre property file:

```
PROPERTY_FILE_FORMAT      ='USER'
USER_SUB_ID               = 815
```

This ensures that the TNO MF-Tyre/MF-Swift 6.1 tyre model is called. This can also be checked in the ADAMS message file (*.msg), the following statement should appear:

```
TYR815 -> DELFT-TYRE MF-Tyre/MF-Swift 6.1 xxxxxxxx-x
```

introducing the tyre using ADAMS/View

To introduce MF-Tyre/MF-Swift 6.1 in an ADAMS model using ADAMS/View commands:

create a road:
Tools -> Command navigator -> vpg_road -> instance -> create
right click on instance name and select "vpg_road" -> "create", fill in the fields

create a tyre:
Tools -> Command navigator -> vpg_tire -> instance -> create
right click on instance name and select "vpg_tire" -> "create", fill in the fields
You get a graphical representation of the tyre after closing the dialog box.

In this way a wheel body including tyre force element is created. You will have to add a revolute joint between the wheel body and vehicle chassis component. ADAMS/Car it is sufficient to select a MF-Tyre/MF-SWIFT 6.1 tyre property file.

selecting an operating mode

In ADAMS the operating mode is selected by setting the value of USE_MODE in the [MODEL] section of the tyre property file. If you want to change the operating mode of the tyre model this has to be done by modifying the tyre property file.

As explained in section 2.1 a four digit number (ABCD) would be required to define the operating mode. When defining a tyre in ADAMS via the graphical user interface the user has to identify a tyre as being "left" or "right". This information can be taken into account by the tyre model. If "A" is not specified (so USE_MODE is a three digit number), MF-Tyre/MF-Swift 6.1 will honour the ADAMS sideflag and adjust the value for "A" accordingly. The user can overrule this by specifying the value "A" in the tyre property file (so USE_MODE is then a four digit number).

Furthermore if ADAMS encounters an old SWIFT 1.2 tyre property file, USE_MODE=24 is automatically replaced by USE_MODE=434. So existing models using MF-Tyre 5.2 or SWIFT 1.2 will run without modifying the tyre property file.

In any case the user will get a clear feedback on the operating mode of the tyre model in the ADAMS message file (*.msg). A typical message would look like this:

```
TYR815: tyre number    1, USE_MODE= 1434
 *tyre side    : left
 *contact      : 2D short wave length (basic functions)
 *dynamics     : rigid ring
 *slip forces  : combined
```

using a local integration scheme

MF-Tyre/MF-Swift 6.1 provides two methods for time integration with ADAMS:

- **global integration**: the tyre differential equations are solved in the ADAMS solver together with the multibody equations
- **local integration**: the tyre differential equations are solved locally inside the tyre model independent of the multi-body model

Local integration can significantly speed up the simulation time when using rigid ring dynamics on an uneven road surface. For calculations on a level road surface without rigid ring dynamics a global integration will be faster and more accurate. The parameters for this local integrator inside the tyre model are set in [MODEL] section of the tyre property file, for example:

```
HMAX_LOCAL                = 0.00025

TIME_SWITCH_INTEG         = 0.1
```

HMAX_LOCAL defines the step size of the local integrator, too big values may result in instability and generally 0.25 ms is a safe value. TIME_SWITCH_INTEG defines the time when the switch is made from global to local integration. It is possible to have ADAMS calculate static equilibrium for the tyre model and at a later stage during the simulation switch to local integration to speed it up.

Switching between local and global integration is only possible if a sufficient states are available in the ADAMS model. The ADAMS message file will provide additional information on this. Some examples:

- `GLOBAL integration of tyre dynamics ( 0/ 4):` 0 states required, 4 available
- `GLOBAL integration of tyre dynamics ( 6/30):` 6 states required, 30 available
- `GLOBAL integration of tyre dynamics (30/30):` 30 states required, 30 available
- `LOCAL  integration of tyre dynamics (30/ 4):` 30 states required, 4 available
- `LOCAL  integration of tyre dynamics (30/30):` 30 states required, 30 available

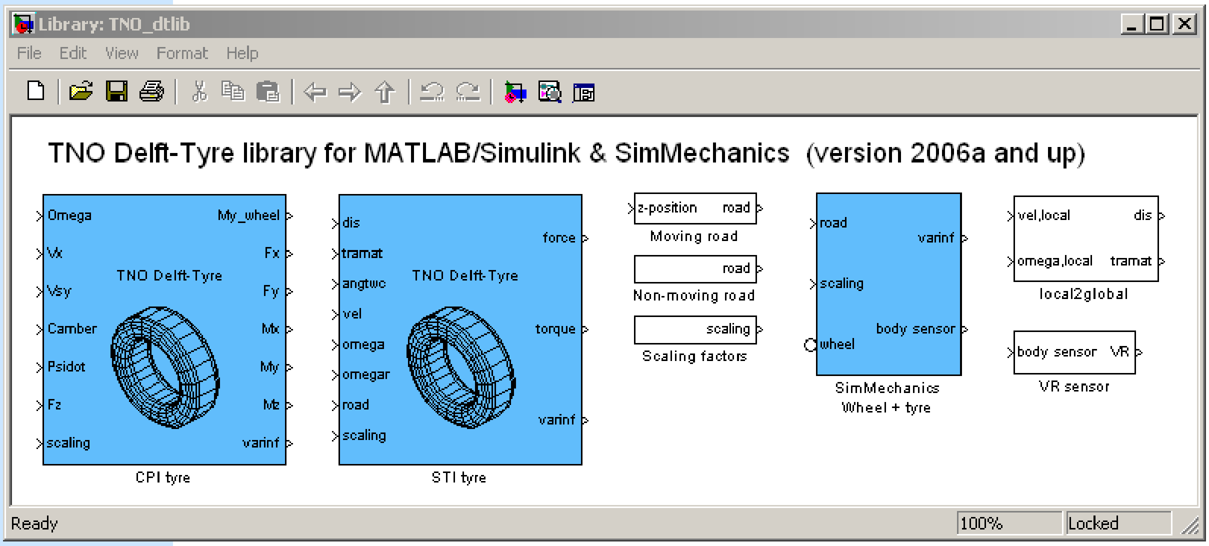
Global integration is only possible when the first number is smaller than or equal to the second one. The number of states available is defined by the tyre GSE.

NOTE 1: when using local integration the maximum step size HMAX of the ADAMS integrator has to be set to 1 ms or smaller, otherwise the simulation results may become inaccurate or unstable.

NOTE 2: to use global integration (if possible), comment out the line defining HMAX_LOCAL from the tyre property file by using a $ or ! character.

5.2 MATLAB/Simulink/SimMechanics

MF-Tyre/MF-Swift 6.1 is offered for MATLAB/Simulink 6.5 and up. The command “dteval” can be used to evaluate the Magic Formula model for series of input variables. For more information on dteval, please type “help dteval” on the MATLAB command line. For simulation model development in MATLAB 2006a and up, blocks are available from the library “TNO_dtlib.mdl” in Simulink.



TNO Delft-Tyre library.

In addition to the normal functionality, the Simulink and SimMechanics blocks allow a user to change tyre scaling factors as a function of time or any other signal available in the model. Further, some blocks are provided to easily model moving and non-moving road surfaces, coordinate system transformation and animation of the wheel using the Virtual Reality Toolbox. See the help function of the blocks and the Simulink and SimMechanics demos for more information.

backward compatibility

For older versions of MATLAB (6.5 and up) the library “TNO_dtlib_v65.mdl” in Simulink can be used. The only difference with respect to the latest library “TNO_dtlib.mdl” is that SimMechanics is not supported.

The MATLAB command line functions “mfread” and “mfeval” have been replaced by the new function “dteval”.

The sequence of the signals in the output vector (varinf) in the Simulink tyre block has changed. Please use the help function of this block to learn more about the new definition. In addition a “Bus Selector” block may be used to select the appropriate output signals based on their names.

mass specification in the SimMechanics block

In the “Wheel and tyre” block the complete wheel (consisting of rim and tyre) is modelled. The “wheel centre connection” port should be connected via a revolute joint to an axle body. In the mask of the “Wheel and tyre” block you specify the mass and inertia of the **rim** only, the mass and inertia of the **tyre** is obtained from the tyre property file. A detailed breakdown of the mass will be shown if “Display debug messages” is switched on. For example:

```
Delft-Tyre 1 -> use_mode=1114
 wheel mass = 19.3 kg
 wheel Ixx  = 1.391 kgm2
 wheel Iyy  = 2.736 kgm2
 tyre mass  = 9.3 kg (belt mass = 7.1 kg)
 tyre Ixx   = 0.391 kgm2 (belt Ixx  = 0.326 kgm2)
 tyre Iyy   = 0.736 kgm2 (belt Iyy  = 0.636 kgm2)
```

Note: When switching on rigid ring dynamics the mass/inertia distribution is adjusted in such a way that the mass and inertia properties of the complete wheel (rim+tyre) remain unchanged.

Initialisation

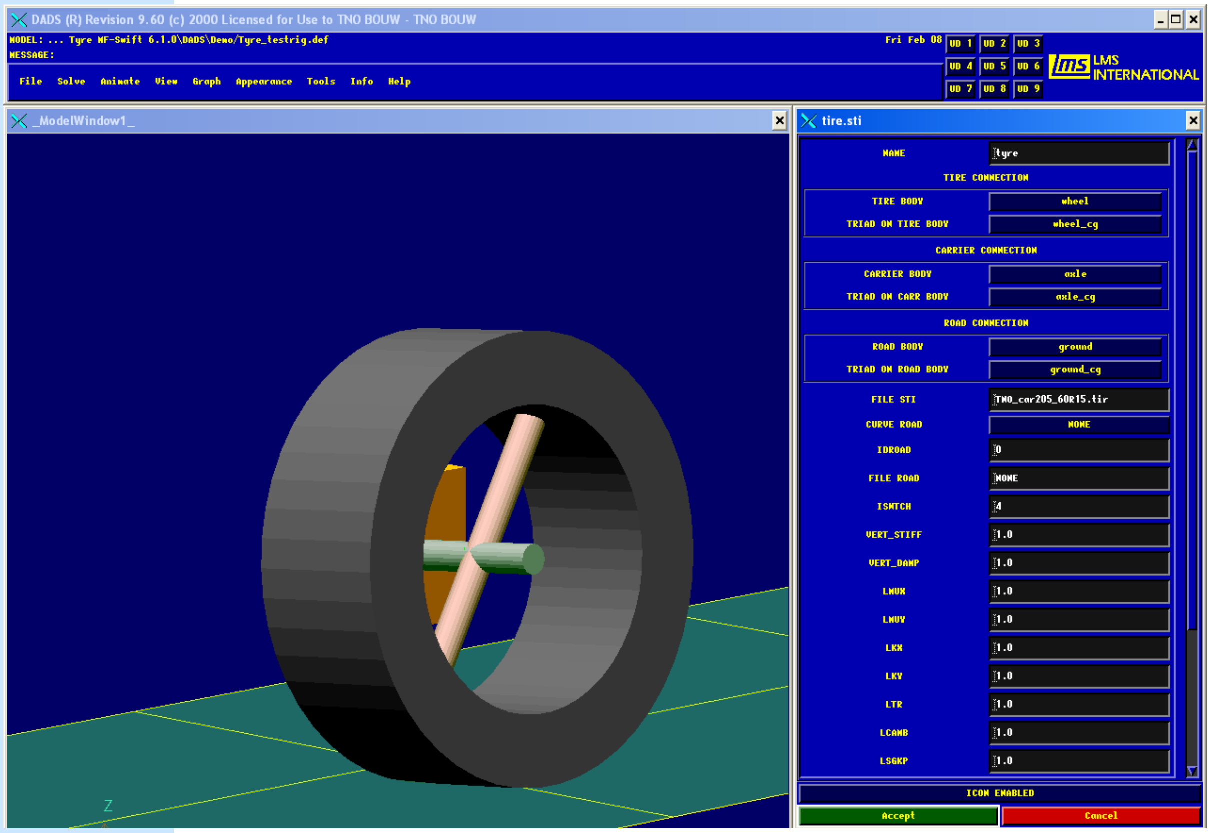
When using "rigid ring + initial statics" the tyre model will give the following messages:

```
Delft-Tyre   1: rigid ring balancing...
 vertical tyre force      :  4721.4 N
 effective rolling radius:  0.3038 m
 angular velocity         :  32.886 rad/s (slip: -0.080 %)
```

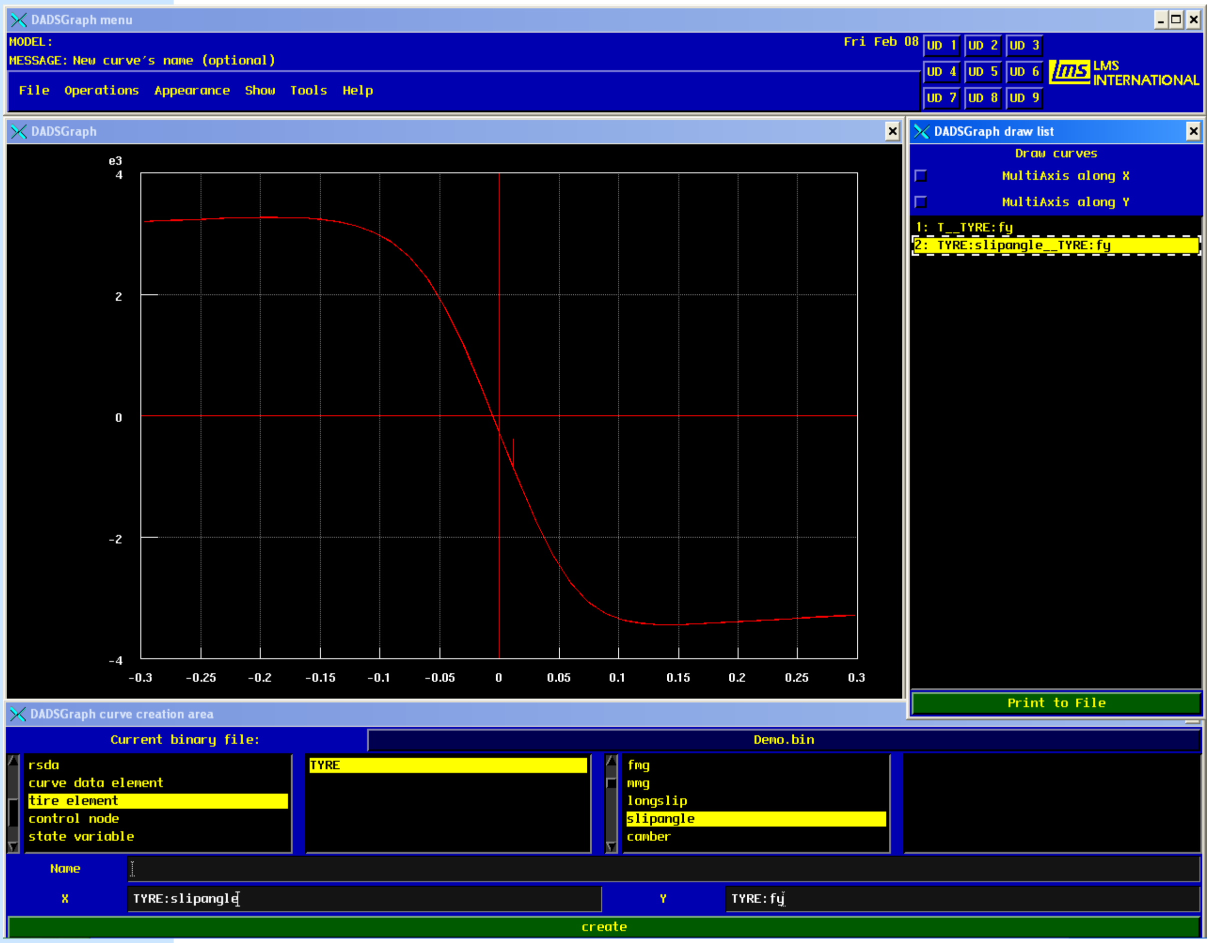
You can use this information to set the correct angular velocity of the wheel when specifying the initial conditions in your model.

5.3 LMS DADS

MF-Tyre/MF-Swift 6.1 is offered for DADS 9.6. To introduce the tyre model and to change the tyre model settings (tyre property file, scale factors, etc.) in the DADS GUI, select Force, Tire, STI in the DADS modelling panel:



To plot the tyre model outputs after having performed a simulation, open the DADSGraph menu and select “tire element” and the signal you want to plot:



5.4 Third party software

MF-Tyre/MF-Swift 6.x is also available in third party simulation software. Some examples are: Virtual.Lab (LMS), SIMPACK (INTEC), MADYMO (TASS), CarSim/BikeSim/TruckSim (MSC). Please contact your simulation package supplier or TNO for more information.

6 References

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[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.