Swift

Using ADAMS/Tire SWIFT

The following sections explain how to use Swift-Tyre with ADAMS/Tire.: ADAMS/Tire SWIFT.

Delft-Tyre

Date: May 2005
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MF-Tool, MF-Tyre and MF-Swift (MSC.ADAMS equivalent name ADAMS/Tire SWIFT) are part of the DELFT-TYRE product line, developed at TNO Automotive, Helmond, The Netherlands.

http://www.delft-tyre.com/

http://www.automotive.tno.nl

1 Tyre model overview

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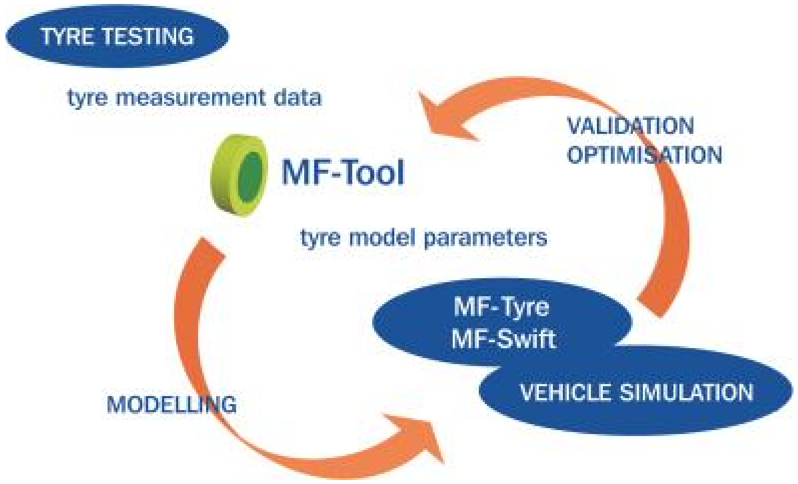
Introduction

The contact interaction between tyres and the road largely affect 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. Delft-Tyre provides a complete chain of tools and services for detailed assessment and modelling of vehicle-tyre-road interaction.



Delft-Tyre chain of tools for tyre analyses

The tyre models MF-Tyre and MF-Swift (MSC.ADAMS equivalent name: **ADAMS/Tire 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 6.0 is the latest 2005 implementation by Delft-Tyre of Pacejkas renowned Magic Formula tyre model. It is included in **ADAMS/Tire SWIFT**. 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 100 Hz, which is particularly useful for vehicle comfort, durability, dynamic vehicle control, or driveline 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.

Delft-Tyres MF-Tyre and MF-Swift are available for all major simulation packages. For availability, please refer to www.delft-tyre.com.

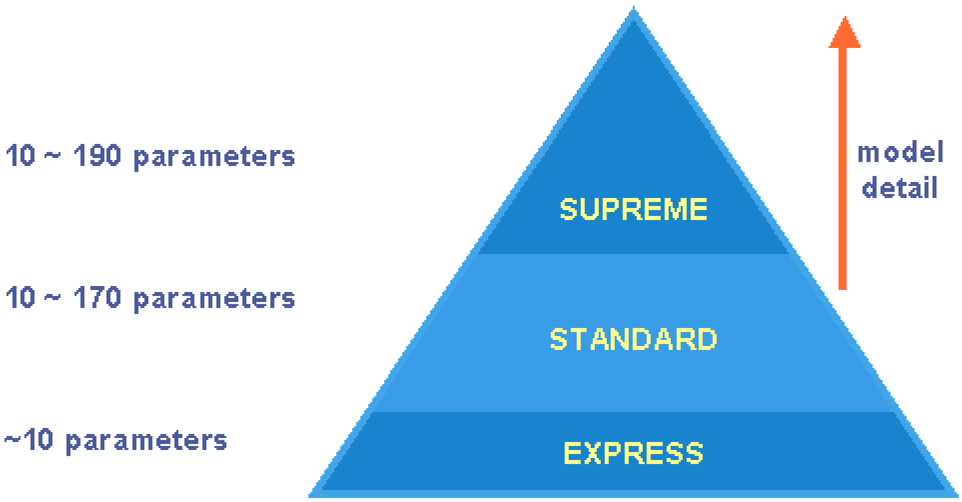
Delft-Tyre makes sure that the tyre model implementation and simulation results are identical and that the same set of tyre model parameters can be used for all different simulation codes.

Model detail levels

The 6.0 version of MF-Tyre/MF-Swift has been significantly improved with respect to former model implementations. Next to several functional improvements (see chapter 2), the user-friendliness has been much improved through a new, modular setup of the tyre models. MF-Tyre and MF-Swift are now completely integrated in one model. The model complexity/detail can be selected easily, depending on the desired application.

There are three fully compatible model versions with increasing level of detail and data requirements (see also chapter 5):

- Express: uses only about 10 model parameters
- Standard: uses from 10 up to ~170 parameters (superset of Express)
- Supreme: uses from 10 up to ~190 parameters (superset of Standard)



Each model detail has different functionality. Summarising:

- Express. Requires only about 10 parameters using a simplified Magic Formula with estimated combined slip and without camber.

- Standard. Uses up to 170 parameters (superset of Express) to add the detail of the former MF-Tyre 5.x and SWIFT 1.x versions to the Express edition. It includes new functionality and improvements to provide an accurate representation of measurement results which usually are available up to 15 degrees side slip and 100% longitudinal slip. Camber validity is 5-10 degrees for different vertical loads.

- Supreme. Uses up to 190 parameters (superset of Standard) to add parking and turn slip behaviour and validity for camber angles over 60 degrees to the Standard edition.

- MF-Swift adds rigid ring dynamics and short wavelength road contact to MF-Tyre.

An overview of the new functionality compared to previous versions is listed in the table below.

(m = MF-Tyre only, m+s = MF-Tyre and MF-Swift, s = MF-Swift only)

	Express	**Standard**	**Supreme**	**MF-Tyre 5.2**	**SWIFT-Tyre 1.1**
real-time capable	m	m	m	m	

flat / inclined / long wavelength smooth road	m+s	m+s	m+s	m	s
pure longitudinal and lateral slip	m+s	m+s	m+s	m	s
linear vertical characteristics	m+s	m+s	m+s	m	s
aligning moment Mz	m+s	m+s	m+s	m	s
transient dynamics (up to 8 Hz)	m+s	m+s	m+s	m	s
estimated combined slip	m+s	m+s	m+s		
camber (up to 10 deg)		m+s	m+s	m	
asymmetric tyre behaviour		m+s	m+s	m	s
supports fitting of combined slip to measurement data		m+s	m+s	m	s
overturning moment Mx		m+s	m+s	m	s
explicit camber stiffness formulation		m+s	m+s		
improved overturning moment Mx formulae		m+s	m+s		
supports fitting of TIME measurement data		m+s	m+s		
parking- and turnslip			m+s		
large camber (up to 55 deg)			m+s		
improved loaded radius (e.g. Fx, Fy dependent)	s	s	m+s		s
non-linear vertical characteristics	s	s	m+s		s
rim impact	s	s	m+s		s
tyre belt dynamics (up to 100 Hz)	s	s	s		s
2D obstacle enveloping	s	s	s		s
generic 3D obstacle enveloping		s	s		

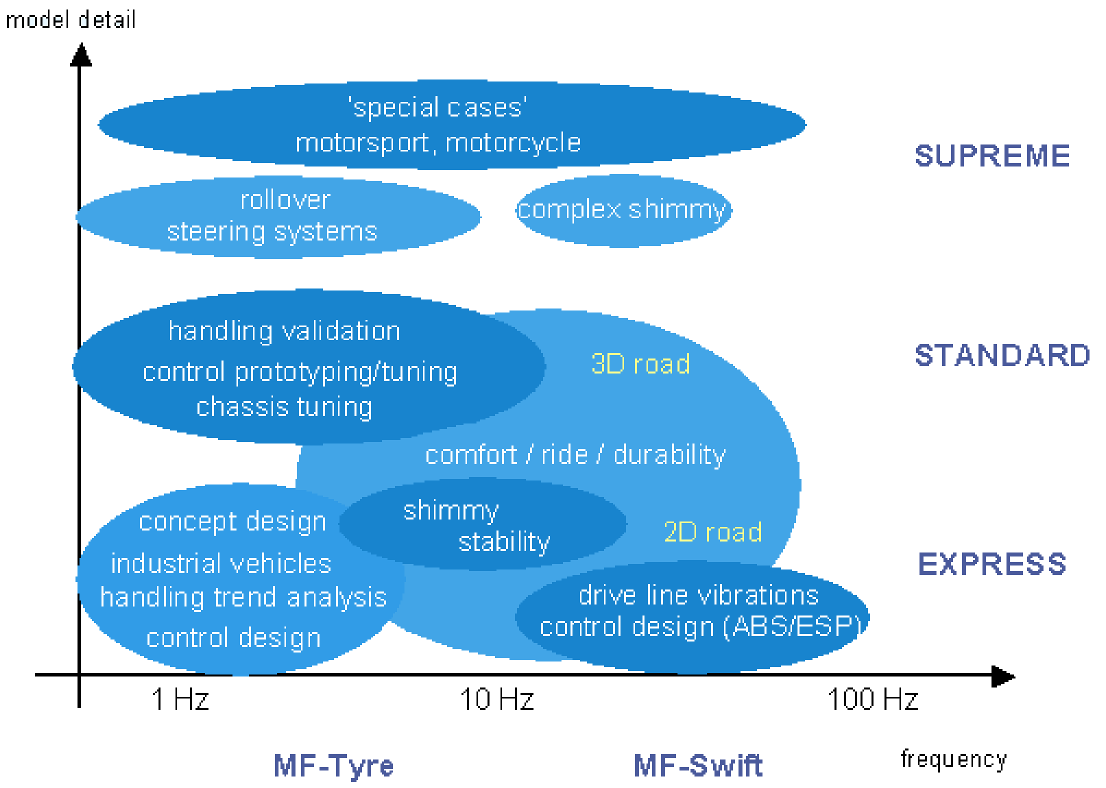
Model application areas

Each model detail level serves a particular application area. To select the model appropriate for your application, there are two main choices:

1. Relevant frequency range: MF-Tyre (<10 Hz) or MF-Swift (10Hz - 100Hz)

2. Required detail level (Express / Standard / Supreme)

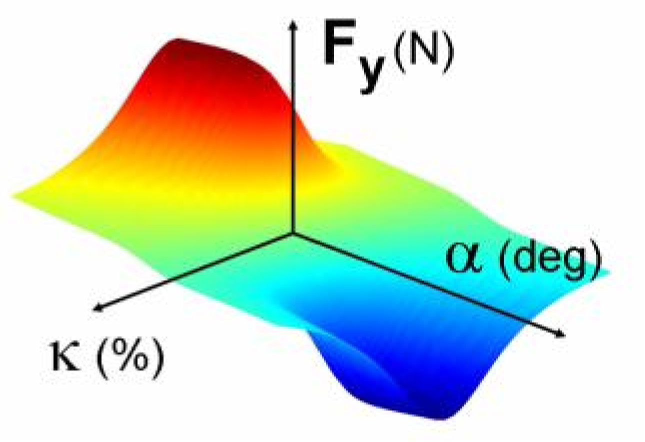
The following diagram shows the main application areas for each model detail level. The horizontal axis shows the valid frequency range (bandwidth) of the tyre model; the vertical axis shows the model detail level.



MF-Tyre 6.0

MF-Tyre is Delft-Tyres implementation of the world-standard Pacejka Magic Formula tyre model, including the latest developments by Prof. Pacejka [1] and [2]. It is included in **ADAMS/Tire SWIFT** from ADAMS version 2003 and up. Delft-Tyres latest tyre model implementation, the 6.0 version from 2005 replaces the former tyre models MF-Tyre 5.2 (Pacejka 96), MF-MCTyre 1.1 and SWIFT-Tyre 1.2.

MF-Tyres 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. The 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 6.0

MF-Tyres is valid for large slip angles (typically over 30 degrees), longitudinal slip (100%) and large load variations (including truck tyre loads). It can handle road undulations which have a wavelength larger than the tyre circumference and is typically applied for vehicle handling simulation.

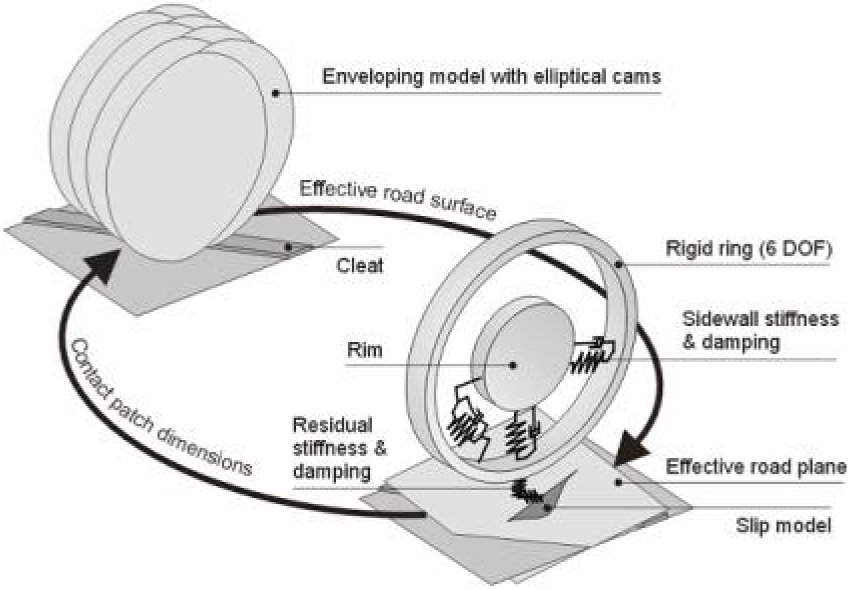
MF-Tyre calculates the forces (Fx, Fy) and moments (Mx, My, Mz) acting on the tyre under pure and combined slip conditions on arbitrary 3D roads, using longitudinal and lateral slip, wheel inclination angle (camber), the vertical force (Fz) as input quantities. With the 6.0 version, the tyre steering velocity (rotational velocity about the vertical tyre axis) has been added as an optional input for parking and turnslip calculation.

MF-Swift 6.0 (ADAMS/Tire 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 properties is up to 50 60 Hz for lateral behaviour and up to 100 Hz for vertical and longitudinal behaviour. 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-Tyre / MF-Swift 6.0 model

Five main elements of the model structure can be distinguished:

1. **Rigid ring.** The inertia of the belt that has been taken into account to properly describe the dynamics of the tyre. Up to frequencies of about 80Hz, the belt can be considered as a rigid circular ring.
2. **Residual stiffness & damping.** These have been introduced between contact patch and rigid ring to ensure that the total

static tyre stiffnesses in vertical, longitudinal, lateral and yaw directions are correct. 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 transverse 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 6.0) describes the non-linear slip force and moment properties in the effective road plane. This enables an accurate response also for handling manoeuvres.

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

2 What's new in version 6.0

The simulation applicability, accuracy and efficiency have been significantly extended with the 6.0 version. This has been achieved through many enhancements and new developments, such as:

- Previous models and new developments are combined into one model;
- Model data requirements have been drastically reduced;
- All functionality for which several incompatible models are available (e.g. MF-Tyre 5.x, MF-MCTyre 1.x, SWIFT-Tyre 1.x, and different tyre models in ADAMS/Tire Handling, ADAMS/Tire Motorcycle) is now covered by the MF-Tyre/MF-Swift 6.0 release.

The new developments are explained in more detail in the sections below.

Improved and combined into one model

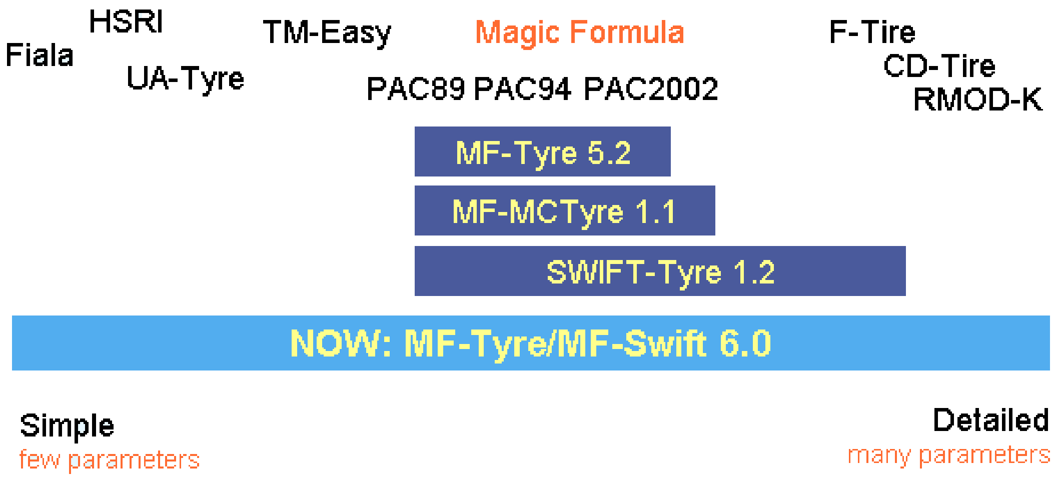
MF-Tyre, MF-MCTyre and SWIFT-Tyre have been improved and combined into one model that covers all Delft-Tyre model functionality: MF-Tyre/MF-Swift 6.0 (MSC.ADAMS equivalent: **ADAMS/Tire SWIFT**). MF-Tyre 6.0 covers the steady-state and transient part, MF-Swift 6.0 adds the extensions to MF-Tyre 6.0 that allow the simulation of tyre dynamic behaviour.

Backward compatibility

MF-Tyre/MF-Swift 6.0 accepts MF-Tyre 5.x, MF-MCTyre 1.x or SWIFT 1.x tyre property files. Under normal driving conditions the simulation results will be the same as with the previous Delft-Tyre models (see paragraph 5.2). To benefit from the new functionality, tyre measurement data can be refitted to 6.0 models using MF-Tool, or the built-in parameter estimation functionality can be addressed (see below).

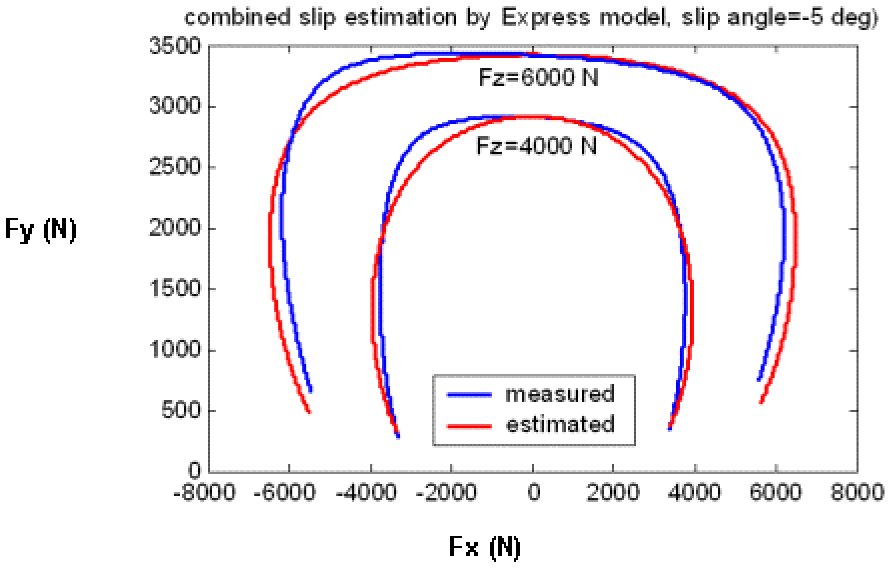
Applicability

The combined model MF-Tyre/MF-Swift 6.0 now covers the full range from accurate steady-state characteristics up to 100 Hz dynamics, and from entry level to state-of-the-art models.



Reduced input parameter requirements

Estimation methods have been built in the tyre model to estimate the parameters that are not provided by the user. The minimum set of required parameters has been drastically reduced (from about 160 to about 15, with physical meaning). For example, if combined slip parameters are not specified, the combined characteristics are now estimated based on Pacejka's Similarity Method.



Similarly you can use all SWIFT functionality while only providing an existing MF-Tyre 5.2 tyre property file: the missing MF-Swift parameters are estimated by the model.

Furthermore, the MF-Swift structural properties can now be parameterised more conveniently using eigenfrequencies as an alternative to belt stiffness and damping values (for details, see the [STRUCTURAL] section of the model parameter list in paragraph 5.3).

Calculation speed / Real-Time capabilities

The MF-Swift road contact algorithm has been improved, which - depending on the simulation package- may result in up to 50% reduction in tyre model computational effort on an articulated road.

The computationally efficient Magic Formula implementation makes MF-Tyre very suitable for real-time simulation. MF-Tyre's real-time capabilities make it an easy task to perform offline and online vehicle control development and prototyping. For example, MF-Tyre is available for The MathWorks™ xPC target and various dSPACE™ targets, also through Real Time Workshop. Dedicated targets can be implemented on demand. For more information, please visit www.delft-tyre.com.

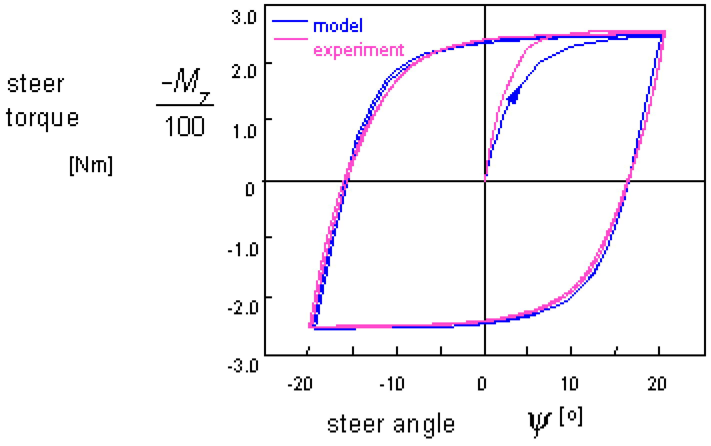
Model operating mode selection

The user can now easily switch between tyre model operating modes: model bandwidth (steady state, linear transient, non-linear transient, dynamic), road contact model (smooth, 2D, 3D etc.), slip force calculation (pure, combined, etc.), mounting (left, right, symmetric).

Stand-still, low-speed and steering oscillations

Pacejka's parking and turnslip behaviour is now included. This allows the simulation of aligning torque (Mz hysterisis loop) at low speeds and standstill, and improves the tyre model response for yaw oscillations.

The overall tyre stiffness properties in the tyre property file now reflect the actual stiffness properties at zero speed, resulting in a more realistic behaviour at standstill and transition from stand-still to sliding and vice versa, in all directions.

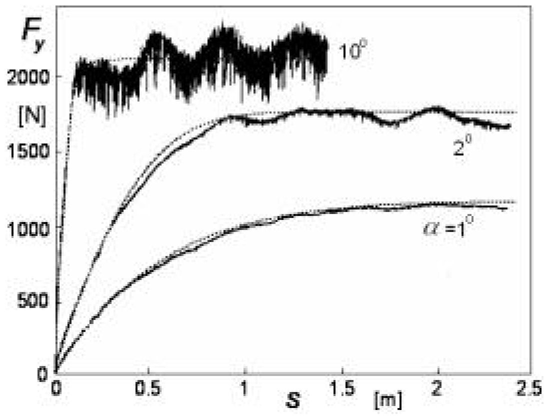


Zero speed steering hysteresis effect

The parking and turnslip equations that have been implemented also work in combination with MF-Swift. The benefits of parking and turnslip can be found in for example steering system design and analysis: parking behaviour and improved accuracy for steering oscillations (e.g. shimmy, also for aircraft landing gear).

Non-linear transient behaviour

Next to the lateral and longitudinal tyre relaxation lengths, a new approach based on the contact patch dynamics has been implemented. This results in a relaxation length which is not constant, but decreases for increasing values of slip, which is confirmed by experiments.

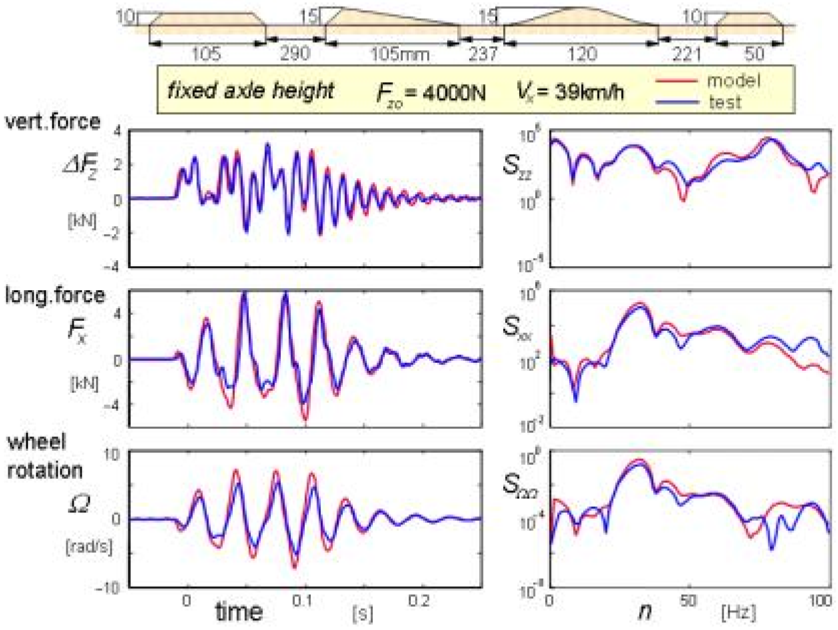


non-linear transient effects, now included in MF-Tyre

Next, the transient characteristics of MF-Tyre and MF-Swift have been synchronised: the definition through either relaxation lengths or structural stiffnesses is now completely compatible between both MF-Tyre and MF-Swift.

3D road contact model

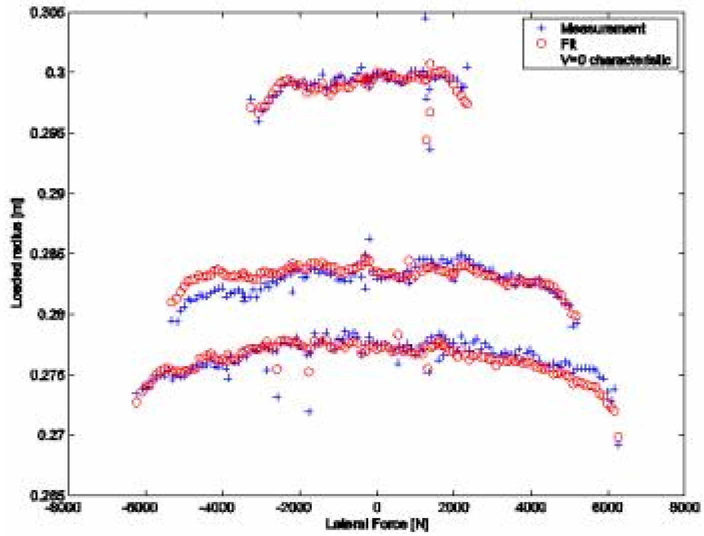
A new 3D ellipsoid road contact method [5] has been added, allowing to drive over an arbitrary 3D road definition that contains obstacles with a short wavelength.



validation results of MF-Swift over a series of cleats

Vertical characteristics

By integrating the MF-Tyre and SWIFT-Tyre into one new model, MF-Tyre now incorporates non-linear vertical characteristics: quadratic force-deflection curve, stiffness increase with speed, rim impact; tyre radius growth with speed. Furthermore, the loaded radius is now dependent on longitudinal and lateral slip forces.



Loaded radius dependency on lateral force for different normal loads

“Moving road”

“Moving road” is now supported in several simulation packages including MSC.ADAMS to simulate for example a four poster test rig including tyres.

Camber influence

The MF-Tyre 6.0 updated camber formulation uses an explicit camber stiffness expression, which is more accurate for both motorcycle tyres (large camber angles) and passenger car tyres (e.g. vehicle roll-over conditions). An additional benefit is that the camber stiffness can now be explicitly modified using scaling factors.

MF-Tyre 6.0 is capable of fitting motorcycle tyre characteristics more accurately than the former MF-MC-Tyre 1.x (or the former MSC.ADAMS equivalent ADAMS/Tire Motorcycle) model.

Main improvements are found in the lateral force characteristics resulting in an average fit error reduction of 7% with respect to the measurement data.

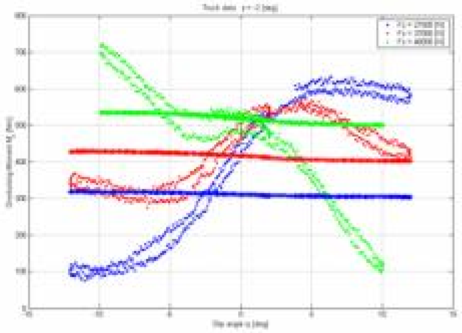
Furthermore, motorcycle tyre behaviour can now be used with the SWIFT rigid ring dynamics, which is beneficial for motorcycle stability, comfort and durability analysis and control design (e.g. ABS).

Support for TIME measurement data

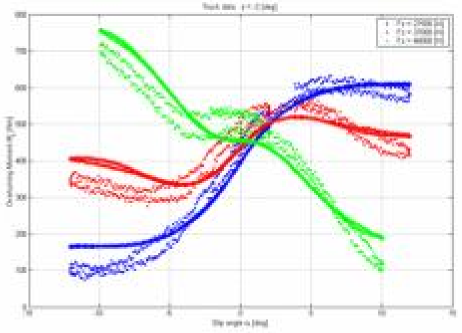
Another advantage of the new camber formulations is that MF-Tyre 6.0 is now suitable to represent measurement data obtained using the TIME measurement protocol [9]. In the older Magic Formula versions and TIME dedicated implementations, especially the camber influence could not be represented with sufficient accuracy. Combined with the new version of MF-Tool, fitting TIME measurement data to MF-Tyre 6.0 has become a straightforward and reliable process.

Overturning moment (Mx)

The overturning moment formulae have been improved to get a much better fit with measurement data, which is important for motorcycle tyre behaviour and vehicle roll-over simulations.



previous Magic Formula
implementations



new version 6.0
implementation

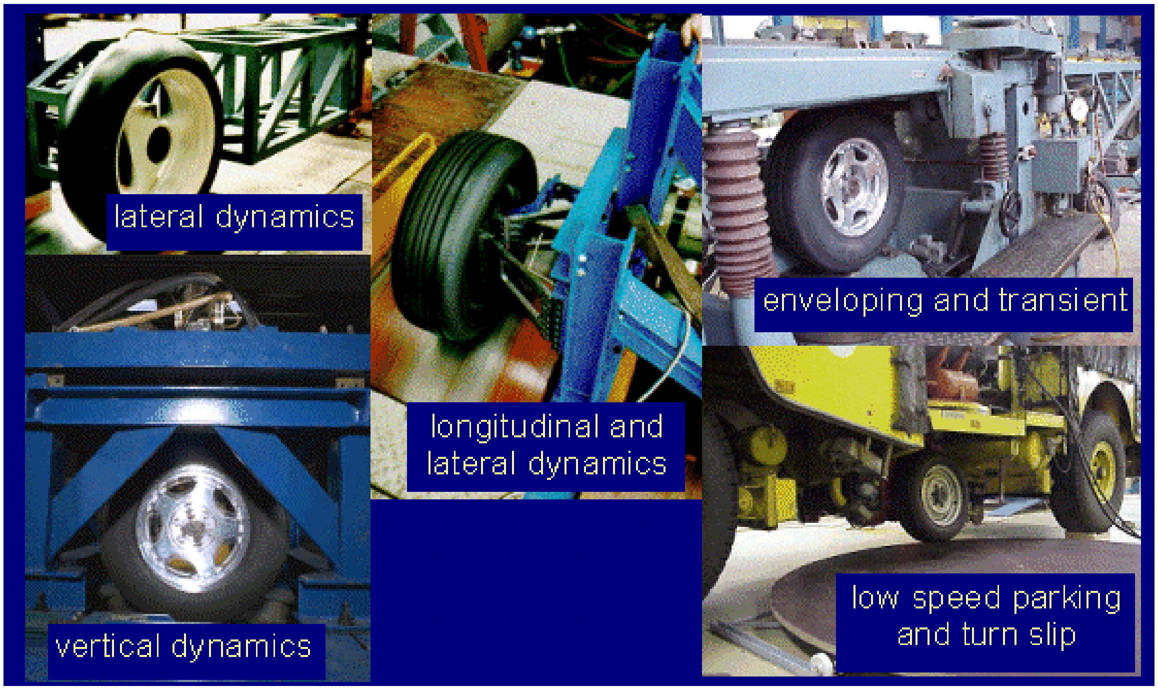
3 Tyre model parameterisation

3 Tyre model parameterisation

Tyre measurements overview

The accuracy of the tyre model largely depends on the model parameters used. The tyre model parameters depend on the type of the tyre and the road conditions. The parameters of both MF-Tyre and MF-Swift can be derived from experimental data obtained from tests using for example TNO Automotives Delft-Tyre measurement truck. For more information on Delft-Tyres measurement services, please refer to www.delft-tyre.com.

The Delft-Tyre measurement truck

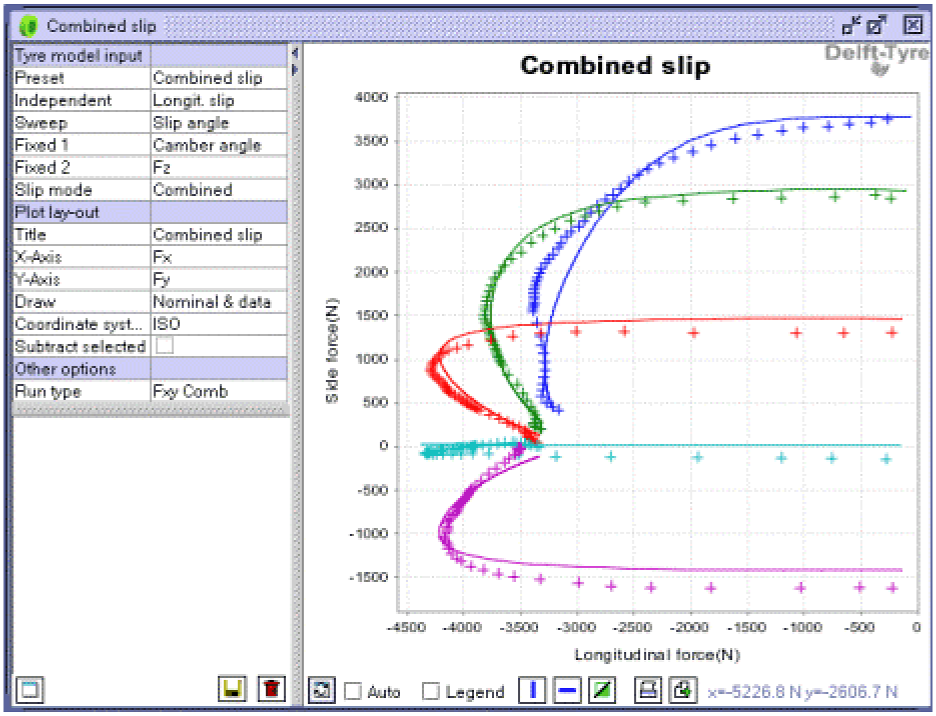


Various Delft-Tyre indoor tyre testing equipment

Model parameter identification

The test data can easily be converted to accurate MF-Tyre/MF-Swift model parameters using Delft-Tyres product MF-Tool. MF-Tool uses tyre measurement data in TYDEX [7] format and identifies the best match for MF-Tyre and MF-Swift parameters from this data.

For more information on MF-Tool, please refer to www.delft-tyre.com.



Tyre model input	
Preset	Combined slip
Independent	Longit. slip
Sweep	Slip angle
Fixed 1	Camber angle
Fixed 2	Fz
Slip mode	Combined
Plot lay-out	
Title	Combined slip
X-Axis	Fx
Y-Axis	Fy
Draw	Nominal & data
Coordinate syst...	ISO
Subtract selected	☐
Other options	
Run type	Fxy Comb

comparison of model and measurement, identified and visualised using MF-Tool

3. Tyre model dataset library

Delft-Tyre also has a library of standard MF-Tyre/MF-Swift datasets (MF-Datasets) for common car, light truck, SUV and motorcycle tyres which can be provided on your request.

MF-Datasets are validated Magic Formula parameter sets identified from measurements on the actual road using the TNO Tyre Test Trailer. The datasets provide an excellent basis for handling simulation using tyre characteristics of various types of tyres.

All relevant handling tyre behaviour is captured in a MF-Tyre Dataset:

- pure slip characteristics for braking and cornering,
- combined braking and cornering slip characteristics,
- transient behaviour (relaxation length),
- influence of normal load and inclination angle (camber),

- conicity and plysteer effects.

The current MF-Datasets library contents are displayed in the next table. For the most recent library contents and pricing, please contact Delft-Tyre at www.delft-tyre.com.

MF-Tyre CAR							
width	make	size	type	pressure (bar)	comments	dry	wet
155	Dunlop	155/65R13	SP10	2.1	PC & PB only*	·	·
175	Michelin	175/65R13	XT1	2.0, 2.6		·	
	Continental	175/65R14		2.3		·	
	Bridgestone	175/70R13		2.2		·	·
	Michelin	175/70R13	MXT	2		·	
	Michelin	175/70R14	MXTE	2.1		·	
185	Michelin	185/60R14	MXT	2.0, 2.6		·	
	Michelin	185/65R14	MXV3A Energy	1.6, 2.1, 2.8	PC only	·	
195	Continental	195/50R15		2.0, 2.8	cam = 0 only*	·	
				2.4		·	
	Michelin	195/65R15	MXV3A Energy	2		·	
	Michelin	195/65R15	MXV3A Pilot HX	2		·	·
	Vredestein	195/65R15	Snowtrac	2		·	·
205	Delft-Tyre	205/55R15	Virtual	2.1		·	
215	Michelin	215/55R16	XSE	2.2		·	
225	Goodyear	225/50R16	Eagle	2.3		·	·
235	Continental	235/60R16	Eco Contact	2.3		·	
	Dunlop	235/60R16	SP Sport 2000 E	2.2, 2.9		·	
	Uniroyal	235/75R15	Tigerpaw	2.2		·	
				2.9	PC & PB only*	·	
	Goodyear	235/75R15	Invicta	2.5		·	·
245	Goodyear	245/70R16	Wrangler AP	2.4		·	
	Goodyear	245/75R16	Wrangler	2.4		·	
255	Goodyear	255/55R18	Wrangler HP	1.9, 2.6		·	
	Goodyear	255/65R16	Wrangler HP	1.9, 2.6, 3.2		·	

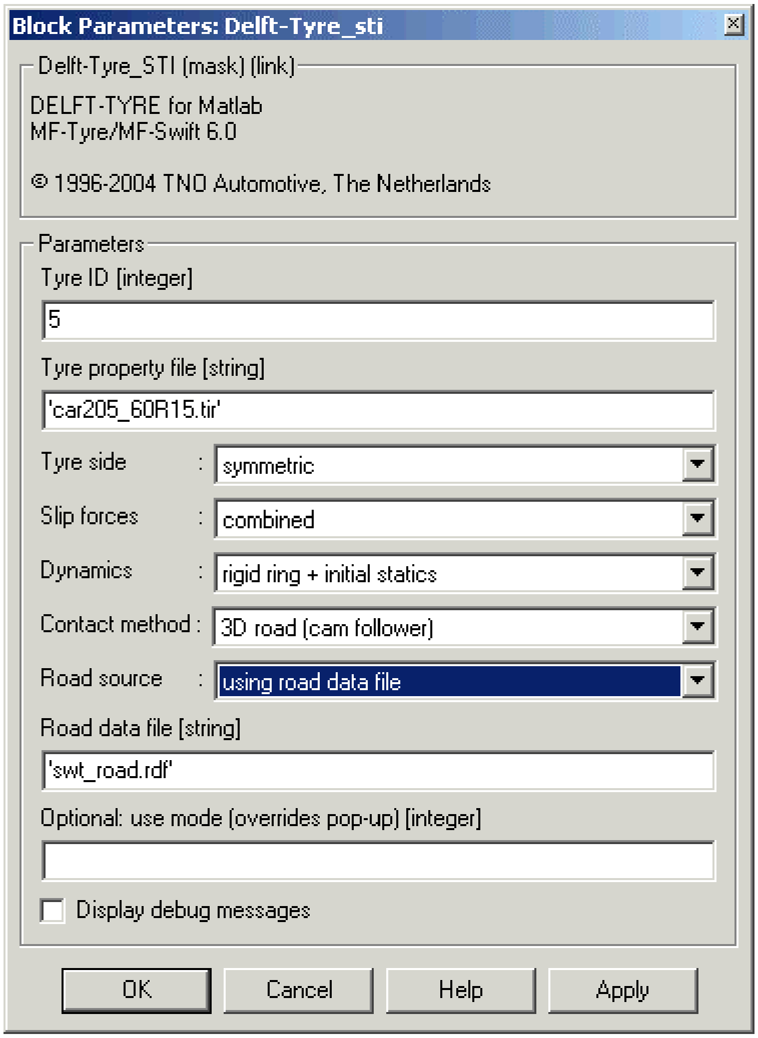
	Michelin	255/65R16	XPC	2.6	PC & PB only*	·	
MF-SWIFT CAR							
width	make	size	type	pressure (bar)		dry	wet
205	Continental	205/55R16	Premium Contact	2.3		·	
235	Continental	235/60R16	Eco Contact	2.3		·	·
MF-Tyre MOTORCYCLE							
width	make	size	type	pressure (bar)		dry	wet
120	Dunlop	120/70R17		2.25		·	·
	Bridgestone	120/70R18	Battlax BT-54F	2.5		·	
130	Dunlop	130/70R16		2.5		·	
160	Bridgestone	160/70R17	Battlax BT-54R	2.9		·	·
170	Bridgestone	170/80R15		2.0		·	
180	Dunlop	180/55R17		2.45		·	
MF-Tyre TRUCK							
width	make	size	type	pressure (bar)		dry	wet
265	Pirelli	265/70R19.5	(trailer axle)	8.5		·	
315	Bridgestone	315/80R22.5	R227	8.25		·	·
* PC = pure cornering, PB = pure braking, cam = camber angle							

4 Model usage

4 Model usage

Operating modes

MF-Tyre/MF-Swift 6.0 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 MSC.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 6.



DELFT-TYRE for Matlab
MF-Tyre/MF-Swift 6.0

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Tyre ID [integer]: 5

Tyre property file [string]: 'car205_60R15.tir'

Tyre side : symmetric

Slip forces : combined

Dynamics : rigid ring + initial statics

Contact method : 3D road (cam follower)

Road source : using road data file

Road data file [string]: 'swt_road.rdf'

Optional: use mode (overrides pop-up) [integer]:

☐ Display debug messages

example operating mode selection: Simulink interface

Basically ISWTCH (or USE_MODE) = 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
4	mirrored tyre characteristics

Contact Method (number B)

Various methods are available to calculate the tyre–road contact point. Smooth road contact can only be used on a smooth road surface with a minimum wavelength bigger than twice the tyre radius. For short wavelength obstacles (e.g. cleats, discrete steps) either the basic function or elliptical cam method should be selected. The elliptical cam method works on both 2D and 3D road surfaces, but is computationally more expensive than the basic function method which works only with 2D road profiles. The moving road is to be used for simulation of a four poster test rig, available from MSC.ADAMS 2003 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 2D road contact using basic functions

5 3D road contact using elliptical cams

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 relaxation lengths. “Non-linear transient effects” uses the new approach based on contact patch dynamics as discussed in paragraph 1.6. “Rigid ring dynamics” refers to a detailed dynamic model, where the tyre belt is modelled as a separate rigid body.

We may select one of the following values for C:

0 Steady-state evaluation (< 1 Hz)

1 Transient effects included, relaxation behaviour (< 10 Hz, linear)

2 Transient effects included, relaxation behaviour (< 10 Hz, non-linear)

3 Rigid ring dynamics included (< 100 Hz, non-linear)

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 don't use 2D or 3D short wavelength road contact 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.

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.

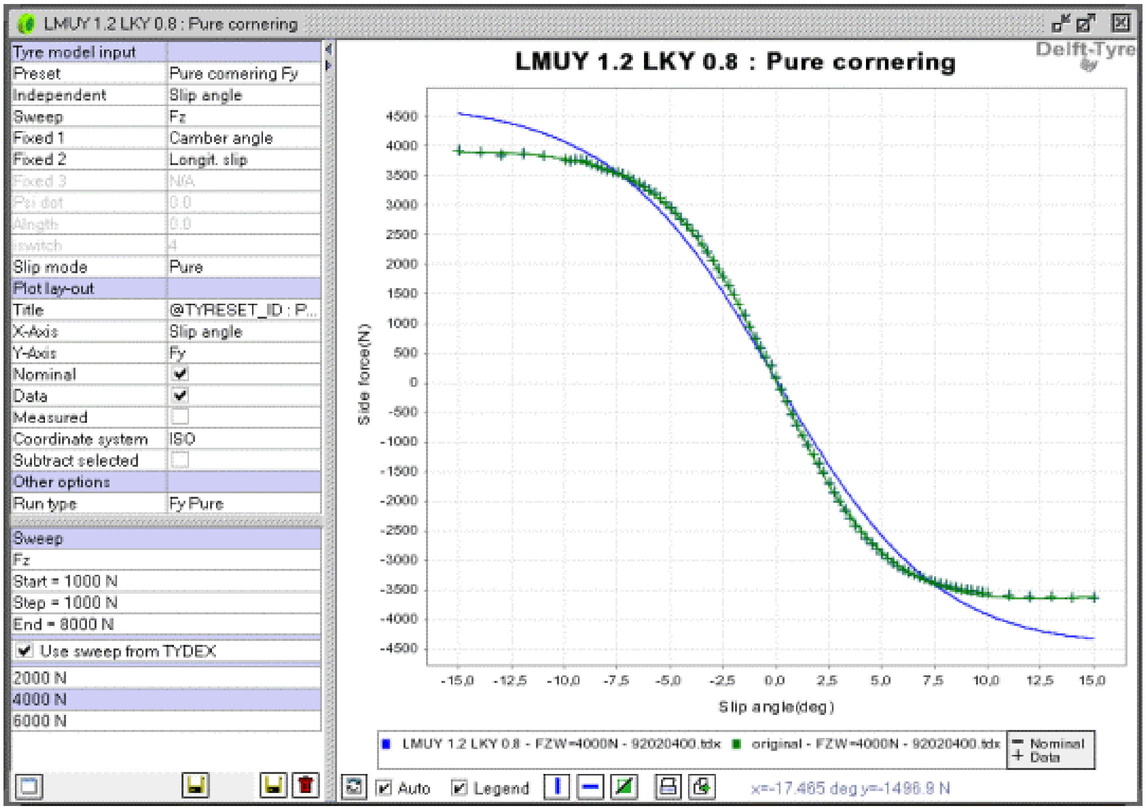
For this purpose scaling factors are included in the tyre model, which allow the user to manipulate and tune the tyre characteristics, for example to get a better match between full vehicle tests and simulation model. Another application of the scaling factors is that they may be used to eliminate some 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 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; a complete overview of all scaling factors can be found in section 5.3.


LMUY 1.2 LKY 0.8 : Pure cornering

Tyre model input	
Preset	Pure cornering Fy
Independent	Slip angle
Sweep	Fz
Fixed 1	Camber angle
Fixed 2	Longit. slip
Fixed 3	N/A
Psi dot	0.0
Alngth	0.0
iswitch	4
Slip mode	Pure
Plot lay-out	
Title	@TYRESET_ID : P...
X-Axis	Slip angle
Y-Axis	Fy
Nominal	☑
Data	☑
Measured	☐
Coordinate system	ISO
Subtract selected	☐
Other options	
Run type	Fy Pure

Sweep
Fz
Start = 1000 N
Step = 1000 N
End = 8000 N
☑ Use sweep from TYDEX
2000 N
4000 N
6000 N

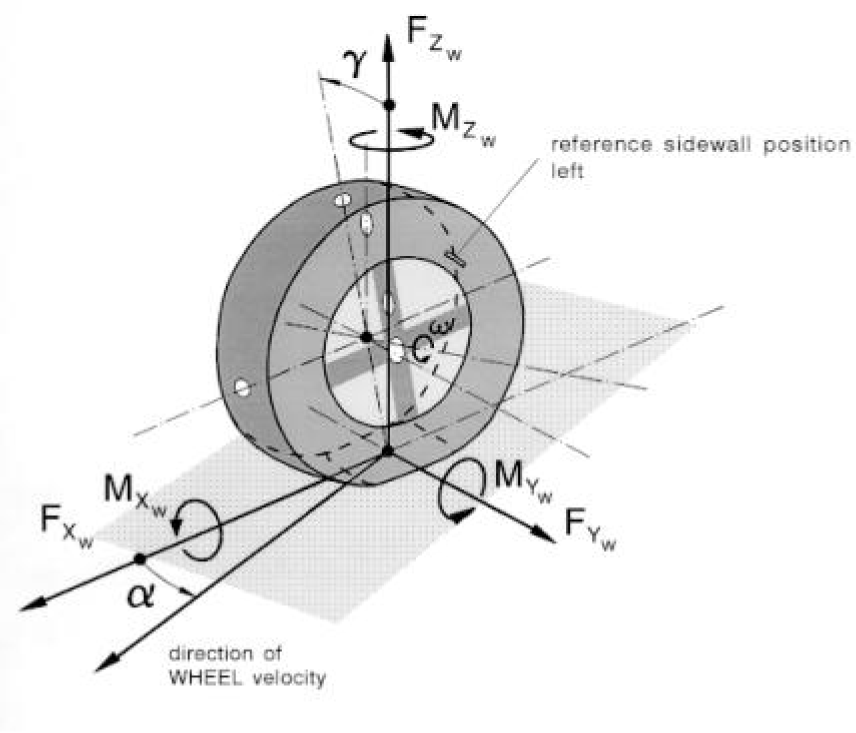
x=-17.465 deg y=-1496.9 N

MF-Tool plot of characteristics with modified scaling factors for cornering stiffness and lateral friction

Axis systems and units

Axis systems

MF-Tyre/MF-Swift 6.0 uses the ISO sign convention a shown in the figure below.



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 multi-body simulation program, as defined in the specification of the Standard Tyre Interface (STI) [8]. However many multibody codes don’t 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.

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	[N]
2	Fy	lateral force Fy	[N]
3	Fz	vertical force Fz	[N]
4	Mx	overturning moment Mx	[Nm]
5	My	rolling resistance moment My	[Nm]
6	Mz	self aligning moment Mz	[Nm]

slip quantities:

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

additional tyre outputs:

11	Vx	tyre 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 slip velocity	[m/s]	
22	Vsy	lateral slip velocity	[m/s]	
23	Vz	tyre compression velocity	[m/s]	
25		corrected/dynamic longitudinal slip kappa (used in MF)	[-]	
26		corrected/dynamic side slip angle alpha (used in MF)	[rad]	
28	s	traveled 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 y 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	effective road height	[m]	(not always available)
38	effective road angle	[rad]	(not always available)
39	effective road curvature	[1/m]	(not always available)

5 The tyre property file

5 The tyre property file

Overview

The tyre property file contains the parameters of the tyre model. 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, the maximum number of parameters is given between brackets.

General and Swift parameters:

[UNITS]	units system used for the definition of the parameters
[MODEL]	parameters on the usage of the tyre model (8)
[DIMENSION]	tyre dimensions (5)
[INERTIA]	tyre and tyre belt mass/inertia properties (7)
[VERTICAL]	vertical stiffness; loaded and effective rolling radius (14)
[STRUCTURAL]	tyre stiffness, damping and eigenfrequencies (15)
[CONTACT_PATCH]	contact length, obstacle enveloping parameters (15)

Magic Formula:

[VERTICAL_FORCE_RANGE]	input limitations to the Magic Formula (2)
[LONG_SLIP_RANGE]	
[SLIP_ANGLE_RANGE]	
[INCLINATION_ANGLE_RANGE]	
[SCALING_COEFFICIENTS]	Magic Formula scaling factors (25), see also section 4.2
[LONGITUDINAL_COEFFICIENTS]	coefficients for the longitudinal force Fx (22)
[OVERTURNING_COEFFICIENTS]	coefficients for the overturning moment Mx (11)
[LATERAL_COEFFICIENTS]	coefficients for the lateral force Fy (37)
[ROLLING_COEFFICIENTS]	coefficients for the rolling

resistance moment My (4)
[ALIGNING_COEFFICIENTS] coefficients for the self aligning moment Mz (31)
[TURNSLIP_COEFFICIENTS] coefficients for turnslip, affects all forces/moments (20)

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. 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 is needed. An example of such a tyre property file is given in paragraph 5.4, where only about 15 coefficients are required to use MF-Swift.

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.

Backward compatibility

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

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 SWIFT minor differences may occur between the 1.x and 6.0 version 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 are negligible.

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 turnslip, rigid ring dynamics and tyre enveloping behaviour, thus already benefiting from the new functionality available in MF-Tyre/MF-Swift 6.0.

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

MF-Tyre/MF-Swift 6.0 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 4.1 the new 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 6.0 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 6.0 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.

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 (blue column).

x: required parameter

(x): optional parameter

		MF-Tyre 6.0			MF-Swi
	description	Express	Standard	Supreme	Expres
[MODEL]					
FITTYP	Magic Formula version number	60	60	60	60
TYRESIDE	Position of tyre during measurements		x	x	
LONGVL	Measurement speed	(x)	x	x	(x)
VXLOW	Lower boundary velocity in slip calculation	(x)	x	x	(x)
ROAD_INCREMENT	Increment in road sampling				(x)
ROAD_DIRECTION	Direction of travelled distance				(x)
PROPERTY_FILE_FORMAT	Tyre model selection (MSC.ADAMS only)	x	x	x	x
USE_MODE	Tyre use mode switch (MSC.ADAMS	x	x	x	x

	only)				
HMAX_LOCAL	Local integration timestep (MSC.ADAMS only)				(x)
TIME_SWITCH_INTEG	Time when local integrator is activated (MSC.ADAMS only)				(x)
[DIMENSION]					
UNLOADED_RADIUS	Free tyre radius	x	x	x	x
WIDTH	Nominal section width of the tyre	(x)	x	x	(x)
RIM_RADIUS	Nominal rim radius	(x)	x	x	(x)
RIM_WIDTH	Rim width	(x)	x	x	(x)
ASPECT_RATIO	Nominal aspect ratio	(x)	x	x	(x)
[INERTIA]					
MASS	Tyre mass	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)
BELT_IXX	Belt diametral moment of inertia				(x)
BELT_IYY	Belt polar moment of inertia				(x)
GRAVITY	Gravity acting on belt in Z direction				(x)
M_B	Portion of tyre mass of tyre belt part				
I_BY	Normalized moment of inertia about Y of tyre belt part				
I_BXZ	Normalized moment of inertia about XZ of tyre belt part				
C_GRV	Gravity constant				
[VERTICAL]					
FNOMIN	Nominal wheel load	x	x	x	x
VERTICAL_STIFFNESS	Tyre vertical stiffness	x	x	x	x
VERTICAL_DAMPING	Tyre vertical damping	x	x	x	x
BREFF	Low load stiffness e.r.r.	(x)	x	x	(x)
DREFF	Peak value of e.r.r.	(x)	x	x	(x)
FREFF	High load stiffness e.r.r.	(x)	x	x	(x)
Q_RE0	Ratio of free tyre radius with nominal tyre radius			x	(x)
Q_V1	Tyre radius increase with speed			x	(x)
Q_V2	Vertical stiffness increase with speed			x	(x)
Q_FZ2	Quadratic term in load vs. deflection			x	(x)
Q_FCX	Longitudinal force influence on vertical stiffness			x	(x)
Q_FCY	Lateral force influence on vertical stiffness			x	(x)
BOTTOM_OFFST	Distance to rim when bottoming			(x)	(x)

Swift

	starts to occur				
BOTTOM_STIFF	Vertical stiffness of bottomed tyre			(x)	(x)

		MF-Tyre 6.0			MF-S
	description	Express	Standard	Supreme	Expr
[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
FREQ_LONG	Undamped frequency fore/aft and vertical mode				(x
FREQ_LAT	Undamped frequency lateral mode				(x
FREQ_YAW	Undamped frequency yaw and camber mode				(x
FREQ_WINDUP	Undamped frequency wind-up mode				(x
DAMP_LONG	Dimensionless damping fore/aft and vertical mode				(x
DAMP_LAT	Dimensionless damping lateral mode				(x
DAMP_YAW	Dimensionless damping yaw and camber mode				(x
DAMP_WINDUP	Dimensionless damping wind-up mode				(x
DAMP_RESIDUAL	Residual damping (proportinal to stiffness)				(x
DAMP_VLOW	Additional low speed damping (proportional to stiffness)				(x
Q_BVX	Load and speed influence on in-plane translation stiffness				(x
Q_BVT	Load and speed influence on in-plane rotation stiffness				(x
C_BX0	In-plane belt translation stiffness				
C_RX	Longitudinal residual stiffness				
C_BT0	In-plane belt rotation stiffness				
C_BY	Out-of-plane belt translation stiffness				
C_RY	Lateral residual stiffness				

C_BGAM	Out-of-plane belt rotation stiffness				
C_RP	Yaw residual stiffness				
K_BX	In-plane belt translation damping				
K_BT	In-plane belt rotation damping				
K_BY	Out-of-plane belt translation damping				
K_BGAM	Out-of-plane belt rotation damping				
[CONTACT_PATCH]					
Q_A2	Linear load term in contact length				(x
Q_A1	Square root load term in contact length				(x
Q_LBF	Length of basic function				(x
Q_LOS1	Basic function offset threshold				(x
Q_LOS2	Basic function offset scaling factor with basic function length				(x
Q_LIMP1	Linear contact length term in basic function shift				(x
Q_LIMP2	Quadratic contact length term in basic function shift				(x
ELLIPS_SHIFT	Scaling of distance between front and rear ellipsoid				
ELLIPS_LENGTH	Semimajor axis of ellipsoid				
ELLIPS_HEIGHT	Semiminor axis of ellipsoid				
ELLIPS_ORDER	Order of ellipsoid				
ELLIPS_MAX_STEP	Maximum height of road step				
ELLIPS_INC	Discretisation increment of ellipsoid contour				
ELLIPS_NWIDTH	Number of parallel ellipsoids				
ELLIPS_NLENGTH	Number of ellipsoids at sides of contact patch				
[VERTICAL_FORCE_RANGE]					
FZMIN	Minimum allowed wheel load	(x)	x	x	(x
FZMAX	Maximum allowed wheel load	(x)	x	x	(x
[LONG_SLIP_RANGE]					
KPUMIN	Minimum valid wheel slip	(x)	x	x	(x
KPUMAX	Maximum valid wheel slip	(x)	x	x	(x
[SLIP_ANGLE_RANGE]					
ALPMIN	Minimum valid slip angle	(x)	x	x	(x
ALPMAX	Maximum valid slip angle	(x)	x	x	(x
[INCLINATION_ANGLE_RANGE]					
CAMMIN	Minimum valid camber angle		x	x	
CAMMAX	Maximum valid camber angle		x	x	

		MF-Tyre 6.0			MF-Swift 6.0	
	description	Express	Standard	Supreme	Express	Stand
[SCALING_COEFFICIENTS]						
LFZO	Scale factor of nominal (rated) load	(x)	x	x	(x)	x
LCX	Scale factor of Fx shape factor	(x)	x	x	(x)	x
LMUX	Scale factor of Fx peak friction coefficient	(x)	x	x	(x)	x
LEX	Scale factor of Fx curvature factor	(x)	x	x	(x)	x
LKX	Scale factor of slip stiffness	(x)	x	x	(x)	x
LHX	Scale factor of Fx horizontal shift	(x)	x	x	(x)	x
LVX	Scale factor of Fx vertical shift	(x)	x	x	(x)	x
LCY	Scale factor of Fy shape factor	(x)	x	x	(x)	x
LMUY	Scale factor of Fy peak friction coefficient	(x)	x	x	(x)	x
LEY	Scale factor of Fy curvature factor	(x)	x	x	(x)	x
LKY	Scale factor of cornering stiffness	(x)	x	x	(x)	x
LKYC	Scale factor of camber stiffness		x	x		x
LKZC	Scale factor of camber moment stiffness		x	x		x
LHY	Scale factor of Fy horizontal shift	(x)	x	x	(x)	x
LVY	Scale factor of Fy vertical shift	(x)	x	x	(x)	x
LTR	Scale factor of Peak of pneumatic trail	(x)	x	x	(x)	x
LRES	Scale factor for offset of residual torque		x	x		x
LXAL	Scale factor of alpha influence on Fx		x	x		x
LYKA	Scale factor of alpha influence on Fx		x	x		x
LVYKA	Scale factor of kappa induced Fy		x	x		x
LS	Scale factor of Moment arm of Fx		x	x		x
LMX	Scale factor of overturning moment		x	x		x
LVMX	Scale factor of Mx vertical shift		x	x		x
LMY	Scale factor of rolling resistance torque	(x)	x	x	(x)	x
LMP	Scale factor of parking moment			x		
LKC	Scale factor of camber stiffness					

LCC	Scale factor of camber shape factor					
LEC	Scale factor of camber curvature factor					
LSGKP	Scale factor of Relaxation length of Fx					
LSGAL	Scale factor of Relaxation length of Fy					
LGYR	Scale factor gyroscopic moment					
[LONGITUDINAL_COEFFICIENTS]						
PCX1	Shape factor Cfx for longitudinal force	(x)	x	x	(x)	x
PDX1	Longitudinal friction Mux at Fznom	x	x	x	x	x
PDX2	Variation of friction Mux with load	(x)	x	x	(x)	x
PDX3	Variation of friction Mux with camber		x	x		x
PEX1	Longitudinal curvature Efx at Fznom	(x)	x	x	(x)	x
PEX2	Variation of curvature Efx with load	(x)	x	x	(x)	x
PEX3	Variation of curvature Efx with load squared	(x)	x	x	(x)	x
PEX4	Factor in curvature Efx while driving	(x)	x	x	(x)	x
PKX1	Longitudinal slip stiffness Kfx/Fz at Fznom	x	x	x	x	x
PKX2	Variation of slip stiffness Kfx/Fz with load	(x)	x	x	(x)	x
PKX3	Exponent in slip stiffness Kfx/Fz with load	(x)	x	x	(x)	x
PHX1	Horizontal shift Shx at Fznom	(x)	x	x	(x)	x
PHX2	Variation of shift Shx with load	(x)	x	x	(x)	x
PVX1	Vertical shift Svx/Fz at Fznom	(x)	x	x	(x)	x
PVX2	Variation of shift Svx/Fz with load	(x)	x	x	(x)	x
RBX1	Slope factor for combined slip Fx reduction		x	x		x
RBX2	Variation of slope Fx reduction with kappa		x	x		x
RBX3	Influence of camber on stiffness for Fx combined		x	x		x
RCX1	Shape factor for combined slip Fx reduction		x	x		x
REX1	Curvature factor of combined Fx		x	x		x
REX2	Curvature factor of combined Fx with load		x	x		x
RHX1	Shift factor for combined slip Fx reduction		x	x		x
PTX1	Relaxation length SigKap0/Fz at					

	Fznom
PTX2	Variation of SigKap0/Fz with load
PTX3	Variation of SigKap0/Fz with exponent of load

		MF-Tyre 6.0			MF-Swift 6.0	
	description	Express	Standard	Supreme	Express	Stan
[OVERTURNING_COEFFICIENTS]						
QSX1	Lateral force induced overturning moment		x	x		x
QSX2	Camber induced overturning couple		x	x		x
QSX3	Fy induced overturning couple		x	x		x
QSX4	Mixed load, lateral force and camber on Mx		x	x		x
QSX5	Load effect on Mx with lateral force and camber		x	x		x
QSX6	B-factor of load with Mx		x	x		x
QSX7	Camber with load on Mx		x	x		x
QSX8	Lateral force with load on Mx		x	x		x
QSX9	B-factor of lateral force with load on Mx		x	x		x
QSX10	Vertical force with camber on Mx		x	x		x
QSX11	B-factor of vertical force with camber on Mx		x	x		x
[LATERAL_COEFFICIENTS]						
PCY1	Shape factor Cfy for lateral forces	(x)	x	x	(x)	x
PDY1	Lateral friction Muy	x	x	x	x	x
PDY2	Variation of friction Muy with load	(x)	x	x	(x)	x
PDY3	Variation of friction Muy with squared camber		x	x		x
PEY1	Lateral curvature Efy at Fznom	(x)	x	x	(x)	x
PEY2	Variation of curvature Efy with load	(x)	x	x	(x)	x
PEY3	Zero order camber dependency of curvature Efy		x	x		x
PEY4	Variation of curvature Efy with		x	x		x

	camber					
PEY5	Camber curvature Efc		x	x		x
PKY1	Maximum value of stiffness Kfy/Fznom	x	x	x	x	x
PKY2	Load at which Kfy reaches maximum value	x	x	x	x	x
PKY3	Variation of Kfy/Fznom with camber		x	x		x
PKY4	Peak stiffness variation with camber squared		x	x		x
PKY5	Lateral stiffness depedency with camber		x	x		x
PKY6	Camber stiffness factor		x	x		x
PKY7	Load dependency of camber stiffness factor		x	x		x
PHY1	Horizontal shift Shy at Fznom	(x)	x	x	(x)	x
PHY2	Variation of shift Shy with load	(x)	x	x	(x)	x
PVY1	Vertical shift in Svy/Fz at Fznom	(x)	x	x	(x)	x
PVY2	Variation of shift Svy/Fz with load	(x)	x	x	(x)	x
PVY3	Variation of shift Svy/Fz with camber		x	x		x
PVY4	Variation of shift Svy/Fz with camber and load		x	x		x
RBY1	Slope factor for combined Fy reduction		x	x		x
RBY2	Variation of slope Fy reduction with alpha		x	x		x
RBY3	Shift term for alpha in slope Fy reduction		x	x		x
RBY4	Influence of camber on stiffness of Fy combined		x	x		x
RCY1	Shape factor for combined Fy reduction		x	x		x
REY1	Curvature factor of combined Fy		x	x		x
REY2	Curvature factor of combined Fy with load		x	x		x
RHY1	Shift factor for combined Fy reduction		x	x		x
RHY2	Shift factor for combined Fy reduction with load		x	x		x
RVY1	Kappa induced side force Svyk/Muy*Fz at Fznom		x	x		x
RVY2	Variation of Svyk/Muy*Fz with load		x	x		x
RVY3	Variation of Svyk/Muy*Fz with camber		x	x		x
RVY4	Variation of Svyk/Muy*Fz with alpha		x	x		x
RVY5	Variation of Svyk/Muy*Fz with kappa		x	x		x
RVY6	Variation of Svyk/Muy*Fz with atan(kappa)		x	x		x

PCY2	Shape factor Cfc for camber forces					
PHY3	Variation of shift Shy with camber					
PTY1	Peak value of relaxation length SigAlp0/R0					
PTY2	Value of Fz/Fznom where SigAlp0 is extreme					
PTY3	Value of Fz/Fznom where Sig_alpha is maximum					
[ROLLING_COEFFICIENTS]						
QSY1	Rolling resistance torque coefficient	(x)	(x)	(x)	(x)	(x
QSY2	Rolling resistance torque depending on Fx	(x)	(x)	(x)	(x)	(x
QSY3	Rolling resistance torque depending on speed	(x)	(x)	(x)	(x)	(x
QSY4	Rolling resistance torque depending on speed ^4	(x)	(x)	(x)	(x)	(x

		MF-Tyre 6.0			MF-Swift 6.0	
	description	Express	Standard	Supreme	Express	Sta
[ALIGNING_COEFFICIENTS]						
QBZ1	Trail slope factor for trail Bpt at Fznom	(x)	x	x	(x)	
QBZ2	Variation of slope Bpt with load	(x)	x	x	(x)	
QBZ3	Variation of slope Bpt with load squared	(x)	x	x	(x)	
QBZ4	Variation of slope Bpt with camber		x	x		
QBZ5	Variation of slope Bpt with absolute camber		x	x		
QBZ9	Slope factor Br of residual torque Mzr	(x)	x	x	(x)	
QBZ10	Slope factor Br of residual torque Mzr	(x)	x	x	(x)	
QCZ1	Shape factor Cpt for pneumatic trail	(x)	x	x	(x)	
QDZ1	Peak trail Dpt" = Dpt*(Fz/Fznom*R0)	(x)	x	x	(x)	
QDZ2	Variation of peak Dpt with load	(x)	x	x	(x)	
QDZ3	Variation of peak Dpt with camber		x	x		
QDZ4	Variation of peak Dpt with camber		x	x		

	squared				
QDZ6	Peak residual torque Dmr = Dmr/(Fz*R0)		x	x	
QDZ7	Variation of peak factor Dmr with load	(x)	x	x	(x)
QDZ8	Variation of peak factor Dmr with camber		x	x	
QDZ9	Variation of peak factor Dmr with camber and load		x	x	
QDZ10	Variation of peak factor Dmr with camber squared		x	x	
QDZ11	Variation of Dmr with camber squared and load		x	x	
QEZ1	Trail curvature Ept at Fznom	(x)	x	x	(x)
QEZ2	Variation of curvature Ept with load	(x)	x	x	(x)
QEZ3	Variation of curvature Ept with load squared	(x)	x	x	(x)
QEZ4	Variation of curvature Ept with sign of Alpha-t	(x)	x	x	(x)
QEZ5	Variation of Ept with camber and sign Alpha-t	(x)	x	x	(x)
QHZ1	Trail horizontal shift Sht at Fznom	(x)	x	x	(x)
QHZ2	Variation of shift Sht with load	(x)	x	x	(x)
QHZ3	Variation of shift Sht with camber		x	x	
QHZ4	Variation of shift Sht with camber and load		x	x	
SSZ1	Nominal value of s/R0: effect of Fx on Mz		x	x	
SSZ2	Variation of distance s/R0 with Fy/Fznom		x	x	
SSZ3	Variation of distance s/R0 with camber		x	x	
SSZ4	Variation of distance s/R0 with load and camber		x	x	
QTZ1	Gyroscopic torque constant				
MBELT	Belt mass of the wheel				
[TURNSLIP_COEFFICIENTS]					
PDXP1	Peak Fx reduction due to spin parameter			x	
PDXP2	Peak Fx reduction due to spin with varying load parameter			x	
PDXP3	Peak Fx reduction due to spin with kappa parameter			x	
PKYP1	Cornering stiffness reduction due to spin			x	
PDYP1	Peak Fy reduction due to spin parameter			x	
PDYP2	Peak Fy reduction due to spin with			x	

	varying load parameter	
PDYP3	Peak Fy reduction due to spin with alpha parameter	x
PDYP4	Peak Fy reduction due to square root of spin parameter	x
PHYP1	Fy-alpha curve lateral shift limitation	x
PHYP2	Fy-alpha curve maximum lateral shift parameter	x
PHYP3	Fy-alpha curve maximum lateral shift varying with load parameter	x
PHYP4	Fy-alpha curve maximum lateral shift parameter	x
PECP1	Camber w.r.t. spin reduction factor parameter in camber stiffness	x
PECP2	Camber w.r.t. spin reduction factor varying with load parameter in camber stiffness	x
QDTP1	Pneumatic trail reduction factor due to turn slip parameter	x
QCRP1	Turning moment at constant turning and zero forward speed parameter	x
QCRP2	Turn slip moment (at alpha=90deg) parameter for increase with spin	x
QBRP1	Residual (spin) torque reduction factor parameter due to side slip	x
QDRP1	Turn slip moment peak magnitude parameter	x
QDRP2	Turn slip moment peak position parameter	x

Obsolete parameters which may be in a tyre property file, but are ignored by MF-Tyre/MF-Swift 6.0

NB: these parameters are also not used in backward compatibility mode.

			compatibility mode		
	description	remark	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

EXPLANATION:

1 parameter was not used

2 used in combination with MSC.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 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

5.4 MF-Tyre/MF-Swift 6.0 Express Tyre property file example

The new Express functionality of MF-Tyre/MF-Swift 6.0 requires only a basic set of parameters. A sample Express tyre property file is listed below. Optional parameters are marked *italic*.

```
!

! MF-Tyre/MF-Swift 6.0 Express sample tyre property file

! Copyright (c) TNO 2004

!

$----------------------------------------------------------------units

[UNITS]

LENGTH                   ='meter'

FORCE                    ='newton'

ANGLE                    ='radians'

MASS                     ='kg'

TIME                     ='second'

!

$----------------------------------------------------------------model

[MODEL]

FITTYP                   = 60          $ MF-Tyre version number 6.0

PROPERTY_FILE_FORMAT     ='SWIFT-TYRE' $ tyre model selection
(MSC.ADAMS only)

USE_MODE                 = 104         $ Tyre use mode switch
(MSC.ADAMS only)

$

$ uncomment the next two lines to use local integration in MSC.ADAMS

! HMAX_LOCAL               = 0.00025    $local integration timestep
(MSC.ADAMS only)
```

```
! TIME_SWITCH_INTEG        = 0.1        $Time when local integrator is
activated (MSC.ADAMS only)

$-----------------------------------------------------------dimensions

[DIMENSION]

UNLOADED_RADIUS          = 0.3          $ Free tyre radius

WIDTH                    = 0.2          $ Nominal section width of the
tyre

RIM_RADIUS               = 0.2          $ Nominal rim radius

$--------------------------------------------------------------inertia

[INERTIA]

MASS                     = 9.3          $ Tyre mass

IXX                      = 0.4          $ Tyre diametral moment of
inertia

IYY                      = 0.7          $ Tyre polar moment of inertia

GRAVITY                  = -9.81        $ Gravity acting on tyre in Z-
direction

!

$--------------------------------------------------------------vertical

[VERTICAL]

FNOMIN                   = 4000         $ Nominal wheel load

VERTICAL_STIFFNESS       = 200000       $ vertical stiffness

VERTICAL_DAMPING         = 50           $ vertical damping

!

$-------------------------------------------------------------
structural

[STRUCTURAL]

LONGITUDINAL_STIFFNESS   = 350000       $ longitudinal stiffness

LATERAL_STIFFNESS        = 120000       $ lateral stiffness
```

```
!

$---------------------------------------------------------longitudinal

[LONGITUDINAL_COEFFICIENTS]

PDX1                     =  1.2        $ Longitudinal friction Mux at
Fznom

PDX2                     = -0.04       $ Variation of friction Mux with
load

PKX1                     = 20          $ Longitudinal slip stiffness
Kfx/Fz at Fznom

!

$--------------------------------------------------------------lateral

[LATERAL_COEFFICIENTS]

PDY1                     =  1.0        $ Lateral friction Muy at Fznom

PDY2                     = -0.15       $ Variation of friction Muy with
load

PKY1                     = -15         $ Maximum value of stiffness
Kfy/Fznom

PKY2                     =  2          $ factor times Fznom at which
Kfy reaches maximum value

!

$---------------------------------------------------rolling resistance

[ROLLING_COEFFICIENTS]

QSY1                     = 0.01        $ Rolling resistance torque
coefficient

!

$-------------------------------------------------------------aligning

[ALIGNING_COEFFICIENTS]

QDZ1                     = 0.12        $ Peak trail/R0 at Fznom
```

6 ADAMS/Tire SWIFT Specific Notes

MF-Tyre/MF-Swift 6.0 is offered as ADAMS/Tire Swift in MSC.ADAMS 12 and up. The user will get the full functionality of MF-Swift 6.0 Supreme.

property file format

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

```
PROPERTY_FILE_FORMAT     ='SWIFT-TYRE'
```

This ensures that the TNO MF-Tyre/MF-Swift 6.0 tyre model is called. This can also be checked in the MSC.ADAMS message file (*.msg), the following statement should appear:

```
TYR915 -> DELFT-TYRE MF-Tyre/MF-Swift 6.0 xxxxxxxx-x
```

introducing the tyre using ADAMS/View

To introduce MF-Tyre/MF-Swift 6.0 in an MSC.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 6.0 tyre property file.

selecting an operating mode

In MSC.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 4.1 a four digit number (ABCD) would be required to define the operating mode. When defining a tyre in MSC.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 6.0 will honour the MSC.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 a four digit number).

Furthermore if MSC.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 MSC.ADAMS message file (*.msg). A typical message would look like this:

```
TYR915: 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 6.0 provides two methods for time integration with MSC.ADAMS:

•€€€€€€€€ **global integration**: the tyre differential equations are solved in the MSC.ADAMS solver together with the multi-body 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 MSC.ADAMS calculate static equilibrium for the tyre model and at a later stage during the simulation switch to local integration to speed it up.

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

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

7 References

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