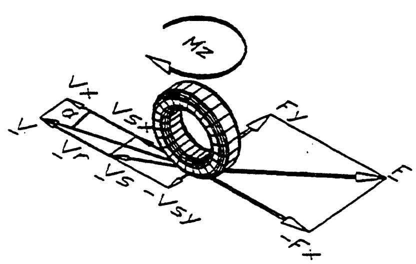
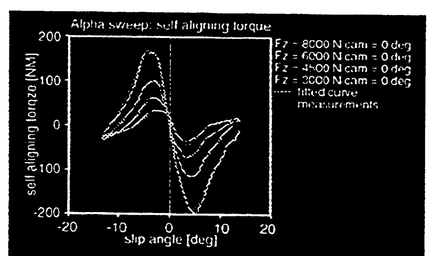
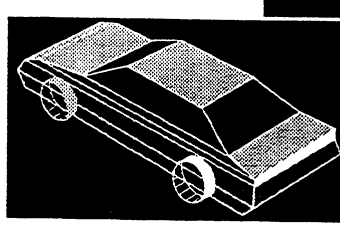
Delft-Tyre
a design and analysis tool...

Delft-Tyre

A design and analysis tool, to support testing and modelling of tyre behaviour, to be used with any dynamic system simulation code







Delft-Tyre

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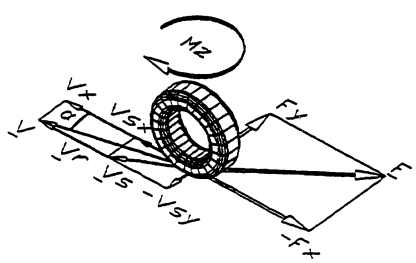
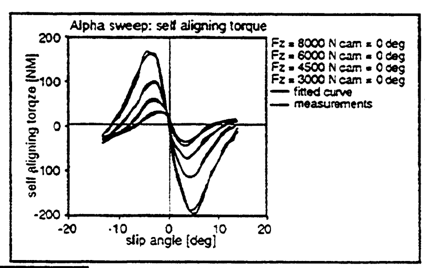
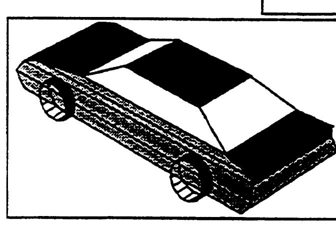
A design and analysis tool, to support testing and modelling of tyre behaviour, to be used with any dynamic system simulation code

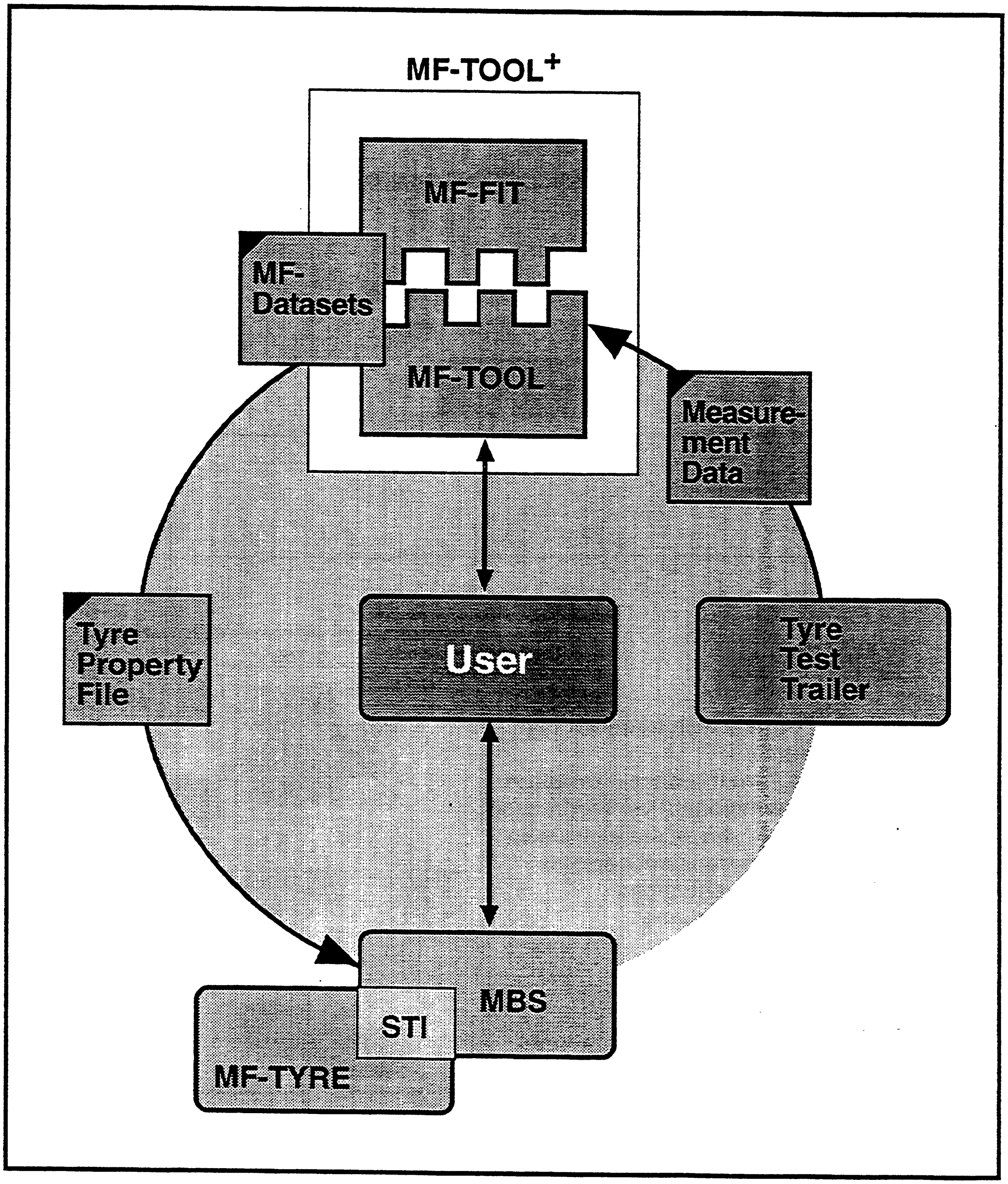






Delft-Tyre

Product range



Delft-Tyre

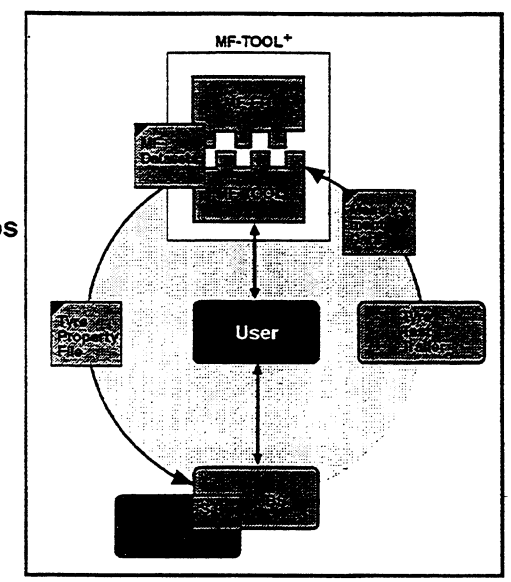
Objectives

To offer a complete range of tools for modelling and simulation of tyre behaviour

- **Tyre model with physical parameters**
- **Integrated with vehicle simulation environment**
- **Integrated with tyre data processing**
- **Tyre characteristic manipulation and tools for tyre-vehicle optimization**
- **Calculation of tyre model parameters from measurement data**
- **Latest developments**
- **Internationally accepted standards**
- **Open and well-known to the user**

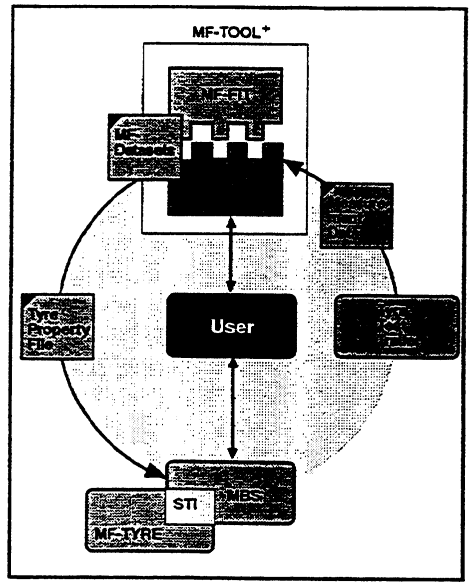
MF-Tyre

- **Magic Formula with transient tyre behaviour**
- **Standard Tyre Interface, developed within International Tyre Workshops**
- **From simple steady state pure slip conditions to transient complex combined slip situations.**
- **Real time applications**



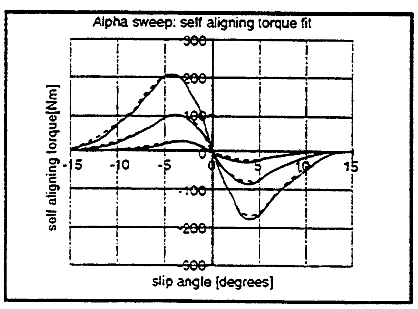
MF-Tool

- Visualisation of tyre characteristics and tyre physical properties
- Adaption and manipulation of tyre characteristics using a graphical interface (user-defined tyre datasets)
- Tyre dataset database
- Preparation of tyre datasets for simulation



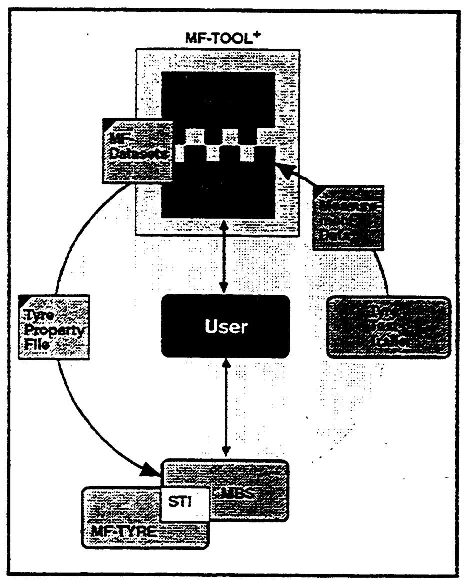
Delft-Tyre

MF-Tool+



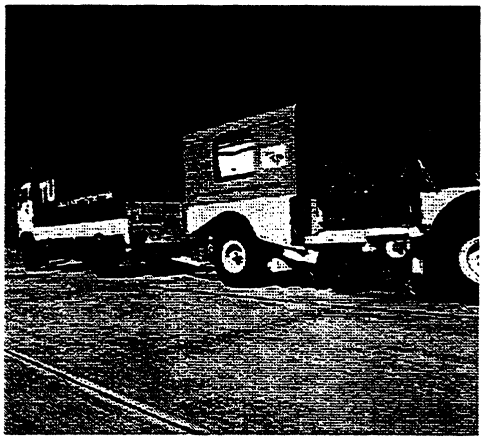
MF-Tool including MF-Fit

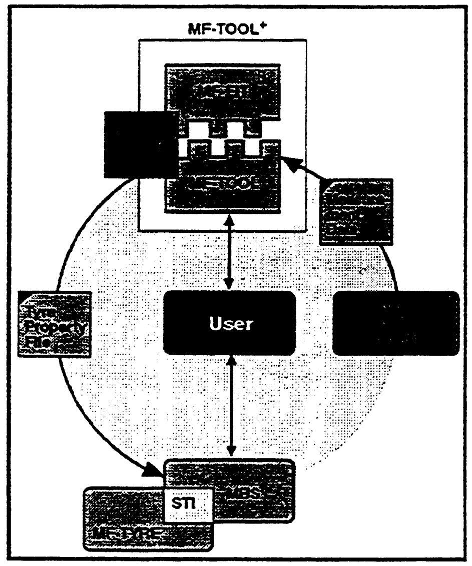
- Calculation of tyre model parameters
- Control of MF-Fit
- Graphical comparison measurement data
- Quality check of fit results
- Tyre data in standardized TYDEX format



Delft-Tyre

MF-Datasets





- Tyre library
  Regular updates and new datasets
- Tailor made datasets

Delft-Tyre

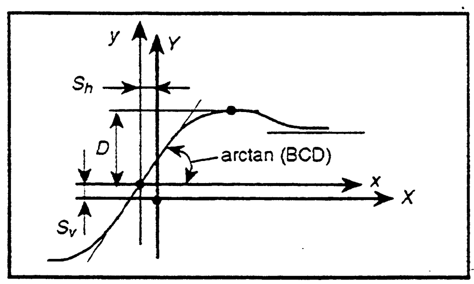
MF-Tyre

- *Steady state:*
  MAGIC FORMULA TYRE MODEL

$$y = D\sin[C\arctan\{Bx - E(Bx - \arctan(Bx))\}]$$

$$Y(x) = y(x) + S_v$$

$$x = X + S_h$$



- *Transient and oscillatory aspects:*
  FIRST ORDER LAGS and GYROSCOPIC COUPLE

Delft-Tyre

MF-Tyre

MAIN PROPERTIES of NEW VERSION:

Steady state pure slip
- aligning torque based on pneumatic trail

Steady state combined slip
- forces using weighting functions
- aligning torque based on pneumatic trail

Dynamic state
- first order lag
- relaxation lengths in x- and y- directions
- gyroscopic couple about z- axis
- start from zero velocity

Non-dimensional model parameters

Scaling factors

Delft-Tyre

Magic Formula

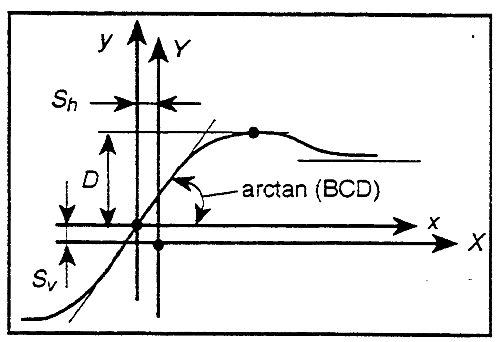
$$y = D\sin[C\arctan\{Bx - E(Bx - \arctan(Bx))\}]$$

$$Y(x) = y(x) + S_v$$

$$x = X + S_h$$

where Y: output variable F_x or F_y
X: input variable α or κ

and B: stiffness factor
C: shape factor
D: peak factor
E: curvature factor
S_h: horizontal shift
S_v: vertical shift



Delft-Tyre

Magic Formula / Pure slip

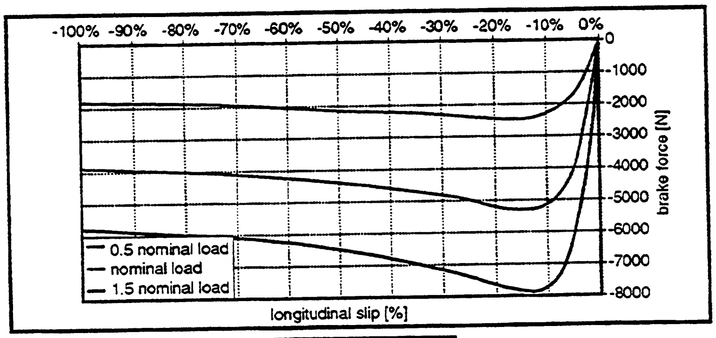
Longitudinal force

$$F_{xo} = D_x \sin [C_x \arctan \{B_x \kappa_x - E_x (B_x \kappa_x - \arctan (B_x \kappa_x))\}] + S_{Vx}$$

$$D_x \quad = (p_{Dx1} + p_{Dx2}\, df_z)\, F_z\, \lambda_{\mu x}$$

$$K_x \quad = BCD_x = F_z\, (p_{Kx1} + p_{Kx2} df_z) \exp(-p_{Kx3} df_z)\, \lambda_{Kx}$$

etc.



Delft-Tyre

Magic Formula / Pure slip

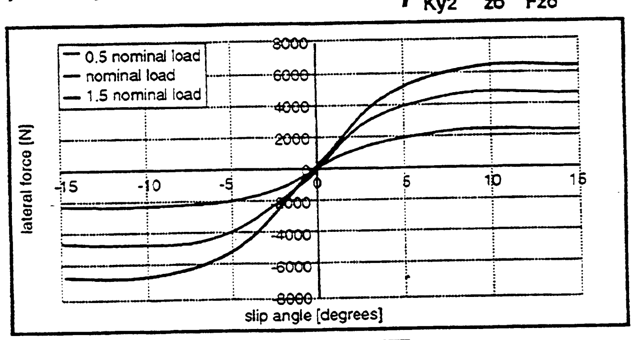
Lateral force

$$F_{yo} \quad = D_y \sin [C_y \arctan \{B_y \alpha_y - E_y (B_y \alpha_y - \arctan (B_y \alpha_y))\}] + S_{Vy}$$

$$D_y \quad = (p_{Dy1} + p_{Dy2}\, df_z)\, F_z\, \lambda_{\mu y}$$

$$K_y \quad = BCD_y = p_{Ky1} F_{zo} \sin [2 \arctan \{\frac{F_z}{p_{Ky2} F_{zo} \lambda_{Fzo}}\}] (1 - p_{Ky3} |\gamma_y|)\, \lambda_{Fzo}\, \lambda_{Ky}$$

etc.



Delft-Tyre

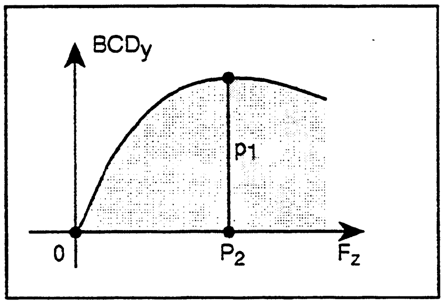
Magic Formula

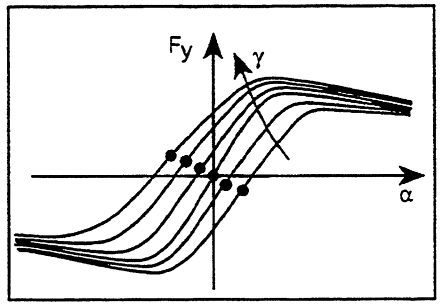
Pure slip

Asymmetry

Curvature factor E $E = E_o + \Delta E \,\mathrm{sign}\,(x)$

Cornering stiffness $BCD_y = p_1 \sin\left[2 \arctan\left(\frac{F_z}{p_2}\right)\right](1 - p_3|\gamma|)$

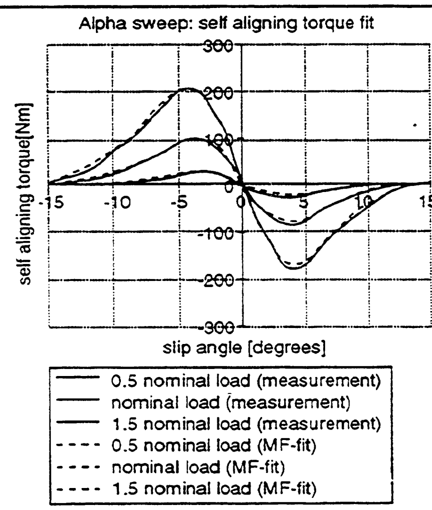


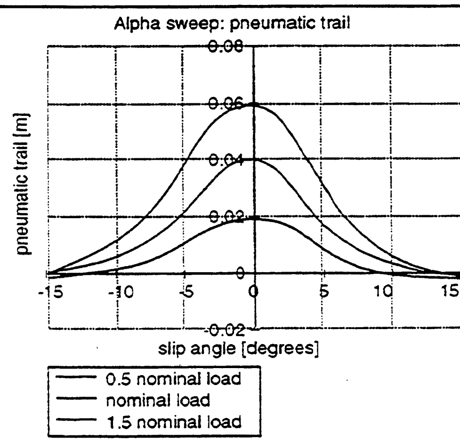


Delft-Tyre

Magic Formula

Aligning torque





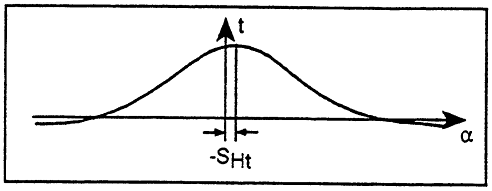
Delft-Tyre

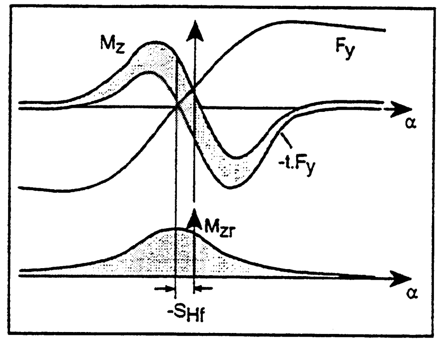
Magic Formula / Pure slip

Aligning torque
$M_{zo} = -t\, F_{yo} + M_{zr}$

Pneumatic trail
$t(\alpha_t) = D_t \cos [C_t \arctan \{B_t\alpha_t - E_t (B_t\alpha_t - \arctan (B_t\alpha_t))\}]$; $\alpha_t = \alpha + S_{Ht}$

Residual torque
$M_{zr}(\alpha_r) = D_r \cos [\arctan (B_r\alpha_r)]$; $\alpha_r = \alpha + S_{Hf}$



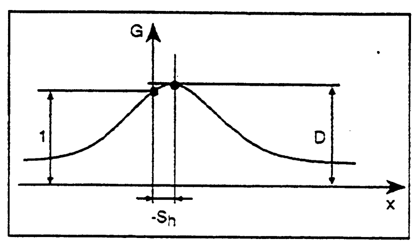


Delft-Tyre

Magic Formula / Combined slip

Weighting functions G multiplied with pure slip functions
Weighting function have a hill shape
Cosine version of Magic Formula is used

$$G = D\cos [C\arctan (Bx)]$$



x is either κ or α (possibly shifted)
D represents the peak value
C determines the height of the hill's base
B influences the sharpness of the hill
E is not needed to improve the fit

Delft-Tyre

Magic Formula

Combined slip

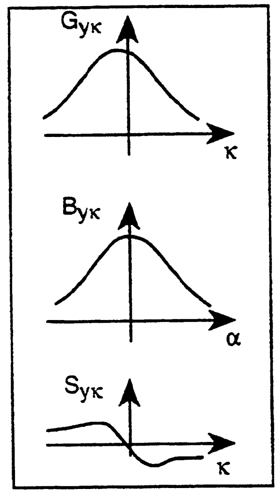
Side force

$$F_y = G_{y\kappa} F_{yo} + S_{Vy\kappa}$$

$$G_{y\kappa} = \frac{\cos[C_{y\kappa} \arctan\{B_{y\kappa}(\kappa + S_{Hy\kappa})\}]}{\cos[C_{y\kappa} \arctan(B_{y\kappa} S_{Hy\kappa})]}$$

$$B_{y\kappa} = r_{By1} \cos[\arctan\{r_{By2}(\alpha - r_{By3})\}]$$

$$S_{Vy\kappa} = \sin[r_{Vy5} \arctan(r_{Vy6}\kappa)]$$

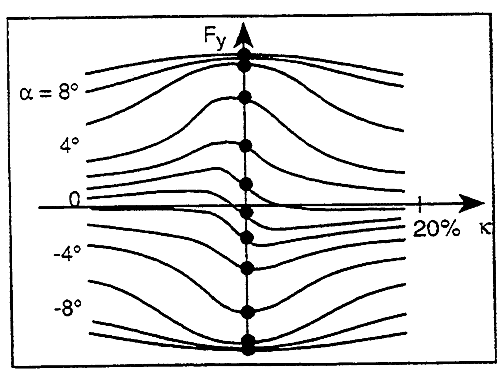


Delft-Tyre

Magic Formula

Combined slip

- F_{yo} is the side force at pure side slip
- $B_{y\kappa}$ influences the sharpness of the hill
- $S_{Vy\kappa}$ is the vertical shift due to 'κ-induced' plysteer.



Delft-Tyre

Magic Formula

Combined slip

Longitudinal force

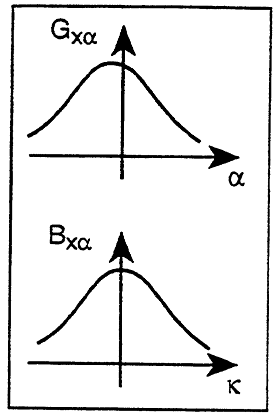
$$F_x = G_{x\alpha} F_{xo}$$

$$G_{x\alpha} = \frac{\cos[C_{x\alpha} \arctan\{B_{x\alpha}(\alpha + S_{Hx\alpha})\}]}{\cos[C_{x\alpha} \arctan(B_{x\alpha} S_{Hx\alpha})]}$$

$$C_{x\alpha} = r_{Cx1}$$

$$B_{x\alpha} = r_{Bx1} \cos[\arctan\{r_{Bx2} \kappa\}]$$

$$S_{Hx\alpha} = r_{Hx1}$$

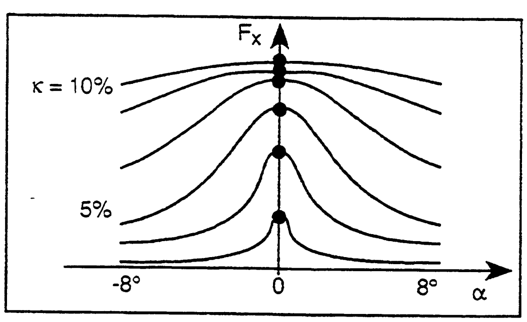


Delft Tyre

Magic Formula

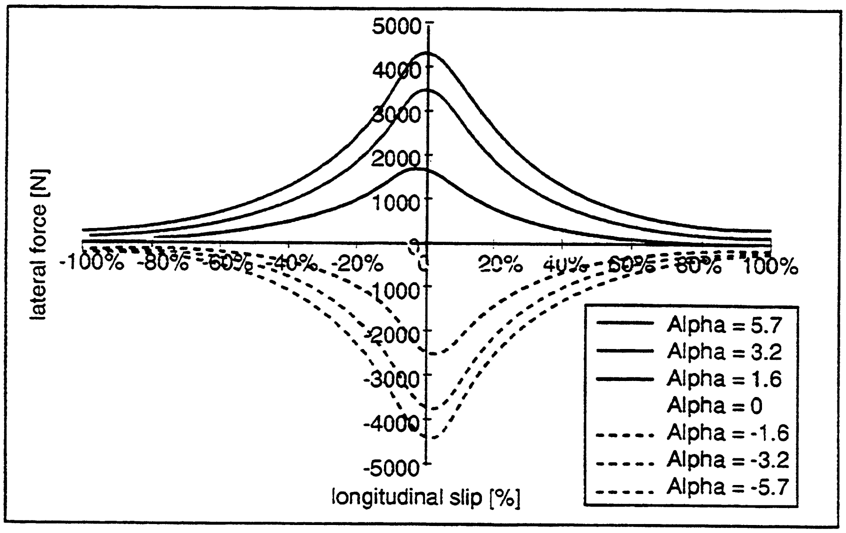
Combined slip

- F_{xo} is the longitudinal force at pure longitudinal slip
- $B_{x\alpha}$ influences the sharpness of the hill
- $C_{x\alpha}$ influences the height of the hill base
- $S_{Hx\alpha}$ is the horizontal shift of the hill peak



Delft Tyre

Magic Formula



Magic Formula

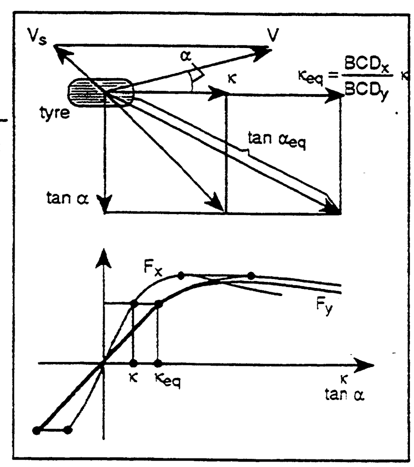
Combined slip

Aligning torque

$$M_z = -t(\alpha_{t,eq})\, F_y + M_{zr}\,(\alpha_{r,eq}) + s(F_y,\gamma)^{*}F_x$$

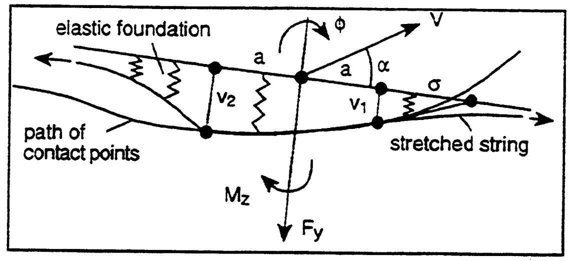
$$\alpha_{t,req} = \text{sign}\,(\alpha_{t,r}).\ \arctan\sqrt{\tan^2(\alpha_{t,r}) + \left(\frac{BCD_x}{BCD_y}\right)^2 \kappa^2}$$

$$s = \{s_{sz1} + s_{sz2}\left(\frac{F_y}{F_{zo}}\right) + (s_{sz3} + s_{sz4}\, df_z)\,\gamma\}\, R_o \lambda_s$$



Transient aspects

$$\frac{1}{V_x}\frac{dv_1}{dt} + \frac{v_1}{\sigma} = \tan(\alpha) - a\phi$$



Multiplication by V_x and σ, neglect turn slip ϕ

$$\sigma\frac{dv_1}{dt} + V_x v_1 = -\sigma V_{sy}$$

NOW POSSIBLE TO START AND STOP!

deflection angle α' $\tan(\alpha') = \frac{v_1}{\sigma}$

Delft-Tyre

Dynamic Combined Slip

- **slip speeds $V_{sx,y}$ input instead of κ and α**
- **longitudinal and lateral deformations u and v**
- **relaxation lengths σ_κ and σ_α**
- **speed of rolling V_r**

$$\sigma_\kappa\frac{du}{dt} + |V_r|\,u = -\sigma_\kappa\,V_{sx} \qquad \sigma_\alpha\frac{dv}{dt} + |V_r|\,v = -\sigma_\alpha\,V_{sy}$$

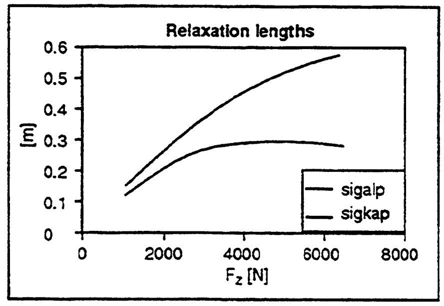
Delft-Tyre

Dynamic Combined Slip

Relaxation lengths depend on vertical load and camber:

$$\sigma_\kappa = F_z\,(p_{Tx1} + p_{Tx2}\,df_z)\,\exp\,(-p_{Tx3}\,df_z)\,(R_0/F_{z0})\lambda_{\sigma\kappa}$$

$$\sigma_\alpha = p_{Ty1}\,\sin\,[2\,\arctan\,\{\frac{F_z}{p_{Ty2}F_{z0}\lambda_{Fz0}}\}]\,(1 - p_{Ky3}|\gamma|)R_0\lambda_{Fz0}\lambda_{\sigma\alpha}$$



Delft-Tyre

Dynamic Combined Slip

Theoretical tyre deformation slip components:

$$\zeta'_x = \frac{u}{\sigma_\kappa} \quad , \qquad \zeta'_y = \frac{v}{\sigma_\alpha}$$

and the practical tyre deformation slip quantities:

$$\kappa' = \frac{\zeta'_x}{\text{sign}\ V_r - \zeta'_x} \quad , \qquad \tan(\alpha') = \frac{\zeta'_y}{\text{sign}\ V_r - \zeta'_x}$$

Forces and moment (steady state formulae)

$$F_x = F_x(\alpha', \kappa', F_z)$$

$$F_y = F_y(\alpha', \kappa', \gamma, F_z)$$

$$M'_z = M'_z(\alpha', \kappa', \gamma, F_z)$$

Delft-Tyre

Gyroscopic Couple

Moment due to tyre inertia acting about the z-axis

$$M_{z,gyr} = C_{gyr} m_t V_r \frac{dv}{dt}$$

Total aligning torque

$$M_z = M_z' + M_{z,gyr}$$

Delft-Tyre

Scaling factors

Pure slip

λ_{Fzo}	nominal load
$\lambda_{\mu x}$, $\lambda_{\mu y}$	peak friction levels F_x,F_y
λ_{Kx}, λ_{Ky}	slip stiffness
$\lambda_{\gamma y}$	camber force stiffness
$\lambda_{\gamma z}$	camber torque stiffness
λ_t	pneumatic trail
λ_{Mr}	residual torque

Delft-Tyre

Scaling factors

Combined slip

$\lambda_{x\alpha}$	**α influence on F_x (κ)**
$\lambda_{y\kappa}$	**κ influence on $F_y(\alpha)$**
$\lambda_{Vy\kappa}$	**κ induced F_y**
λ_s	**M_z moment arm of F_x**

Transient response

$\lambda_{\sigma\kappa}$	**relaxation length for F_x**
$\lambda_{\sigma\alpha}$	**relaxation length for F_y**
λ_{gyr}	**tyre mass (gyroscopic couple)**

Delft-Tyre

TYDEX Workshops

International group of vehicle and tyre manufacturers with the objective to standardize interfaces between

vehicle models - tyre models - tyre data

- **Standard Tyre Interface (STI)**
  Interface between vehicle model and any tyre model to enable simple exchange of tyre models
- **TYDEX data format**
  Format for simple exchange of tyre test data and parameters of tyre models
- **International Colloquia on Tyre Modelling**

Delft-Tyre

MF-Datasets
Library

Contents (Jan. 1996)

tyre	manufacturer	type	conditions
175/70 R13	Michelin	MXT	dry
195/65 R15	Michelin	MXV3a Energy	dry
195/65 R15	Michelin	Pilot HX MXV3a	dry, wet
195/65 R15	Vredestein	Snowtrac	dry
225/50 R16	Goodyear	Eagle GST	dry, wet
235/75 R15	Goodyear	Invicta GS	dry, wet

Delft-Tyre

MF-Datasets

Tyre datasets

Steady state:
- Pure and combined slip
- Effective tyre radius
- Vertical tyre stiffness

Dynamic:
- Tire lags depending on load

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