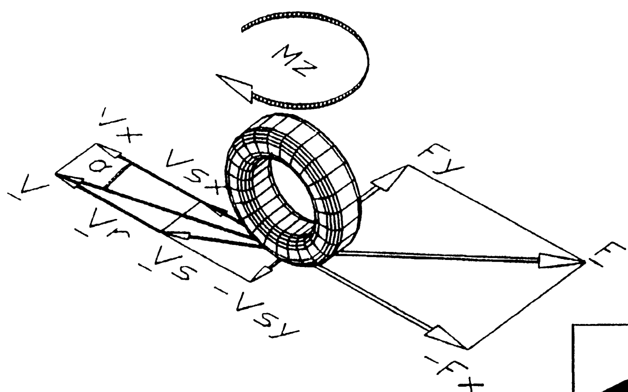
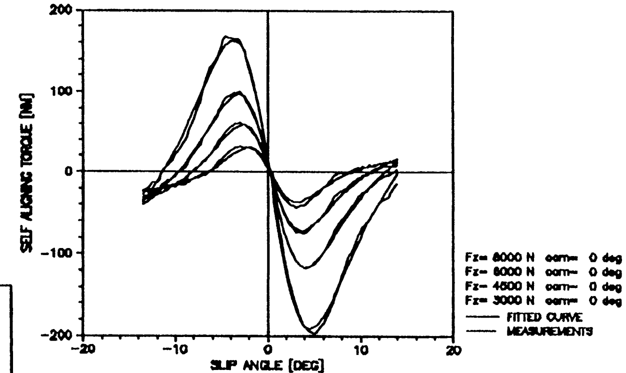
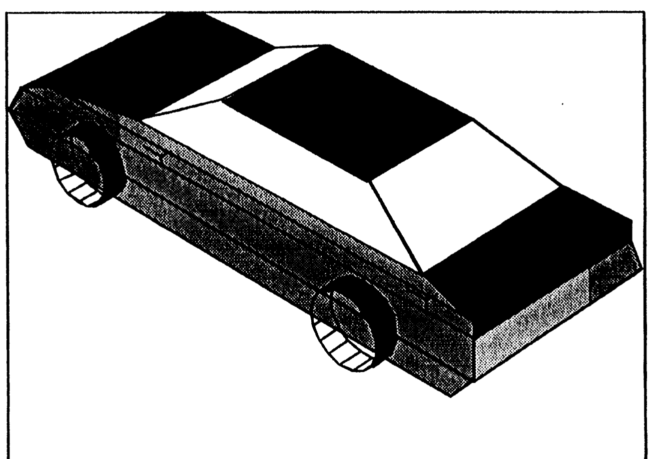
Delft-Tyre

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







Simulation model

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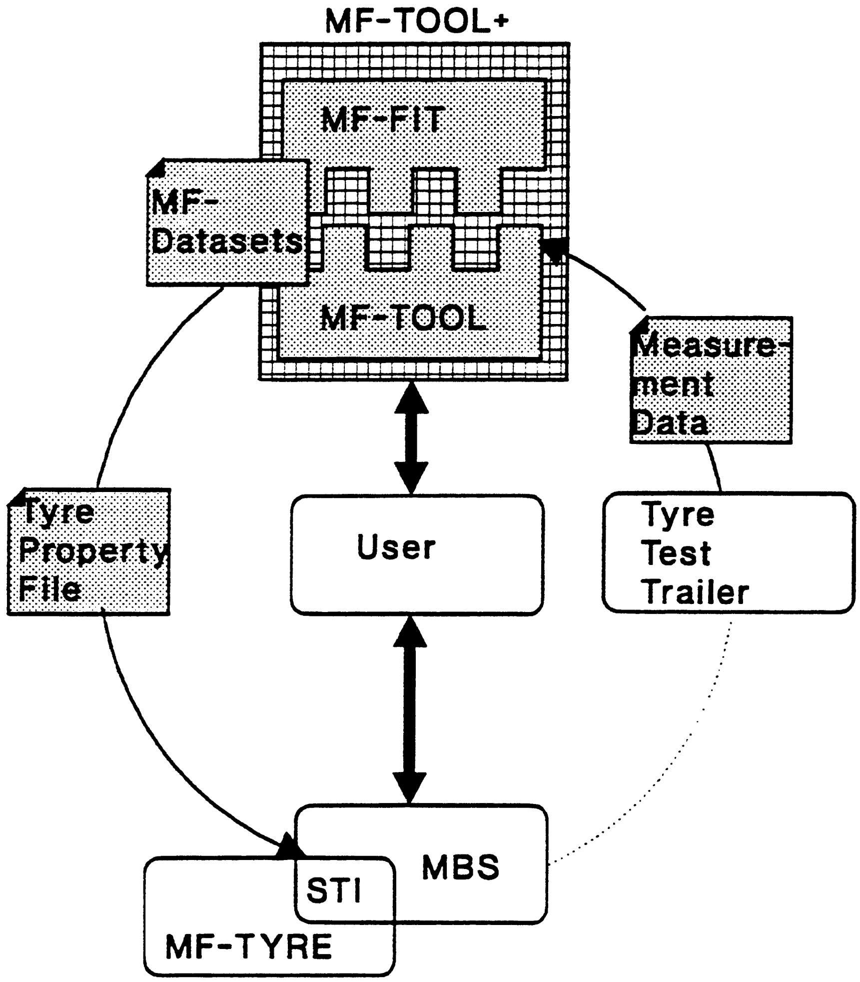
Delft-Tyre

Product Range



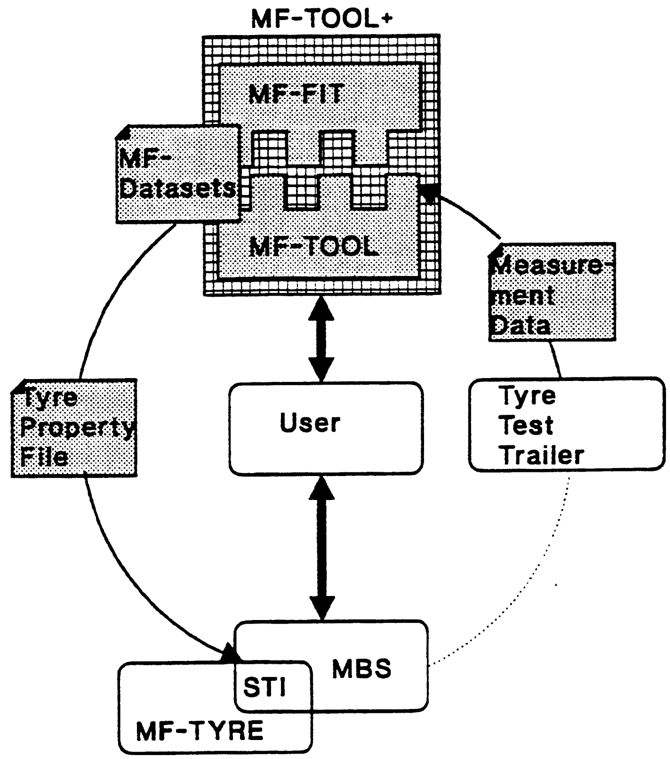
Objectives

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

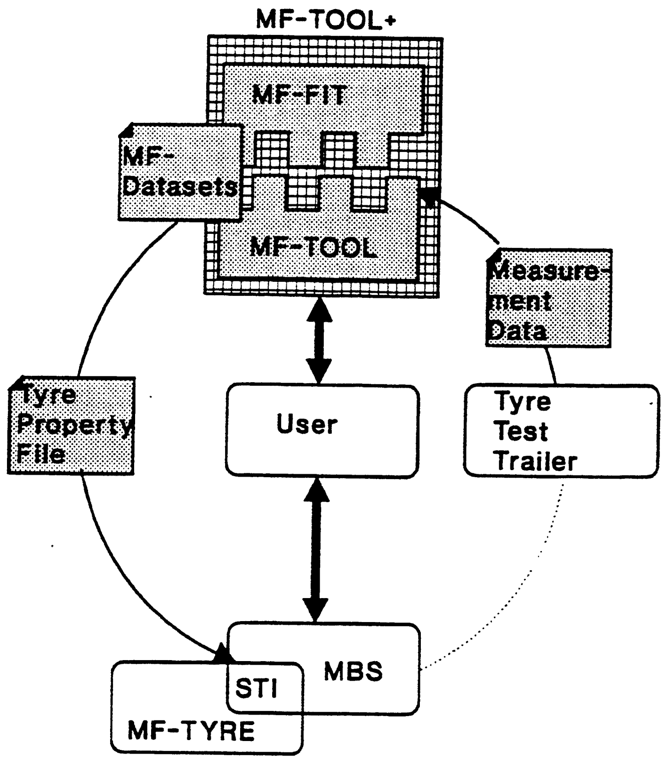
Delft Tyre

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

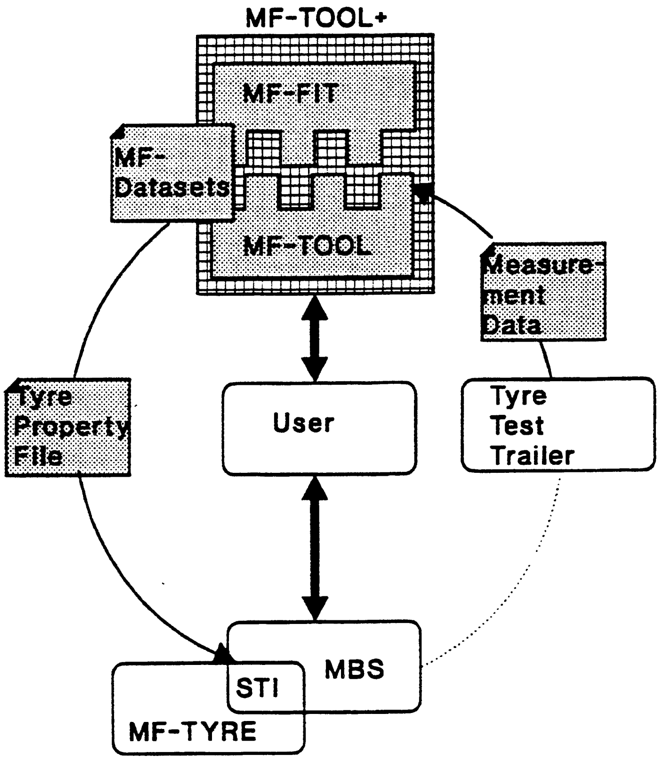
MF-Tool

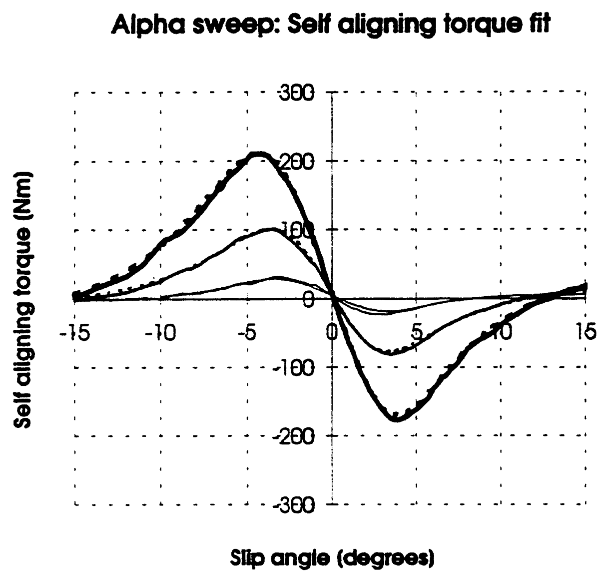


- Visualisation of tyre characteristics and tyre physical properties
- Adaption and manipulation of tyre characteristics using a graphical interface (user-defined tyre datasets)
- Tyre dataset database
- Preparation of tyre datasets for simulation

Delft-Tyre

MF-Tool+





MF-Tool including MF-Fit

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

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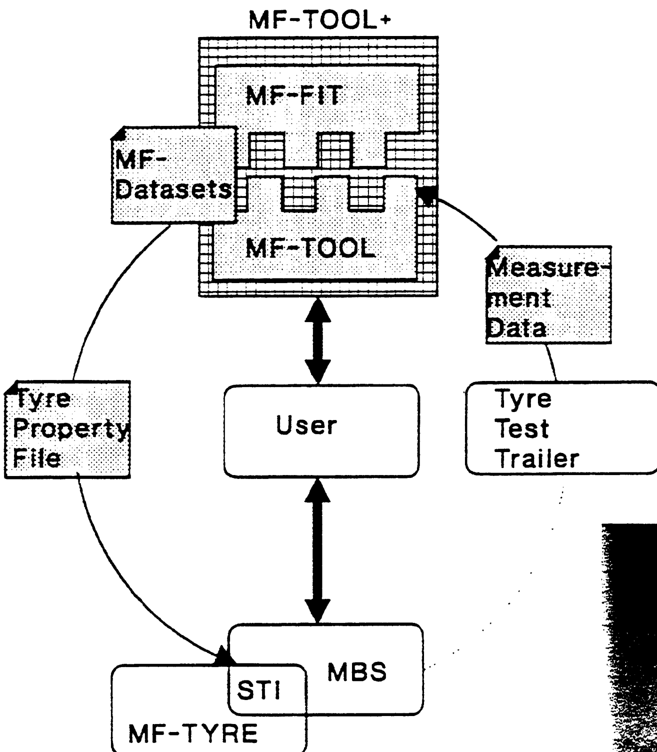
MF-Datasets



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

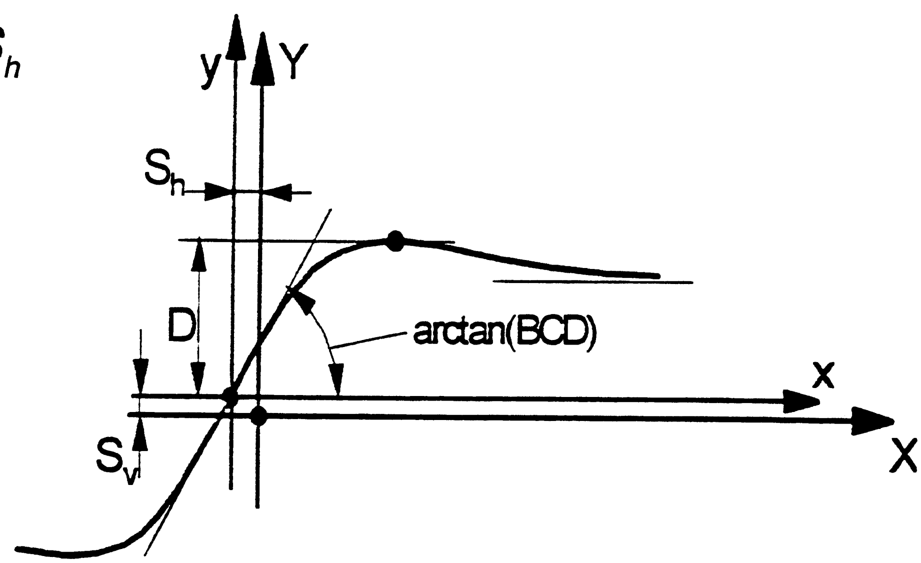
MF-Tyre

- Steady state:
  MAGIC FORMULA TYRE MODEL

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

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

$$x = X + S_h$$



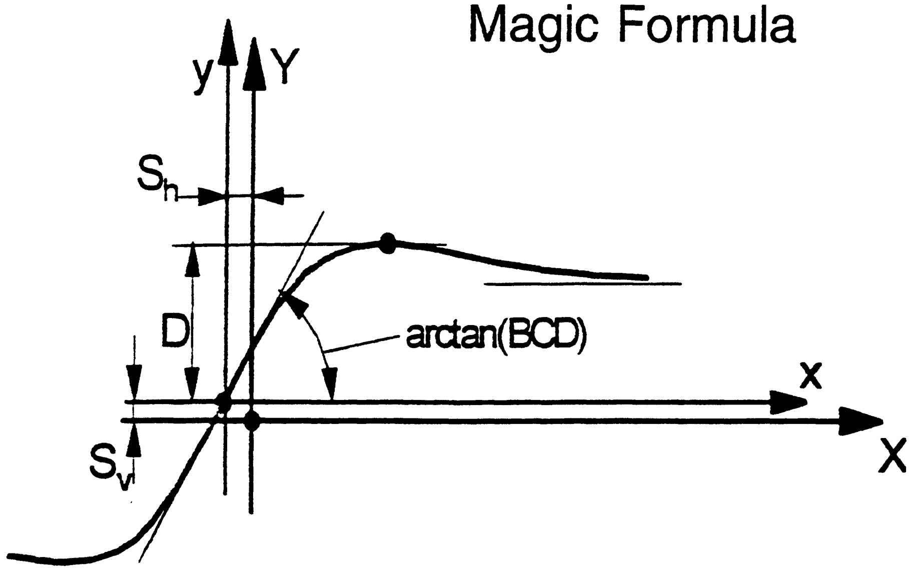
- Transient and oscillatory aspects:
  FIRST ORDER LAGS and
  GYROSCOPIC COUPLE

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*

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

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Magic Formula
Pure slip

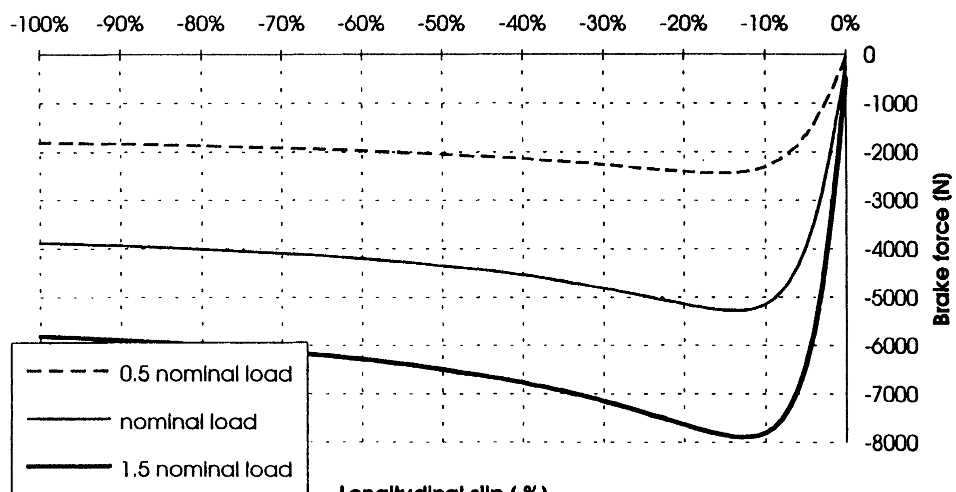
Longitudinal force

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

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

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

etc.



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Magic Formula
Pure slip

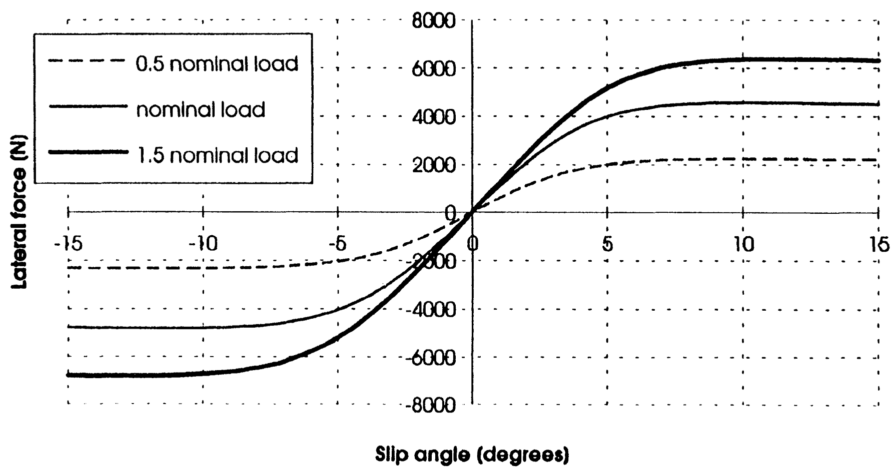
Lateral force

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

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

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

etc.



Magic Formula
Pure slip

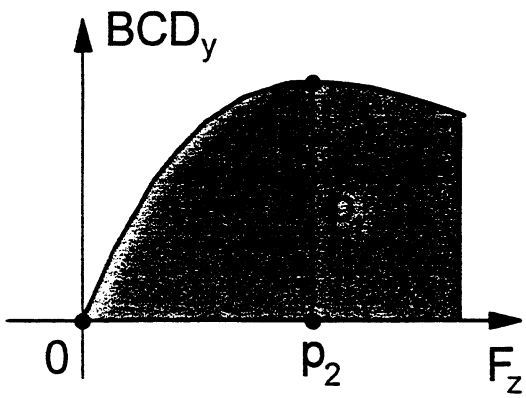
ASYMMETRY

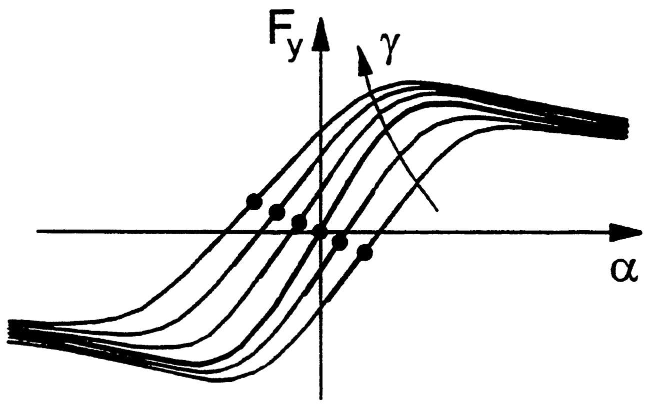
Curvature factor E

$$E = E_0 + \Delta E \operatorname{sign}(x)$$

Cornering stiffness

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





Magic Formula
Pure slip

Aligning Torque

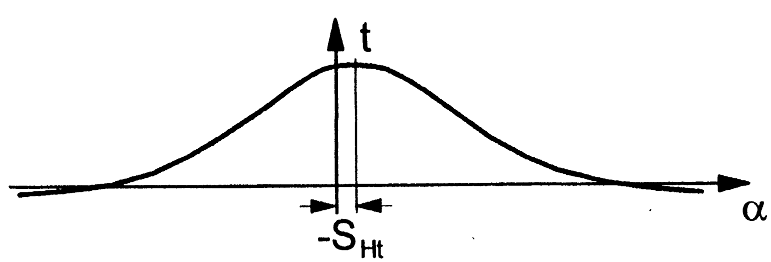
$$M_{zo} = -t\ F_{yo} + M_{zr}$$

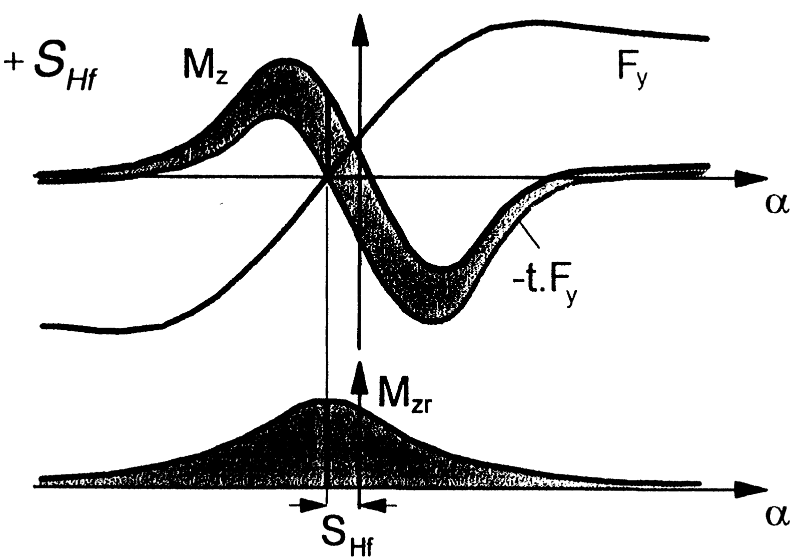
pneumatic trail

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

residual torque

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





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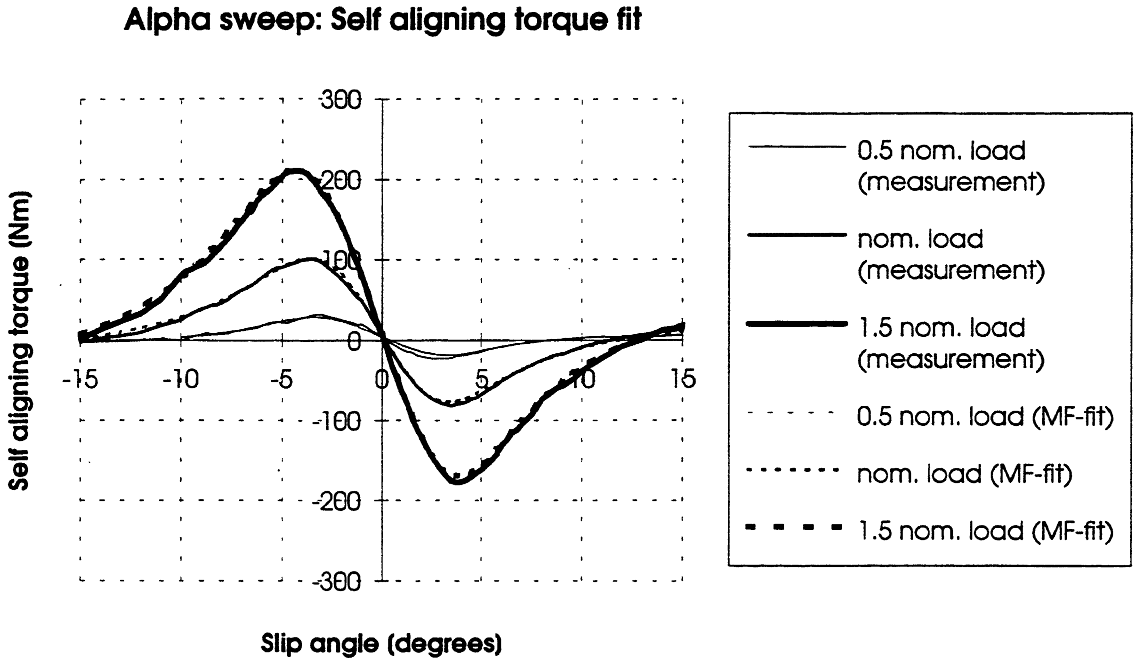
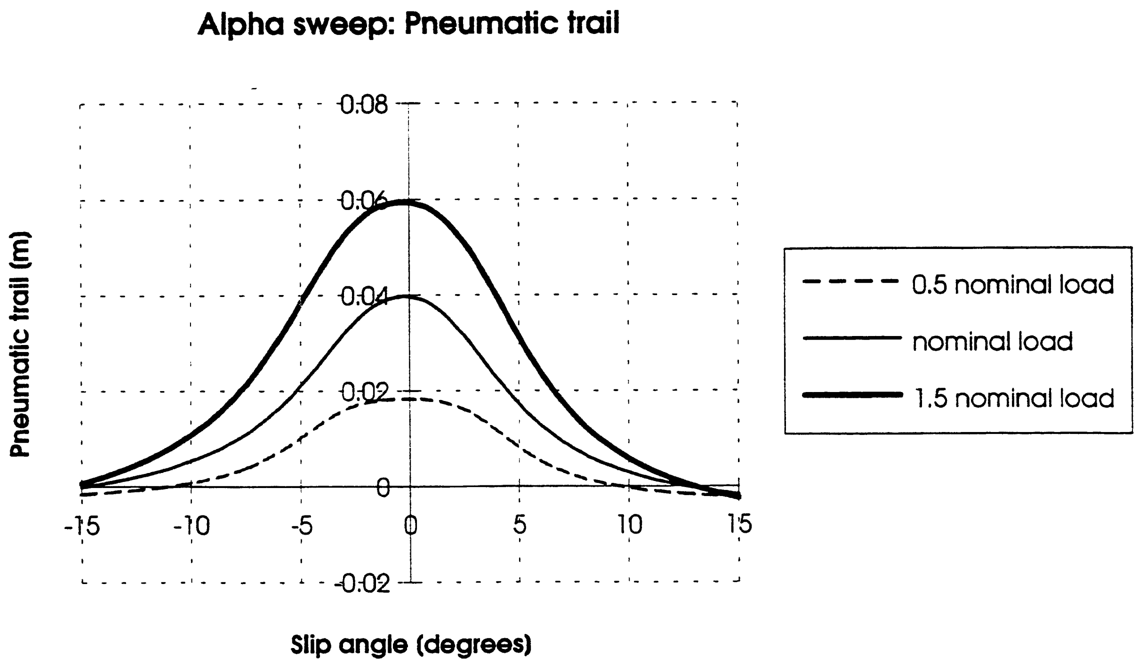
Magic Formula
Aligning Torque





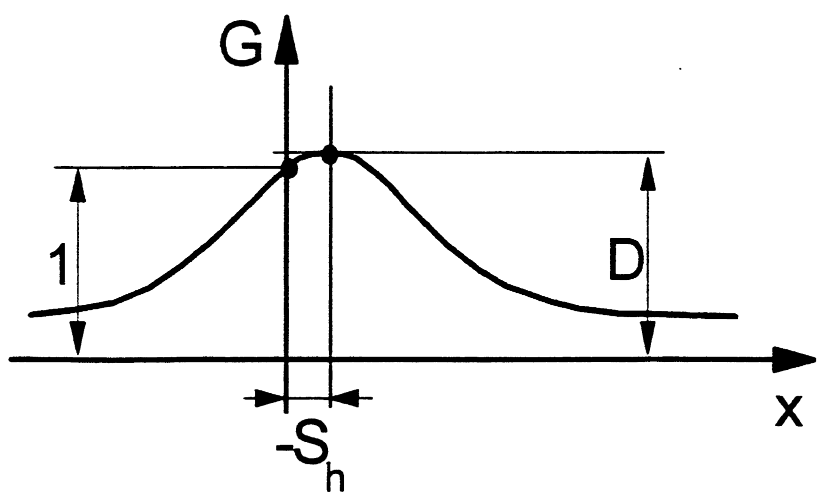
Delft-Tyre

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

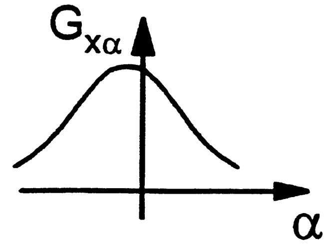


Delft-Tyre

Magic Formula
Combined slip

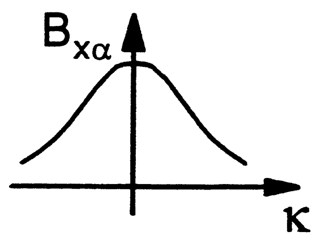
Longitudinal force

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



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

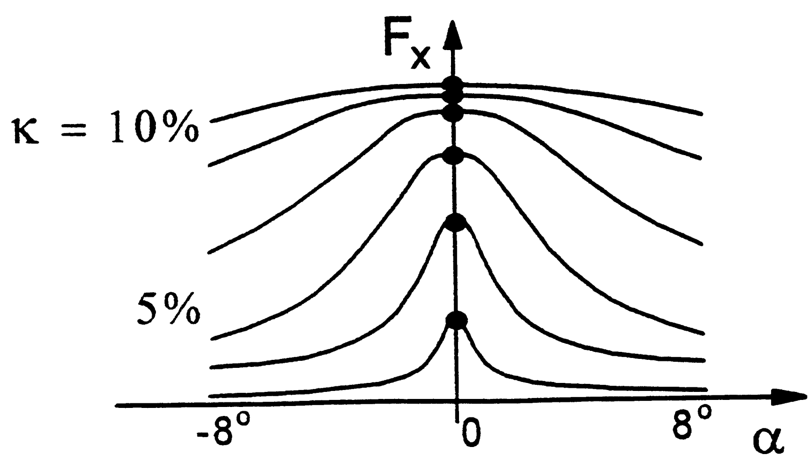
$$C_{x\alpha} = r_{Cx1}$$



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

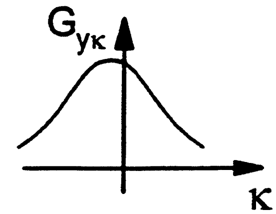
$$S_{Hx\alpha} = r_{Hx1}$$

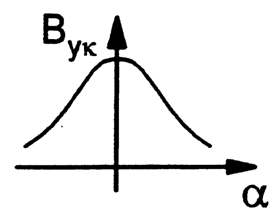
- F_{xo} is the longitudinal force at pure longitudinal slip
- $B_{x\alpha}$ influences the sharpness of the hill
- $C_{x\alpha}$ influences the height of the hill base
- $S_{Hx\alpha}$ is the horizontal shift of the hill peak

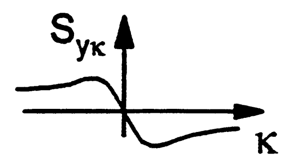


Delft-Tyre

Magic Formula
Combined slip







Side force

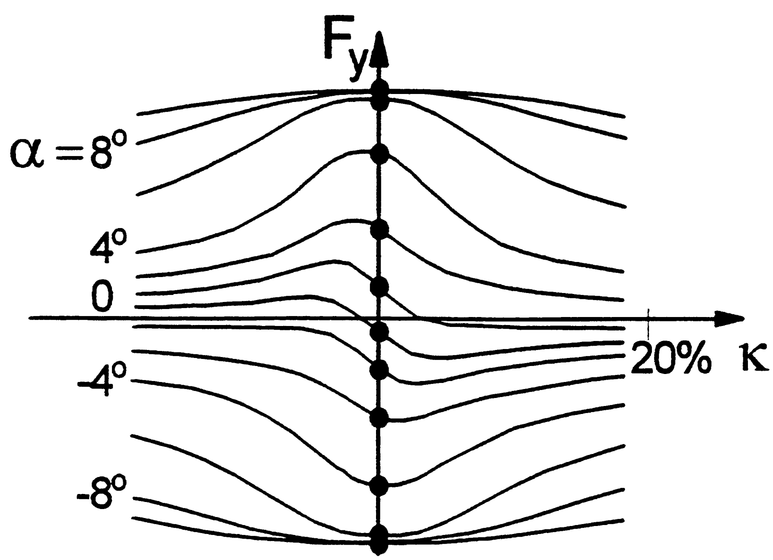
$$F_y = G_{y\kappa} F_{yo} + S_{Vy\kappa}$$

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

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

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

- 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' ply-steer



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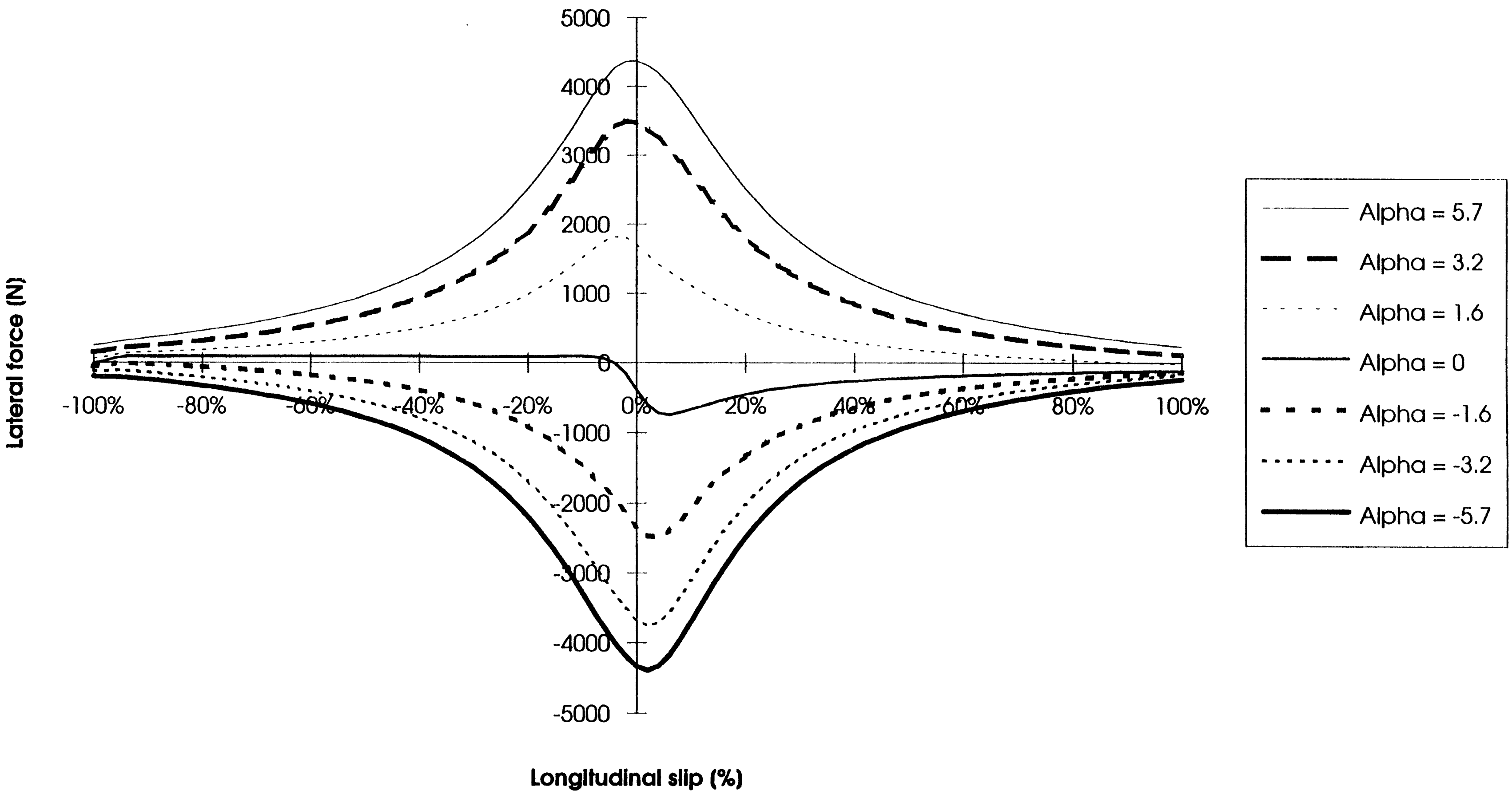
Magic Formula
Combined slip



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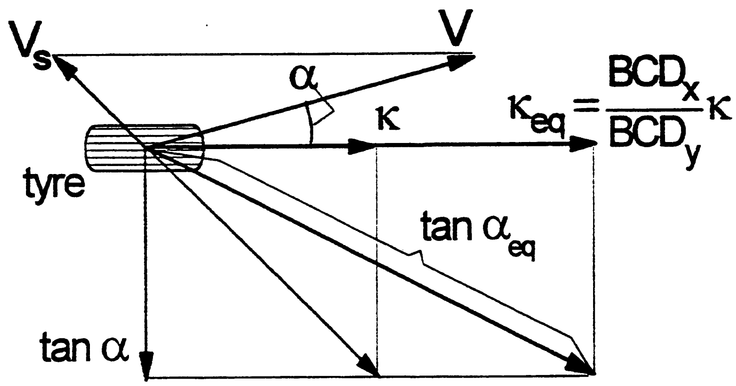
Magic Formula
Combined slip

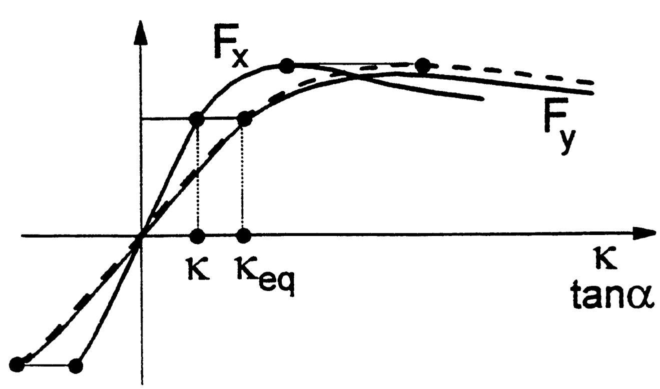
Aligning torque

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

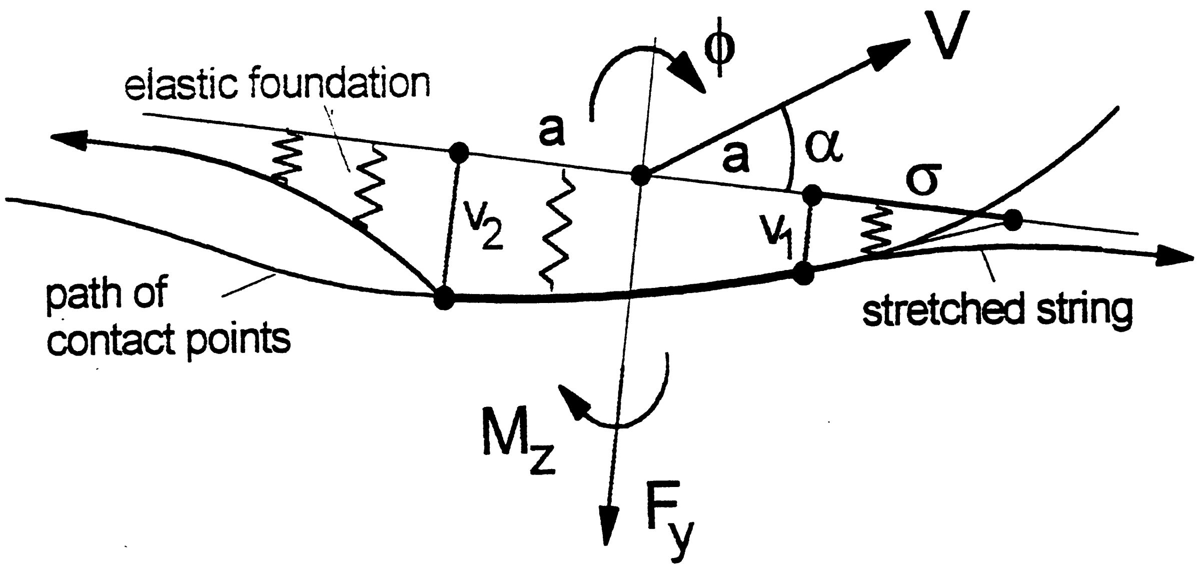
$$\alpha_{t,req} = \arctan\sqrt{\tan^2(\alpha_{t,r}) + \left(\frac{BCD_x}{BCD_y}\right)^2 \kappa^2}\ \ \mathrm{sign}(\alpha_{t,r})$$

$$s = \{s_{sz1} + s_{sz2}\left(\frac{F_y}{F_{zo}}\right) + (s_{sz3} + s_{sz4}\,df_z)\gamma\}\,R_0\lambda_s$$





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

$$\sigma_\kappa \frac{du}{dt} + |V_r|\, u = -\sigma_\kappa V_{sx}$$

$$\sigma_\alpha \frac{dv}{dt} + |V_r|\, v = -\sigma_\alpha V_{sy}$$

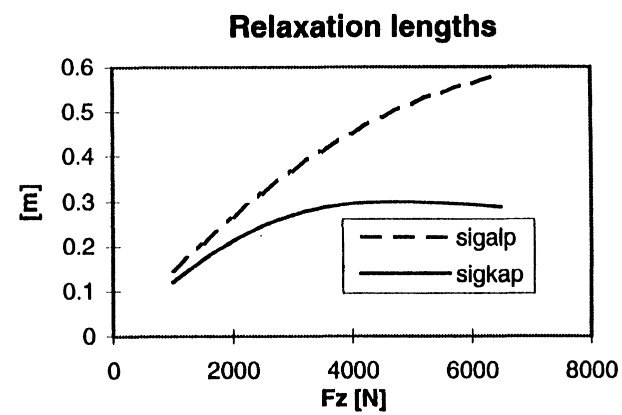
Delft-Tyre

Dynamic Combined Slip

Relaxation lengths depend on vertical load and camber:

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

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



Dynamic Combined Slip

Theoretical tyre deformation slip components:

$$\zeta_x' = \frac{u}{\sigma_\kappa}, \qquad \zeta_y' = \frac{v}{\sigma_\alpha}$$

and the practical tyre deformation slip quantities:

$$\kappa' = \frac{\zeta_x'}{\operatorname{sign} V_r - \zeta_x'}, \qquad \tan(\alpha') = \frac{\zeta_y'}{\operatorname{sign} V_r - \zeta_x'}$$

Forces and moment (steady state formulae)

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

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

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

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

$$M_z = M_z^{/} + M_{z,gyr}$$

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

Scaling factors

- Combined slip

$\lambda_{x\alpha}$	α influence on $F_x(\kappa)$
$\lambda_{y\kappa}$	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)

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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

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

companies involved:

Mercedes Benz	TNO	Porsche
Peugeot SA	TUD	Bosch
Volvo	Nedcar	Daimler-Benz
Goodyear	IPG	TU Berlin
Continental	BMW	DRA
Michelin	FIAT	Steyer-Daimler-Puch
Toyota	Uni Karlsruhe	