Continental
The Future in Motion

Continental Formula Student Tire

Competition Tire 2017 (C17) – C16 Documentation UPDATE

Introduction

Dear Formula Student Teams,

with this document we would like to inform you on changes for our 2017 Formula Student Tires, namely “C17”.

We wish you maximum success with the tires and are looking forward to your feedback in order to further improve the tires!

Sincerely,

Your Formula Student Tire Development Team.

Contents

1. General Information
Change overview C17

Continental C17 Slick:

- no significant change to C16

Continental C17 Wet:

- softer compound for wet tire to improve performance especially for cold and slippery conditions

Tire documentation and tire models for C17

- The **tire documentation** as well as the **tire model** of the **C16 slick** tire are **still valid** for the C17 slick tire
- Therefore, the content of this document is equal to last year and still refers to the C16 tire

1. General Information
Dimensions & Weight

	Continental C16 Slick	Continental C16 Wet
› Tire Dimension:	205 / 470 R13	<
› Outside Diameter[1]:	470,2 mm	<
› Overall Tire Width[1]:	200 mm	<
› Tire Weight:	3.75 kg	3.80 kg
› Recommended Rim:	7J x 13	<

All test results shown in this report were obtained using a 7J x 13 test rim.

The slick and the wet tire are based on the same tire design, except for the tread compound and the tread pattern.

[1] with 80 kPa inflation pressure

2. Test Procedure Force & Moment

For the C16 slick tire, the following force & moment (F&M) tests were conducted on our “Flat Trac 3” test machine:

Test Sequence	Purpose
1. Break-In*	condition tire and clean tread surface from mold release agents
2. Vertical Stiffness	obtain vertical stiffness of rolling tire for different inclination angles
3. Cold-to-Hot	observe the tire’s pure lateral slip F&M characteristic during warm-up; warm-up the tire for the Cornering procedure
4. Cornering	obtain pure lateral slip F&M data of the tire for different loads and inclination angles at operating temperature
5. Relaxation Length*	obtain dynamic tire behavior

The tests were specially designed to operate the tire under similar conditions compared to the real dynamic events

On the following pages, the results of these tests will be presented*

* Not further considered in this report

3. Vertical Stiffness

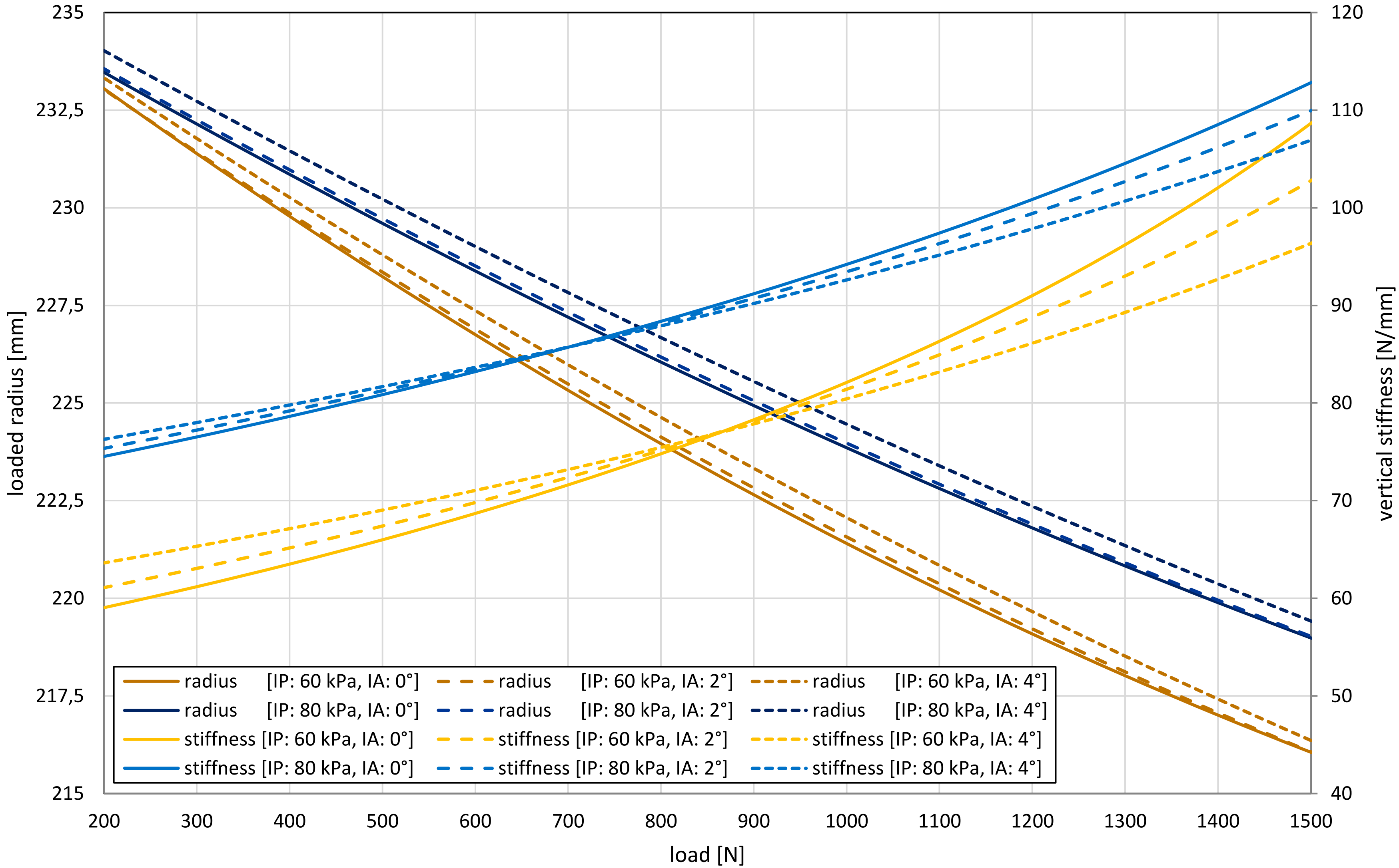
The vertical stiffness measurement was carried out with the following settings:

Parameter	Abbreviation	Values
Load	Fz	500 N to 1600 N variable / sweeps
Inclination Angle	IA	0 °, 2 °, 4 ° const. / steps
Slip Angle	SA	0 ° const.
Speed	v	40 km/h const. (free rolling)
Inflation pressure	IP	60 kPa, 80 kPa const. / steps

The vertical stiffness of the rolling tire is obtained by deriving a 3rd order polynomial function that was fitted to the raw data of the loaded radius as a function of the vertical load

The results are presented on the next page:

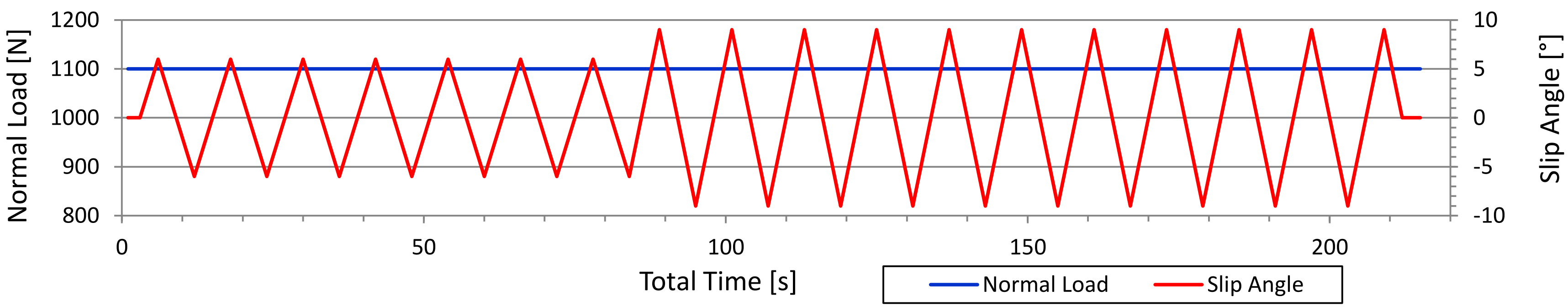
3. Vertical Stiffness loaded radius and vertical stiffness



4. Cold-to-Hot

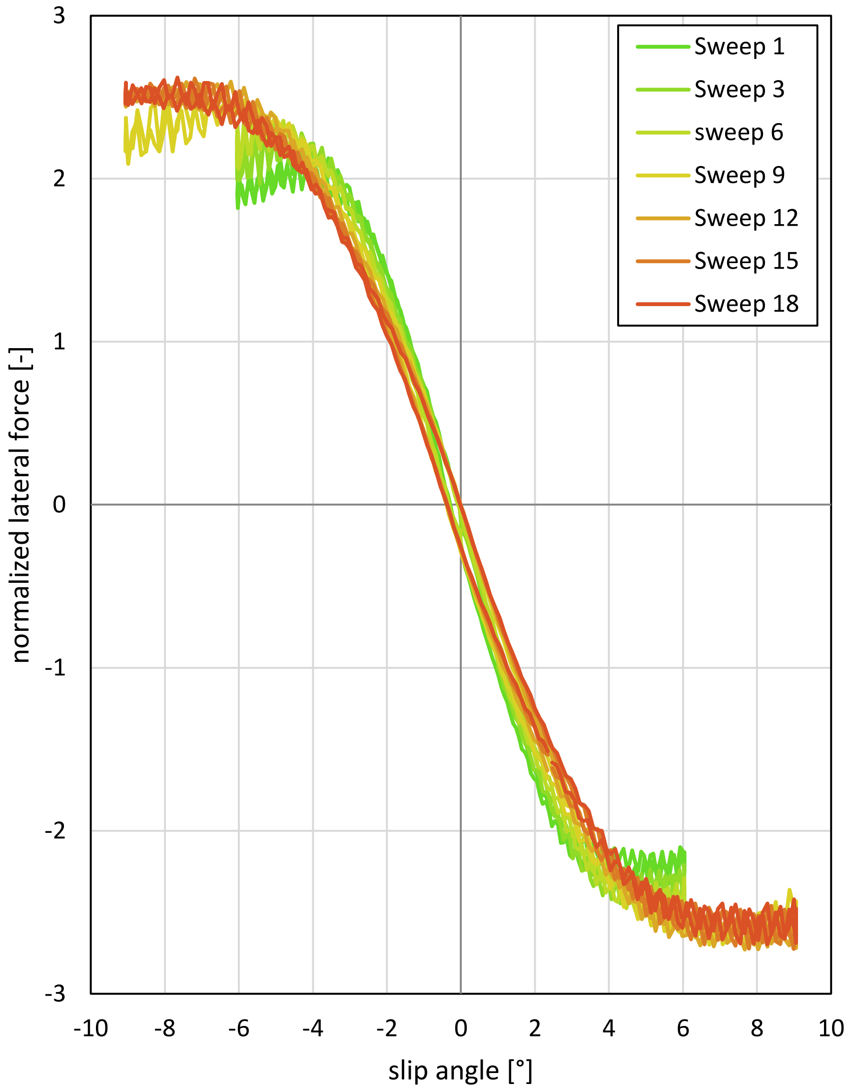
The following table and graph describe the Cold-to-Hot test:

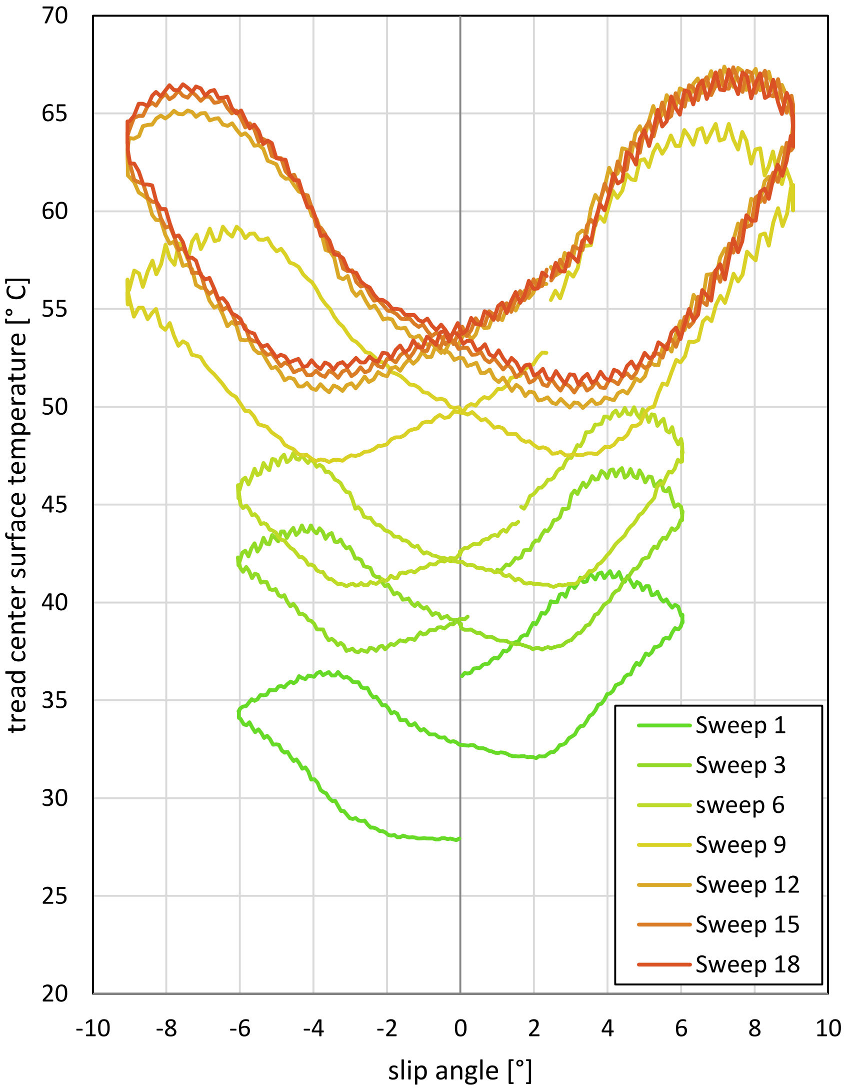
Parameter	Abbreviation	Values
Load	Fz	1100 N const.
Inclination Angle	IA	0 ° const.
Slip Angle	SA	+6° to -6° (7x), +9° to -9° (11x) variable / sweeps
Speed	v	40 km/h const. (free rolling)
Inflation pressure	IP	80 kPa const.



On the next page, measured test data for tread surface temperature and load normalized lateral force vs. slip angle are shown for selected sweeps throughout the cold-to-hot test

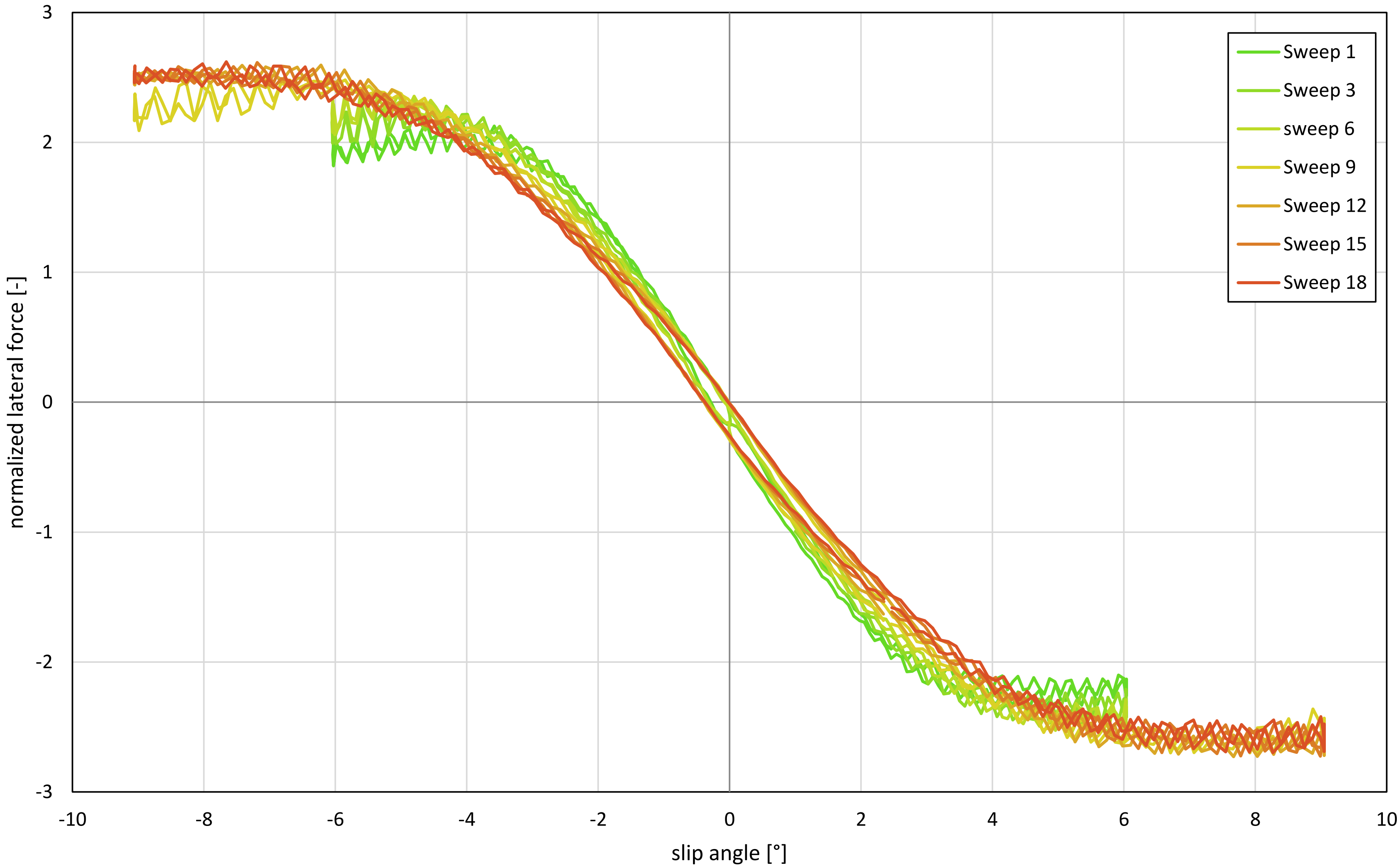
4. Cold-to-Hot Overview: lat. force and tread temperature



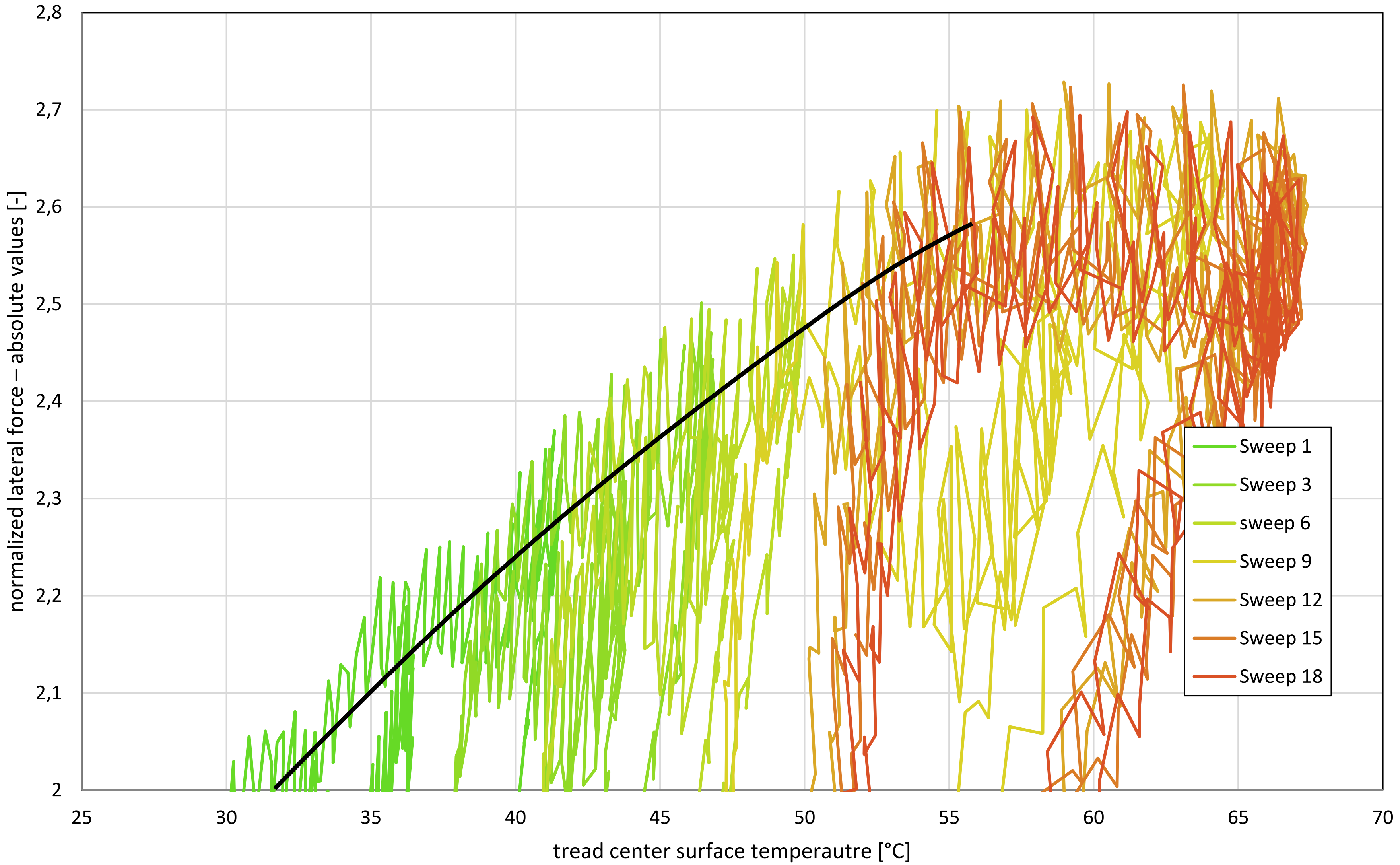


4. Cold-to-Hot

lateral force vs. slip angle



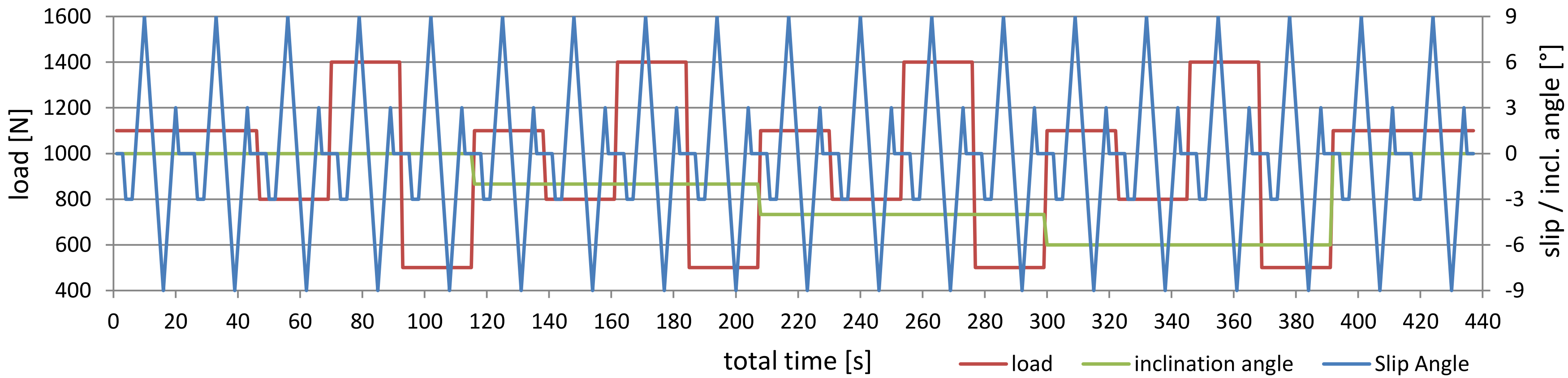
4. Cold-to-Hot lateral force temperature sensitivity



5. Cornering

In the following table and graph the cornering sequence is described:

Parameter	Abbreviation	Values
Load	Fz	500 N, 800 N, 1100 N, 1400 N const. / steps
Inclination Angle	IA	0 °, -2 °, -4 °, -6 ° const. / steps
Slip Angle	SA	+ 9 ° to - 9 ° variable / sweeps
Speed	v	40 km/h const. (free rolling)
Inflation Pressure	IP	80 kPa const.



5.1 Cornering – Tire Model Fitting

A Pacejka Magic Formula 5.2 tire model has been fitted to the raw data from the cornering sequence in order to:

- get representations of the raw data without noise & hysteresis effects from the measurement
- be able to reasonably interpolate/extrapolate between/beyond the measured test conditions
- obtain further representations like derivatives (e.g. cornering stiffness) or normalized values, extreme values etc. (e.g. coefficient of friction)
- have a mathematical representation of the tire F&M characteristics to be used for vehicle dynamics simulations etc.

5.1 Cornering – Tire Model Fitting

The Magic Formula 5.2 tire model coefficients that were identified by the fitting of the raw data are stored in a *.tir file. This file can be used by vehicle dynamic simulation software. It is also possible to extract the coefficients manually or by a custom made software routine.

The formulas in the Magic Formula 5.2 are documented in Section 7 at the end of the report and can be used in any other analysis tool

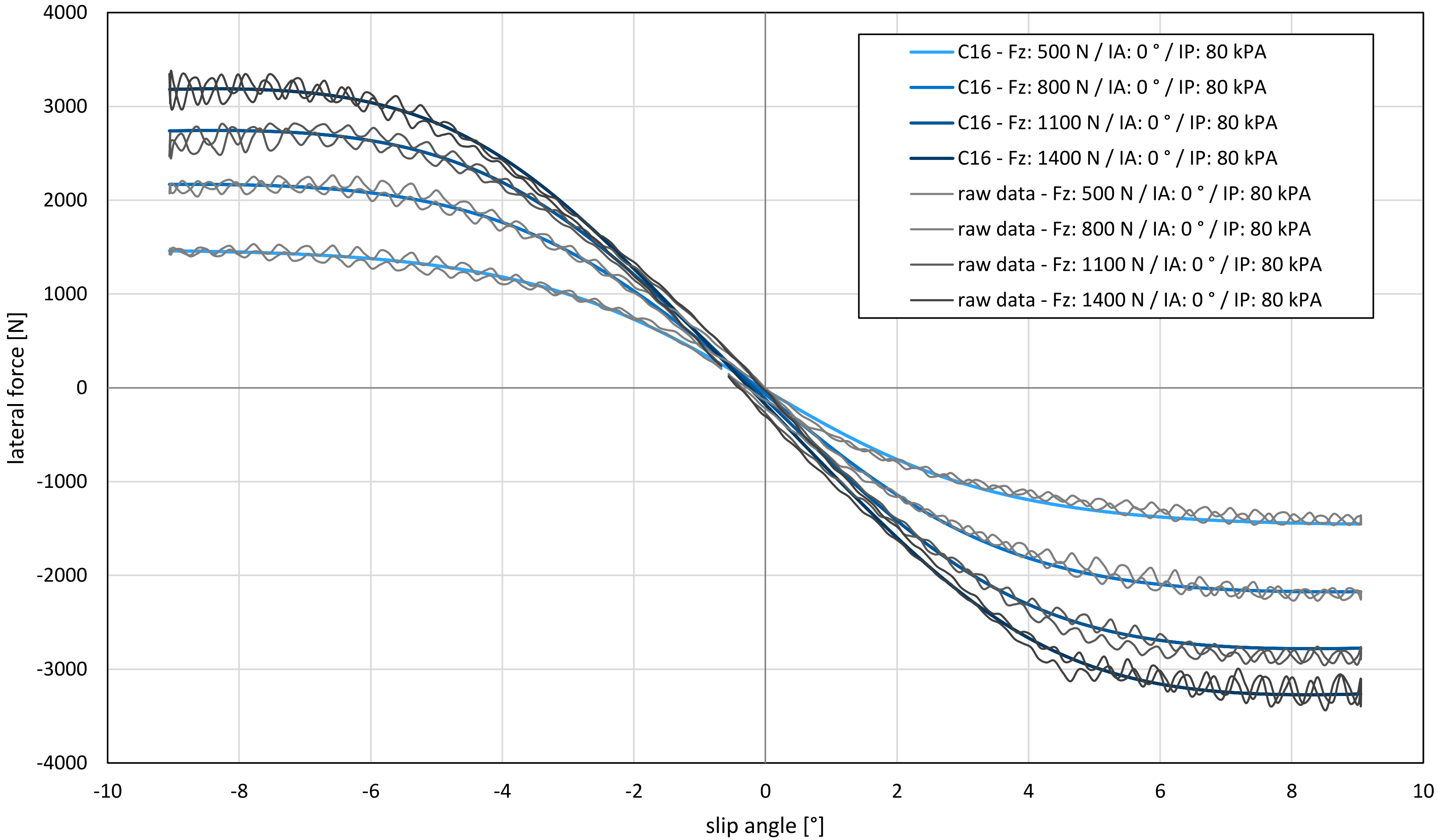
- The MF 5.2 coefficients for the C16 slick tire is available in the following file:
  - C16_CONTINENTAL_FORMULASTUDENT_205_470_R13_80kPa.tir

5.2 Cornering – Comparison of Fit & Raw Data

On the next pages, some comparisons between the raw data and the MF5.2 tire model output are plotted to give an impression on the quality of the model fit.

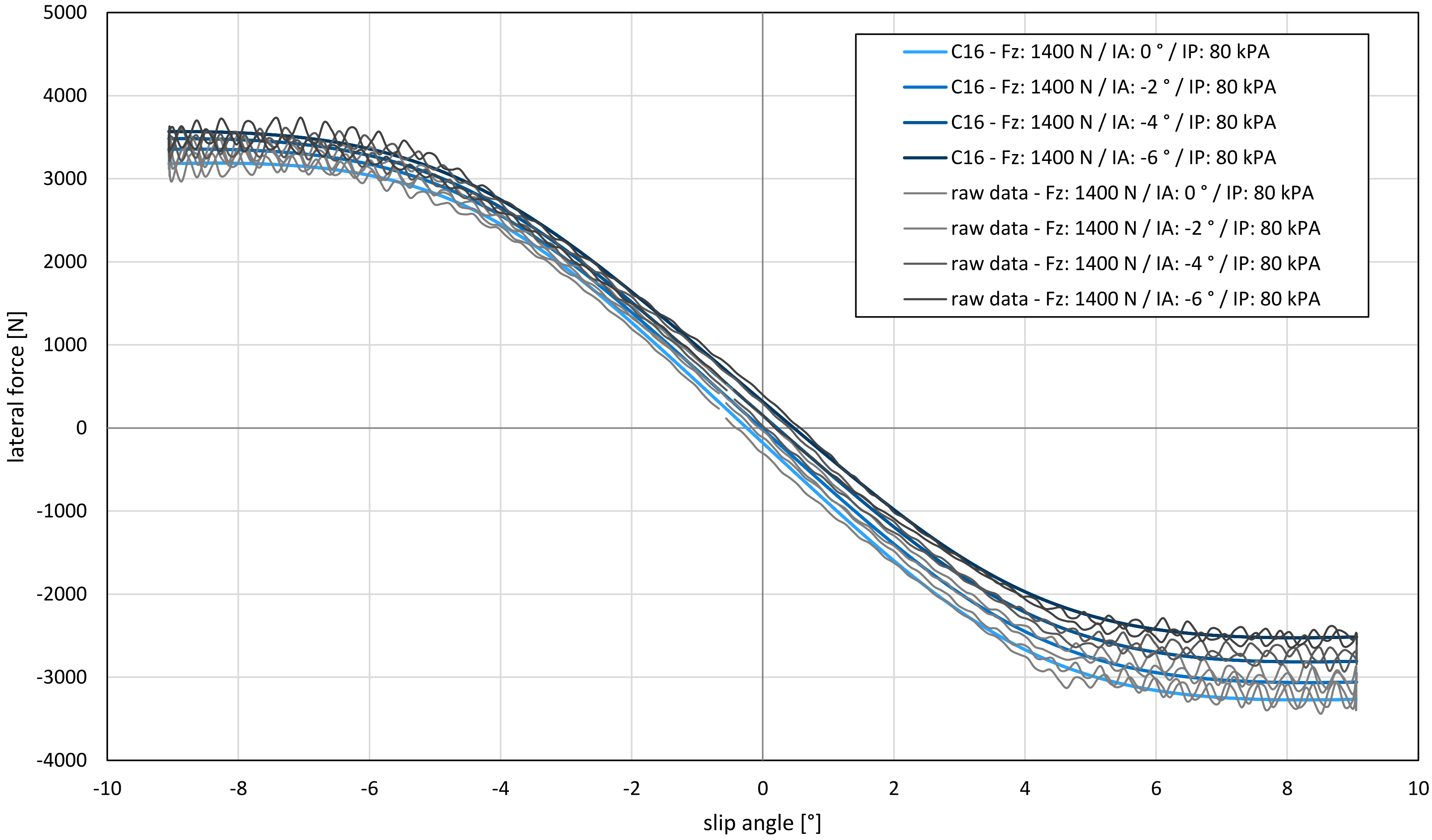
5.2 Cornering – Comparison of Fit & Raw Data

lateral force load dependency



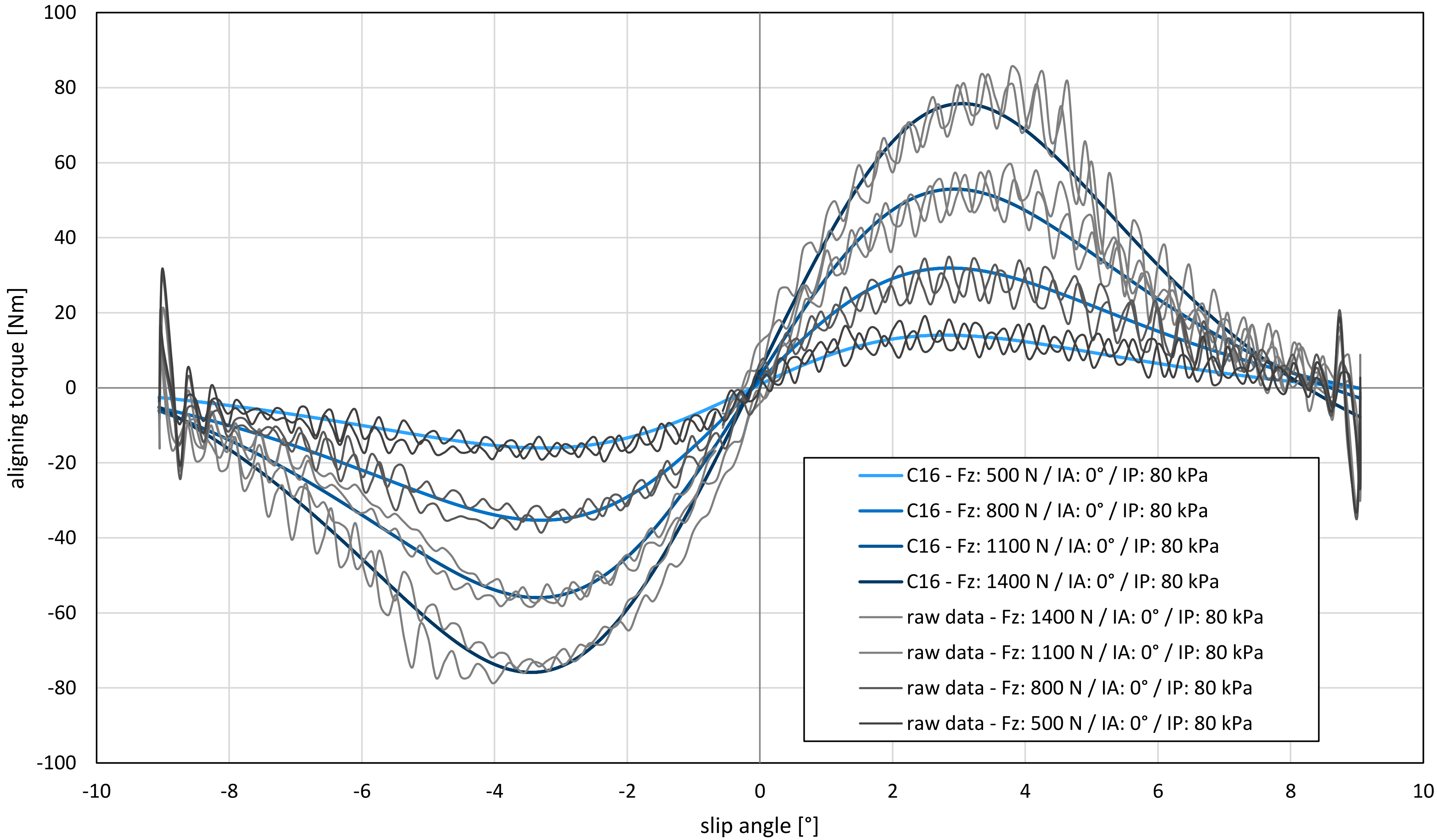
5.2 Cornering – Comparison of Fit & Raw Data

lateral force camber dependency



5.2 Cornering – Comparison of Fit & Raw Data

aligning torque load dependency



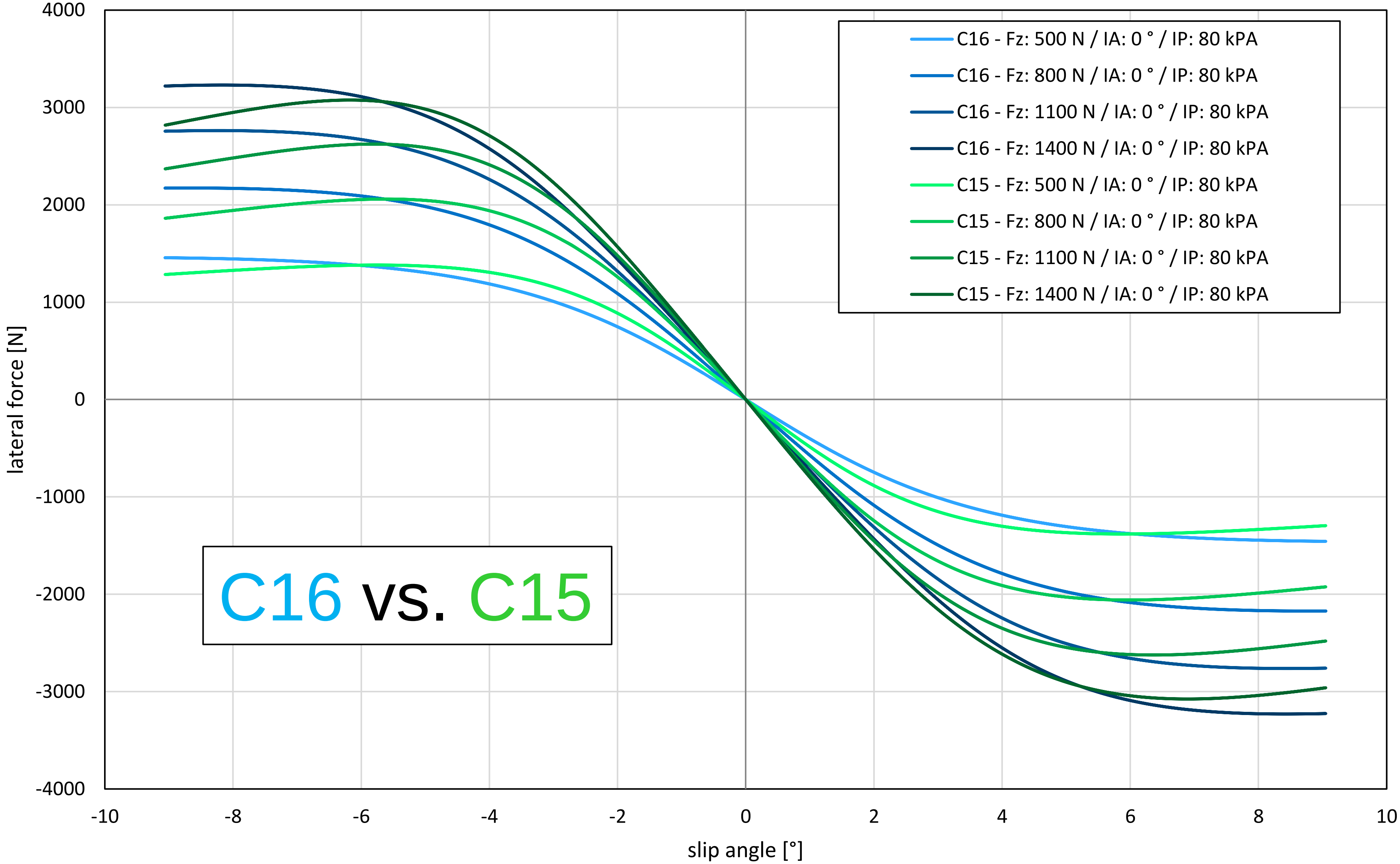
5.3 Cornering – Results

On the next pages, the fitted tire model will be used to plot certain tire characteristics.

A comparison to the predecessor C15 is also shown.

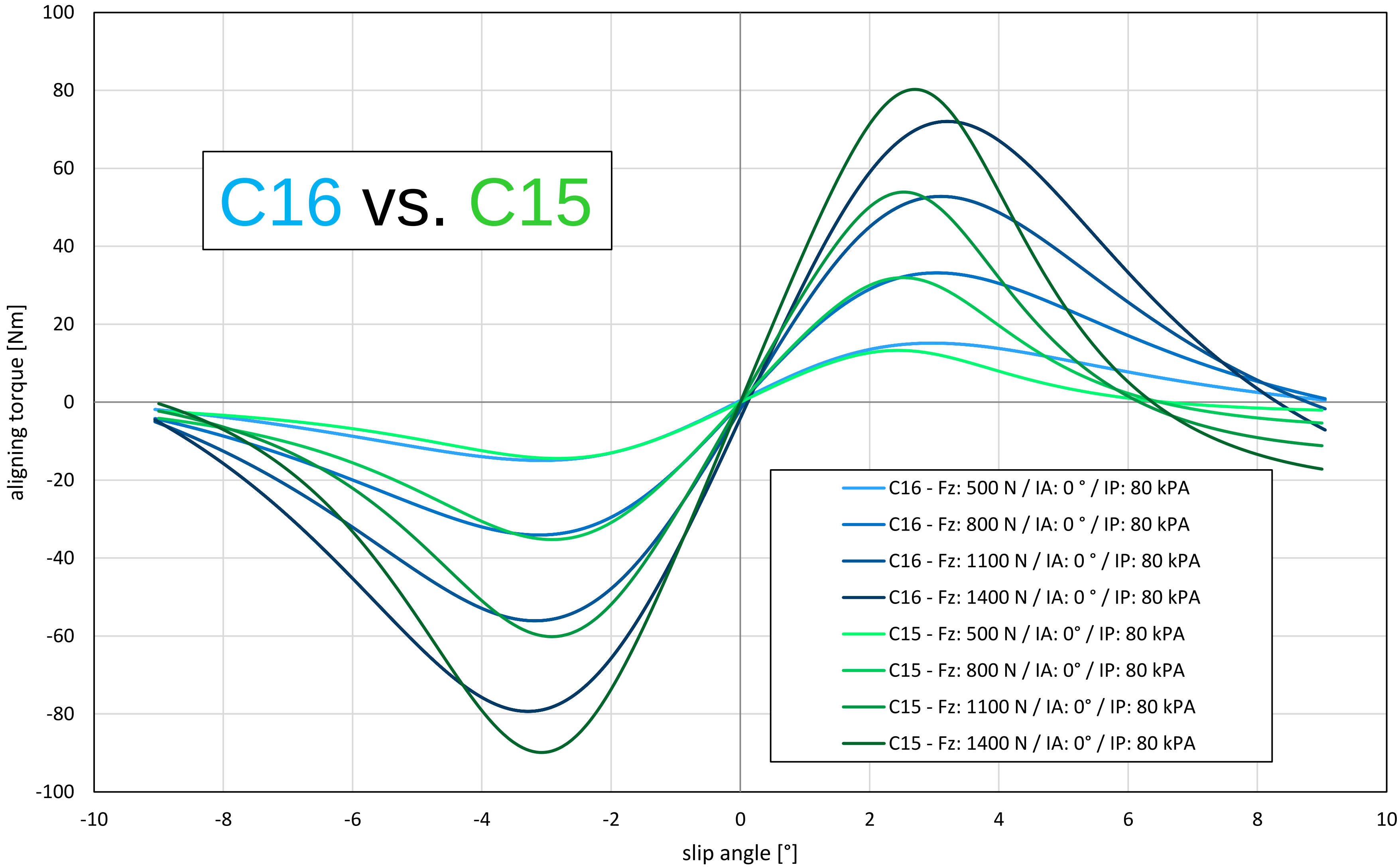
5.3 Cornering – Results

lateral force



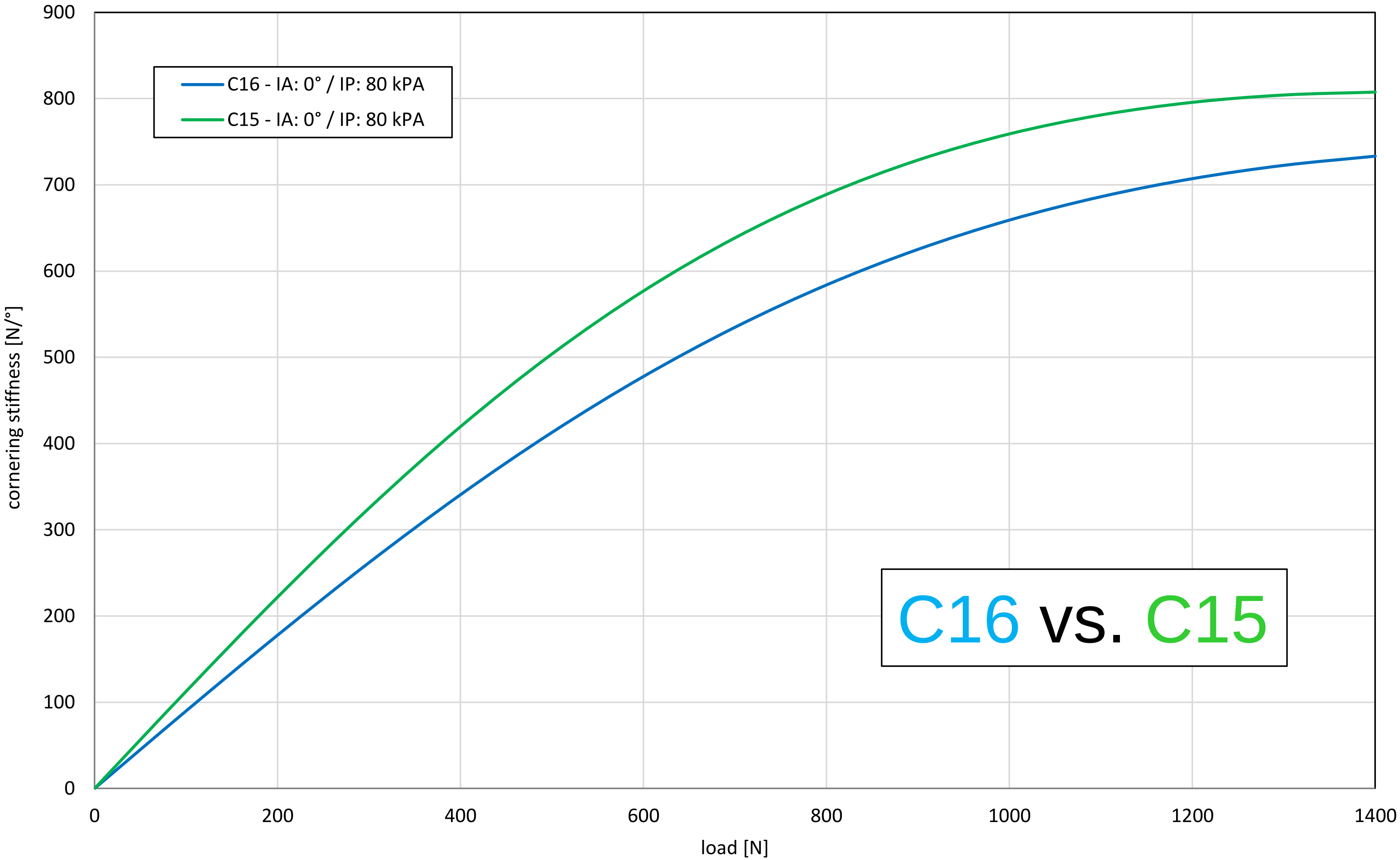
5.3 Cornering – Results

aligning torque



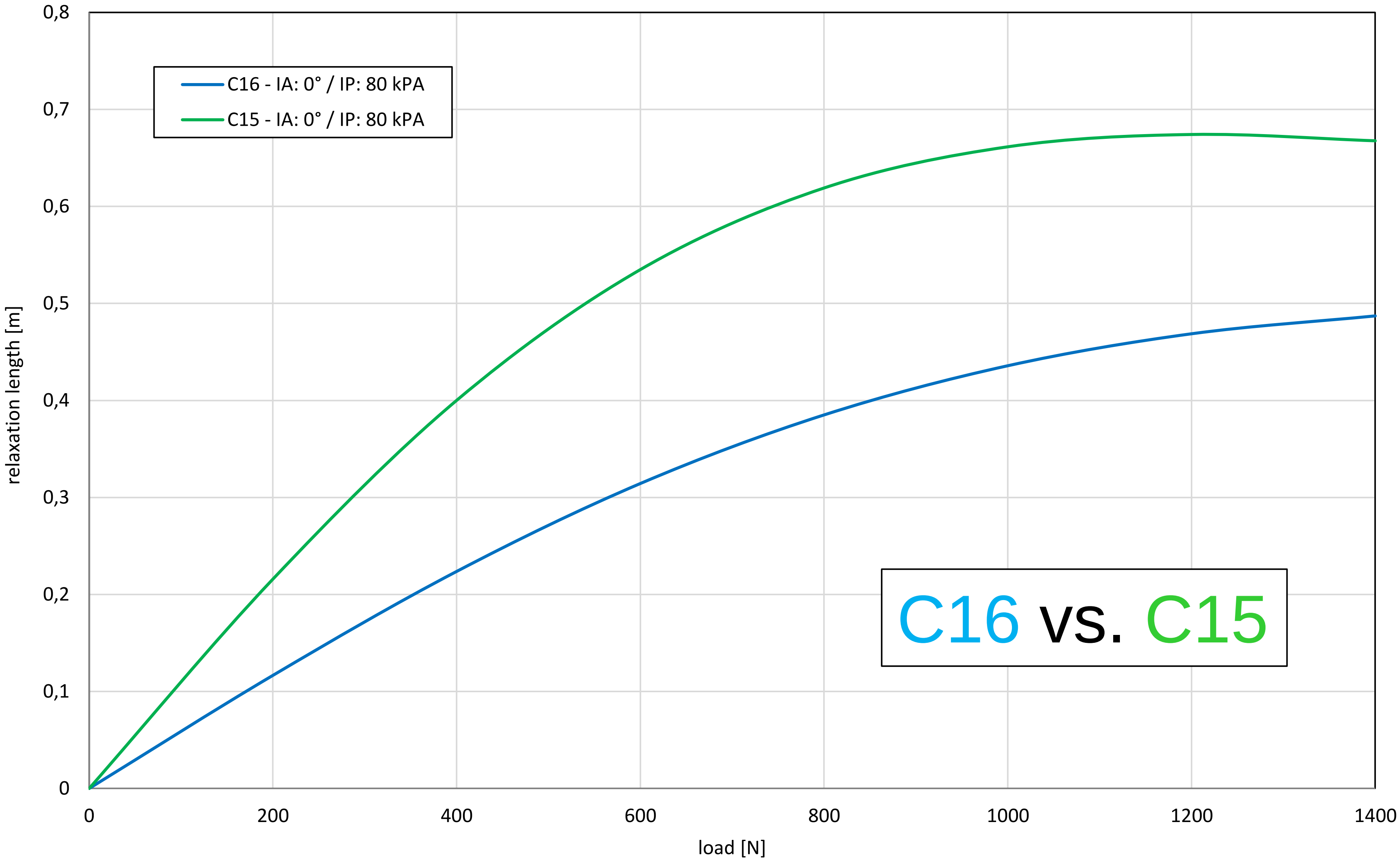
5.3 Cornering – Results

cornering stiffness



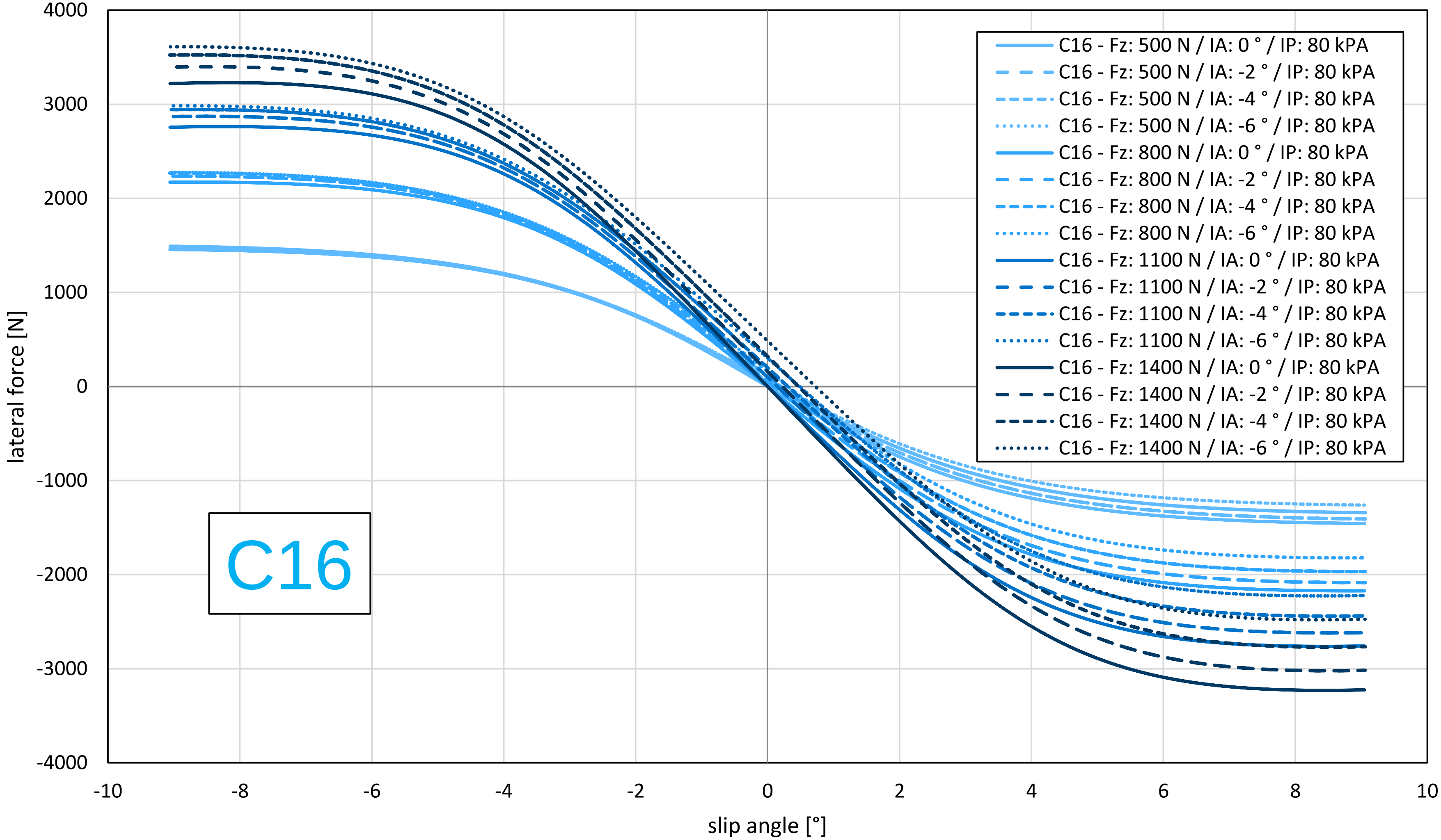
5.3 Cornering – Results

relaxation length



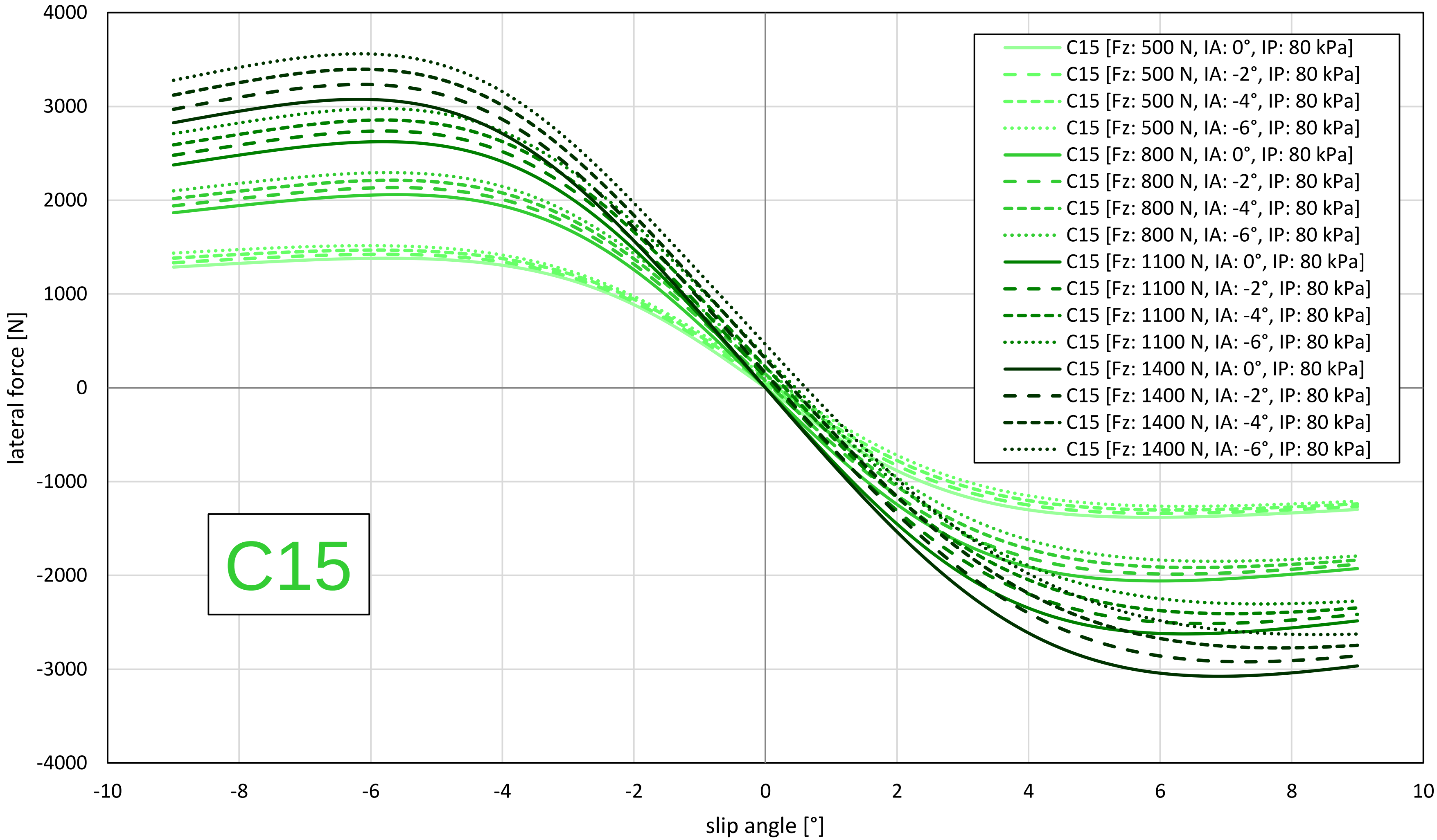
5.3 Cornering – Results

Influence of incl. angle on lateral force



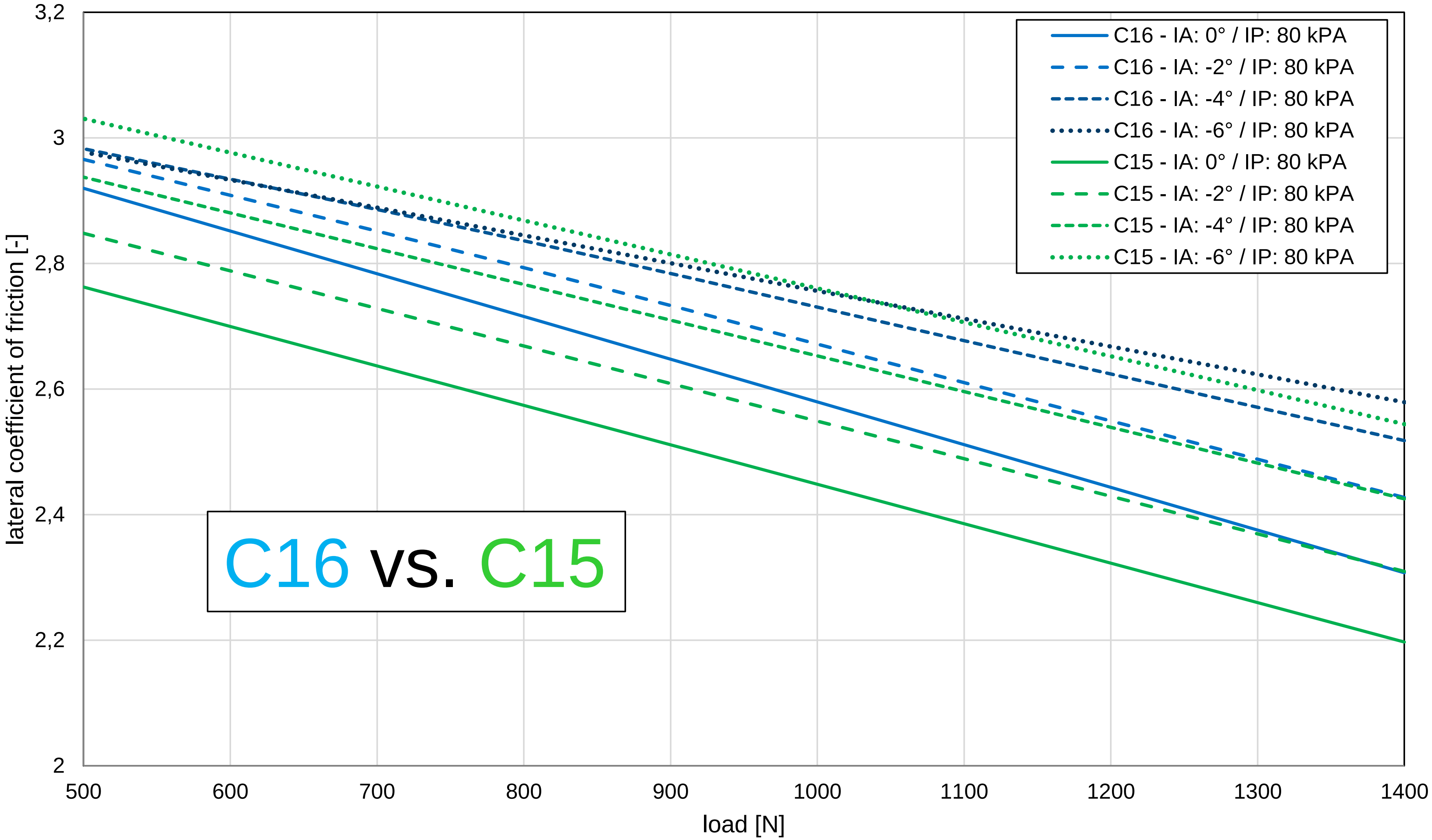
5.3 Cornering – Results

Influence of incl. angle on lateral force



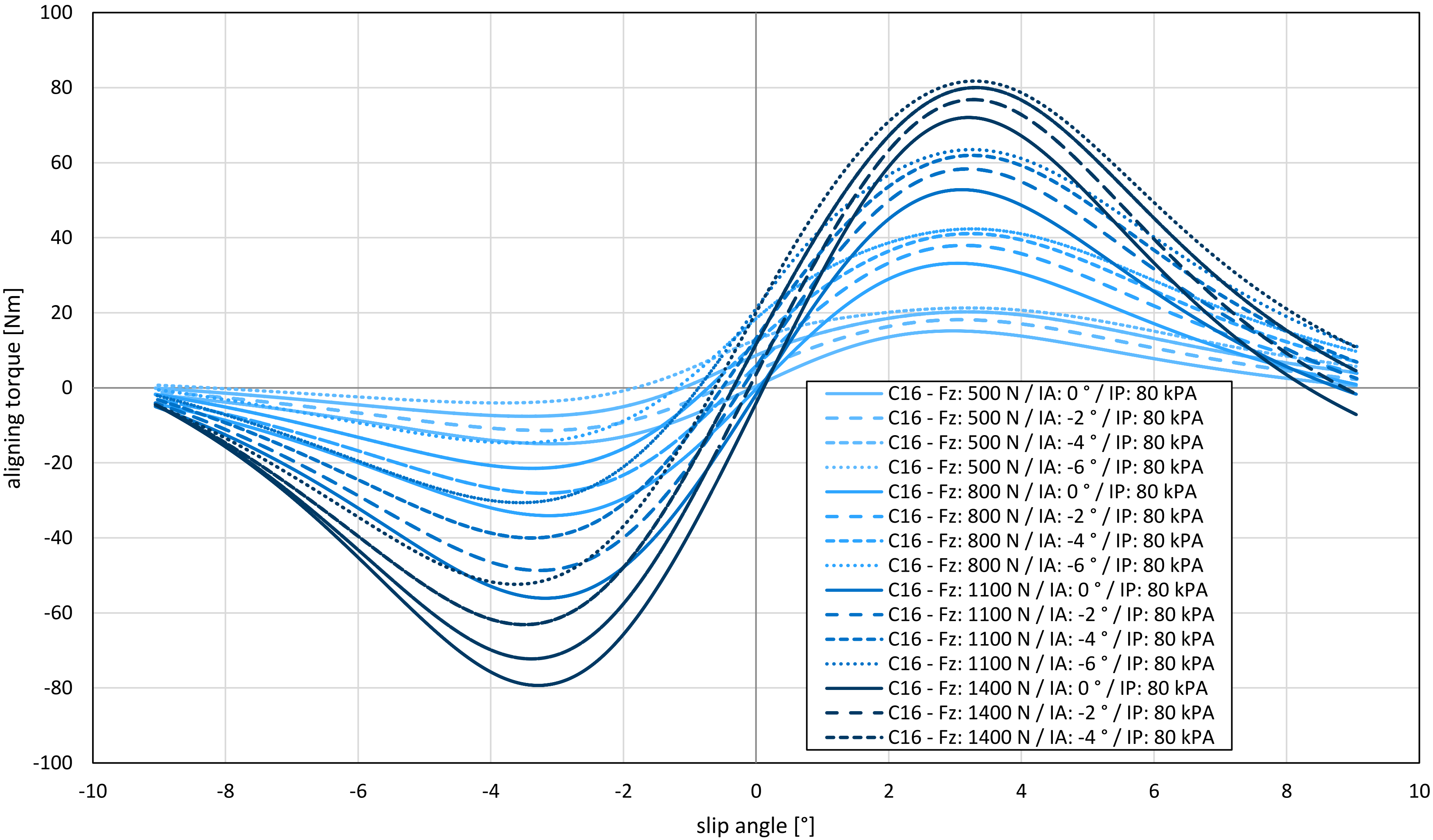
5.3 Cornering – Results

Influence of load and incl. angle on lat. coefficient of friction



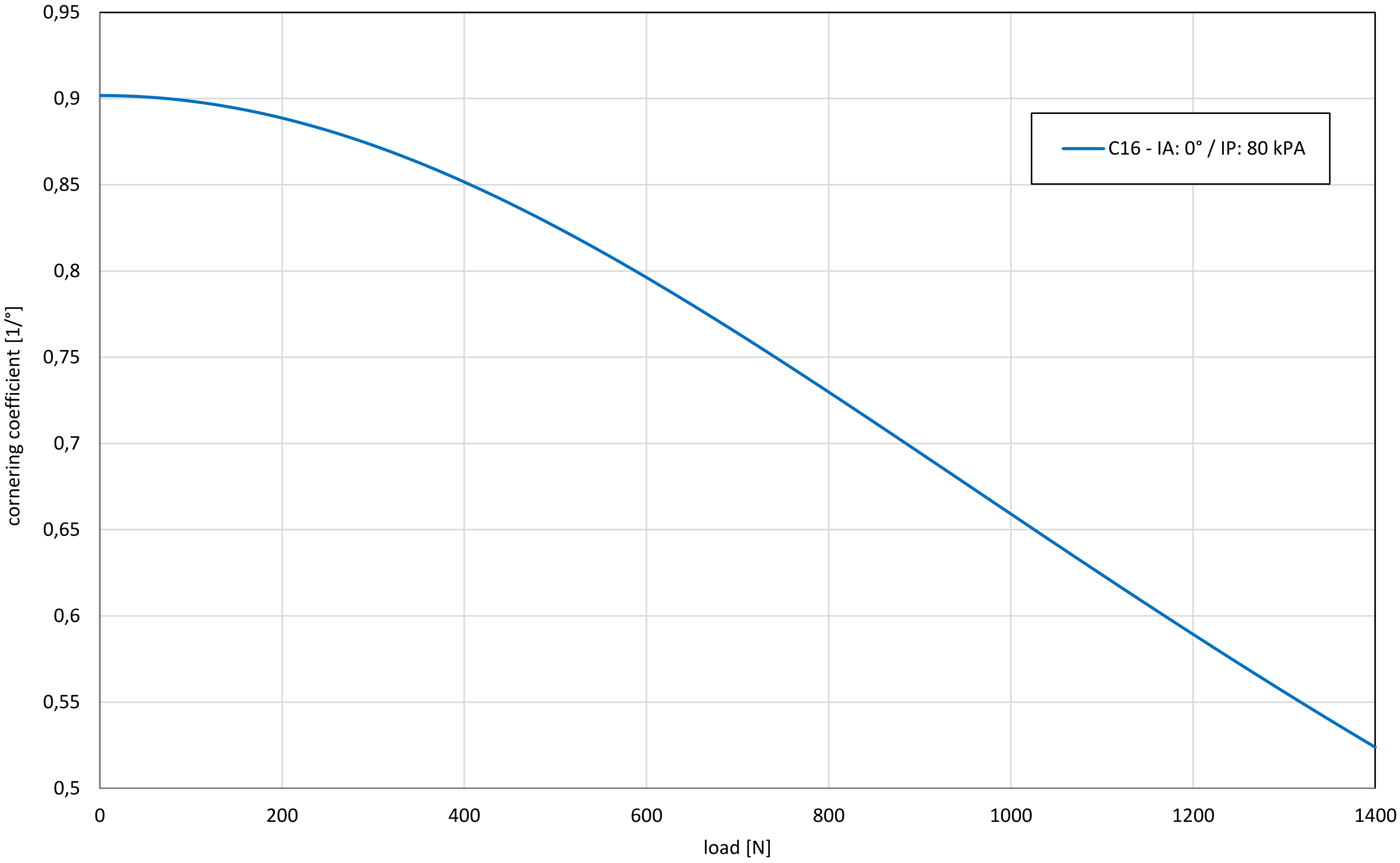
5.3 Cornering – Results

Influence of inclination angle on aligning torque



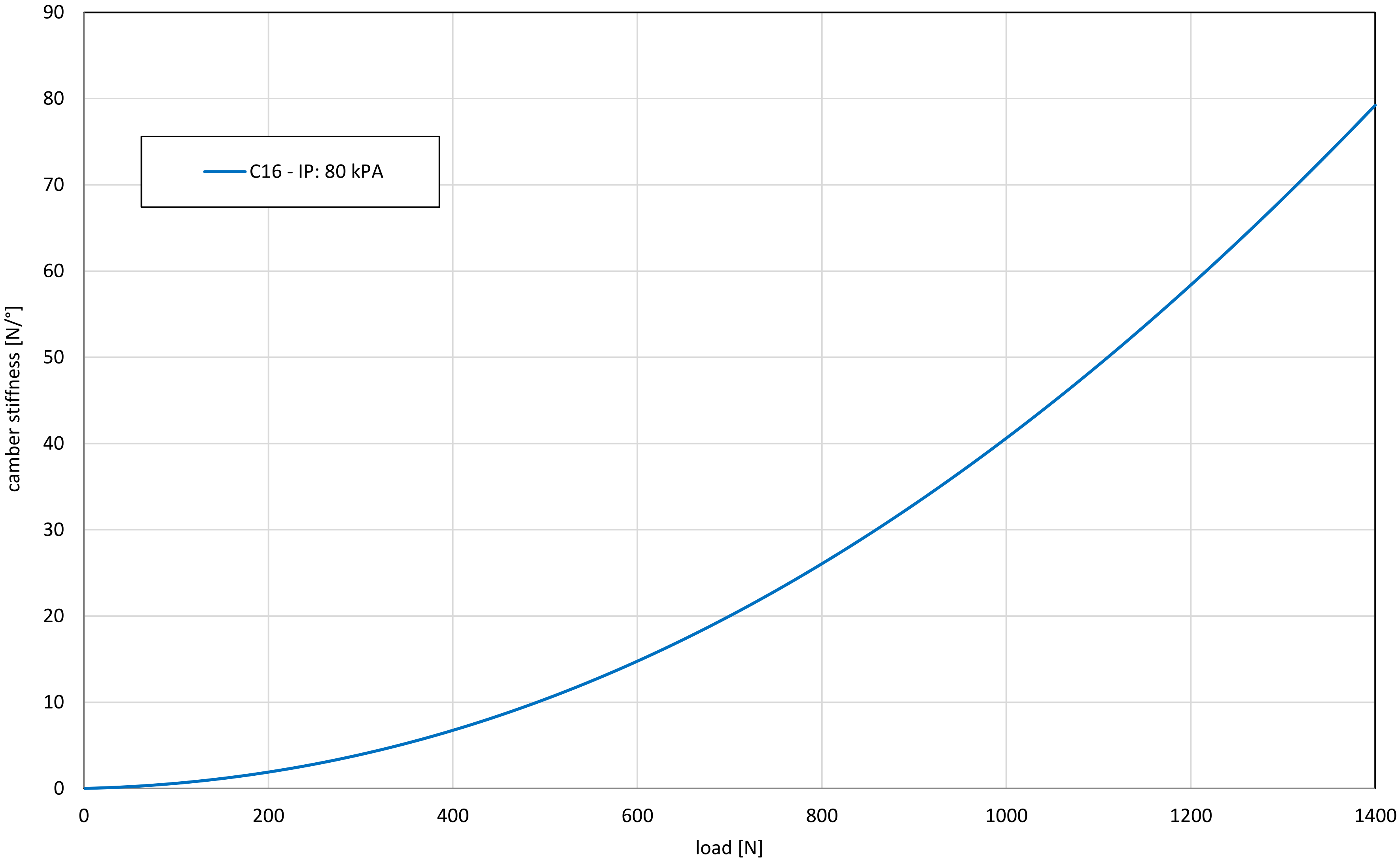
5.3 Cornering – Results

cornering coefficient



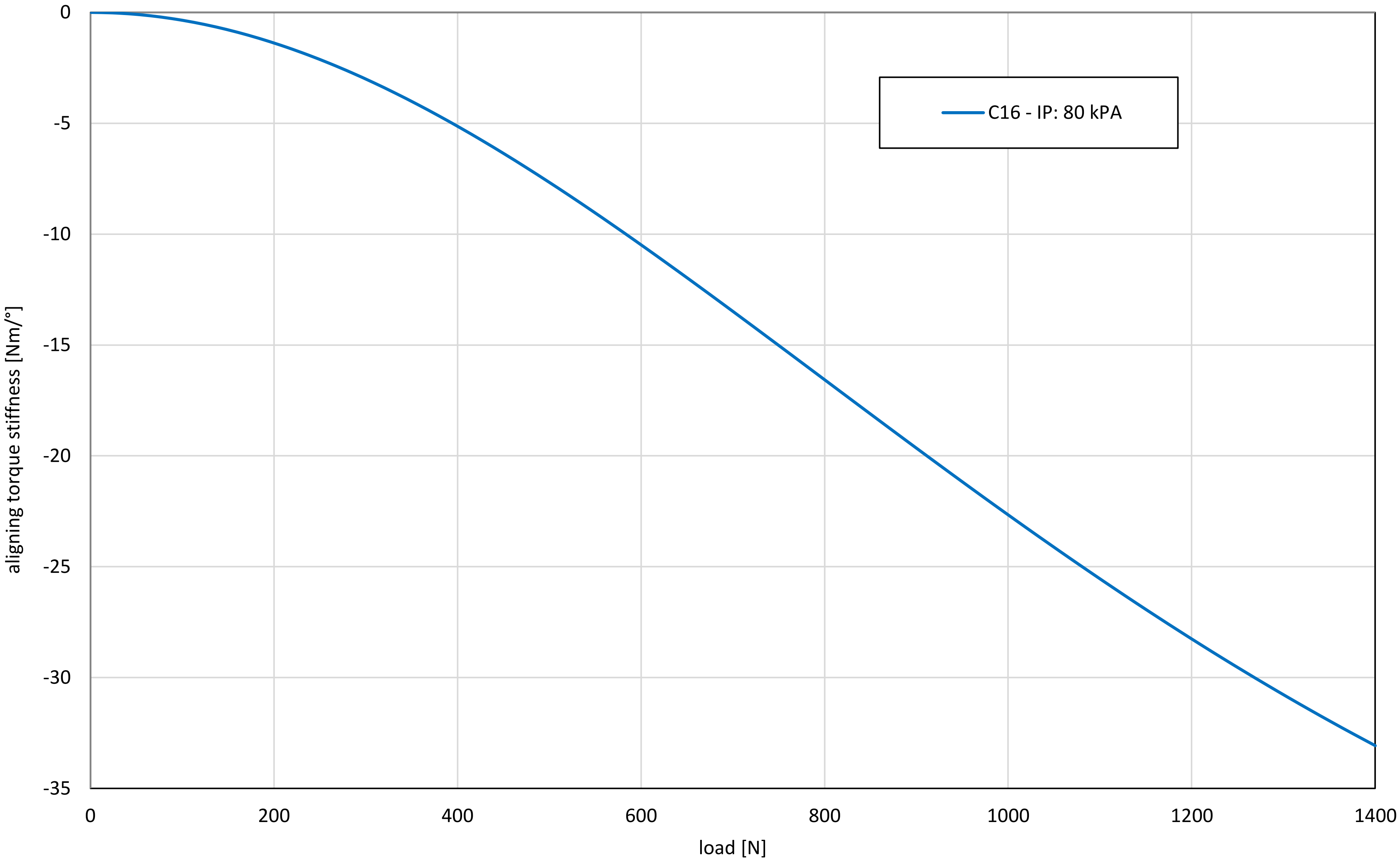
5.3 Cornering – Results

camber stiffness



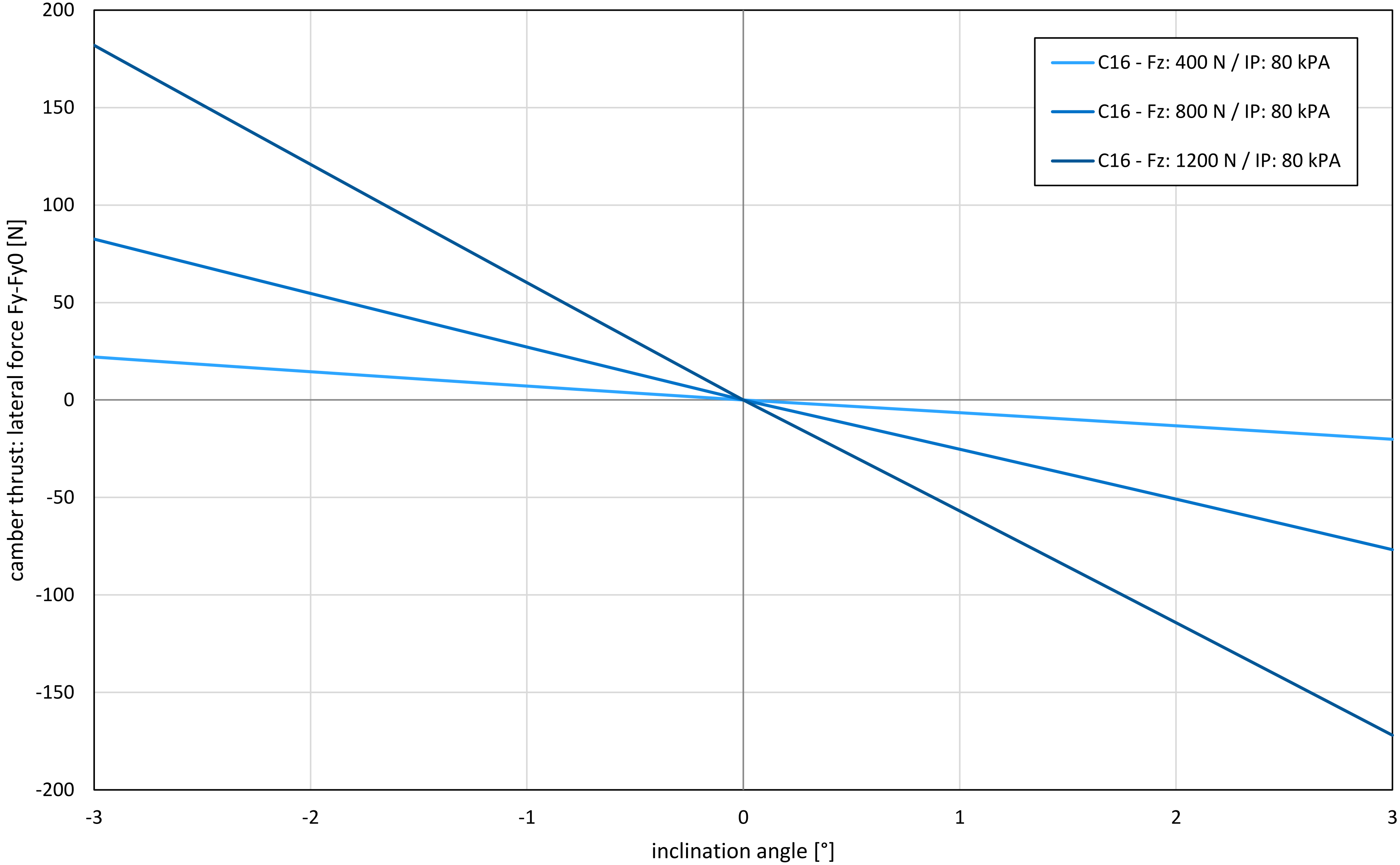
5.3 Cornering – Results

aligning torque stiffness



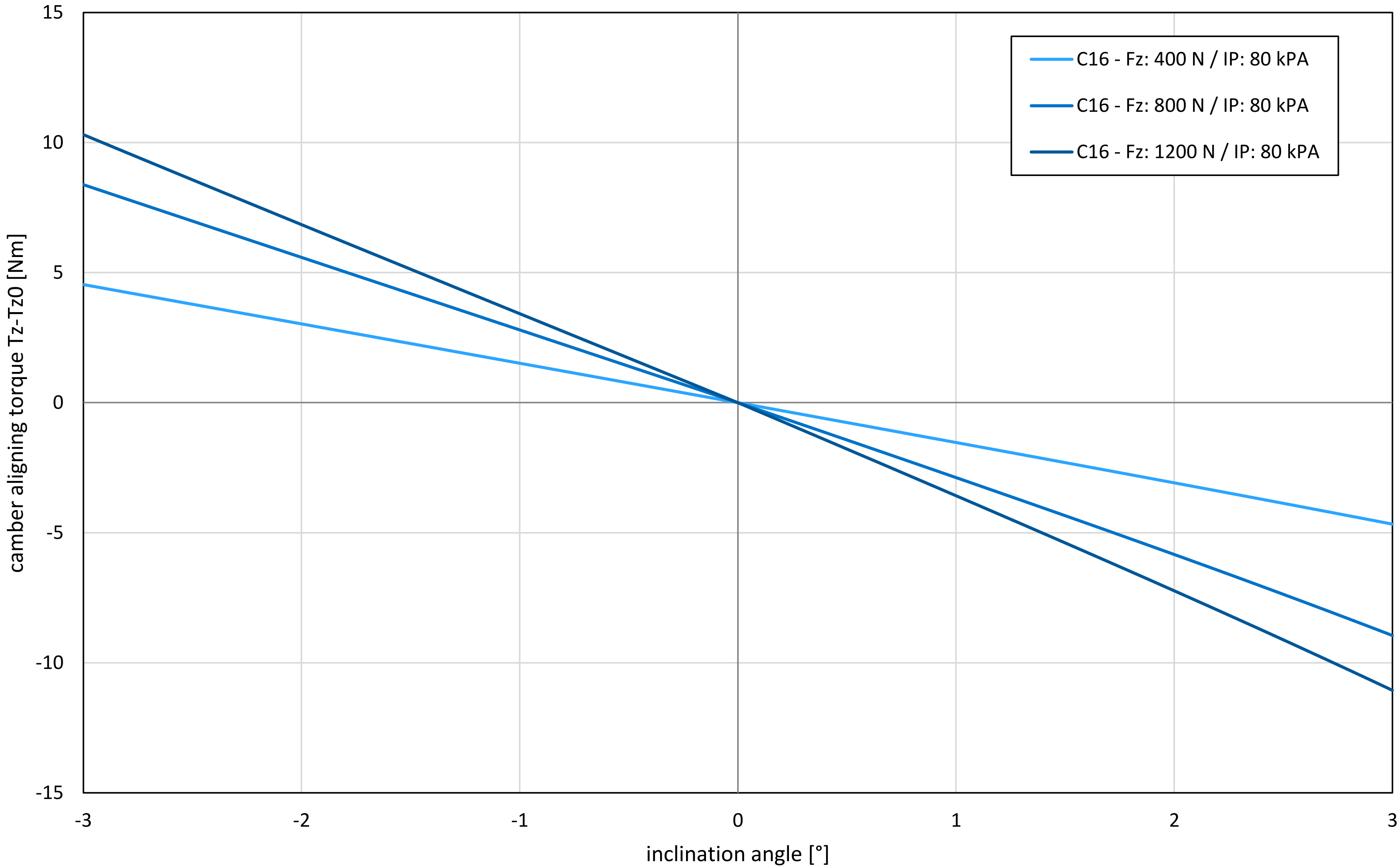
5.3 Cornering – Results

camber thrust



5.3 Cornering – Results

camber aligning torque



6. Longitudinal & Combined Slip

It should be noted that the MF5.2 tire model for the C16 contains coefficients for the longitudinal and combined slip conditions that are actually **not** fitted to measured raw data from the Flat Trac.

Instead, the longitudinal and combined model was designed based on experience and reference test data

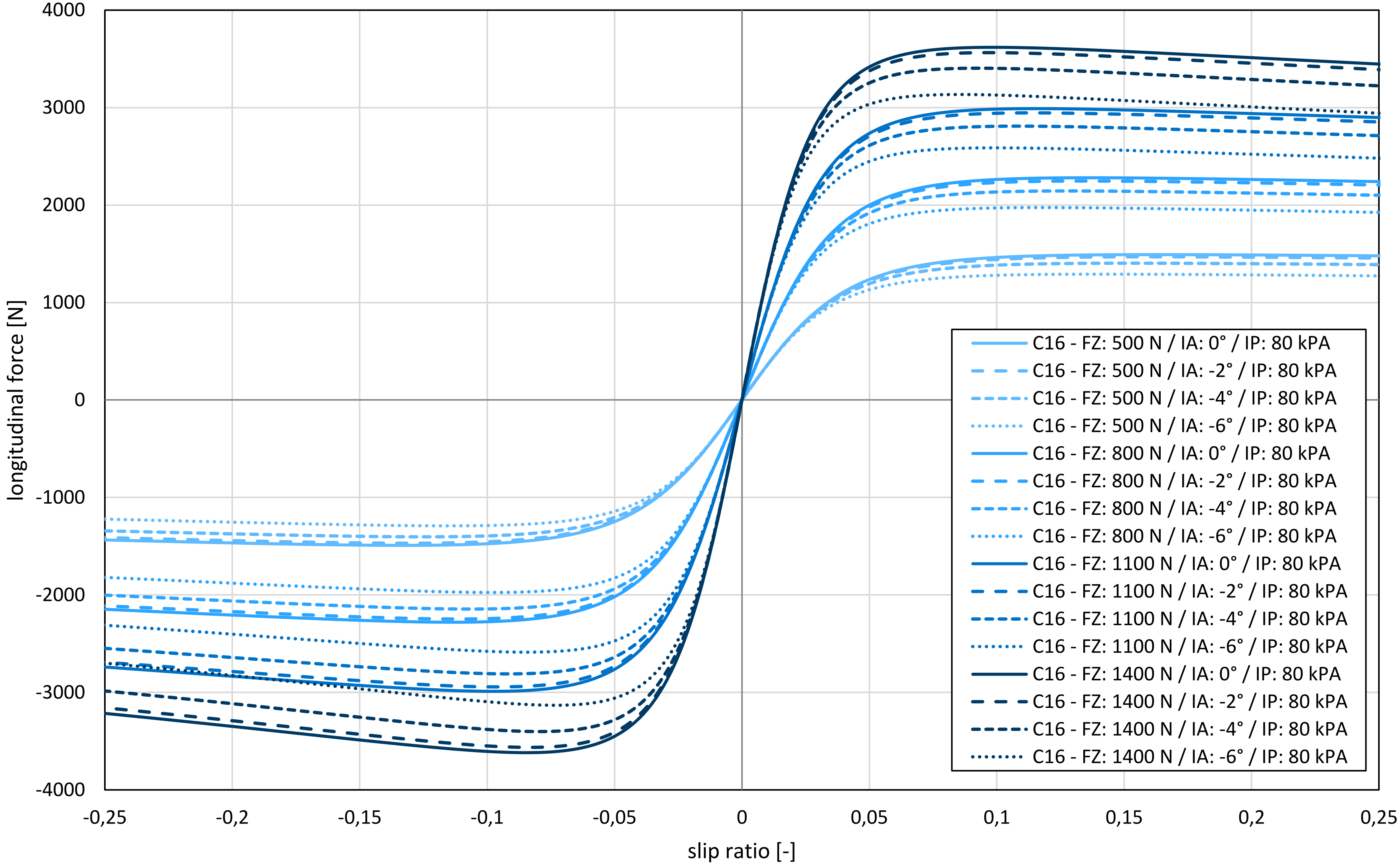
As a result, the C16 tire model reflects longitudinal and combined slip behavior in a reasonable way, but is not directly proven by measurement data!

Thus, the model output for longitudinal and combined slip should be used with engineering judgment when it comes to the interpretation of the tire characteristic or further simulation outputs.

On the next pages, some tire model outputs for longitudinal and combined are shown.

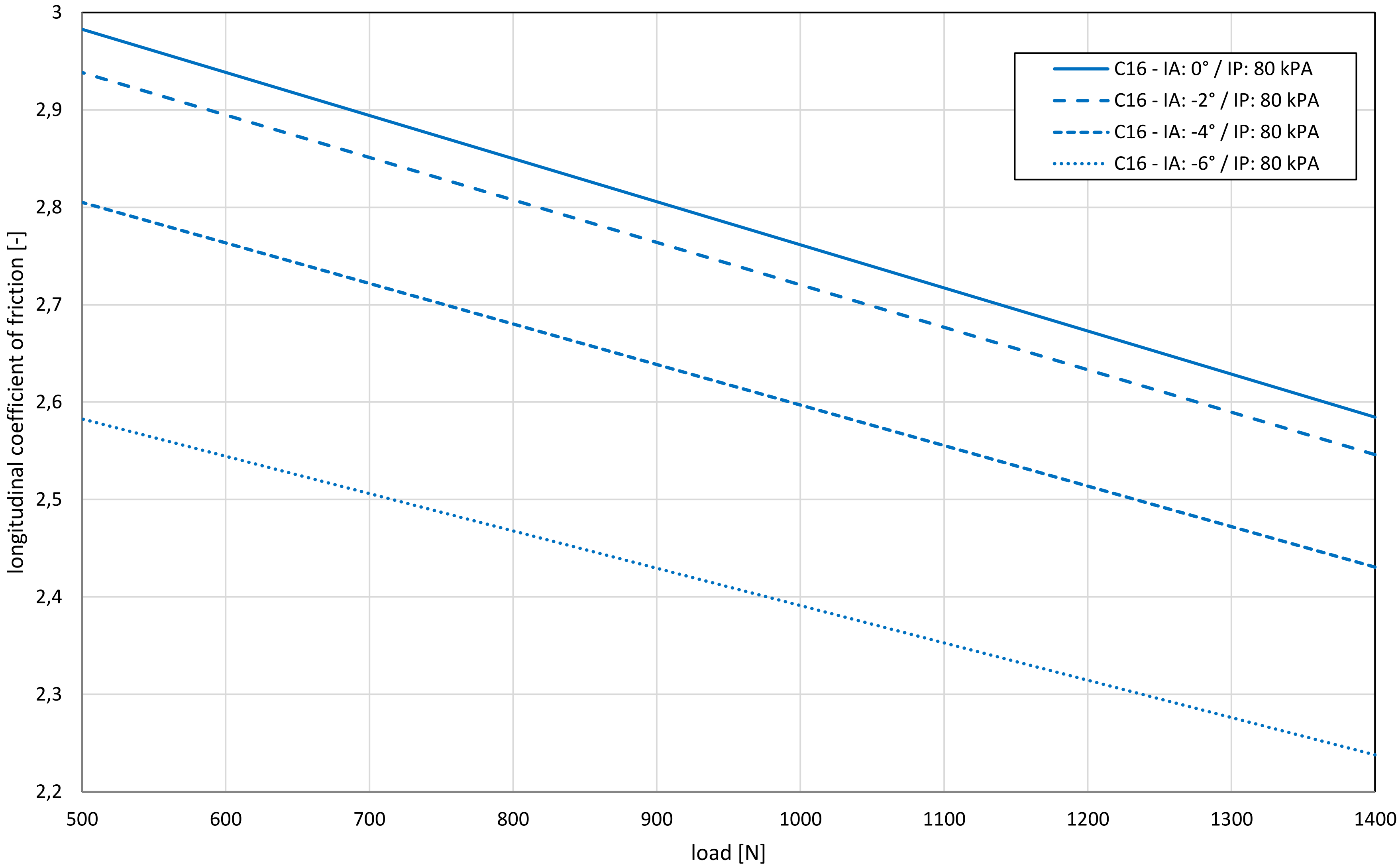
6.1 Longitudinal Slip

Influence of camber on long. force



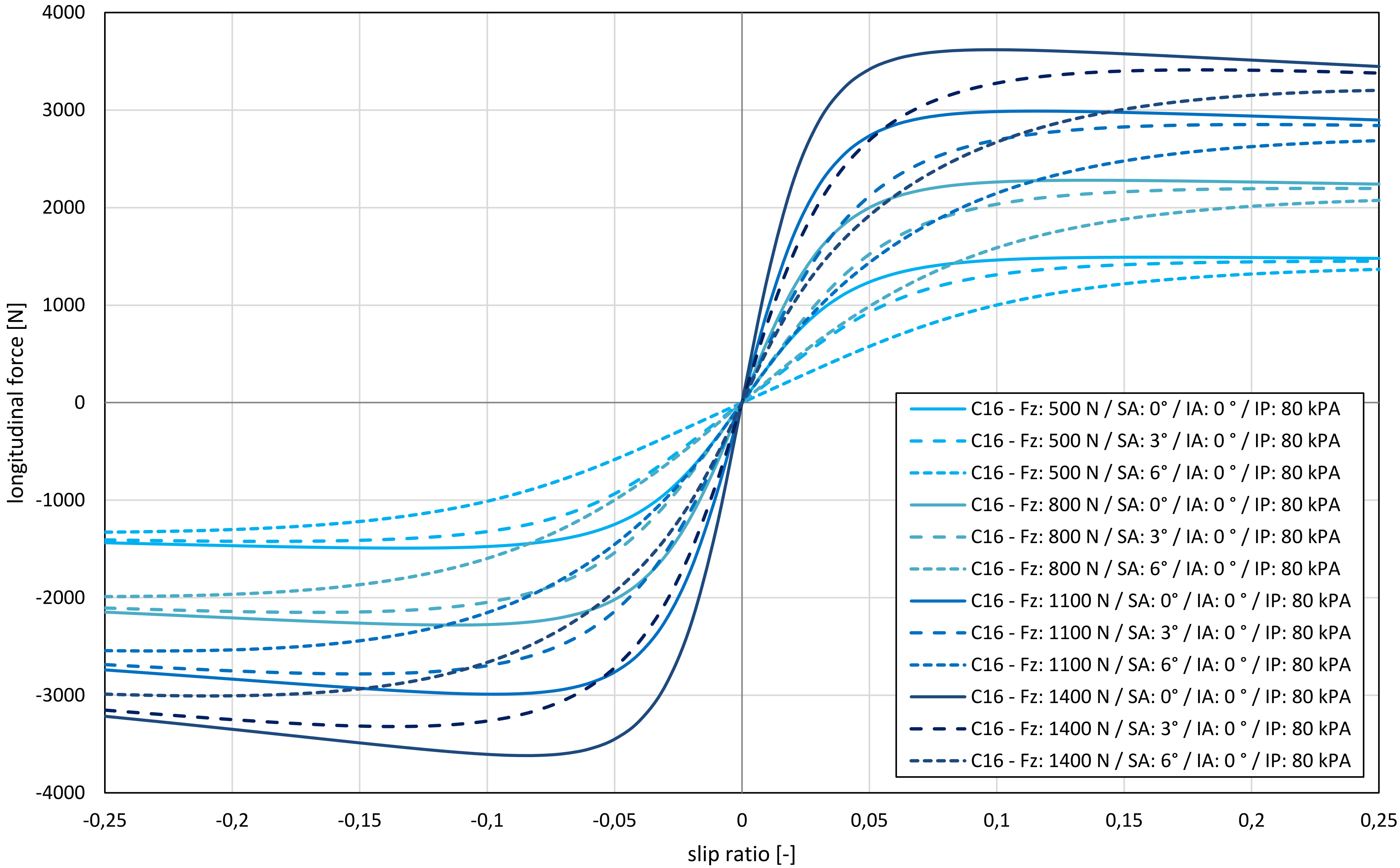
6.1 Longitudinal Slip

Influence of camber on long. force



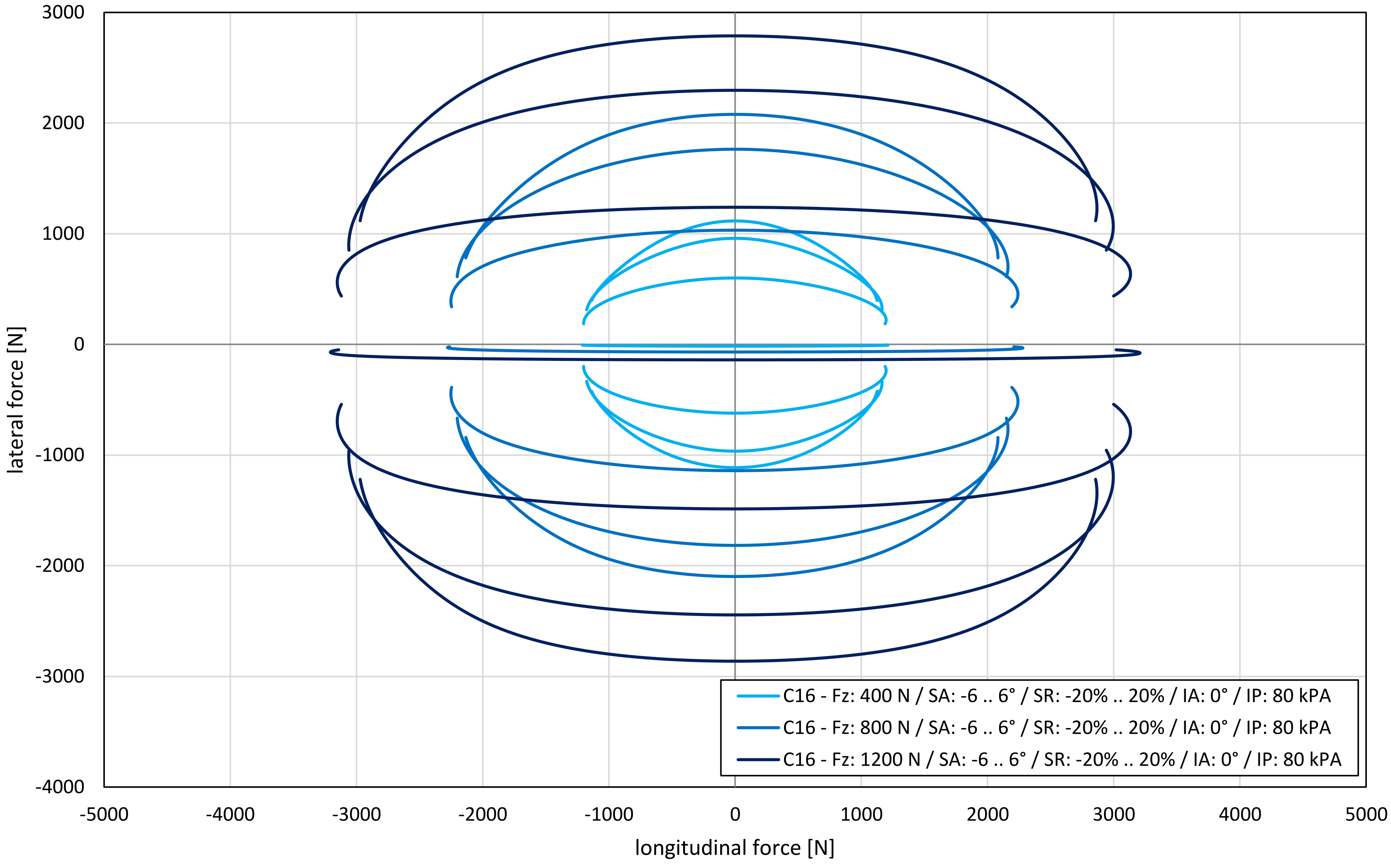
6.2 Combined Slip

Influence of slip angle on long. force



6.2 Combined Slip

Friction Elipse



7.1 Tire Model Guide – Model Limitations

The created tire model is valid within the given boundaries.

Parameter	min. Value	max. Value
Normal Load Range	230 N	1600 N
Long. Slip Range	-25 %	+25 %
Slip Angle Range	-9 °	+9 °
Inclination Angle Range	-6 °	+6 °

If needed, the boundaries can be edited in the *.tir-file.

It should be noted, that if the model parameters are increased beyond the boundaries the results can become unreasonable. Therefore, the model outputs should be checked carefully when leaving the given boundaries.

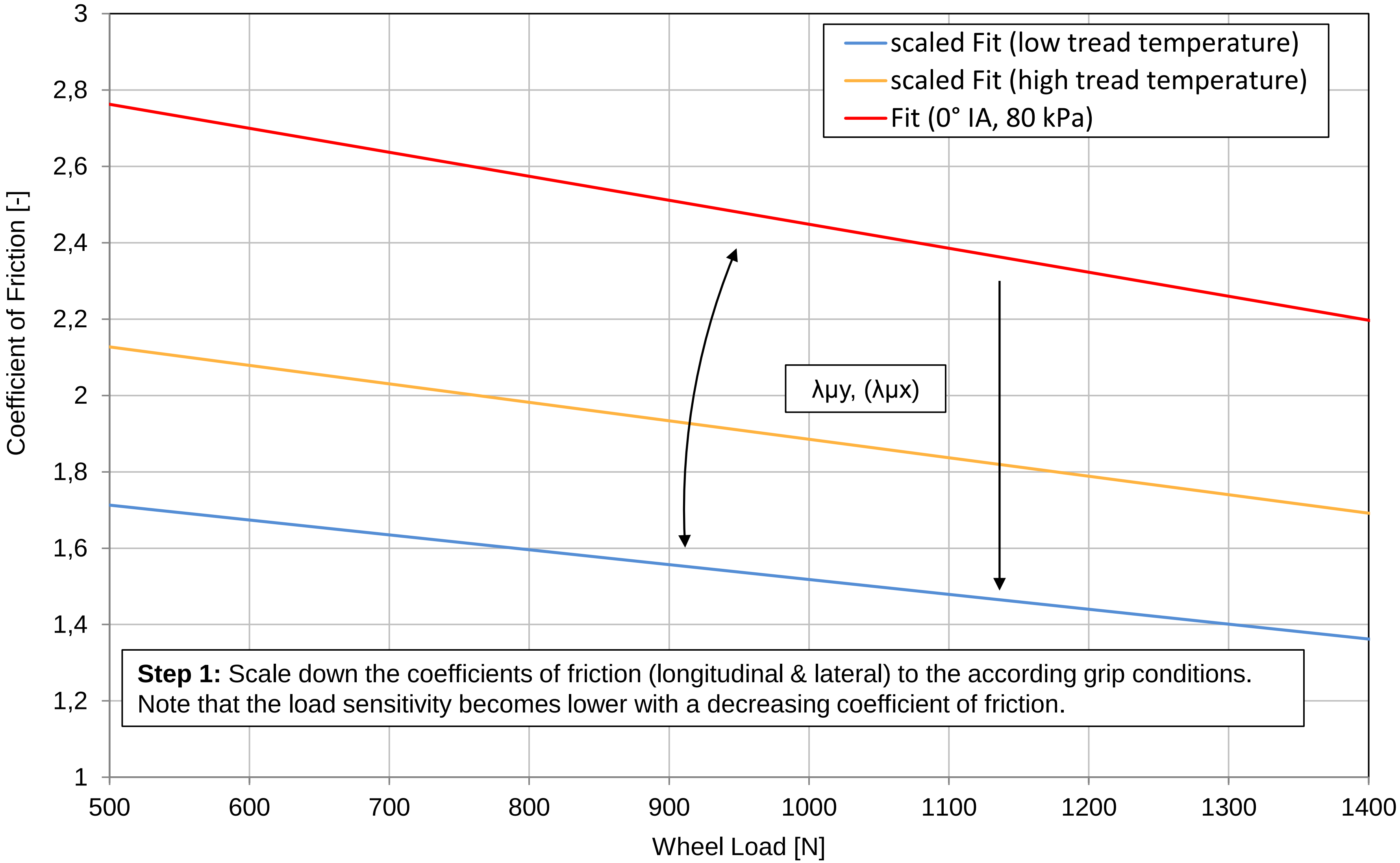
7.2 Tire Model Guide – Scaling Factors

Using the provided tire model for vehicle dynamic simulations, it is possible to investigate trends and analyze target conflicts to find preferred vehicle configurations for the different dynamic events.

However, looking at the coefficients of friction it becomes obvious, that absolute assumptions have to be made very carefully. The tire grip on the Flat Trac is about 20% to 40% higher compared to typical Formula Student operating conditions. The differences in grip are mainly caused by the influences of the surface properties, i.e. micro- and macro-roughness as well as contaminations with dust, stones and other particles.

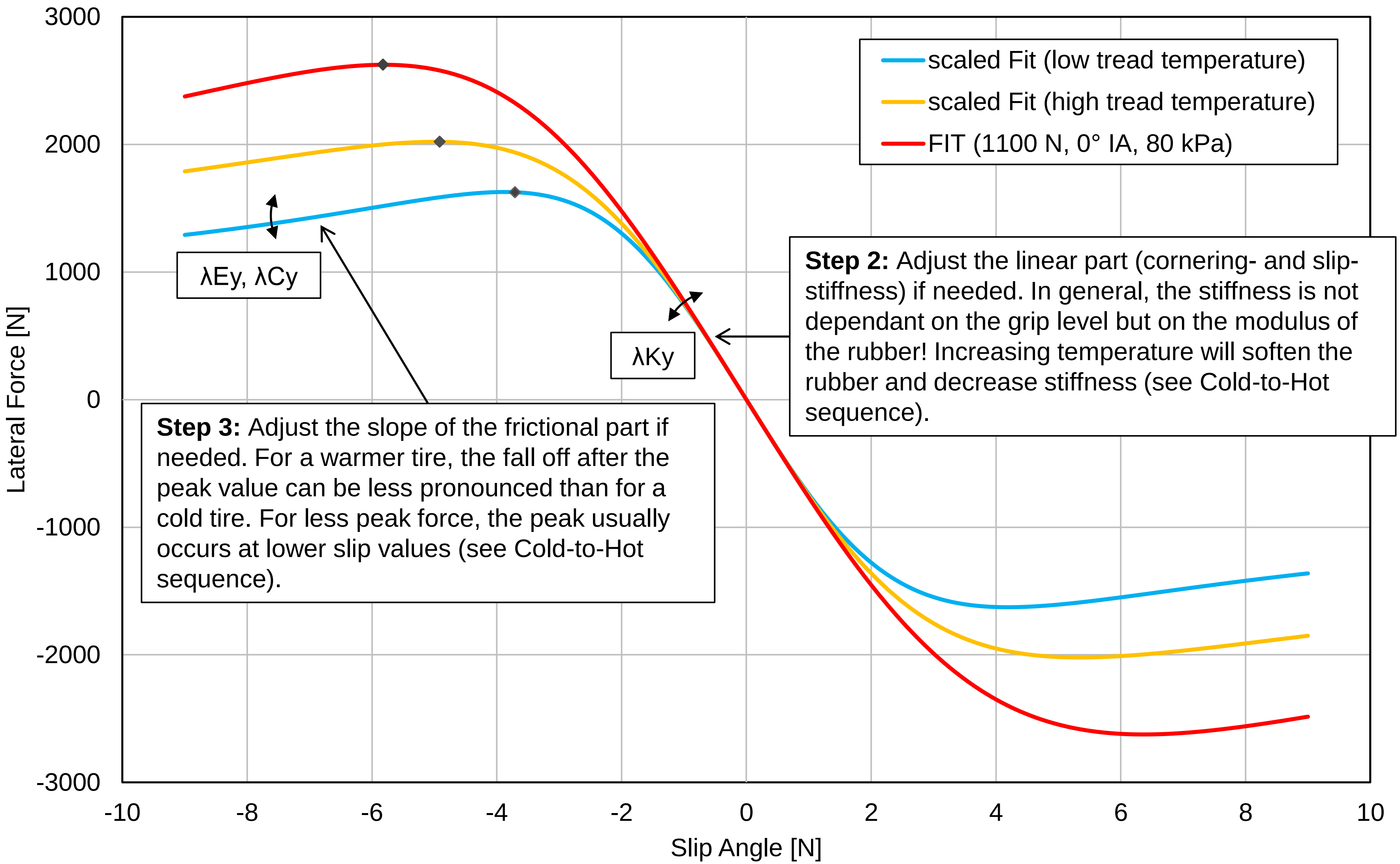
To have a more realistic simulation result, the tire model can be scaled down to appropriate grip conditions. Some explanations regarding the scaling of the model can be found on the following pages. Additionally, a set of exemplary scaling factors are provided as a starting point for further model scaling.

7.2 Tire Model Guide – Scaling Factors

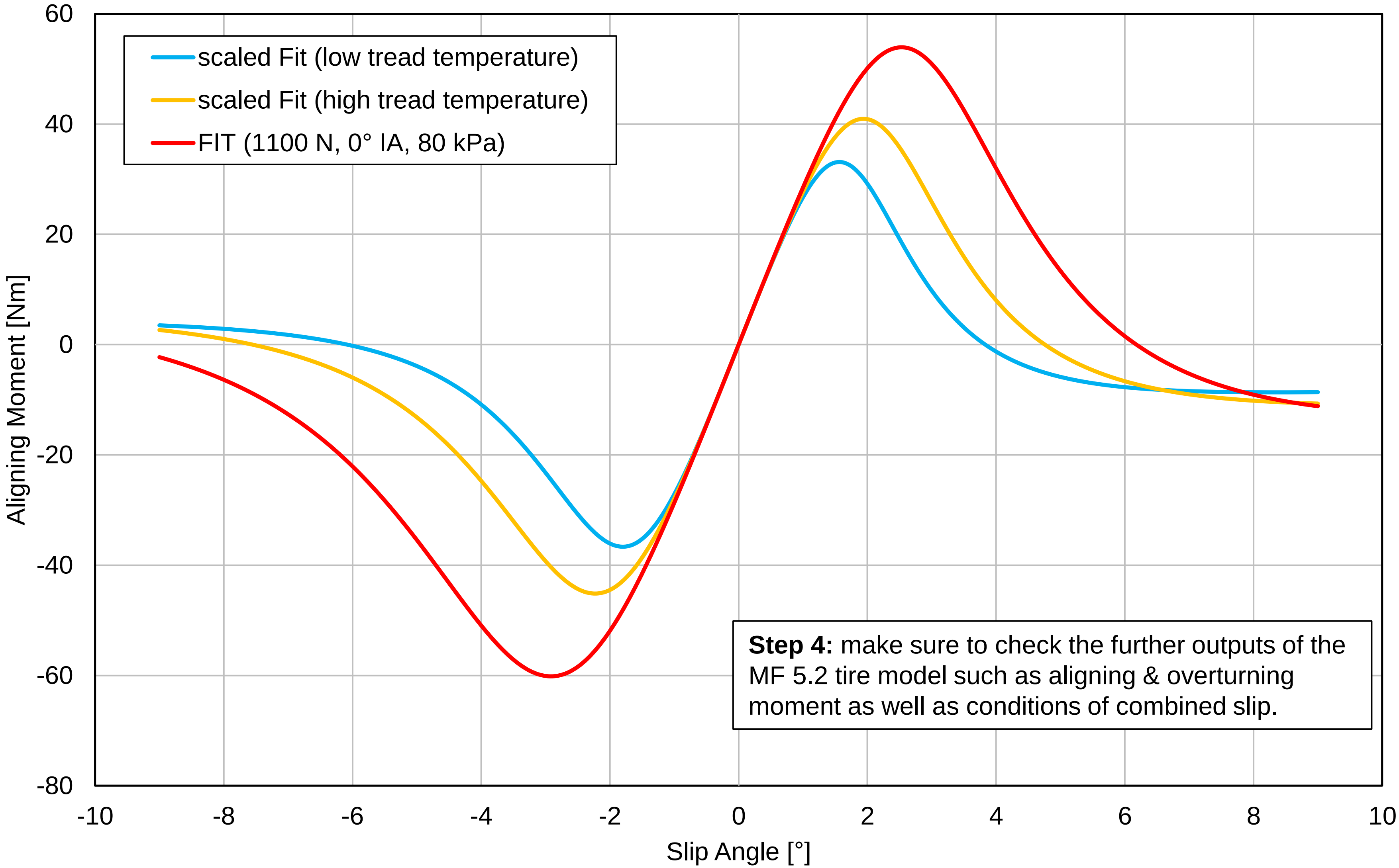


Step 1: Scale down the coefficients of friction (longitudinal & lateral) to the according grip conditions. Note that the load sensitivity becomes lower with a decreasing coefficient of friction.

7.2 Tire Model Guide – Scaling Factors



7.2 Tire Model Guide – Scaling Factors



Step 4: make sure to check the further outputs of the MF 5.2 tire model such as aligning & overturning moment as well as conditions of combined slip.

7.2 Tire Model Guide – Exemplary Scaling Factors

Exemplary Scaling Factors for Operating Tire Temperature

Name	Name used in tire property file	Standard Value	Exemplary Value	Explanation:
λFzo	LFZO	1	1	Scale factor of nominal (rated) load
λCx	LCX	1	1	Scale factor of Fx shape factor
λμx	LMUX	1	0.72	Scale factor of Fx peak friction coefficient
λEx	LEX	1	1	Scale factor of Fx curvature factor
λKx	LKX	1	1	Scale factor of Fx slip stiffness
λHx	LHX	1	1	Scale factor of Fx horizontal shift
λVx	LVX	1	1	Scale factor of Fx vertical shift
λγx	LGAX	1	1	Scale factor of camber for Fx
λCy	LCY	1	0.98	Scale factor of Fy shape factor
λμy	LMUY	1	0.77	Scale factor of Fy peak friction coefficient
λEy	LEY	1	0.55	Scale factor of Fy curvature factor
λKy	LKY	1	1	Scale factor of Fy cornering stiffness
λHy	LHY	1	1	Scale factor of Fy horizontal shift
λVy	LVY	1	1	Scale factor of Fy vertical shift
λγy	LGAY	1	0.8	Scale factor of camber for Fy
λt	LTR	1	1	Scale factor of Peak of pneumatic trail
λMr	LRES	0	0	Scale factor for offset of residual torque
λγz	LGAZ	1	1	Scale factor of camber for Mz
λMx	LMX	1	1	Scale factor of overturning couple
λvMx	LVMX	1	1	Scale factor of Mx vertical shift
λMy	LMY	1	1	Scale factor of rolling resistance torque
λxα	LXAL	1	1.36	Scale factor of alpha influence on *Fx*
λyκ	LYKA	1	1.30	Scale factor of alpha influence on *Fy*
λ*Vy*κ	LVYKA	1	1	Scale factor of kappa induced *Fy*
λs	LS	1	1.5	Scale factor of Moment arm of *Fx*

7.2 Tire Model Guide – Exemplary Scaling Factors

Exemplary Scaling Factors for very low Tire Temperature

Name	Name used in tire property file	Standard Value	Exemplary Value	Explanation:
λFzo	LFZO	1	1	Scale factor of nominal (rated) load
λCx	LCX	1	1	Scale factor of Fx shape factor
$\lambda \mu x$	LMUX	1	0.62	Scale factor of Fx peak friction coefficient
λEx	LEX	1	1	Scale factor of Fx curvature factor
λKx	LKX	1	1	Scale factor of Fx slip stiffness
λHx	LHX	1	1	Scale factor of Fx horizontal shift
λVx	LVX	1	1	Scale factor of Fx vertical shift
$\lambda \gamma x$	LGAX	1	1	Scale factor of camber for Fx
λCy	LCY	1	0.97	Scale factor of Fy shape factor
$\lambda \mu y$	LMUY	1	0.62	Scale factor of Fy peak friction coefficient
λEy	LEY	1	0.68	Scale factor of Fy curvature factor
λKy	LKY	1	1	Scale factor of Fy cornering stiffness
λHy	LHY	1	1	Scale factor of Fy horizontal shift
λVy	LVY	1	1	Scale factor of Fy vertical shift
$\lambda \gamma y$	LGAY	1	0.75	Scale factor of camber for Fy
λt	LTR	1	1	Scale factor of Peak of pneumatic trail
λMr	LRES	0	0	Scale factor for offset of residual torque
$\lambda \gamma z$	LGAZ	1	1	Scale factor of camber for Mz
λMx	LMX	1	1	Scale factor of overturning couple
λvMx	LVMX	1	1	Scale factor of Mx vertical shift
λMy	LMY	1	1	Scale factor of rolling resistance torque
$\lambda x\alpha$	LXAL	1	1.39	Scale factor of alpha influence on *Fx*
$\lambda y\kappa$	LYKA	1	1.45	Scale factor of alpha influence on *Fy*
$\lambda V y\kappa$	LVYKA	1	1	Scale factor of kappa induced *Fy*
λs	LS	1	1.9	Scale factor of Moment arm of *Fx*

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Variables and Parameters

Input:

Nominal (rated) load	F_{z0}	[N]
Unloaded tire radius	R_0	[m]
Longitudinal slip	κ	[-]
Slip angle	α	[rad]
Camber angle	γ	[rad]
Normal wheel load	F_z	[N]

Output:

Longitudinal force	F_x	[N]
Lateral force	F_y	[N]
Overturning couple	M_x	[Nm]
Rolling resistance torque	M_y	[Nm]
Aligning torque	M_z	[Nm]

Normalized vertical load increment:

$$df_z = \frac{F_z - F'_{z0}}{F'_{z0}}$$

$$F'_{z0} = F_{z0} \cdot \lambda_{F_{z0}}$$

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Pure Lateral Slip

$$F_y = F_{y0}(\alpha, \gamma, F_z)$$

$$F_{y0} = D_y \sin[C_y \arctan\{B_y\alpha_y - E_y(B_y\alpha_y - \arctan(B_y\alpha_y))\}] + S_{Vy}$$

$$\alpha_y = \alpha + S_{Hy}$$

$$\gamma_y = \gamma \cdot \lambda_{\gamma y}$$

Coefficients

$$B_y = K_y/(C_y D_y)$$

$$C_y = p_{Cy1} \cdot \lambda_{Cy}$$

$$D_y = \mu_y \cdot F_z$$

$$K_y = p_{Ky1} F_{z0} \sin[2\arctan\{F_z/(p_{ky2} F_{z0} \lambda_{F_{z0}})\}] \cdot (1 - p_{Ky3}|\gamma_y|) \cdot \lambda_{F_{z0}} \cdot \lambda_{Ky}$$

$$((= B_y C_y D_y = \frac{\partial F_{y0}}{\partial \alpha_y} \text{ at } \alpha_y = 0)$$

$$\mu_y = (p_{Dy1} + p_{Dy2} df_z) \cdot (1 - p_{Dy3}\gamma_y^2) \cdot \lambda_{\mu y}$$

$$E_y = (p_{Ey1} + p_{Ey2} df_z) \cdot \{1 - (p_{Ey3} + p_{Ey4}\gamma_y)\operatorname{sgn}(\alpha_y)\} \cdot \lambda_{Ey}(\quad \leq 1)$$

$$S_{Hy} = (P_{Hy1} + P_{Hy2} df_z) \cdot \lambda_{Hy} + P_{Hy3}\gamma_y$$

$$S_{Vy} = F_z \cdot \{(p_{Vy1} + p_{Vy2} df_z) \cdot \lambda_{Vy} + (p_{Vy3} + p_{vy4} \cdot df_z) \quad \cdot \gamma_y\} \cdot \lambda_{\mu y}$$

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Coefficients – Pure Lateral Slip

Name:	Name used in tire property file:	Explanation:
pCy1	PCY1	Shape factor Cfy for lateral forces
pDy1	PDY1	Lateral friction Muy
pDy2	PDY2	Variation of friction Muy with load
pDy3	PDY3	Variation of friction Muy with squared camber
pEy1	PEY1	Lateral curvature Efy at Fznom
pEy2	PEY2	Variation of curvature Efy with load
pEy3	PEY3	Zero order camber dependency of curvature Efy
pEy4	PEY4	Variation of curvature Efy with camber
pKy1	PKY1	Maximum value of stiffness Kfy/Fznom
pKy2	PKY2	Load at which Kfy reaches maximum value
pKy3	PKY3	Variation of Kfy/Fznom with camber
pHy1	PHY1	Horizontal shift Shy at Fznom
pHy2	PHY2	Variation of shift Shy with load
pHy3	PHY3	Variation of shift Shy with camber
pVy1	PVY1	Vertical shift in Svy/Fz at Fznom
pVy2	PVY2	Variation of shift Svy/Fz with load
pVy3	PVY3	Variation of shift Svy/Fz with camber
pVy4	PVY4	Variation of shift Svy/Fz with camber and load

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Pure Longitudinal Slip

$$F_x = F_{x0}(\kappa, F_z)$$

$$F_{x0} = D_x \sin[C_x \arctan\{B_x\kappa_x - E_x(B_x\kappa_x - \arctan(B_x\kappa_x))\}] + S_{Vx}$$

$$\kappa_x = \kappa + S_{Hx}$$

$$\gamma_x = \gamma \cdot \lambda_{\gamma x}$$

Coefficients

$$B_x = K_x/(C_x D_x)$$

$$C_x = p_{Cx1} \cdot \lambda_{Cx}$$

$$D_x = \mu_x \cdot F_z$$

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

$$\left(K_x = B_x C_x D_x = \frac{\partial F_{x0}}{\partial \kappa_x} \text{ at } \kappa_x = 0\right)$$

$$\mu_x = (p_{Dx1} + p_{Dx2} df_z) \cdot (1 - p_{Dx3} \cdot \gamma_x^2)\lambda_{\mu x}$$

$$E_x = (p_{Ex1} + p_{Ex2} df_z + p_{Ex3} df_z^2) \cdot \{1 - p_{Ex4} \operatorname{sgn}(\kappa_x)\} \cdot \lambda_{Ex}(\ \leq 1)\ )$$

$$S_{Hx} = (p_{Hx1} + p_{Hx2} \cdot df_z)\lambda_{Hx}$$

$$S_{Vx} = F_z \cdot (p_{Vx1} + p_{Vx2} df_z) \cdot \lambda_{Vx} \cdot \lambda_{\mu x}$$

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Coefficients – Pure Longitudinal Slip

Name:	Name used in tire property file:	Explanation:
pCx1	PCX1	Shape faxtor Cfx for longitudinal force
pDx1	PDX1	Longitudinal friction Mux at Fznom
pDx2	PDX2	Variation of friction Mux with load
pDx3	PDX3	Variation of friction Mux with camber
pEx1	PEX1	Longitudinal curvature Efx at Fznom
pEx2	PEX2	Variation of curvature Efx with load
pEx3	PEX3	Variation of curvature Efx with load squared
pEx4	PEX4	Factor in curvature Efx while driving
pKx1	PKX1	Longitudinal slip stiffness Kfx/Fz at Fznom
pKx2	PKX2	Variation of slip stiffness Kfx/Fz with load
pKx3	PKX3	Exponent in slip stiffness Kfx/Fz with load
pHx1	PHX1	Horizontal shift Shx at Fznom
pHx2	PHX2	Variation of shift Shx with load
pVx1	PVX1	Vertical shift Svx/Fz at Fznom
pVx2	PVX2	Variation of shift Svx/Fz with load

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Aligning Torque

$$M_z' = M_{z0}(\alpha, \gamma, F_z)$$

$$M_{z0} = -t \cdot F_{y0} + M_{zr}$$

$$\gamma_z = \gamma \cdot \lambda_{\gamma z}$$

with the residual torque

$$\alpha_r = \alpha + S_{Hr}$$

$$M_{zr}(\alpha_r) = D_r \cos[\arctan(B_r \alpha_r)] \cos(\alpha)$$

$$S_{Hf} = S_{Hy} + S_{Vy}/K_y$$

with the pneumatic trail

$$\alpha_t = \alpha + S_{Ht}$$

$$t(\alpha_t) = D_t \cos[C_t \arctan\{B_t\alpha_t - E_t(B_t\alpha_t - \arctan(B_t\alpha_t))\}] \cos(\alpha)$$

Coefficients:

$$C_t = q_{Cz1}$$

$$B_r = q_{Bz9} \cdot \lambda_{Ky}/\lambda_{\mu y} + q_{Bz10} \cdot B_y \cdot C_y$$

$$B_t = (q_{Bz1} + q_{Bz2} df_z + q_{Bz3} df_z^2) \cdot (1 + q_{Bz4}\gamma_z + q_{Bz5}|\gamma_z|) \cdot \lambda_{Ky}/\lambda_{\mu y}$$

$$D_t = F_z \cdot (q_{Dz1} + q_{Dz2} df_z) \cdot (1 + q_{Dz3}\gamma_z + q_{Dz4}\gamma_z^2) \cdot (R_0/F_{z0}) \cdot \lambda_t$$

$$D_r = F_z \cdot ((q_{Dz6} + q_{Dz7} \cdot df_z) \quad \cdot \lambda_r + (q_{Dz8} + q_{Dz9} \cdot df_z) \quad \cdot \gamma_z) \cdot R_o \cdot \lambda_{\mu\gamma}$$

$$E_t = (q_{Ez1} + q_{Ez2} df_z + q_{Ez3} df_z^2) \left\{1 + (q_{Ez4} + q_{Ez5}\gamma_z) \cdot \left(\frac{2}{\pi}\right) \cdot \arctan(B_t \cdot C_t \cdot \alpha_t)\right\} \le 1$$

$$S_{Ht} = q_{Hz1} + q_{Hz2} df_z + (q_{Hz3} + q_{Hz4} \cdot df_z)\gamma_z$$

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Coefficients – Aligning Torque (Pure Slip)

Name:	Name used in tire property file:	Explanation:
qBz1	QBZ1	Trail slope factor for trail Bpt at Fznom
qBz2	QBZ2	Variation of slope Bpt with load
qBz3	QBZ3	Variation of slope Bpt with load squared
qBz4	QBZ4	Variation of slope Bpt with camber
qBz5	QBZ5	Variation of slope Bpt with absolute camber
qBz9	QBZ9	Slope factor Br of residual torque Mzr
qBz10	QBZ10	Slope factor Br of residual torque Mzr
qCz1	QCZ1	Shape factor Cpt for pneumatic trail
qDz1	QDZ1	Peak trail Dpt" = Dpt*(Fz/Fznom*R0)
qDz2	QDZ2	Variation of peak Dpt" with load
qDz3	QDZ3	Variation of peak Dpt" with camber
qDz4	QDZ4	Variaion of peak Dpt" with camber squared.
qDz6	QDZ6	Peak residual torque Dmr" = Dmr/ (Fz*R0)
qDz7	QDZ7	Variation of peak factor Dmr" with load
qDz8	QDZ8	Variation of peak factor Dmr" with camber
qDz9	QDZ9	Variation of peak factor Dmr" with camber and load
qEz1	QEZ1	Trail curvature Ept at Fznom
qEz2	QEZ2	Variation of curvature Ept with load
qEz3	QEZ3	Variation of curvature Ept with load squared
qEz4	QEZ4	Variation of curvature Ept with sign of Alpha-t
qEz5	QEZ5	Variation of Ept with camber and sign Alpha-t
qHz1	QHZ1	Trail horizontal shift Sht at Fznom
qHz2	QHZ2	Variation of shift Sht with load
qHz3	QHZ3	Variation of shift Sht with camber
qHz4	QHZ4	Variation of shift Sht with camber and load

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Overturning Moment

$$M_x = R_o \cdot F_z \cdot \{q_{Sx1} \cdot \lambda_{Vmx} + (-q_{Sx2} \cdot \gamma + q_{Sx3} \cdot F_y / F_{z0}) \cdot \lambda_{Mx}\}$$

Name:	Name used in tire property file:	Explanation:
qsx1	QSX1	Lateral force induced overturning couple
qsx2	QSX2	Camber induced overturning couple
qsx3	QSX3	Fy induced overturning couple

Rolling Resistance

$$M_y = R_o \cdot F_z \cdot \{q_{Sy1} + q_{Sy2} F_x / F_{z0} + q_{Sy3} \left| V_x / V_{ref} \right| + q_{Sy4} (V_x / V_{ref})^4\}$$

Name:	Name used in tire property file:	Explanation:
qsy1	QSY1	Rolling resistance torque coefficient
qsy2	QSY2	Rolling resistance torque depending on Fx
qsy3	QSY3	Rolling resistance torque depending on speed
qsy4	QSY4	Rolling resistance torque depending on speed^4
Vref	LONGVL	Measurement speed

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Lateral Slip (Combined Slip)

$$F_y = F_{y0} \cdot G_{y\kappa}(\alpha, \kappa, \gamma, F_z) + S_{Vy\kappa}$$

$$F_y = D_{y\kappa} \cos[C_{y\kappa} \arctan\{B_{y\kappa}\kappa_s - E_{y\kappa}(B_{y\kappa}\kappa_s - \arctan(B_{y\kappa}\kappa_s))\}] + S_{Vy\kappa}$$

$$\kappa_s = \kappa + S_{Hy\kappa}$$

with weighting function:

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

Coefficients:

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

$$C_{y\kappa} = r_{Cy1}$$

$$D_{y\kappa} = \frac{F_{yo}}{\cos[C_{y\kappa} \arctan\{B_{y\kappa}S_{Hy\kappa} - E_{yk}(B_{y\kappa}S_{Hy\kappa} - \arctan(B_{y\kappa}S_{Hy\kappa}))\}]}$$

$$D_{Vy\kappa} = \mu_y F_z \cdot (r_{Vy1} + r_{Vy2} df_z + r_{Vy3}\gamma) \cdot \cos[\arctan(r_{Vy4}\alpha)]$$

$$E_{y\kappa} = r_{Ey1} + r_{Ey2} df_z$$

$$S_{Hy\kappa} = r_{Hy1} + r_{Hy2} df_z$$

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

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Coefficients – Lateral Slip (Combined Slip)

Name:	Name used in tire property file:	Explanation:
rBy1	RBY1	Slope factor for combined Fy reduction
rBy2	RBY2	Variation of slope Fy reduction with alpha
rBy3	RBY3	Shift term for alpha in slope Fy reduction
rCy1	RCY1	Shape factor for combined Fy reduction
rEy1	REY1	Curvature factor of combined Fy
rEy2	REY2	Curvature factor of combined Fy with load
rHy1	RHY1	Shift factor for combined Fy reduction
rHy2	RHY2	Shift factor for combined Fy reduction with load
rVy1	RVY1	Kappa induced side force Svyk/Muy*Fz at Fznom
rVy2	RVY2	Variation of Svyk/Muy*Fz with load
rVy3	RVY3	Variation of Svyk/Muy*Fz with camber
rVy4	RVY4	Variation of Svyk/Muy*Fz with alpha
rVy5	RVY5	Variation of Svyk/Muy*Fz with kappa
rVy6	RVY6	Variation of Svyk/Muy*Fz with atan (kappa)

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Pure Longitudinal Slip

$$F_x = F_{x0} \cdot G_{x\alpha}(\alpha, \kappa, F_z)$$

$$F_x = D_{x\alpha} \cos[C_{x\alpha} \arctan\{B_{x\alpha}\alpha_s - E_{x\alpha}(B_{x\alpha}\alpha_s - \arctan(B_{x\alpha}\alpha_s))\}]$$

$$\alpha_s = \alpha + S_{Hx\alpha}$$

with weighting function:

$$G_{x\alpha} = \frac{\cos[C_{x\alpha} \arctan\{B_{x\alpha}\alpha_s - E_{x\alpha}(B_{x\alpha}\alpha_s - \arctan(B_{x\alpha}\alpha_s))\}]}{\cos[C_{x\alpha} \arctan[B_{x\alpha}S_{Hxa} - E_{x\alpha}(B_{x\alpha}S_{Hx\alpha} - \arctan(B_{x\alpha}S_{Hx\alpha}))]]}$$

Coefficients:

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

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

$$D_{x\alpha} = \frac{F_{xo}}{\cos[C_{x\alpha} \arctan\{B_{x\alpha}S_{Hx\alpha} - E_{x\alpha}(B_{x\alpha}S_{Hx\alpha} - \arctan(B_{x\alpha}S_{Hx\alpha}))\}]}$$

$$E_{x\alpha} = r_{Ex1} + r_{Ex2} df_z$$

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

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Aligning Torque (Combined Slip)

$$M_z' = -t \cdot F_y' + M_{zr} + s \cdot F_x$$

$$t = t(\alpha_{t,eq})$$

$$= D_t \cos[C_t \arctan\{B_t \alpha_{t,eq} - E_t(B_t \alpha_{t,eq} - \arctan(B_t \alpha_{t,eq}))\}] \cos(\alpha)$$

with:

$$F'_{y,\gamma=0} = F_y - S_{Vy\kappa}$$

$$M_{zr} = M_{zr}(\alpha_{r,eq}) = D_r \cos[\arctan(B_r \alpha_{r,eq})] \cos(\alpha)$$

$$s = \{s_{sz1} + s_{sz2}(F_y / F_{z0}) + (s_{sz3} + s_{sz4} df_z)\gamma\} \cdot R_0 \cdot \lambda_s$$

with the arguments:

$$\alpha_{t,eq} = \arctan\sqrt{\tan^2\alpha_t + \left(\frac{K_x}{K_y}\right)^2 \kappa^2} \cdot \mathrm{sgn}(\alpha_t) \qquad \alpha_{r,eq} = \arctan\sqrt{\tan^2\alpha_r + \left(\frac{K_x}{K_y}\right)^2 \kappa^2} \cdot \mathrm{sgn}(\alpha_r)$$

7.3 Tire Model Guide – Magic Formula 5.2 Equations

Coefficients – Longitudinal Slip (Combined Slip)

Name:	Name used in tire property file:	Explanation:
rBx1	RBX1	Slope factor for combined slip Fx reduction
rBx2	RBX2	Variation of slope Fx reduction with kappa
rCx1	RCX1	Shape factor for combined slip Fx reduction
rEx1	REX1	Curvature factor of combined Fx
rEx2	REX2	Curvature factor of combined Fx with load
rHx1	RHX1	Shift factor for combined slip Fx reduction

Coefficients – Aligning Torque (Combined Slip)

Name:	Name used in tire property file:	Explanation:
ssz1	SSZ1	Nominal value of s/R0 effect of Fx on Mz
ssz2	SSZ2	Variation of distance s/R0 with Fy/Fznom
ssz3	SSZ3	Variation of distance s/R0 with camber
ssz4	SSZ4	Variation of distance s/R0 with load and camber

8. Inflation Pressure Guide

For good performance of the tire, the footprint should be large while the contact pressure distribution should be as homogeneous as possible. To achieve this, the right inflation pressure for the right application is crucial. In general, less inflation pressure gives a larger contact area, but increases tire deformation. Low inflation pressures can be of benefit for the longitudinal performance, i.e. in the acceleration event, but decrease the lateral performance of the car in terms of grip and handling.

The inflation pressure guide aims to provide a range of appropriate inflation pressures regarding the actual tire load (dynamically loaded tire) and application.

Explanations:

x-axis (Normal Load):	the dynamic tire load for the condition of interest (*static load + load transfer from longitudinal / lateral acceleration + aerodynamic load*)
y-axis (Inflation Pressure):	
lat. performance zone:	recommended range for cornering performance
long. performance zone:	recommended range for drive/brake performance

8. Inflation Pressure Guide