

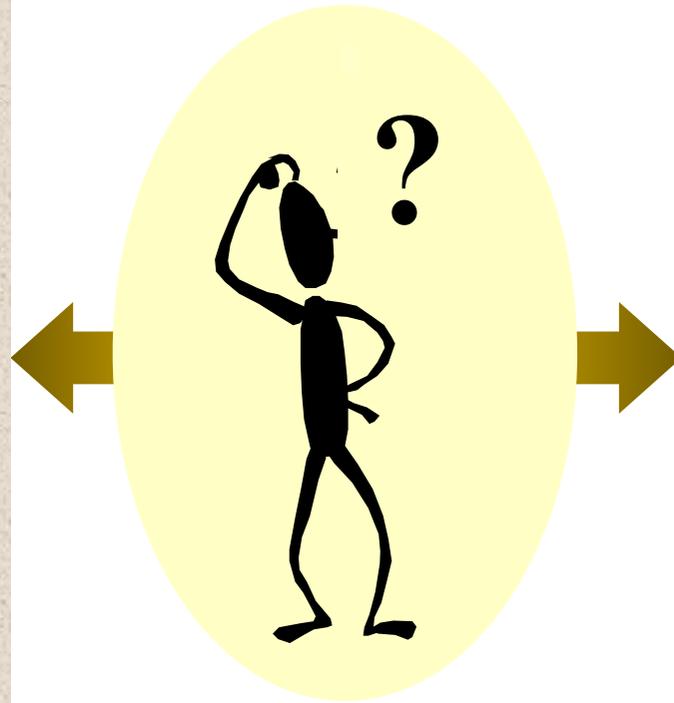
Role of Tire Modeling on the Design Process of a Tire and Vehicle System

Gwanghun Gim, Yongchul Choi*

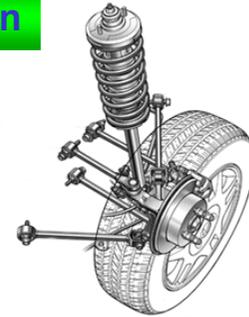
Nov., 2001

Hankook Tire Co., Ltd.

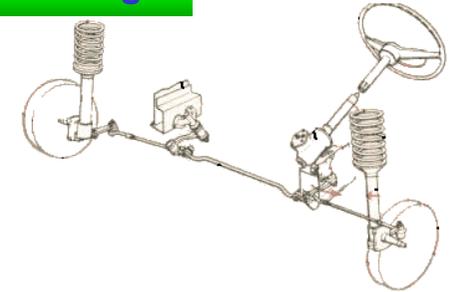
- Application of a tire model
- Tire characteristic
- Semi-physical tire model
- Validation
- Conclusion



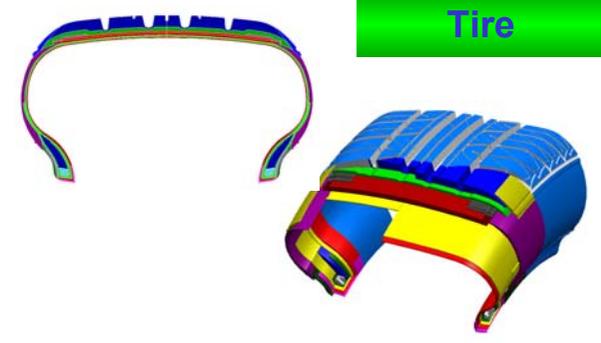
Suspension

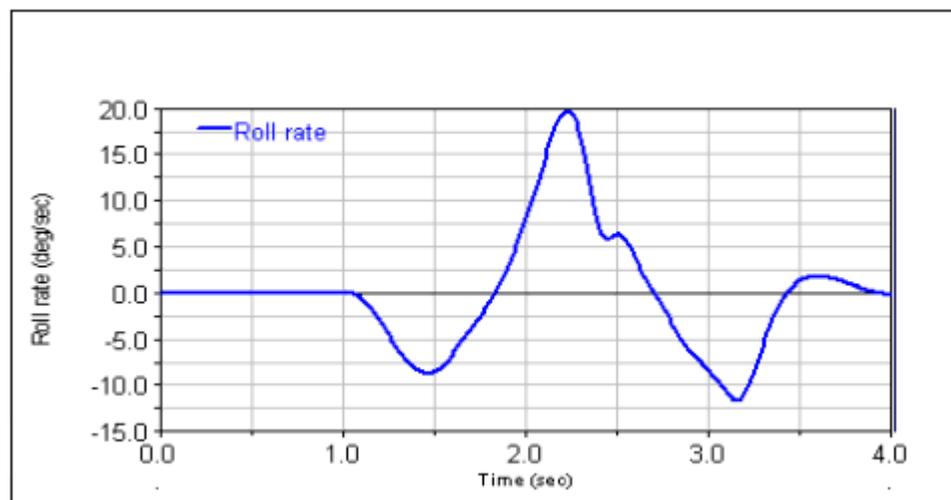
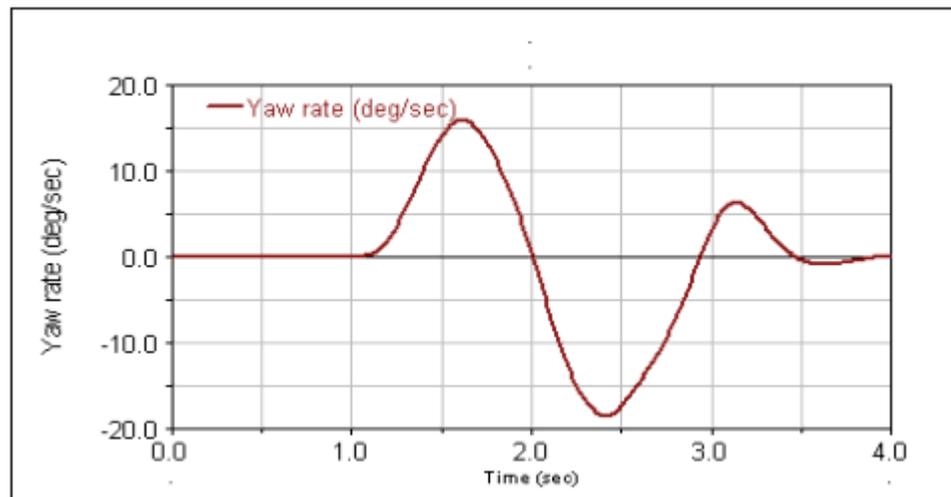
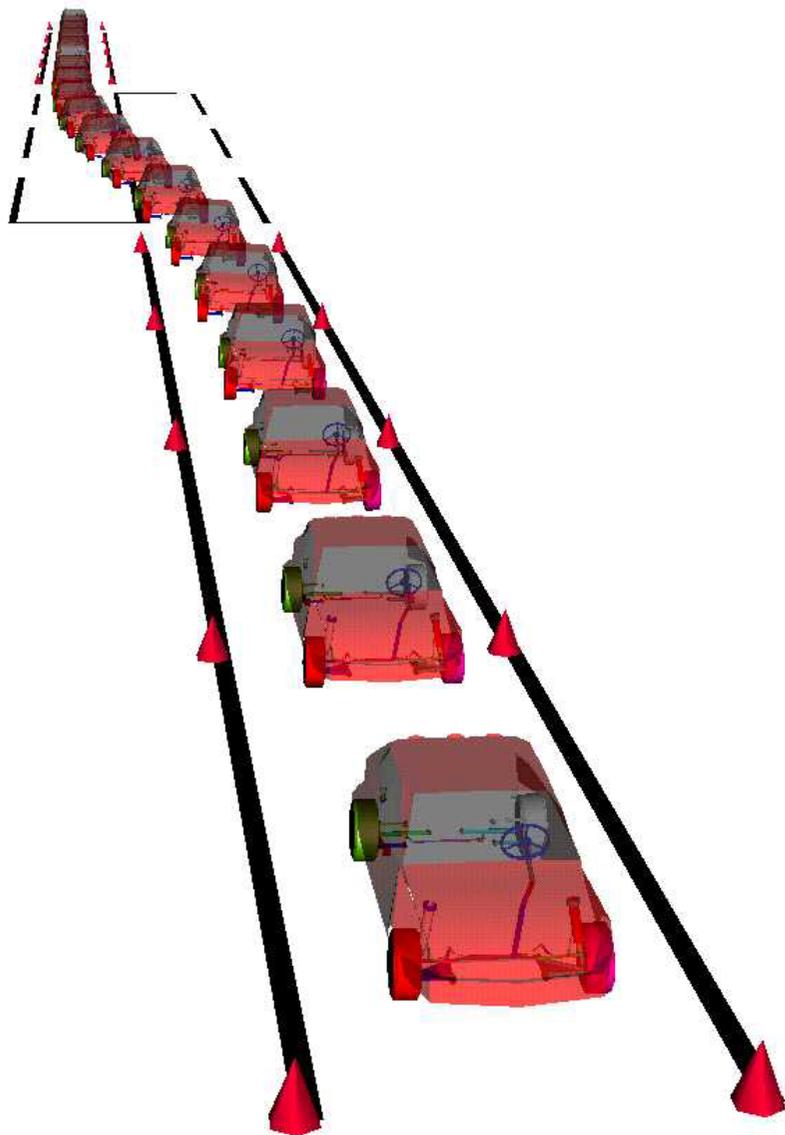


Steering



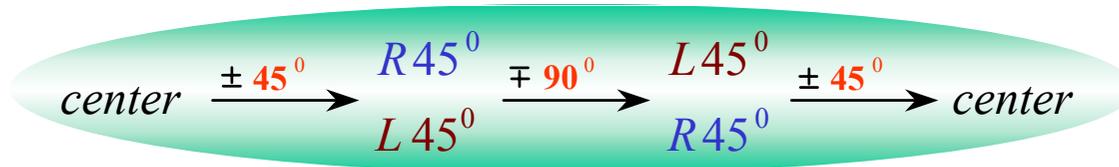
Tire





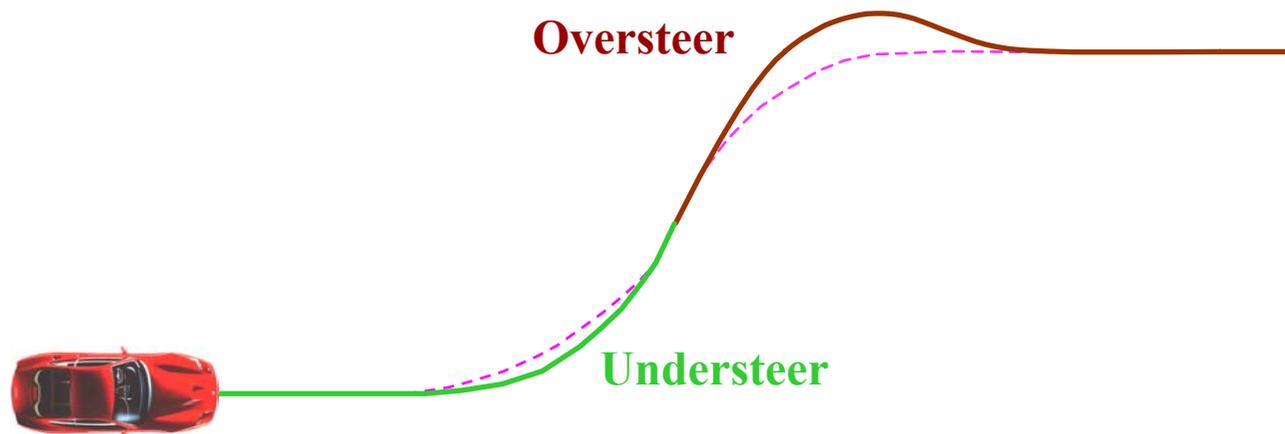


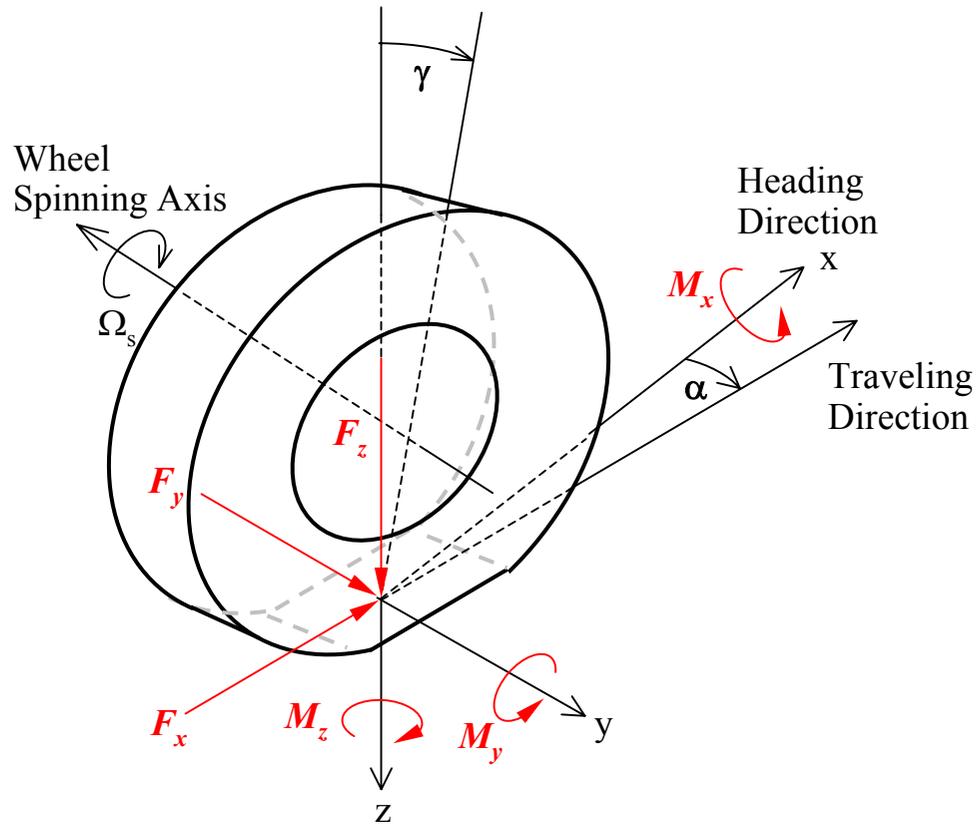
Subjective Test Procedure

Lane change

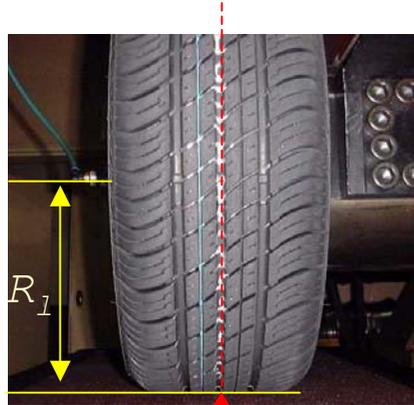
- ☞ *Smooth* steering input
- ☞ Constant speed near limit speed

Subjective Assessment

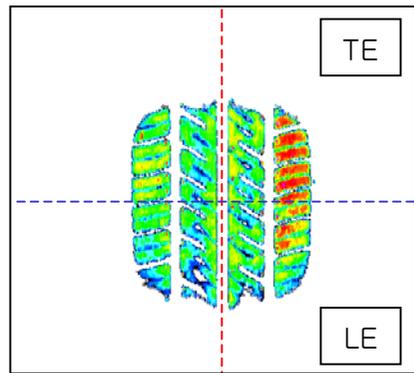




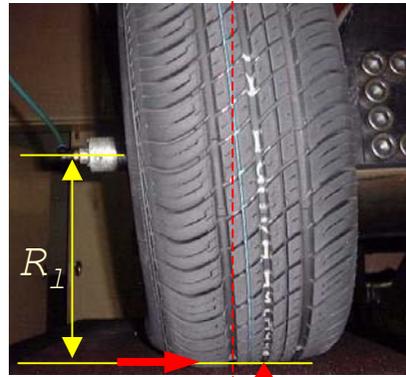
Straight Running



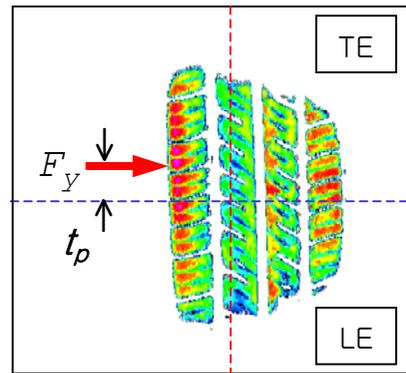
F_z



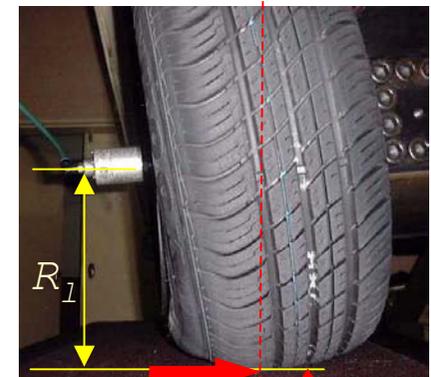
Normal Cornering



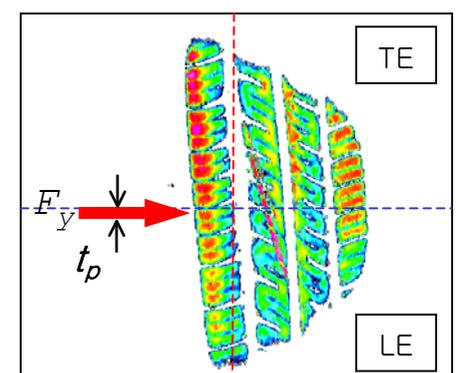
F_y δ_y F_z



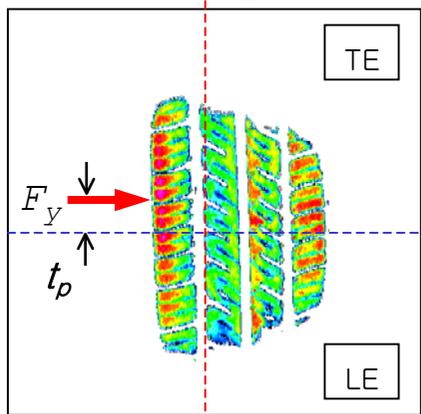
Severe Cornering



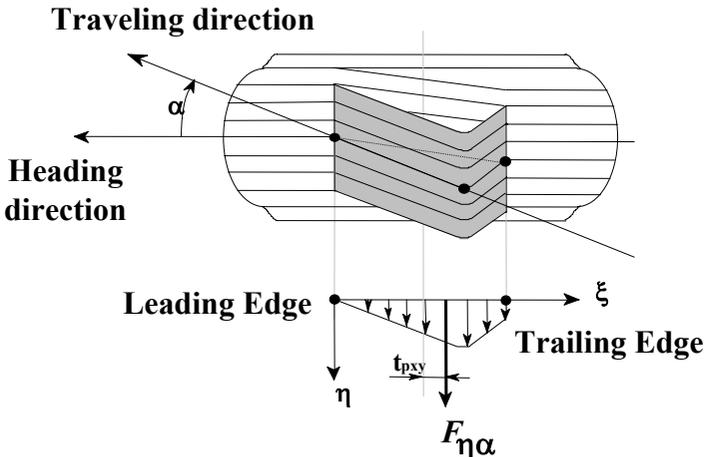
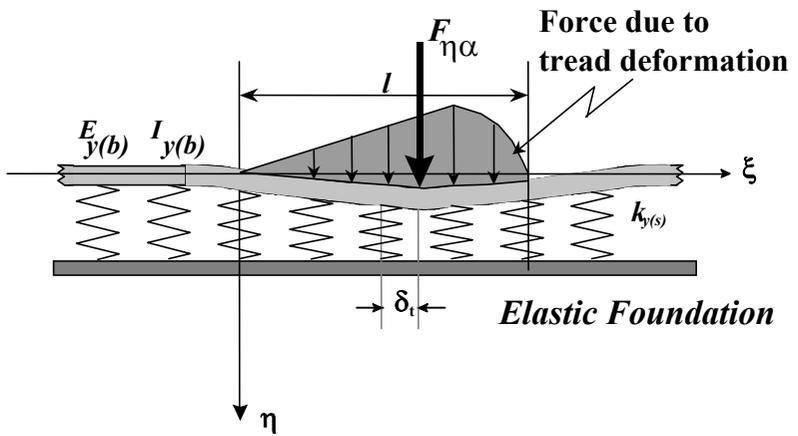
F_y δ_y F_z



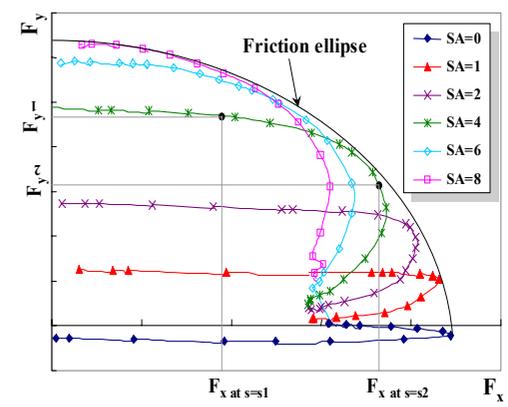
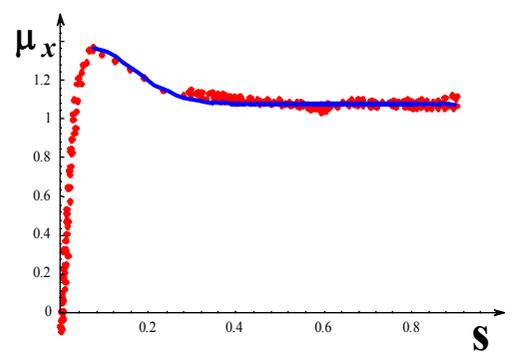
New Concept



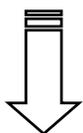
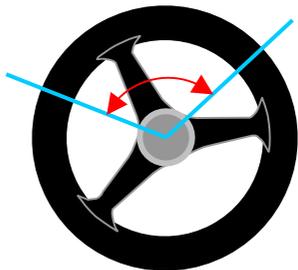
Physical modeling



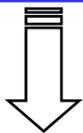
Empirical Fitting



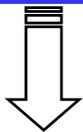
Steering wheel angle



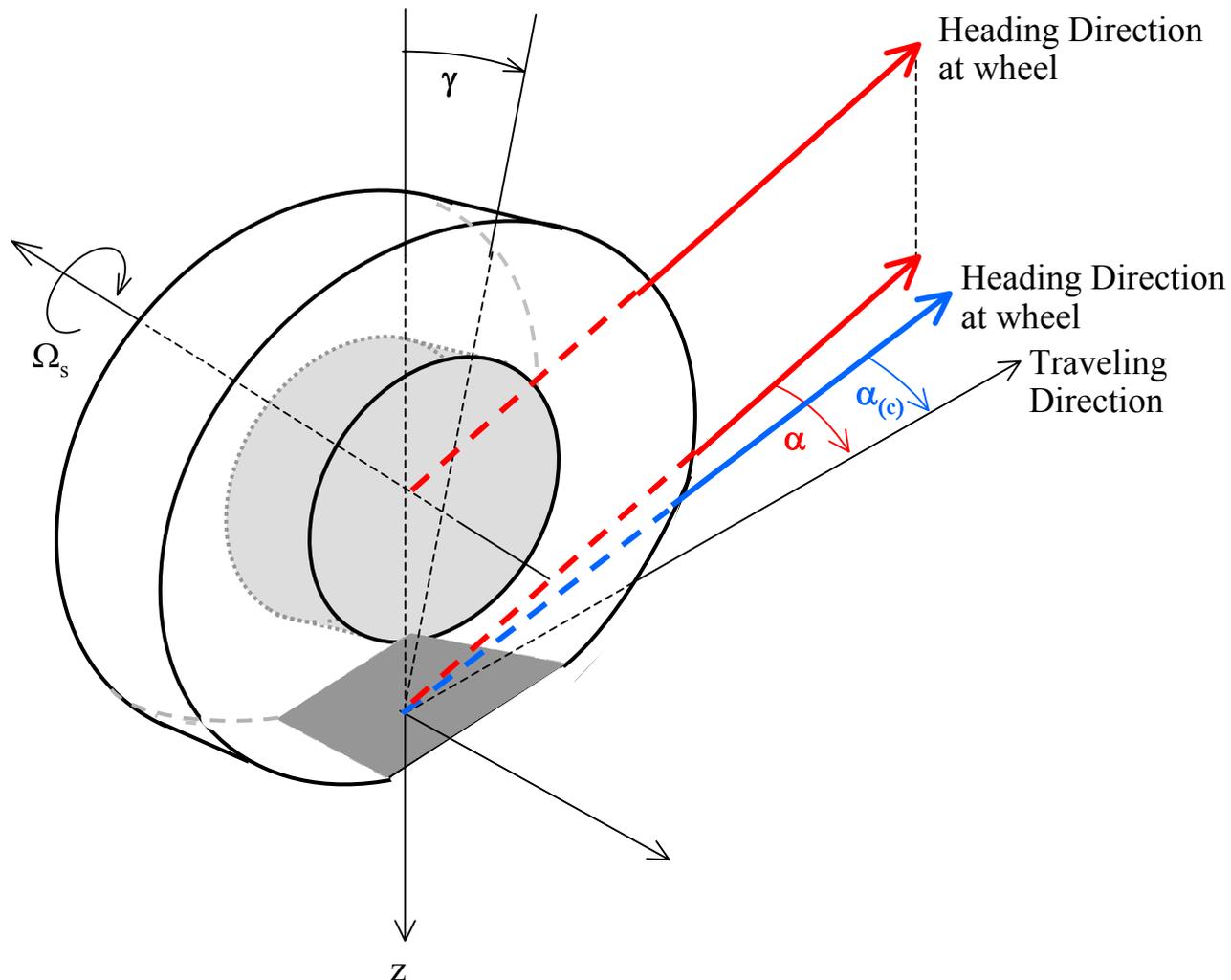
Slip angle at wheel center



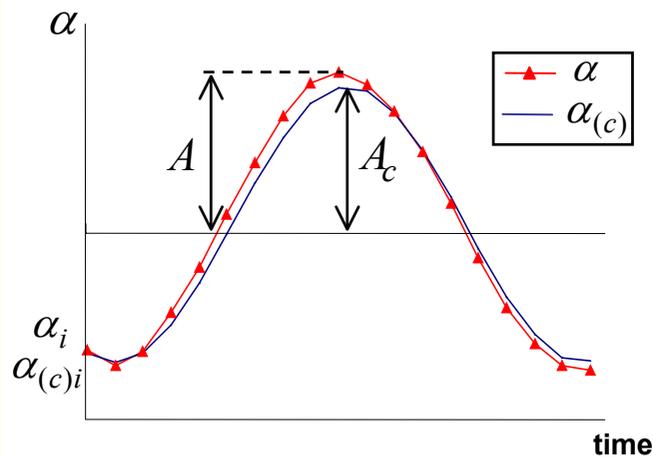
Slip angle at contact patch



Lateral force, F_y

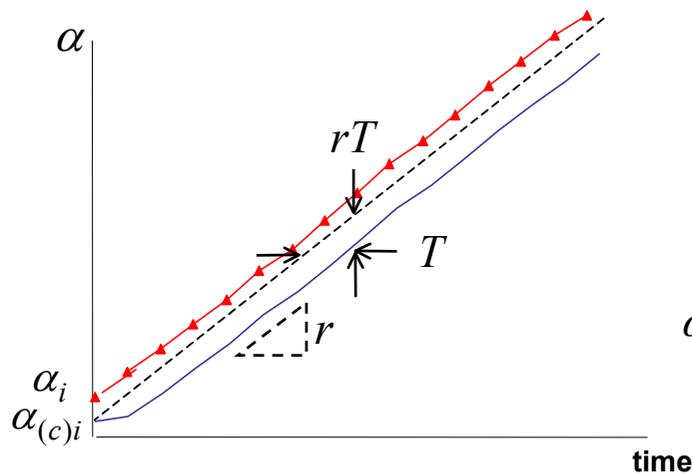


Sinusoidal



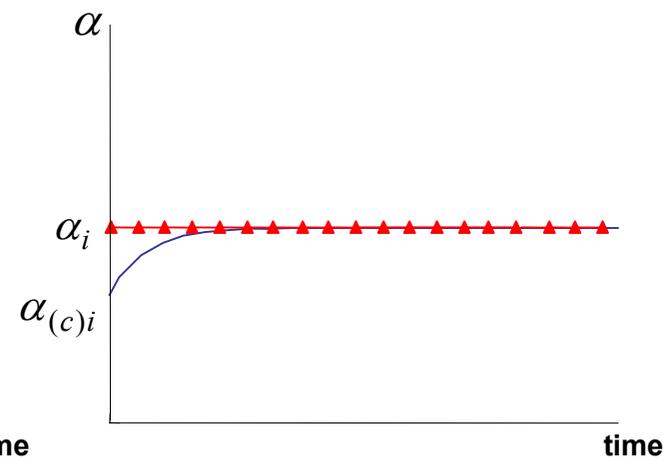
$$\alpha(t) = A \sin(\omega t)$$

Ramp



$$\alpha(t) = \alpha_i + r \cdot t$$

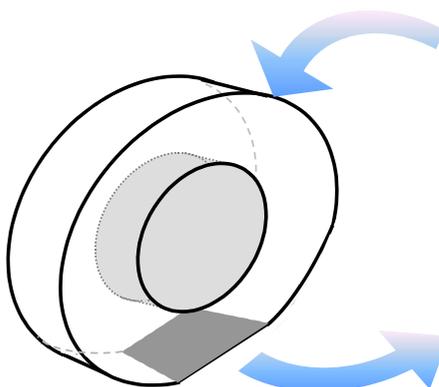
Constant



$$\alpha(t) = \alpha_i$$

2nd order diff. equation

$$\ddot{\alpha}_{(c)} + 2\xi\omega_n\dot{\alpha}_{(c)} + \omega_n\alpha_{(c)} = \alpha$$

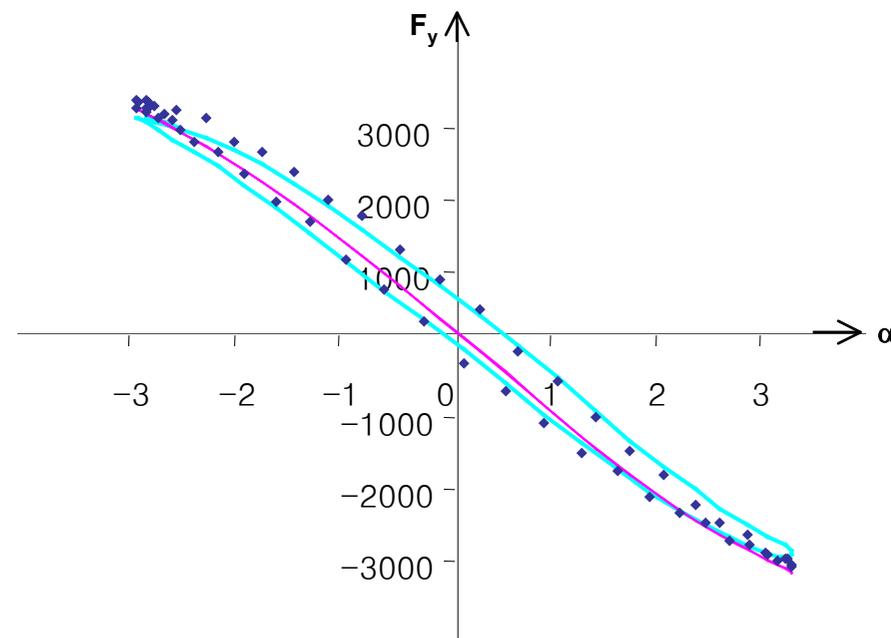
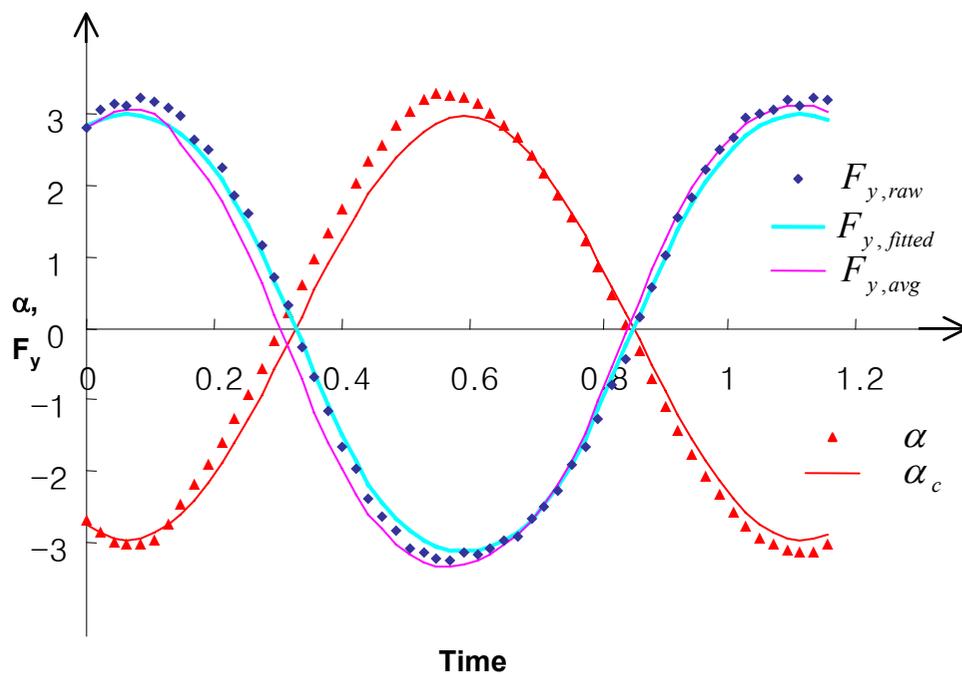


Slip angle at wheel center

$$\alpha(t) = A \sin(\omega t)$$

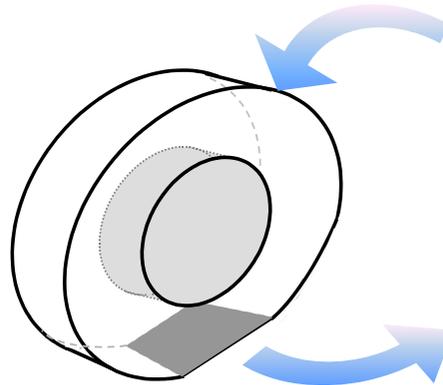
Slip angle at contact patch

$$\alpha_{(c)}(t) = A_C \sin(\omega t + \phi)$$



1st order diff. equation

$$T\dot{\alpha}_{(c)} + \alpha_{(c)} = \alpha$$

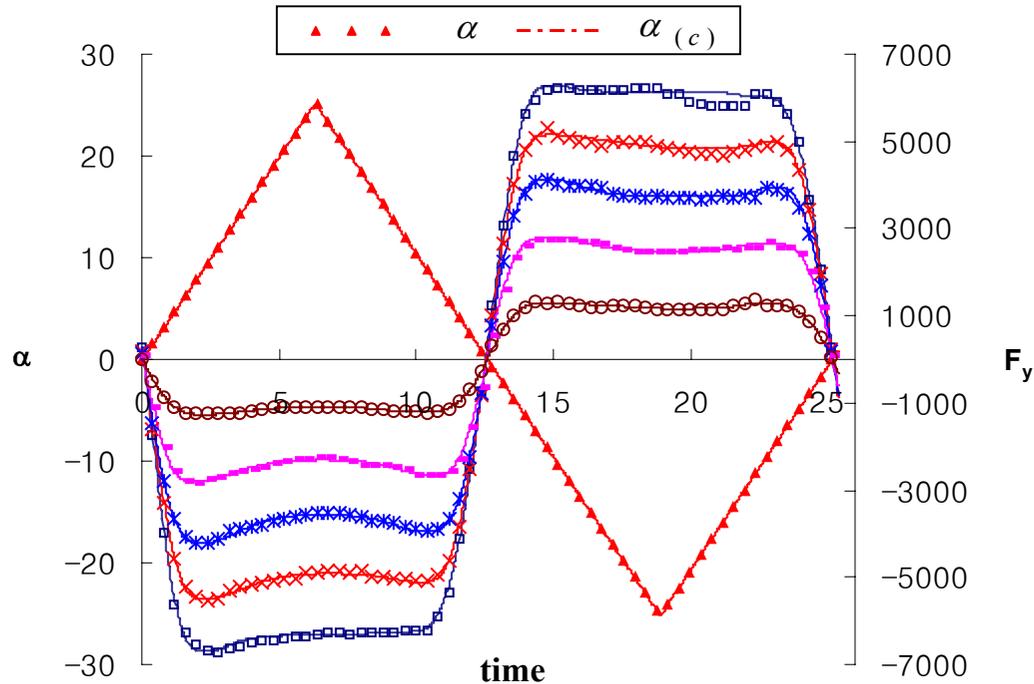


Slip angle at wheel center

$$\alpha = \alpha_i + rt$$

Slip angle at contact patch

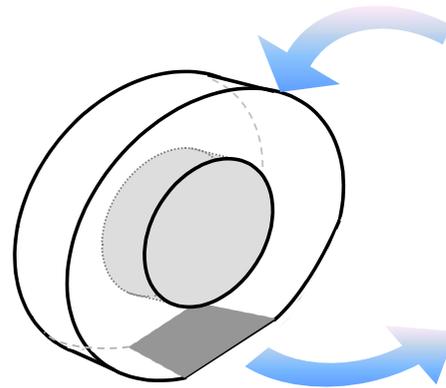
$$\alpha_{(c)}(t) = \alpha_i + r(t-T) + (\alpha_{(c)i} - \alpha_i + rT)e^{-\frac{t}{T}}$$



Exp.	Pred.	load
□	—	175%Fz
×	—	137%Fz
*	—	100%Fz
■	—	67%Fz
○	—	25%Fz

1st order diff. equation

$$T\dot{\alpha}_{(c)} + \alpha_{(c)} = \alpha$$

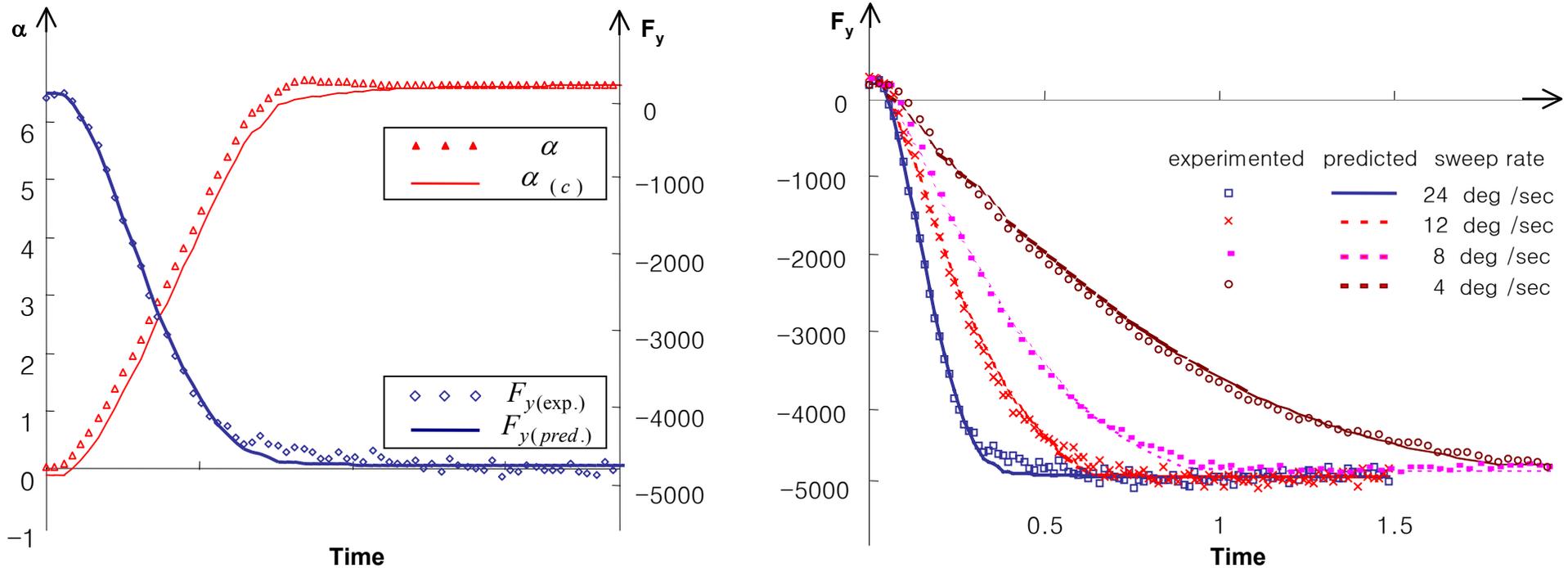


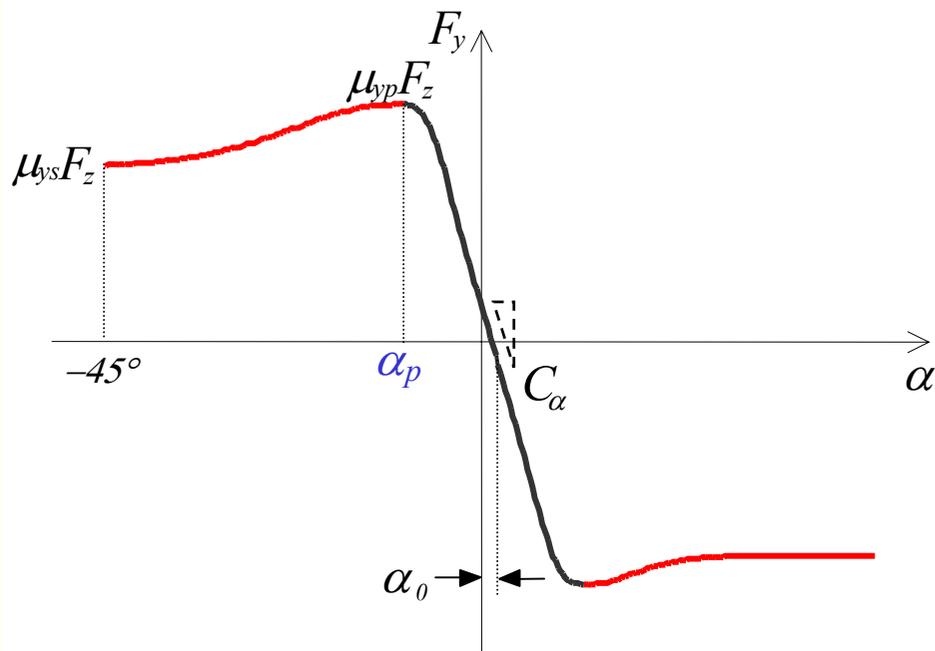
Slip angle at wheel center

$$\alpha = \alpha_i$$

Slip angle at contact patch

$$\alpha_{(c)}(t) = \alpha_i + (\alpha_{(c)i} - \alpha_i)e^{-\frac{t}{T}}$$





Analytical Formulation of Lateral Force

For $|\tan \alpha_{(c)}| < |\tan \alpha_{(c)p}|$

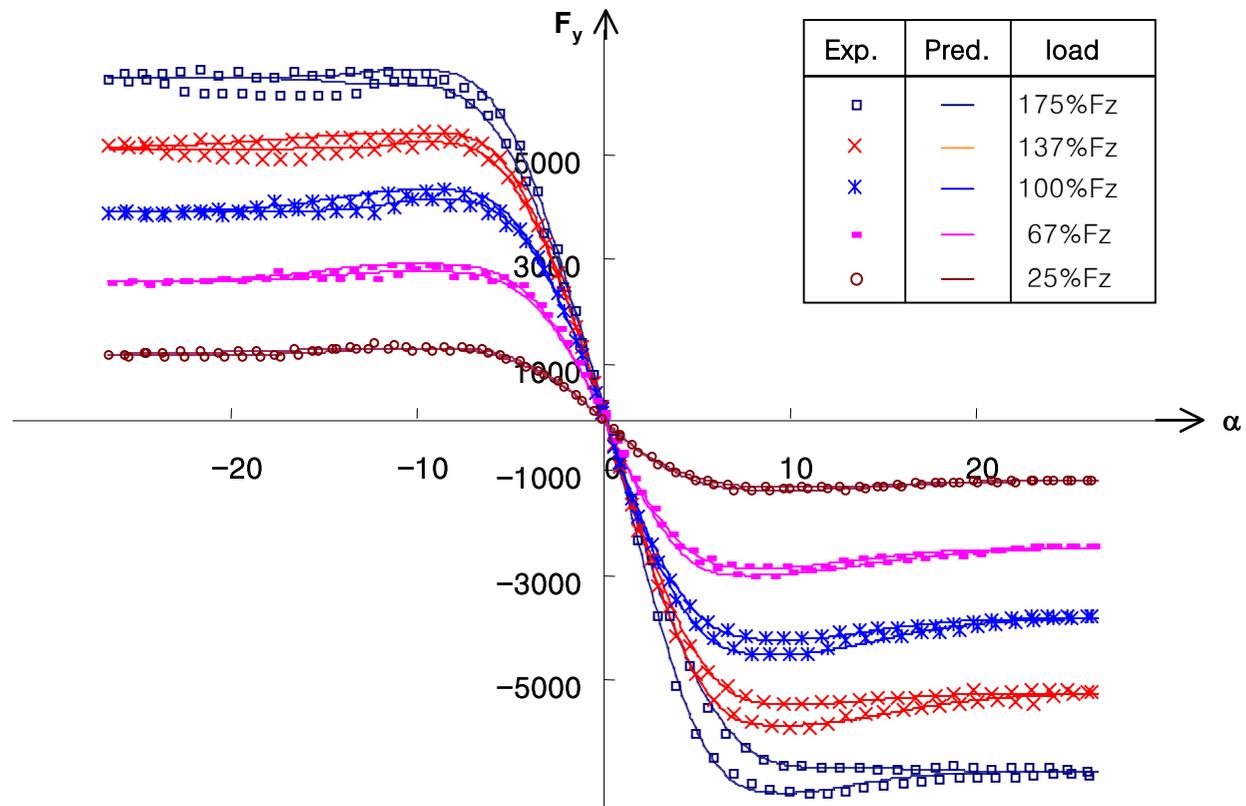
$$F_y(\alpha, F_z) = C_\gamma \sin(\gamma - \gamma_0) + C_\alpha \tan(\alpha_{(c)} - \alpha_0) l_n^2 + \left\{ -C_\gamma \sin(\gamma - \gamma_0) + \mu_{yp} F_z \right\} (1 - 3l_n^2 + 2l_n^3)$$

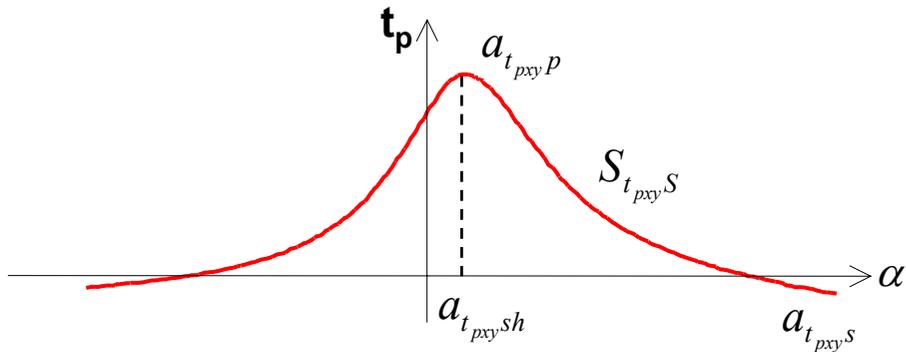
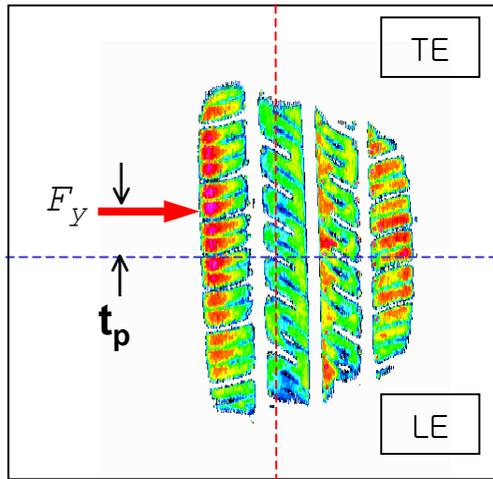
Empirical Formulation of Lateral Friction

For $|\tan \alpha_{(c)}| > |\tan \alpha_{(c)p}|$

$$F_y(\alpha, F_z) = \left[\mu_{ys} + (\mu_{yp} - \mu_{ys}) \operatorname{sech} \left\{ S_{\mu y} \frac{|\tan \alpha_{(c)}| - |\tan \alpha_{(c)p}|}{1 - |\tan \alpha_{(c)}|} \right\} \right] F_z$$

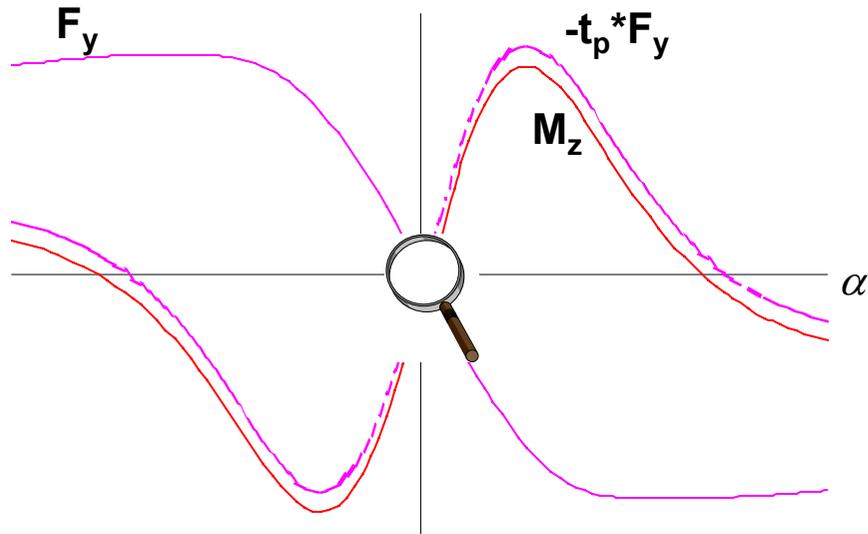
Lateral Force





**Empirical Formulation
of Pneumatic Trail**

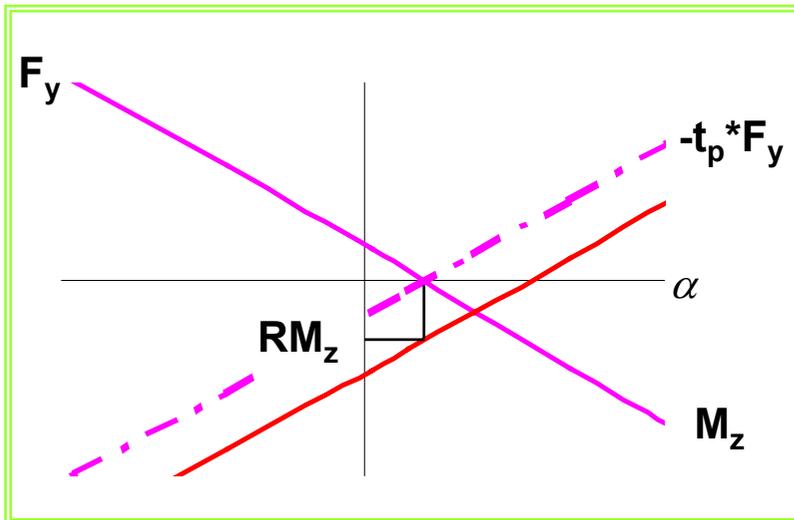
$$t_{pxy} = a_{t_{pxy}S} + (a_{t_{pxy}S} - a_{t_{pxy}P}) \operatorname{sech} \left[S_{t_{pxy}S} \frac{|\alpha| - |a_{t_{pxy}Sh}|}{1 - |\alpha|} \right]$$



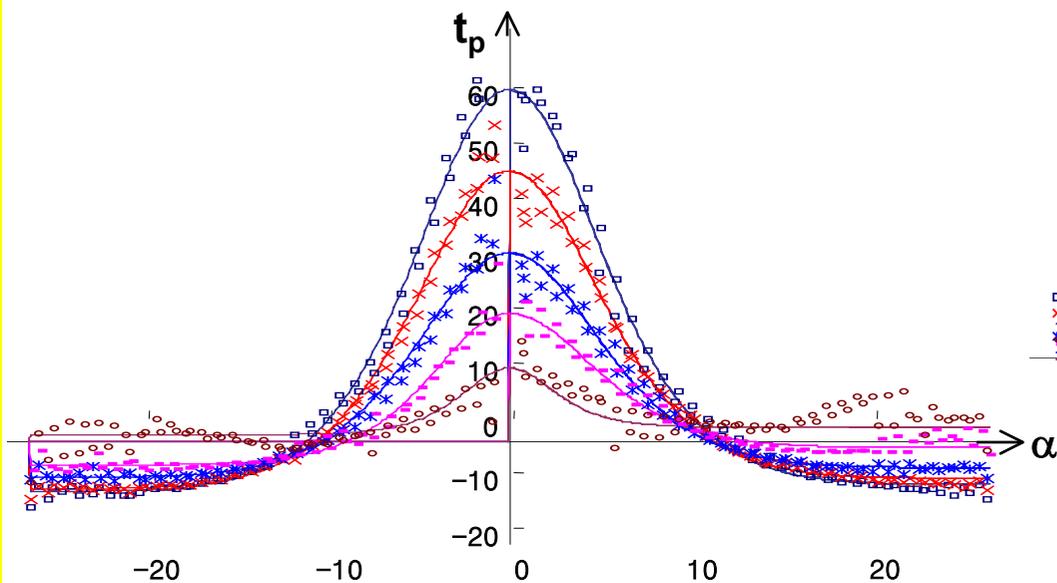
Self-aligning Moment

$$M_z = RM_z - t_p \cdot F_y$$

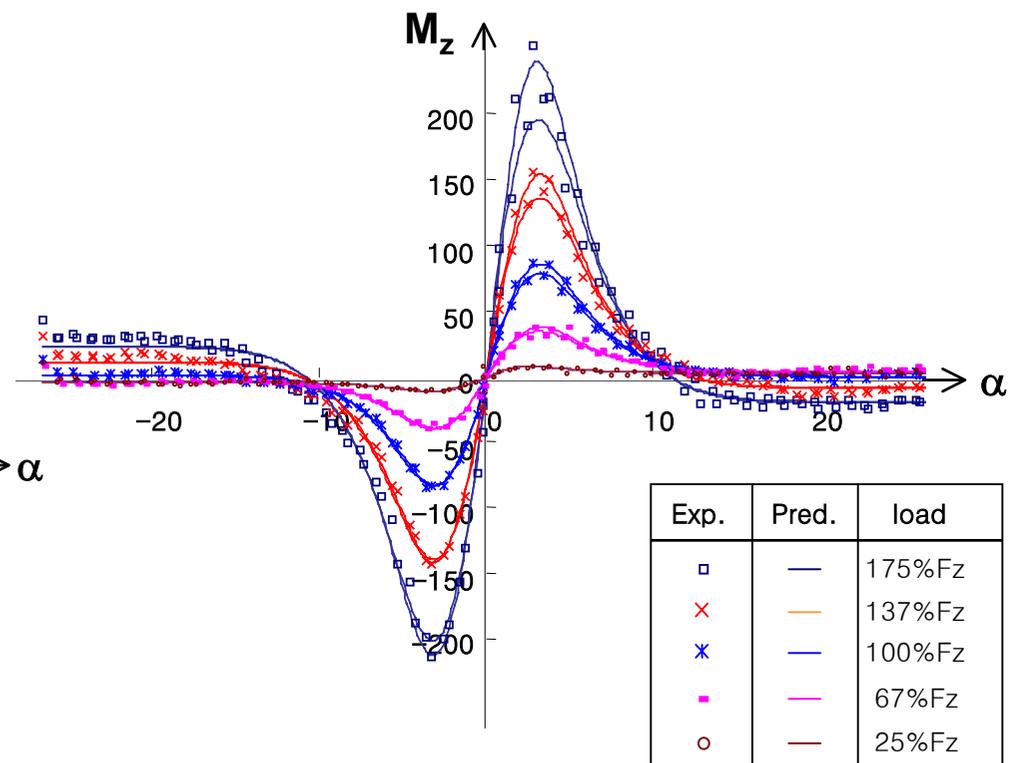
RM_z : Residual aligning moment



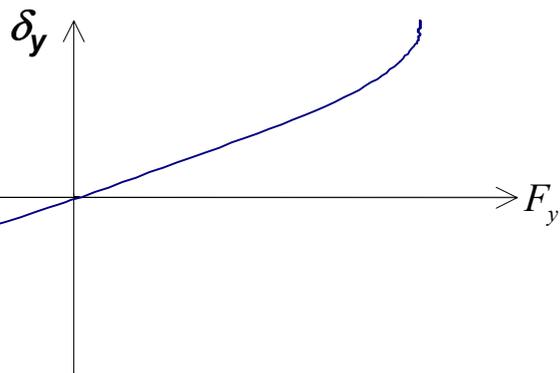
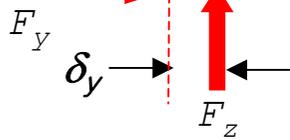
Pneumatic trail



Self-aligning moment



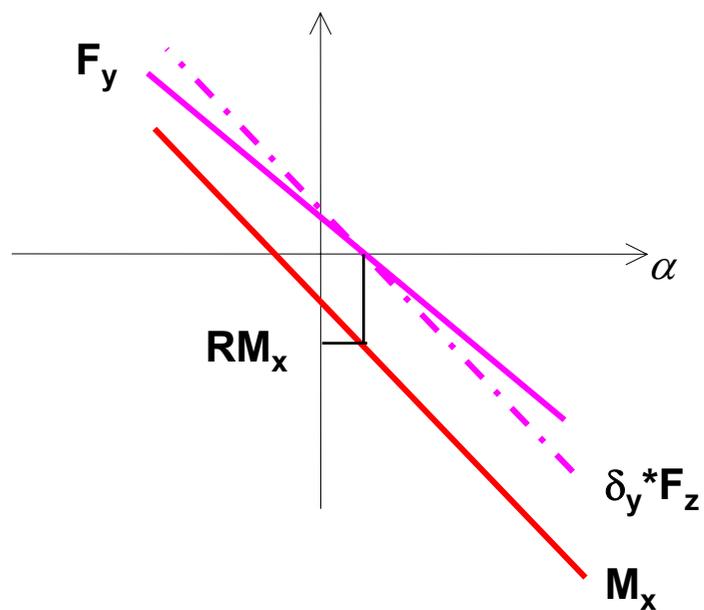
Exp.	Pred.	load
□	—	175%Fz
×	—	137%Fz
*	—	100%Fz
■	—	67%Fz
○	—	25%Fz



Empirical Formulation of *Lateral Deformation*

$$\delta_y = a_{\delta_y,3} \bar{F}_y^3 + a_{\delta_y,2} \bar{F}_y^2 + a_{\delta_y,1} \bar{F}_y + a_{\delta_y,0}$$

where $\bar{F}_y = \frac{F_y}{F_z}$

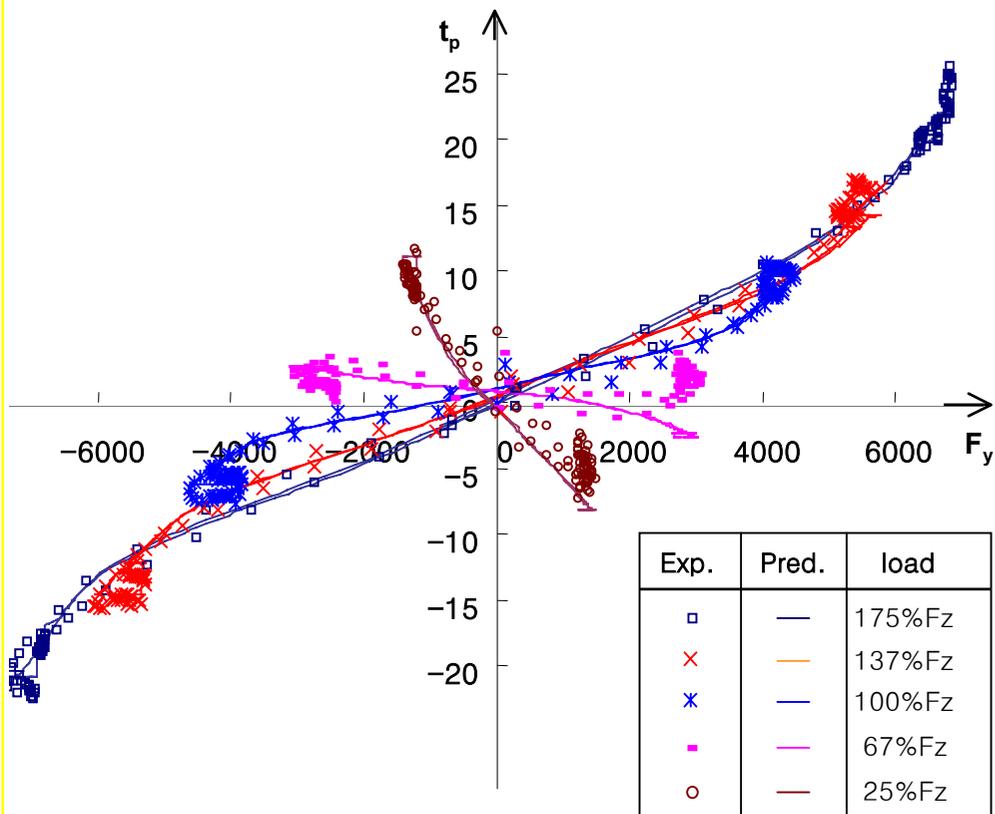


Overturning moment

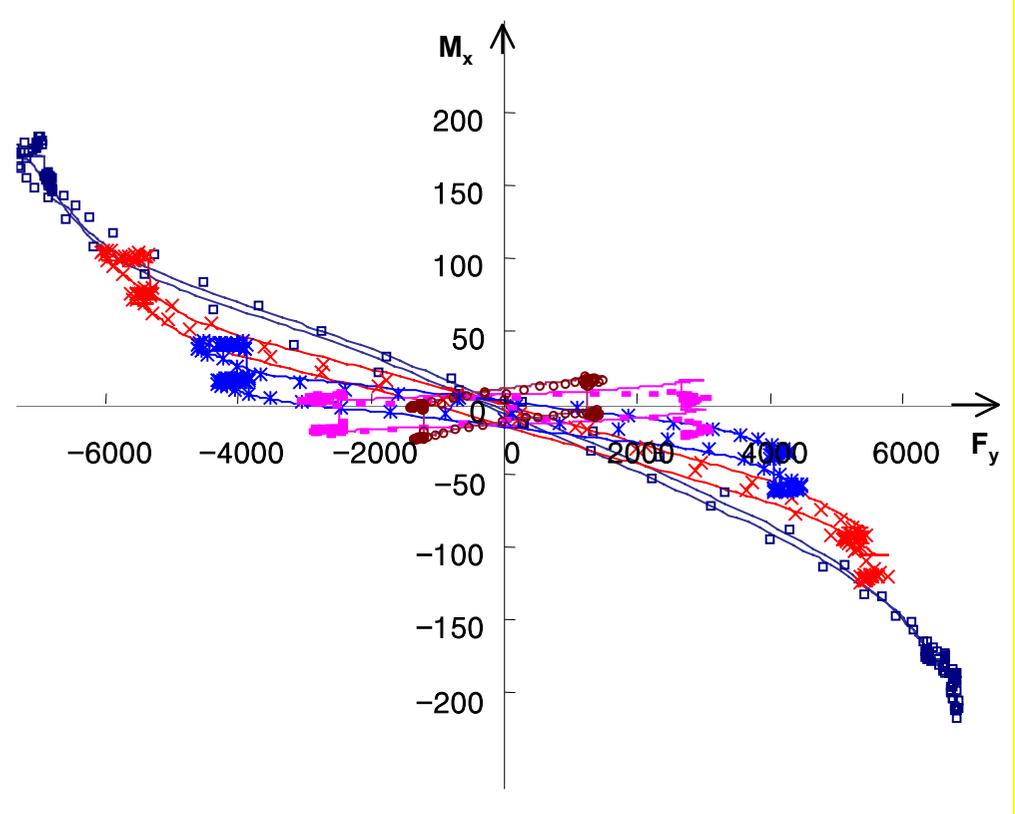
$$M_x = RM_x + \delta_y \cdot F_z$$

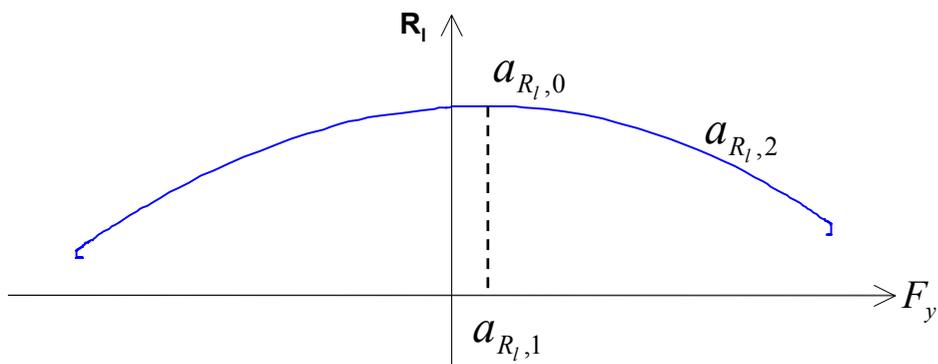
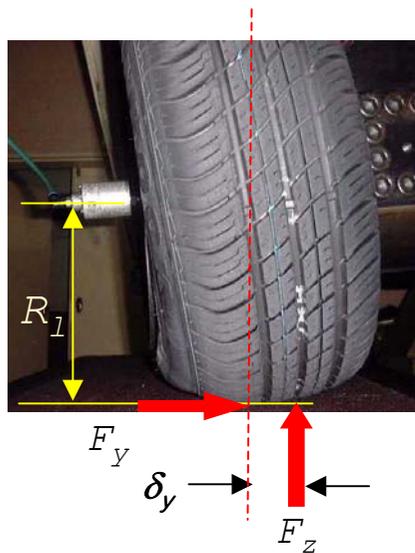
RM_x : Residual overturning moment

Lateral deformation



Overturning moment





Empirical Formulation of Loaded Radius

$$R_l = a_{R_l,2} (\bar{F}_y - a_{R_l,1})^2 + a_{R_l,0}$$

where $\bar{F}_y = \frac{F_y}{F_z}$

Loaded radius

