List of Symbols

a	distance front axle to c.g.; half of contact length
a_x	longitudinal acceleration
a_y	lateral acceleration
a_μ	slip velocity dependency coefficient for friction
A_r	rolling resistance coefficient
b	distance rear axle to c.g.; half contact width
B	stiffness factor in *'Magic Formula'*
B_1	brake force of rolling wheel
c	stiffness; factor
c_c	lateral carcass stiffness per unit length
c_{gyr}	non-dimensional gyroscopic coefficient
$c_{px,y}$	tread element stiffness per unit length of circumference
c'_{px}	tread element longitudinal stiffness per unit area
C	cornering stiffness ; sum front and rear
C_i	cornering stiffness, sum left and right
C	contact centre (point of intersection)
C	shape factor in *'Magic Formula'*
C_{dA}	air drag coefficient
C_{Fx}	longitudinal stiffness of standing tyre
C_{Fy}	lateral stiffness of standing tyre
C_{Fz}	stiffness of tyre normal to the road
$C_{F\alpha}$	cornering stiffness
$C_{F\kappa}$	longitudinal slip stiffness
$C_{F\gamma}$	camber stiffness for side force
$C_{F\varphi}$	spin stiffness for side force
C_{gyr}	tyre gyroscopic coefficient
$C_{M\alpha}$	aligning torque stiffness
$C_{M\gamma}$	camber stiffness for aligning torque
$C_{M\varphi}$	spin stiffness for aligning torque
$C_{M\psi}$	torsional yaw stiffness of standing tyre
$C_{Mx\gamma}$	overturning couple stiffness against camber
$C_{cx,y}$	carcass horizontal stiffness of standing tyre
C_{gyr}	gyroscopic coefficient
df_z	normalised change in normal load, Eq.(4.E2)
d_t	tread depth
D	peak factor in *'Magic Formula'*; dissipation function

E	curvature factor in 'Magic Formula'
e	caster length; tread element deflection
f	trail of c.g.
f_r	rolling resistance coefficient
F_{ax}	force for forward acceleration
F_d	air drag force
$F_{x,tot}$	sum of longitudinal tyre forces
F_x	longitudinal tyre force
F_y	lateral tyre force
F_z	vertical (normal) tyre force (load) (>0), in Chap.9: F_z<0
F_r	rolling resistance force (>0)
F_N	tyre normal force (>0)
F_{No}	reference vertical load, nominal load (= $\|F_{zo}\|$)
F_V	tyre vertical force
F_H	tyre longitudinal horizontal force
g	acceleration due to gravity; feedback rider control gain
G	weighting factor
h	height
H	height; sharpness factor in 'Magic Formula'
H	transform; Hurwitz determinant
i	$\sqrt{-1}$
i_z	radius of inertia
I	moment of inertia
I_w	wheel polar moment of inertia
I_p	wheel polar moment of inertia
j	$\sqrt{-1}$
k	radius of inertia; viscous damping coefficient
K	centrifugal force; force acting in belt, wheel centre
l	wheel base
l_s	shift; two-point follower length
l_b	length of basic curve
l_f	offset
$\boldsymbol{l}$	unit vector along line of intersection
m	mass; fraction of $2a$ where adhesion occurs
m_c	contact patch mass (dummy)
m_t	tyre mass
m_m	mass of mainframe (including lower part of rider)
m_{mr}	mass of mainframe plus rider
m_r	mass of upper torso
$M_{B,D}$	brake, drive torque

M_x	overturning couple
M_y	rolling resistance moment
M_z	(self) aligning torque
M_z'	(self) aligning torque due to lateral deflections
M_z^*	aligning torque due to longitudinal deflections
$M_{z,gyr}$	gyroscopic couple
M_δ	steer torque
n	number of elements; frequency [Hz]
$\boldsymbol{n}$	unit vector normal to the road $=(0,0,-1)^T$
n_{st}	steer system ratio
p	Laplace variable [1/m]
p_i	inflation pressure
q	average vehicle yaw resistance arm; generalised coordinate
q	contact force per unit length of circumference, vector
Q	generalised force
r	yaw rate; tyre (loaded) radius
r_c	radius of carcass (belt), unloaded; cross section crown radius
r_{yo}	free tyre radius varying along cross section contour, $r_{yo} = r_{yo}(y_{co})$
r_e	effective rolling radius of freely rolling wheel
r_f	free unloaded tyre radius
r_l	loaded radius
r_o	free unloaded tyre radius ($=R_o$)
R	radius of curvature
R_o	free unloaded tyre radius ($=r_o$)
s	forward position of neutral steer point; half track width
s	Laplace variable; travelled distance
s_{sx}	κ (practical slip component)
s_{sy}	$\tan\alpha$ (practical slip component)
$\boldsymbol{s}$	unit vector along wheel spin axis
S	wheel slip point; impulse; string tension force
$S_{V,H}$	vertical, horizontal shift
t	pneumatic trail; time
t_c	caster length
t_r	rise time
$\boldsymbol{t}$	unit vector in road plane perpendicular to line of intersection $\boldsymbol{l}$
T	kinetic energy; moment acting around belt, wheel centre
u	forward velocity of c.g.; longitudinal deflection
U	potential energy
v	lateral velocity of c.g.; lateral deflection
V	speed of travel of c.g. (with x, y components)

V	speed of travel of wheel centre (with x, y components)
V_c	speed of contact centre C (with x, y components)
V_g	speed of sliding (with x, y components)
V_o	reference velocity $=\sqrt{gR_o}$
V_r	wheel linear speed of rolling ($= V_{cx} - V_{sx}$)
V_s	wheel slip velocity of slip point S (with x, y components)
V_x	longitudinal speed component of wheel centre
V_s^*	velocity of contact patch mass (with x, y components)
w	vertical road (effective) profile (positive downwards)
W	work
x,y,z	longitudinal, lateral, vertical displacement
x,y,z	coordinates with respect to moving axes system, z axis vertical
x^o,y^o,z^o	global coordinates
$\bar{x},\bar{y},\bar{z}$	global coordinates
X	longitudinal horizontal tyre force
X,Y,Z	global coordinates
y_{co}	distance from wheel centre plane
y_{mr}	lateral offset of m_{mr} c.g.
α	wheel (side) slip angle; axle (side) slip angle
α	road transverse slope angle
α'	transient tyre slip angle
α_a	virtual axle slip angle
β	vehicle side slip angle; tyre yaw torsion angle
$\beta_{x,y}$	road transverse, forward (effective) slope angle
β_{gyr}	gyroscopic wheel coupling coefficient, Eq.(6.35)
γ	camber (wheel inclination) angle
γ'	transient tyre camber angle
Γ	unit step response function
δ	steer angle of front wheels
δ_o	$\approx l/R$, steer angle at $V \to 0$
Δ	increment
ε	roll steer coefficient; rake angle of steering axis
ε	string length ratio, Eq.(5.153); eff. roll. radius gradient $-\partial r_e/\partial d_t$
ε_γ	camber stiffness reduction factor
ε_{NL}	non-lagging part
ε	small quantity to avoid singularity
ζ	damping ratio; spin factor (=1 if spin influence is disregarded)
ζ_h	height ratio, Eq.(6.36)
ζ_α	cornering stiffness load transfer coefficient

ζ_γ	camber stiffness load transfer coefficient
η	understeer coefficient; effective rolling radius gradient $-\partial r_e/\partial \rho_z$
η_y	c.g. offset steer coefficient
θ	tyre model parameter, Eqs.(3.6,3.24,3.46)
θ	angular displacement about η axis; pitch angle
θ_c	string model composite parameter, Eq.(5.160)
κ	longitudinal wheel slip
κ'	transient longitudinal tyre slip
κ^*	damping coefficient due to tread width
λ	wavelength; root characteristic equation
λ	fraction of $2a$ where adhesion occurs; user scaling factor
μ	coefficient of friction
ρ	tyre radial (vertical) deflection
$\rho_{x,y,z}$	tyre longitudinal, lateral, normal deflection
σ	relaxation length; load transfer coefficient
σ	theoretical slip, vector, Eq.(3.34)
σ^*	intersection length in string model with tread elements
σ_c	string model length parameter, Eq.(5.153)
σ_c	contact patch relaxation length
τ	roll camber coefficient
φ	body roll angle; spin slip
φ'	transient spin slip
φ_t	turn slip
ϕ	phase angle
ψ	yaw angle; steer angle
ψ_{cl}	compliance steer angle
ψ_{io}	toe angle
ω	frequency [rad/s]
ω_o	undamped natural frequency
$\omega_{1,2}$	natural frequencies
ω_n	damped natural frequency
ω_s	path frequency [rad/m]
Ω	wheel speed of revolution
ξ,η,ζ	moving axes system, η axis along spin axis, ξ horizontal

Subscripts and superscripts

a	axle; from belt to wheel rim centre
b	belt; from belt centre to rim
c	compliance (steer)

c	contact patch; from contact patch centre to belt; crown; contour
D	drag
e	effective
eff	effective (cornering stiffness)
eq	equivalent
f	free, unloaded; of front frame
g	global
i	1: front, 2: rear
L,R	left, right
m	of mainframe
mr	of mainframe plus rider
NL	non-lagging
o	original; initial; average
o	unloaded; nominal; at vanishing speed; natural
r	roll; rolling; rolling resistance; of residual spring; of rider
s	slip; from road surface to contact patch; of front sub-frame
sl	at verge of total sliding
sf	side force (steer)
ss	steady state
st	static
stw	steering wheel
t	transition from adhesion to sliding
w	wheel
x,y,z	forward (longitudinal), lateral (to the right), downward
zr	residual (torque)
ξ,η,ζ	along, around ξ,η,ζ axes
1,2	front, rear; leading, trailing edge