SimBALink

1 Vehicle

This system models the forces acting on the vehicle.

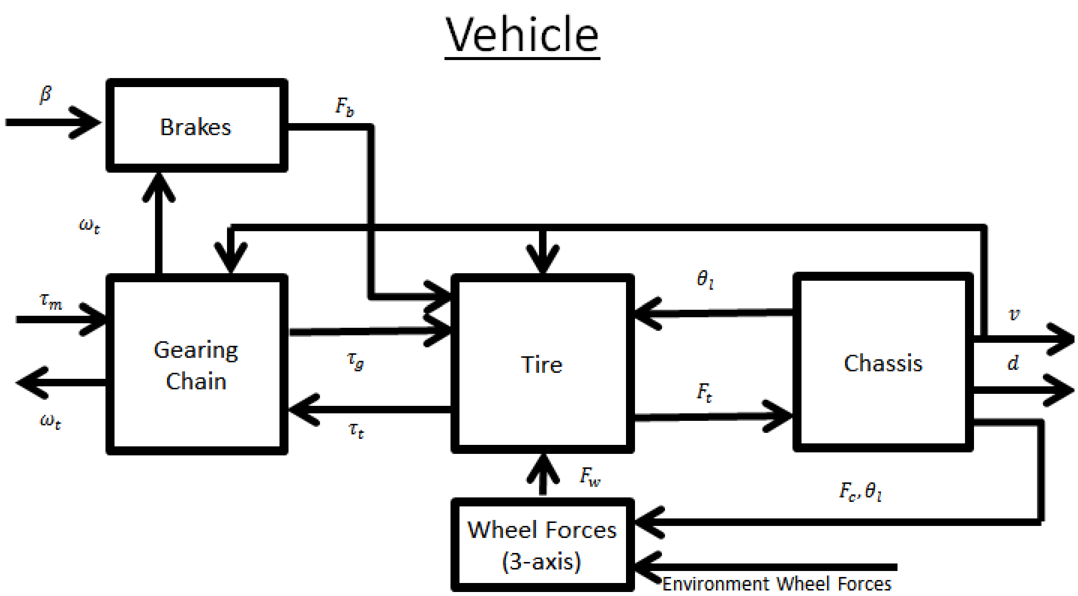

Figure 1: Vehicle Diagram

1.1 Gearing and Chain

This system models the gear and chain in such a way to allow for wheel slip.

1.2 Inputs and outputs

1.2.1 Inputs

Input	Symbol	Unit
Motor Torque	τ_m	Nm
Tire Torque	τ_t	Nm

1.2.2 Outputs

Output	Symbol	Unit
Tire Velocity	ω_t	rad/s
Gear Torque	τ_g	Nm

1.2.3 Background, rationale, modeling strategy

The tire, chain, gear, and motor are modeled as a lumped inertia that is accelerated by the motor torque and tire torque(modeled as a load). The chain is modeled lossey through an efficiency map. Gearing is modeled as a ratio that linearly changes motor torque to gear torque. This method of modeling allows for wheel slip down the line.

$$\dot{\omega}_t = \frac{\tau_m - \tau_t}{J_m + J_g + J_t + J_c} \tag{1}$$

$$\tau_g = \frac{\tau_m \eta_c(\omega_t)}{R_g} \tag{2}$$

1.2.4 States

State	Symbol	Unit
Tire Velocity	ω_t	rad/s

1.2.5 Variables

Output	Symbol	Unit
Motor inertia	J_m	$kg * m^2$
Gear inertia	J_g	$kg * m^2$
Chain inertia	J_c	$kg * m^2$
Tire inertia	J_t	$kg * m^2$
Gear Ratio	R_g	$\frac{\tau_m}{\tau_g}$

1.2.6 Functions

$\eta_c(\omega_t)$

Type	Description	Symbol	Unit
Input	Wheel Speed	ω_t	rad/s
Output	Chain Efficiency	n/a	%

The function is modeled as a look up table following the curve below described in the paper "Optimization of Chain Drives in Sports Motorcycles".

1.2.7 Assumptions

- The chain and gearing is rigid (no chain/gear dynamics)
- Chain efficiency is only a function of wheel speed

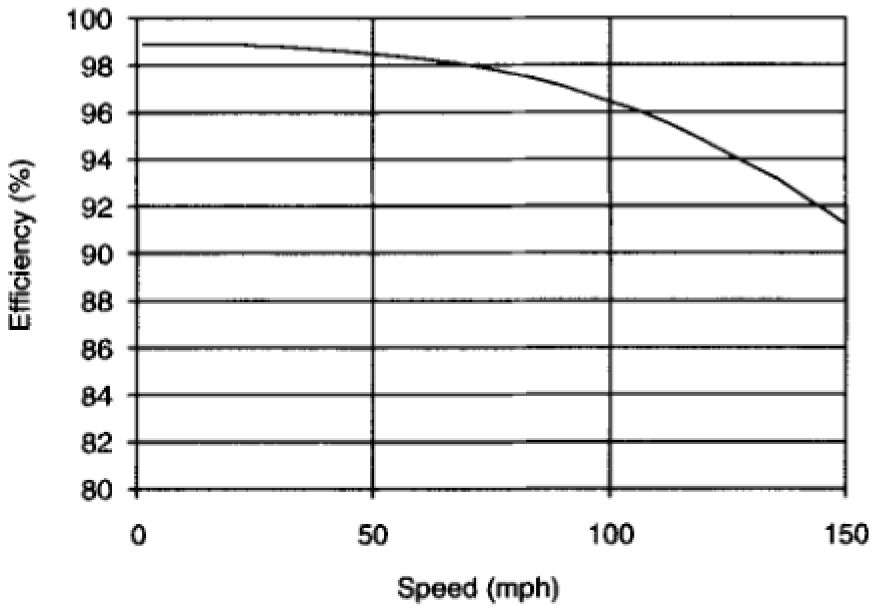

Figure 2: Estimated Chain Efficiency

1.3 Brakes

1.4 Inputs and outputs

1.4.1 Inputs

Input	Symbol	Unit
Brake Command	$beta$	%
Wheel Speed	ω_t	rad/s

1.4.2 Outputs

Output	Symbol	Unit
Brake Force on Tire	F_b	N

1.4.3 Background, rationale, modeling strategy

The brake is modeled as a friction force

$$F_b = \mu_b \omega_t \beta \tag{3}$$

1.4.4 Variables

Output	Symbol	Unit
Brake Coefficenct of Friction	μ_b	$\frac{N}{rad/s}$

1.4.5 Parameters

No tuning parameters

1.4.6 Assumptions

- Brake percentage to friction force is linear

1.5 Tires

1.6 Inputs and outputs

1.6.1 Inputs

Input	Symbol	Unit
Brake Force	F_b	N
Gear Torque	τ_g	Nm
Wheel Forces[3]	F_w	N[3]
Vehicle Velocity	v	m/s
Lead Angle	θ_l	rad

1.6.2 Outputs

Output	Symbol	Unit
Tire Torque	τ_t	Nm
Tire Reaction Force	F_t	N

1.6.3 Background, rationale, modeling strategy

The tire is modeled in three parts, rolling resistance, Load and Torque, and Traction Limiting. Force directions are defined as longitudinal(long), lateral(lat), and normal(n). Longitudinal is along the direction of the motorcycle (when moving straight). Lateral is orthogonal to Longitudinal axis. Normal 3-D orthogonal to lateral and longitudinal, in general the axis to the road on no incline.

In general the tire model provides a load on the Gear/Chain and gives the vehicle a reaction force. Load is caused by the forces from the road(from the vehicle) and rolling resistance. the reaction force caused by traction limiting which is a function of wheel slip. The amount of reaction force i saturated at the maximum force the tire can apply given wheel slip.

Rolling Resistance

$$K_t = \begin{cases} 0.0085 + \frac{0.18}{p_t} + \frac{1.59*10^{-6}}{p_t} & : v_{kph} \leq 165(km/h) \\ \frac{0.18}{p_t} + \frac{2.91*10^{-6}}{p_t} & : v_{kph} > 165(km/h) \end{cases} \tag{4}$$

Wheel Slip

$$\kappa = \frac{v - \omega_t r_t(\theta_l)}{v} \tag{5}$$

$$\mu_{t,gnd} = D_\kappa \sin(C_\kappa \arctan[B_\kappa \kappa - E_\kappa(B_\kappa \kappa - \arctan B_\kappa \kappa)]) \tag{6}$$

Load and Torque

$$\tau_t = \tau_g - F_{w,long} r_t(\theta_l) - F_b r_b - K_t F_{w,n} v_{kph}^2 \tag{7}$$

Traction Limiting

$$F_{max} = \mu_{t,gnd} F_{w,n} \tag{8}$$

$$F = \tau r_t((\theta_l) \tag{9}$$

$$F_t = \begin{cases} F & : -F_{max} \leq F \leq F_{max} \\ F_{max} & : -F_{max} > F > F_{max} \end{cases} \tag{10}$$

The tire coefficient ($\mu_{t,gnd}$) is modeled using the "Magic Formula" as shown below. Where D_κ is the maximum tire coefficient of the tire.

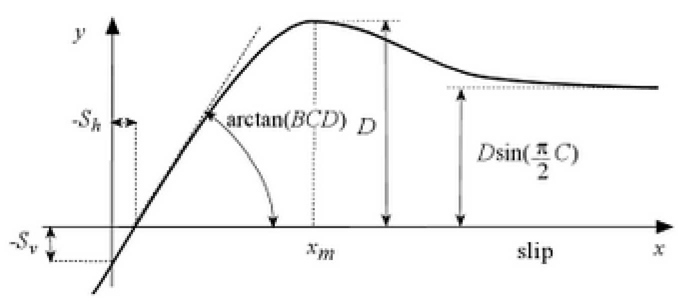

Figure 3: Magic Formula

1.6.4 Variables

Var	Symbol	Unit
Tire Pressure	p_t	*bar*
Brake Caliper Radius	r_b	m

1.6.5 Parameters

Param.	Symbol	Unit
Magic Formula		
	$A_\kappa, B_\kappa, C_\kappa, D_\kappa$	n/a

1.6.6 Function

$r_t(\theta_l)$

Type	Description	Symbol	Unit
Input	Lean Angle	θ_l	rad
Output	Tire Radius	n/a	m

1.6.7 Assumptions

- Maximum acceleration force should also depend on lateral forces on the vehicle. However this is not modeled because it requires modeling of high-side and low-side dynamics. The Rider model should control for a safe operating area of the motorcycle to compensate for this assumption.
- No tire deformation
- No tire temperature dynamics
- No change in rolling resistance with lean angle

1.7 Wheel Forces

Wheel Forces does nothing. It would allow for the environment to affect tire forces.

$$F_{\omega,long} = F_{c,long} \tag{11}$$
$$F_{\omega,n} = F_{c,n} \tag{12}$$

1.8 Chassis

This system models the chassis of the motorcycle including the velocity of the motorcycle and forces on the road.

1.9 Inputs and outputs

1.9.1 Inputs

Input	Symbol	Unit
Tire Force	F_t	N
Air Density	ρ	kg/m^3
Road Gradient	θ_r	rad

1.9.2 Outputs

Output	Symbol	Unit
Vehicle Velocity	v	m/s
Distance Traveled	d	m
Lean Angle	θ_l	rad

1.9.3 Background, rationale, modeling strategy

The Chassis is modeled point mass with drag.

$$F_a = \frac{1}{2}\rho C_d A v^2 \tag{13}$$

$$F_{c,long} = F_a + gm\sin(\theta_r) \tag{14}$$

$$F_{c,n} = mg\cos(\theta_r) \tag{15}$$

$$\dot{v} = mF_t \tag{16}$$

$$\dot{d} = v \tag{17}$$

1.9.4 States

State	Symbol	Unit
Distance	d	m
Velocity	v	m/s

1.9.5 Variables

Output	Symbol	Unit
Gravity	g	m/s^2
Mass of Motorcycle	m	kg

1.9.6 Parameters

Param.	Symbol	Unit
Drag Area	C_dA	$\frac{N}{rad/s}$

1.9.7 Look Up table

$\theta_l(d)$

Type	Description	Symbol	Unit
Input	Distance Traveled	d	m
Output	Lean Angle	n/a	rad

1.9.8 Assumptions

- The full weight of the motorcycle is always on the correct tire for breaking or acceleration. That is not a bad assumption because maximum braking or acceleration will happen at wheelie or stoppie when there is only one tire on the ground.

- Lean angle does not affect Aero Drag
- No lateral forces

2 Environment

This system models the environment of the motorcycle is riding in.

Force directions are defined as longitudinal(long), lateral(lat), and normal(n). Longitudinal is along the direction of the motorcycle (when moving straight). Lateral is orthogonal to Longitudinal axis. Normal 3-D orthogonal to lateral and longitudinal, in general the axis to the road on no incline.

2.1 Inputs and outputs

2.1.1 Inputs

Input	Symbol	Unit
Distance Travel	d	m

2.1.2 Outputs

Output	Symbol	Unit
Environment Forces on Tire[3]	F_t	N[3]
Road Gradient	θ_r	rad
Ambient Temperature	T_{amb}	K
Air Pressure	P	Pa
Air Density	ρ	kg/m^3

2.1.3 Background, rationale, modeling strategy

The Environment only models air density, air temperature, and road gradient.

$$\theta_r = \frac{d}{dd}h(d) \tag{18}$$

$$T_amb = T_0 - Lh(d) \tag{19}$$

$$P = P_0 \left(1 - \frac{Lh(d)}{T_0}\right)^{\frac{gM}{RL}} \tag{20}$$

$$\rho = \frac{PM}{1000RT} \tag{21}$$

2.1.4 Variables

Output	Symbol	Unit
Temperature Lapse	L	K/m
Initial Pressure	P_0	Pa
Initial Temperature	T_0	K
Gravity	g	m/s^2
Molar mass of Dry Air	M	kg/mol
Ideal Gas Constant	R	$\frac{J}{mol*K}$

2.1.5 Look up Table

$h(d)$

Type	Description	Symbol	Unit
Input	Distance Travel	d	m
Output	height	n/a	m

2.1.6 Assumptions

- The air is dry
- Temperature lapse rate right is correct (no inversion)