

Equations:

(1) Body:  $\sum F = ma$

$$\begin{aligned}
& \uparrow \sum Fb = mb\ddot{z}b \\
& Fsfl1 + Fsfl2 + Fdfl1 + Fdfl2 + Fsfr1 + Fsfr2 + Fdfr1 + Fdfr2 + \\
& Fsrl1 + Fsrl2 + Fdrl1 + Fdrl2 + Fsrr1 + Fsrr2 + Fdrr1 + Fdrr2 = mb\ddot{z}b \\
& 2 \left( ks1 \left( zwfl - zb + lf\theta - \frac{t}{2}\theta \right) \right) + 2 \left( cs1 \left( z\dot{w}fl - \dot{z}b + lf\dot{\theta} - \frac{t}{2}\dot{\theta} \right) \right) + \\
& 2 \left( ks1 \left( zwfr - zb + lf\theta + \frac{t}{2}\theta \right) \right) + 2 \left( cs1 \left( z\dot{w}fr - \dot{z}b + lf\dot{\theta} + \frac{t}{2}\dot{\theta} \right) \right) + \quad (3.1) \\
& 2 \left( ks2 \left( zwrl - zb - lr\theta - \frac{t}{2}\theta \right) \right) + 2 \left( cs2 \left( z\dot{w}rl - \dot{z}b - lr\dot{\theta} - \frac{t}{2}\dot{\theta} \right) \right) + \\
& 2 \left( ks2 \left( zwrr - zb - lr\theta + \frac{t}{2}\theta \right) \right) + 2 \left( cs2 \left( z\dot{w}rr - \dot{z}b - lr\dot{\theta} + \frac{t}{2}\dot{\theta} \right) \right) \\
& = mb\ddot{z}b
\end{aligned}$$

(2) Roll

$$\begin{aligned}
& \sum Mr = Ir\ddot{\theta} \\
& (Fsfl1 + Fsfl2 + Fdfl1 + Fdfl2) \left( \frac{t}{2} \right) - (Fsfr1 + Fsfr2 + Fdfr1 + Fdfr2) \left( \frac{t}{2} \right) \\
& + (Fsrl1 + Fsrl2 + Fdrl1 + Fdrl2) \left( \frac{t}{2} \right) - (Fsrr1 + Fsrr2 + Fdrr1 + Fdrr2) \left( \frac{t}{2} \right) \\
& [2 \left( ks1 \left( zwfl - zb + lf\theta - \frac{t}{2}\theta \right) \right) + 2 \left( cs1 \left( z\dot{w}fl - \dot{z}b + lf\dot{\theta} - \frac{t}{2}\dot{\theta} \right) \right) + \quad (3.2) \\
& 2 \left( ks2 \left( zwrl - zb - lr\theta - \frac{t}{2}\theta \right) \right) + 2 \left( cs2 \left( z\dot{w}rl - \dot{z}b + lf\dot{\theta} - \frac{t}{2}\dot{\theta} \right) \right)] \frac{t}{2} - \\
& [2 \left( ks1 \left( zwfr - zb + lf\theta + \frac{t}{2}\theta \right) \right) + 2 \left( cs1 \left( z\dot{w}fr - \dot{z}b + lf\dot{\theta} + \frac{t}{2}\dot{\theta} \right) \right) + \\
& 2 \left( ks2 \left( zwrr - zb - lr\theta + \frac{t}{2}\theta \right) \right) + 2 \left( cs2 \left( z\dot{w}rr - \dot{z}b - lr\dot{\theta} + \frac{t}{2}\dot{\theta} \right) \right)] \left( \frac{t}{2} \right) = Ir\ddot{\theta}
\end{aligned}$$

(3) Pitch

$$\begin{aligned}
\sum MP &= IP\ddot{\theta} \\
& (Fsrl1 + Fsrl2 + Fdrl1 + Fdrl2)lr + (Fsrr1 + Fsrr2 + Fdrr1 + Fdrr2)lr - \\
& (Fsfl1 + Fsfl2 + Fdfl1 + Fdfl2)lf - (Fsfr1 + Fsfr2 + Fdfr1 + fdfr2)lf \\
& [2\left(ks2\left(zwrl - zb - lr\theta - \frac{t}{2}\theta\right)\right) + 2\left(cs2\left(z\dot{w}rl - \dot{z}b + lr\dot{\theta} - \frac{t}{2}\dot{\theta}\right)\right) + \\
& 2\left(ks2\left(zwrr - zb - lr\theta + \frac{t}{2}\theta\right)\right) + 2\left(cs2\left(z\dot{w}rr - \dot{z}b + lr\dot{\theta} + \frac{t}{2}\dot{\theta}\right)\right)]lr \quad (3.3) \\
& -[2\left(ks1\left(zwfl - zb + lf\theta - \frac{t}{2}\theta\right)\right) + 2\left(cs1\left(z\dot{w}fl - \dot{z}b + lf\dot{\theta} - \frac{t}{2}\dot{\theta}\right)\right) + \\
& 2\left(ks1\left(zwfr - zb + lf\theta + \frac{t}{2}\theta\right)\right) + 2\left(cs1\left(z\dot{w}fr - \dot{z}b + lf\dot{\theta} + \frac{t}{2}\dot{\theta}\right)\right)]lf \\
& = IP\ddot{\theta}
\end{aligned}$$

$$(4) \Sigma Fwfl = MwflZ\ddot{w}fl$$

$$\begin{aligned}
Ftfl - Fsfl1 - Fsfl2 - Fdfl1 - Fdfl2 &= MwflZ\ddot{w}fl \\
ktfl(zrfl - zwfl) - 2\left(ks1\left(zwfl - zb + lf\theta - \frac{t}{2}\theta\right)\right) + 2\left(cs1\left(z\dot{w}fl - \dot{z}b + lf\dot{\theta} - \frac{t}{2}\dot{\theta}\right)\right) \quad (3.4) \\
&= MwflZ\ddot{w}fl
\end{aligned}$$

$$(5) \Sigma Fwfr = Mwfr\ddot{Z}wfr$$

$$\begin{aligned}
Ftfr - Fsfr1 - Fsfr2 - Fdfr1 - fdfr2 &= Mwfr\ddot{Z}wfr \\
ktfr(zrfr - zwfr) - 2(ks1(zwfr - zb + lf\theta + \frac{t}{2}\theta)) + 2(cs1(z\dot{w}fr - \dot{z}b + lf\dot{\theta} + \frac{t}{2}\dot{\theta})) \quad (3.5) \\
&= Mwfr\ddot{Z}wfr
\end{aligned}$$

$$(6) \Sigma Fwrl = Mwrl\ddot{Z}wrl$$

$$\begin{aligned}
Ftrl - Fsrl1 - Fsrl2 - Fdrl1 - Fdrl2 &= Mwrl\ddot{Z}wrl \\
ktrl(zrrl - 2wrl) - 2\left(ks2\left(zwrl - zb - lr\theta - \frac{t}{2}\theta\right)\right) + 2\left(cs2\left(z\dot{w}rl - \dot{z}b - lr\dot{\theta} - \frac{t}{2}\dot{\theta}\right)\right) \quad (3.6) \\
&= Mwrl\ddot{Z}wrl
\end{aligned}$$

$$(7) \Sigma Fwrr = Mwrr\ddot{Z}wrr$$

$$\begin{aligned}
Ftrr - Fsrr1 - Fsrr2 - Fdrr1 - Fdrr2 &= Mwrr\ddot{Z}wrr \\
ktrr(zrrr - zwrr) - 2(ks2(zwrr - zb - lr\theta + \frac{t}{2}\theta)) + 2(cs2(z\dot{w}rr - \dot{z}b - lr\dot{\theta} + \frac{t}{2}\dot{\theta})) \quad (3.7) \\
&= Mwrr\ddot{Z}wrr
\end{aligned}$$

Where:  
(tire)

$$\begin{aligned}F_{tfl} &= k_{tfl}(z_{rfl} - z_{wfl}) \\F_{tfr} &= k_{tfr}(z_{rfr} - z_{wfr}) \\F_{trl} &= k_{trl}(z_{rrl} - z_{wrl}) \\F_{trr} &= k_{trr}(z_{rrr} - z_{wrr})\end{aligned}$$

(spring)

$$\begin{aligned}F_{sfl1} &= k_{s1}(z_{wfl} - z_{bfl}) \\F_{sfl2} &= k_{s1}(z_{wfl} - z_{bfl}) \\F_{sfr1} &= k_{s1}(z_{wfr} - z_{bfr}) \\F_{sfr2} &= k_{s1}(z_{wfr} - z_{bfr}) \\F_{srl1} &= k_{s2}(z_{wrl} - z_{brl}) \\F_{srl2} &= k_{s2}(z_{wrl} - z_{brl}) \\F_{srr1} &= k_{s2}(z_{wrr} - z_{brr}) \\F_{srr2} &= k_{s2}(z_{wrr} - z_{brr})\end{aligned}$$

(damper)

$$\begin{aligned}F_{dfl1} &= c_{s1}(\dot{z}_{wfl} - \dot{z}_{bfl}) \\F_{dfl2} &= c_{s1}(\dot{z}_{wfl} - \dot{z}_{bfl}) \\F_{dfr1} &= c_{s1}(\dot{z}_{wfr} - \dot{z}_{bfr}) \\F_{dfr2} &= c_{s1}(\dot{z}_{wfr} - \dot{z}_{bfr}) \\F_{drl1} &= c_{s2}(\dot{z}_{wrl} - \dot{z}_{brl}) \\F_{drl2} &= c_{s2}(\dot{z}_{wrl} - \dot{z}_{brl}) \\F_{drr1} &= c_{s2}(\dot{z}_{wrr} - \dot{z}_{brr}) \\F_{drr2} &= c_{s2}(\dot{z}_{wrr} - \dot{z}_{brr})\end{aligned}$$

for roll:

$$\begin{aligned}z_{bfl} &= z_b + \frac{t}{2 \sin \theta} \\z_{bfr} &= z_b - \frac{t}{2 \sin \theta} \\z_{brl} &= z_b + \frac{t}{2 \sin \theta} \\z_{brr} &= z_b - \frac{t}{2 \sin \theta}\end{aligned}$$

$$\begin{aligned}z_{bfl} &= -lf \sin \theta \\z_{bfr} &= -lf \sin \theta \\z_{brl} &= lr \sin \theta \\z_{brr} &= lr \sin \theta\end{aligned}$$