

$$\begin{aligned}
& \ddot{\theta}(I + ma^2 \sin^2 \theta + kma \sin \theta (R - a \cos \theta)(-\dot{x}_c \sin \phi + \dot{y}_c \cos \phi + (R - a \cos \theta)\dot{\theta})) \\
&= -\underbrace{(I_3 - I)\dot{\phi}^2 \sin \theta \cos \theta}_{=0} - I_3 \dot{\phi} \sin \theta \dot{\psi} + (g + a\dot{\theta}^2 \cos \theta)(-ma \sin \theta - km(R - a \cos \theta) \\
&(-\dot{x}_c \sin \phi + \dot{y}_c \cos \phi + (R - a \cos \theta)\dot{\theta}))
\end{aligned}$$

$$\begin{aligned}
\ddot{\phi} I \sin \theta &= -\underbrace{(2I - I_3)}_{=I} \dot{\phi} \dot{\theta} \cos \theta + I_3 \dot{\theta} \dot{\psi} \\
&- km(g + a \cos \theta \dot{\theta}^2 + a \sin \theta \ddot{\theta})(a - R \cos \theta)(\dot{x}_c \cos \phi + \dot{y}_c \sin \phi + (a\dot{\phi} + \dot{\psi}R) \sin \theta)
\end{aligned}$$

$$\begin{aligned}
\ddot{\psi} I_3 &= -I_3(\ddot{\phi} \cos \theta - \dot{\phi} \dot{\theta} \sin \theta) \\
&- km(g + a \cos \theta \dot{\theta}^2 + a \sin \theta \ddot{\theta})(R \sin \theta)(\dot{x}_c \cos \phi + \dot{y}_c \sin \phi + (a\dot{\phi} + \dot{\psi}R) \sin \theta)
\end{aligned}$$

$$m\ddot{x}_c = -km(g + a \cos \theta \dot{\theta}^2 + a \sin \theta \ddot{\theta})(\dot{x}_c + (a\dot{\phi} + \dot{\psi}R) \sin \theta \cos \phi + (a \cos \theta - R) \sin \phi \dot{\theta})$$

$$m\ddot{y}_c = -km(g + a \cos \theta \dot{\theta}^2 + a \sin \theta \ddot{\theta})(\dot{y}_c + (a\dot{\phi} + \dot{\psi}R) \sin \theta \sin \phi + (R - a \cos \theta) \cos \phi \dot{\theta})$$