A3) $z = \begin{bmatrix} x \\ \dot{x} \\ I \end{bmatrix} = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \end{bmatrix}$ $\dot{z} = \begin{bmatrix} z_2 \\ \frac{5m}{7}\left(mg\sin\phi + \frac{cz_3^2}{(\delta - z_1)^2} - k(z_1-d) - bz_2\right) \\ \frac{1}{L_0 + L_1 e^{-\alpha(\delta - z_1)}}(V - z_3 R) \end{bmatrix}$

$$\dot{z}_1 = z_2$$
$$\dot{z}_2 = \frac{5m}{7}\left(mg\sin\phi + \frac{cz_3^2}{(\delta - z_1)^2} - k(z_1 - d) - bz_2\right)$$
$$\dot{z}_3 = \frac{1}{L_0 + L_1 e^{-\alpha(\delta - z_1)}}(V - z_3 R)$$

Characterising the equilibrium point : $f(z^e, v^e) = 0$

as $z_2^e = 0$

$$0 = z_2^e$$
$$0 = \frac{5m}{7}\left(mg\sin\phi + \frac{c(z_3^e)^2}{(\delta - z_1^e)^2} - k(z_1^e - d) - 0\right)$$
$$0 = \frac{1}{L_0 + L_1 e^{-\alpha(\delta - z_1^e)}}(v^e - z_3^e R)$$

makes sense as ~~speed~~ vel of ball=0

Subtracting:

$$\dot{z}_1 = z_2 - z_2^e$$
$$\dot{z}_2 = \frac{5m}{7}\left(mg\sin\phi + \frac{cz_3^2}{(\delta - z_1)^2} - k(z_1 - d) - bz_2\right) - \frac{5m}{7}\left(mg\sin\phi + \frac{c(z_3^e)^2}{(\delta - z_1^e)^2} - k(z_1^e - d)\right)$$
$$\dot{z}_3 = \frac{V - z_3 R}{L_0 + L_1 e^{-\alpha(\delta - z_1)}} - \frac{v^e - z_3^e R}{L_0 + L_1 e^{-\alpha(\delta - z_1^e)}}$$

$$\ast \quad \dot{z}_1 = z_2 - z_2^e \quad \ast$$

$$\dot{z}_2 = \cancel{\frac{5m\sin\phi}{7}} + \frac{5mc}{7}\left[\frac{z_3^2}{(\delta - z_1)^2}\right] - \frac{5mkz_1}{7} + \cancel{\frac{5mk\delta}{7}} - \frac{5mbz_2}{7}$$

$$- \cancel{\frac{5mmg\sin\phi}{7}} - \frac{5mc}{7}\left[\frac{(z_3^e)^2}{(\delta - z_1^e)^2}\right] + \frac{5mkz_1^e}{7} - \cancel{\frac{5mk\delta}{7}}$$

$$\ast \quad \dot{z}_2 = \frac{5m}{7}\left[c\left(\frac{z_3^2}{(\delta - z_1)^2} - \frac{(z_3^e)^2}{(\delta - z_1^e)^2}\right) - k(z_1 - z_1^e) - bz_2\right] \quad \ast$$

$$\dot{z}_3 = \frac{V - z_3R}{L_0 + L_1 e^{\alpha(z_1 - \delta)}} - \frac{V^e - z_3^eR}{L_0 + L_1 e^{\alpha(z_1^e - \delta)}}$$

$$\boxed{\begin{aligned} \dot{z}_1 &= z_2 - z_2^e \\ \dot{z}_2 &= \frac{5m}{7}\left[c\left(\frac{z_3^2}{(\delta - z_1)^2} - \frac{(z_3^e)^2}{(\delta - z_3^e)^2}\right) - k(z_1 - z_1^e) - bz_2\right] \\ \dot{z}_3 &= \frac{V - z_3R}{L_0 + L_1 e^{\alpha(z_1 - \delta)}} - \frac{V^e - z_3^eR}{L_0 + L_1 e^{\alpha(z_1^e - \delta)}} \end{aligned}}$$