$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = \ddot{\psi} = \frac{1}{J} M_z = \frac{1}{2J} \rho V_{cpp}^2 \, l \, A_{ref} \left( C_{L0} + C_{L1}(u_r + \gamma_r) \right) \cos \gamma_r$$

$$= \alpha_1 + \alpha_2 u_r$$

where

$$\alpha_1 = \frac{1}{2J} \rho V_{cpp}^2 \, l \, A_{ref} (C_{L0} + C_{L1} \gamma_r) \cos \gamma_r$$

$$\alpha_2 = \frac{1}{2J} \rho V_{cpp}^2 \, l \, A_{ref} \, C_{L1} \cos \gamma_r$$

choose a reference model

$$\frac{Y_{des}(s)}{Y_{sp}(s)} = \frac{1}{(\tau_r s + 1)^2}$$

$$(\tau_r s + 1)^2 Y_{des}(s) = Y_{sp}(s)$$

$$(\tau_r^2 s^2 + 2\tau_r s + 1) Y_{des}(s) = Y_{sp}(s)$$

$$\tau_r^2 \ddot{y}_{des} + 2\tau_r \dot{y}_{des} + y_{des} = y_{sp}$$

let $z_1 = y_{des}$ , $z_2 = \dot{y}_{des}$

$$\dot{z}_1 = z_2$$

$$\dot{z}_2 = \frac{1}{\tau_r^2} \left( y_{sp} - 2\tau_r z_2 - z_1 \right)$$

define error states, $e_1 = x_1 - z_2$ , $e_2 = x_2 - z_2$

goal is to choose $u_r$ so that $e_1 \to 0$, $e_2 \to 0$

$$\dot{e}_1 = \dot{x}_1 - \dot{z}_1 = e_2$$

$$\dot{e}_2 = \dot{x}_2 - \dot{z}_2 = \alpha_1 + \alpha_2 u_r - \frac{1}{\tau_r^2} (y_{sp} - 2\tau_r z_2 - z_1)$$

would be nice if $\dot{e}_2 = -b_1 e_1 - b_2 e_2$

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$$\alpha_1 + \alpha_2 u_r - \frac{1}{\tau_r^2}(y_{sp} - 2\tau_r z_2 - z_1) = -b_1 e_1 - b_2 e_2$$

$$\alpha_2 u_r = -b_1 e_1 - b_2 e_2 - \alpha_1 + \frac{1}{\tau_r^2}(y_{sp} - 2\tau_r z_2 - z_1)$$

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