$$x = \begin{bmatrix} z \\ \phi \\ \theta \\ \psi \\ \dot z \\ \dot\phi \\ \dot\theta \\ \dot\psi \end{bmatrix} \begin{matrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \end{matrix} \Rightarrow \dot x = \begin{bmatrix} \dot z \\ \dot\phi \\ \dot\theta \\ \dot\psi \\ \ddot z \\ \ddot\phi \\ \ddot\theta \\ \ddot\psi \end{bmatrix} = \begin{matrix} x_5 \\ x_6 \\ x_7 \\ x_8 \\ \frac{1}{m}\left(\cos(x_2)\cdot\cos(x_3)\right)\cdot u_1 - g \\ \frac{1}{I_x}\left\{x_7\cdot x_8\cdot\left(I_y - I_z\right) - I_p\,\Omega\, x_7 + \cdot u_2\right\} \\ \frac{1}{I_y}\left\{x_6\, x_8\left(I_z - I_x\right) + I_p\,\Omega\cdot x_6 + \cdot u_3\right\} \\ \frac{1}{I_z}\left\{x_6\cdot x_7\left(I_x - I_y\right) + u_4\right\} \end{matrix}$$

① * Designing z :-

$$s_1 = \dot e + \lambda_1 e = (\dot z - \dot z_d) + \lambda_1 (z - z_d)$$
$$= (x_5 - \dot z_d) + \lambda_1 (x_1 - z_d)$$
$$\dot s_1 = \dot x_5 - \ddot z_d + \lambda_1 (\dot x_1 - \dot z_d)$$
$$= \frac{1}{m}\left\{\cos(x_2)\cdot\cos(x_3)\, u_1 - g\right\} - \ddot z_d + \lambda_1 \left(x_5 - \dot z_d\right)$$

$$s_1 \dot s_1 = s_1 \cdot \left\{ \frac{\cos(x_2)\cdot\cos(x_3)}{m} \left\{ \frac{m\{\lambda_1 (x_5 - \dot z_d) - \ddot z_d\} - g}{\cos(x_2)\cdot\cos(x_3)} + u_1 \right\} \right\}$$

$$\rho(x) \geq \frac{m\left(\lambda_1 (x_5 - \dot z_d) - \ddot z_d\right) - g}{\cos(x_2)\cdot\cos(x_3)}$$

$$u_1 = -\left\{ \frac{m\left(\lambda_1 (x_5 - \dot z_d) - \ddot z_d\right) - g}{\cos(x_2)\cos(x_3)} + K_1 \right\} \cdot \mathrm{sat}(s_1)$$

② * Designing ϕ :-

$$s_2 = \dot e + \lambda_2 e = (\dot\phi - \dot\phi_d) + \lambda_2 (\phi - \phi_d)$$
$$\dot s_2 = (\ddot\phi - \cancel{\ddot\phi_d}^{\,0}) + \lambda_2 (\dot\phi - \cancel{\dot\phi_d}^{\,0})$$
$$= \left\{ \frac{1}{I_x}\left\{\left(x_7 x_8 (I_y - I_z) - I_p\cdot\Omega\, x_7 + u_2\right) + \lambda_2 I_x \left(x_6\right)\right\}\right\}$$

$$s_2 \dot s_2 = \frac{s_2}{I_x} \left\{ \left(x_7 x_8 (I_y - I_z) - I_p\cdot\Omega\cdot x_7 + \lambda_2 I_x x_6\right) + u_2 \right\}$$

$$u_2 = -\left\{ x_7 x_8 (I_y - I_z) - I_p \Omega\, x_7 + \lambda_2 I_x x_6 + K_2 \right\} \cdot \mathrm{sat}(s_2)$$

③ Designing θ :-

$$s_3 = \dot e + \lambda_3 e = (\dot\theta - \dot\theta_d) + \lambda_3 (\theta - \theta_d)$$
$$\dot s_3 = (\ddot\theta - \ddot\theta_d) + \lambda_3 (\dot\theta - \dot\theta_d)$$
$$= \frac{1}{I_y} \left\{ x_6 x_8 (I_z - I_x) + I_p \Omega x_6 + u_3 \right\} + \lambda_3 x_7$$

$$s_3 \dot s_3 = \frac{s_3}{I_y} \left\{ \left(x_6 x_8 (I_z - I_x) + I_p \Omega x_6 + \lambda_3 I_y x_7\right) + u_3 \right\}$$

$$u_3 = -\left(x_6 x_8 (I_z - I_x) + I_p \Omega x_6 + \lambda_3 I_y x_7 + K_3 \right) \cdot \mathrm{sat}(s_3)$$

can we chose $\Omega = \omega_1 - \omega_2 + \omega_3 - \omega_4$
$= \omega_1 + \omega_3 - (\omega_2 + \omega_4)$
$\Downarrow$
& $\mathrm{Max}(\Omega) = \max(\omega_1 + \omega_3) - \min(\omega_2 + \omega_4)$
$\mathrm{Max}(\Omega) = 2 \times \max(\omega)$

④ Designing ψ :-

$$s_4 = \dot e + \lambda_4 e = (\dot\psi - \dot\psi_d) + \lambda_4 (\psi - \psi_d)$$
$$\dot s_4 = (\ddot\psi - \cancel{\ddot\psi_d}^{\,0}) + \lambda_4 (\dot\psi - \cancel{\dot\psi_d}^{\,0})$$
$$\dot s_4 = \frac{1}{I_z} \left\{ x_6 x_7 (I_x - I_y) + u_4 \right\} + \lambda_4 x_8$$

$$s_4 \dot s_4 = s_4 \cdot \frac{1}{I_z} \left\{ x_6 x_7 (I_x - I_y) + \lambda_4 I_z x_8 + u_4 \right\}$$

$$u_4 = -\left(x_6 x_7 (I_x - I_y) + \lambda_4 I_z x_8 + K_4 \right) \cdot \mathrm{sat}(s_4)$$