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$$\eta = [p^e \Theta]^T : p^e = [xyz]^T, \Theta = [\varphi \theta \psi]^T$$

$$\nu = [v_o^b \omega_{nb}^b]^T : v_o^b = [uvw]^T, \omega_{nb}^b = [pqr]^T$$

$$\tau = [f_o^b m_o^b]^T : f_o^b = [XYZ]^T, m_o^b = [KMN]^T$$

$$\begin{array}{l} \eta \\ BODY \\ J_1(\Theta) \\ \Theta \\ p^e \end{array}$$

(1)

$$\dot{p}_e = v_o^n = J_1(\Theta) v_o^b$$

$$\begin{array}{l} J_1(\Theta) \\ J_1^{-1}(\Theta) = J_1^T(\Theta) \\ s \equiv \\ sin() \\ c \equiv \\ cos() \end{array}$$

(2)

$$J_1(\Theta) = c\psi c\vartheta - s\psi c\vartheta + c\psi s\vartheta s\varphi s\psi s\vartheta + c\psi c\varphi s\vartheta s\psi c\vartheta c\psi c\vartheta + s\varphi s\vartheta s\psi - c\psi s\vartheta + s\vartheta s\psi c\varphi - s\vartheta c\vartheta s\varphi c\vartheta c\varphi$$
$$\begin{array}{l} b- \\ frame \\ n- \\ frame \end{array}$$

(3)

$$\begin{array}{l} \dot{\Theta} = J_2(\Theta) \omega_{nb}^b \\ J_2(\Theta) \end{array}$$

(4)

$$J_2(\Theta) = 1s\varphi t\vartheta c\varphi t\vartheta 0c\varphi - s\varphi 0s\varphi / c\vartheta c\varphi / c\vartheta$$
$$\begin{array}{l} J_2(\Theta) \\ (\theta) = \\ \pm 90^o \end{array}$$

(5)

$$\dot{p}_e \Theta = J_1(\Theta) 0_{3 \times 3} 0_{3 \times 3} J_2(\Theta) v_o^b \omega_{nb}^b$$

(6)

$$M_{RB} \dot{\nu} + C_{RB}(\nu) \nu = \tau_{RB}$$

$$\begin{array}{l} M_{RB} : \\ C_{RB} : \\ \tau_{RB} : \\ \nu : \\ b- \\ frame \\ \tau_{RB} \\ \tau_H^E \\ \tau_E^E \end{array}$$

(7)

$$\tau_{RB} = \tau_H + \tau_E + \tau$$

(8)

$$\tau_H = -M_A \dot{\nu} - C_A(\nu) \nu - D(\nu) \nu - g(\eta)$$

$$\begin{array}{l} M_A : \\ C_A : \\ D(\nu) : \\ g(\eta) : \end{array}$$

(9)

$$M \dot{\nu} = -C(\nu) \nu - D(\nu) \nu - g(\eta) + \tau_E + \tau$$

$$\begin{array}{l} M = M_{RB} + M_A \\ C(\nu) = C_{RB}(\nu) + C_A(\nu) \end{array}$$

$$\begin{array}{l} surge \\ sway \\ yaw \\ \eta = \end{array}$$

$$\begin{array}{l} [xyz]^T \\ \nu \equiv \\ [uvr]^T \end{array}$$

$$\begin{array}{l} roll \\ pitch \\ heave \end{array}$$

(10)

$$M_{RB} \dot{\nu} + C_{RB}(\nu) \nu = \tau_{RB}$$

(11)

$$m000mmx_g0mx_gI_Z\dot{\nu}+00-m(x_gr+v)00mum(x_gr+v)-mu0\nu = XY N$$

$$\begin{array}{l} \tau_{RB} \\ \dot{u}, \delta, T) \\ Y = \\ Y(v, r, \dot{v}, \dot{r}, \delta) \\ N = \\ N(v, r, \dot{v}, \dot{r}, \delta) \end{array}$$

$$\begin{matrix} \nu = \\ [uvpr]^T \end{matrix}$$

$$(12) \quad M_{RB} \dot{\nu} + C_{RB}(\nu) \nu = \tau_{RB}$$

$$\begin{matrix} \overset{RB}{m}00- \\ \overset{m}{m}y_g \\ 0\overset{m}{m}- \\ \overset{m}{m}z_gmx_g \\ 0- \\ \overset{m}{m}z_gI_X- \\ I_{XZ} \\ - \\ \overset{m}{m}y_gmx_g- \\ I_{ZX}I_Z\tau_{RB} = \\ \overset{X}{Y} \\ \overset{K}{N} \\ \overset{RB}{m}(\nu) = \\ 00\overset{m}{m}z_gr- \\ \overset{m}{m}(x_gr+ \\ v) \\ 00- \\ \overset{m}{m}y_gp\overset{m}{m}(y_gr- \\ u) \\ - \\ \overset{m}{m}z_g\overset{r}{m}y_gp0I_{YZ}r+ \\ I_{XY}p \\ \overset{m}{m}(x_gr+ \\ v)\overset{m}{m}(y_gr- \\ u)- \\ I_{YZ}r- \\ I_{XY}p0 \end{matrix}$$