$$T_u = b_u^{-1} \sec\theta_a \sec\psi_a \left[\dot{u}_l^D + \gamma_u^{-1} \left(\gamma_R \tilde{r}_e + k_u U l e \right) \right]$$

$$T_q = b_q^{-1} \left[\lambda_q^{-1} \left(k_q e_q + \delta_\theta \theta_{le} b_\theta \right) + \dot{\alpha}_q \right]$$

$$T_r = b_r^{-1} \left[\lambda_r^{-1} \left(k_r e_r + \delta_\psi u_{le} \sec\theta \right) + \dot{\alpha}_r \right]$$

$$u_l^D = u_{ld} A + \gamma_R^{-1} k_R \tilde{r}_e$$

$$\dot{A} = \cos\theta_{ld} \left[\cos\theta_b \cdot \sin(\psi_{ld} - \psi_b) \dot{\psi}_b - \sin\theta_b \cdot \cos(\psi_{ld} - \psi_b) \dot{\theta}_b \right]$$

$$+ \sin\theta_{ld} \cos\theta_b \dot{\theta}_b$$

$$\boxed{\dot{u}_l^D = u_{ld} \dot{A} + \gamma_R^{-1} k_R \dot{\tilde{r}}_e}$$

where $\dot{r}_e = u_{ld} A - u_l \left[\cos\theta_l \cos\theta_b (\cos\psi_{le} - 1) + \cos\theta_{le} \right]$

$$\dot{\theta}_l^D = \dot{\theta}_b = \frac{(x_e^2 + y_e^2)\dot{z}_e - z_e (x_e \dot{x}_e + y_e \dot{y}_e)}{r_e^2 \sqrt{x_e^2 + y_e^2}}$$

$$\dot{\psi}_l^D = \dot{\psi}_b = \frac{x_e \dot{y}_e - y_e \dot{x}_e}{x_e^2 + y_e^2}$$

where

$$\dot{x}_e = u_l \cos\theta_l \cos\psi_l - u_{ld} \cos\theta_{ld} \cos\psi_{ld}$$

$$\dot{y}_e = u_l \cos\theta_l \sin\psi_l - u_{ld} \cos\theta_{ld} \sin\psi_{ld}$$

$$\dot{z}_e = -u_l \sin\theta_l + u_{ld} \sin\theta_{ld}$$

$(u_e^D - u_e)$

$\theta_a, \psi_a, r_e, u_e, \dot{u}_e^D \longrightarrow$

T_U
T_q
T_r
U
V
W
θ
ψ
q
r

$\longrightarrow \dot{x}, \dot{y}, \dot{z}, \dot{\theta}, \dot{\psi}, \dot{u}, \dot{v}, \dot{w}, \dot{q}, \dot{r}$

Scanned by TapScanner

$$u_e^D = u_{ed} A + \gamma_R^{-1} k_R r_e$$

$$\dot{u}_e^D = u_{ed} \dot{A} + \dot{\gamma}_e^{-1} k_R \dot{r}_e$$

$$\dot{\theta}_e^D = \dot{\theta}_b = \frac{d}{dx}\left(\operatorname{atan}\left(\frac{z_e}{\sqrt{x_e^2+y_e^2}}\right)\right)$$

$$= \frac{1}{1+\frac{z_e^2}{x_e^2+y_e^2}} \frac{d}{dx}\left(\frac{z_e}{\sqrt{x_e^2+y_e^2}}\right)$$

$$= \frac{x_e^2+y_e^2}{r_e^2}\left[\frac{\sqrt{x_e^2+y_e^2}\,\dot{z}_e - \frac{z_e(x_e\dot{x}_e + y_e\dot{y}_e)}{\sqrt{x_e^2+y_e^2}}}{x_e^2+y_e^2}\right]$$

$$\boxed{\dot{\theta}_e^D = \frac{(x_e^2+y_e^2)\dot{z}_e - z_e(x_e\dot{x}_e + y_e\dot{y}_e)}{r_e^2\sqrt{x_e^2+y_e^2}}}$$

$$\dot{\psi}_e^D = \dot{\psi}_b = \frac{d}{dx}\left[\operatorname{atan2}(y_e, x_e)\right]$$

$$= \frac{\cancel{x_e^2}}{x_e^2 + y_e^2}\left[\frac{x_e\dot{y}_e - y_e\dot{x}_e}{\cancel{x_e^2}}\right]$$

$$\boxed{\dot{\psi}_e^D = \frac{x_e\dot{y}_e - y_e\dot{x}_e}{x_e^2 + y_e^2}}$$

10

11

12

1

$$\alpha_q = q + e_q$$
$$\alpha_r = r + e_r$$

$$T_u = b_u^{-1} \sec\theta_a \sec\psi_a \left[\dot{U}_e^D + \gamma_u^{-1} \left(\gamma_k r_e + k_u U_e \right) \right]$$

$$\alpha_q = b_\theta^{-1} \left\{ \dot{\theta}_e^D - F_{\theta_1} + \gamma_\theta^{-1} \left[k_\theta \theta_e + \frac{Sh^2(\theta_e/2)}{(\theta_e/2)} \right] \right\}$$

$$\alpha_r = \cos\theta \left\{ \dot{\psi}_e^D - F_{\psi e} + \gamma_\psi^{-1} \left[k_\psi \psi_e + \frac{Sh^2(\psi_e/2)}{(\psi_e/2)} \right] \right\}$$

$$\dot{e}_q = \dot{\alpha}_q - b_q T_q - d_q$$
$$\dot{e}_r = \dot{\alpha}_r - b_r T_r - d_r$$

$$T_q = b_q^{-1} \left[\gamma_q^{-1} \left(k_q e_q + \gamma_\theta \theta_e b_\theta \right) + \dot{\alpha}_q \right]$$

$$T_r = b_r^{-1} \left[\gamma_r^{-1} \left(k_r e_r + \gamma_\psi \psi_e \sec\theta \right) + \dot{\alpha}_r \right]$$

$$\ddot{q}_q = b_0^{-1}\left[\theta_l^{(5)} - F_{\theta l} + s_0^{-1}\left[b_0 \theta_e + \frac{F_i(q_d)}{(q_d)}\right]\right].$$

$$\theta_l^{(4)} = \frac{1}{r_e^2\sqrt{x_e^2+y_e^2}}\Big[\ddot{z}_e(x_e^2+y_e^2) + \dot{z}_e(2x_e\dot{x}_e+2y_e\dot{y}_e) - \dot{z}_e(x_e\dot{x}_e+y_e\dot{y}_e) - z_e(x_e\ddot{x}_e+\dot{x}_e^2+\dot{y}_e^2+y_e\ddot{y}_e)\Big]$$

$$-\frac{\left[(x_e^2+y_e^2)\dot{z}_e - z_e(x_e\dot{x}_e+y_e\dot{y}_e)\right]\times\left(\frac{r_e^2(x_e\dot{x}_e+y_e\dot{y}_e)}{\sqrt{x_e^2+y_e^2}} + 2r_e\dot{r}_e\sqrt{x_e^2+y_e^2}\right)}{r_e^4(x_e^2+y_e^2)}$$

$$\dot{\theta}_e^D = \frac{r_e^2\sqrt{x_e^2+y_e^2}\left[\dot{z}_e\left(x_e^2+y_e^2\right)+\dot{z}_e\left(x_e\dot{x}_e+y_e\dot{y}_e\right)-z_e\left(x_e\ddot{x}_e+\dot{x}_e^2+\dot{y}_e^2+y_e\ddot{y}_e\right)\right]-\left[\left(x_e^2+y_e^2\right)\dot{z}_e-z_e\left(x_e\dot{x}_e+y_e\dot{y}_e\right)\right]\left[\frac{r_e^2\left(x_e\dot{x}_e+y_e\dot{y}_e\right)}{\sqrt{x_e^2+y_e^2}}+2r_e\dot{r}_e\sqrt{x_e^2+y_e^2}\right]}{r_e^4\left(x_e^2+y_e^2\right)}$$

$$= \frac{r_e^2\cancel{\left(x_e^2+y_e^2\right)}\left[\cancel{\dot{z}_e}\left(x_e^2+y_e^2+\cancel{x_e\dot{x}_e+y_e\dot{y}_e}\right)-z_e\left(x_e\ddot{x}_e+y_e\ddot{y}_e+\dot{x}_e^2+\dot{y}_e^2\right)\right]-\left[\cancel{\dot{z}_e\left(x_e^2+y_e^2\right)}-z_e\left(x_e\dot{x}_e+y_e\dot{y}_e\right)\right]\left[\cancel{r_e^2\left(x_e\dot{x}_e+y_e\dot{y}_e\right)}+2r_e\dot{r}_e\left(x_e^2+y_e^2\right)\right]}{r_e^4\left(x_e^2+y_e^2\right)^{3/2}}$$

$$= \frac{r_e^2\left(x_e^2+y_e^2\right)\left[\dot{z}_e\left(x_e^2+y_e^2\right)\right]-r_e^2\left(x_e^2+y_e^2\right)z_e\left(x_e\ddot{x}_e+y_e\ddot{y}_e+\dot{x}_e^2+\dot{y}_e^2\right)-2r_e\dot{r}_e\dot{z}_e\left(x_e^2+y_e^2\right)^2-z_e\left(\dot{x}_e x_e+\dot{y}_e y_e\right)\left[r_e^4\left(x_e\dot{x}_e+y_e\dot{y}_e\right)+2r_e\dot{r}_e\left(x_e^2+y_e^2\right)\right]}{r_e^4\left(x_e^2+y_e^2\right)^{3/2}}$$

$$\dot{\psi}_e^D = \frac{x_e \dot{y}_e - y_e \dot{x}_e}{x_e^2 + y_e^2}$$

$$\ddot{\psi}_e^D = \frac{(x_e^2 + y_e^2)\left[x_e \ddot{y}_e + \dot{y}_e \dot{x}_e - y_e \ddot{x}_e - \dot{y}_e \dot{x}_e\right] - \left[x_e \dot{y}_e - y_e \dot{x}_e\right](2 x_e \dot{x}_e + 2 y_e \dot{y}_e)}{(x_e^2 + y_e^2)^2}$$

10