ホバリング時のつり合い

$\dot{u} = -g\sin\theta - (qw - rv) - \frac{d}{m}u$

$\dot{v} = g\cos\theta\sin\phi - (ru - pw) - \frac{d}{m}v$

$\dot{w} = -\frac{T}{m} + g\cos\theta\cos\phi - (pv - qu) - \frac{d}{m}w$

$\dot{u} = 0$, $\dot{v} = 0$, $\dot{w} = 0$. $w = 0$, $\theta, \phi = 0$. $p_0, q_0 = 0$

$\boxed{T_0 = mg}$, $T = T_0 + \Delta T$

$\frac{T_0}{m} = g$

$\dot{w} = -\frac{\Delta T + T_0}{m} + \cdots$

$= -\frac{\Delta T}{m} - \cancel{(pv - qu)} - \frac{d}{m}w$

$\dot{w} = -\frac{d}{m}W - \frac{1}{m}\Delta T$

線形化

並

$m(q_0 w_0 - r_0 v_0) = -mg\sin\theta_0 - d_u u_0$

$m(r_0 u_0 - p_0 w_0) = mg\cos\theta_0\sin\phi_0 - d_v v_0$

$m(p_0 v_0 - q_0 u_0) = mg\cos\theta_0\cos\phi_0 - d_w w_0$

機体x方向へはTは働かない。Tは重力のcosを打ち消し、残りの重力のsinを使って進む

$v_0 = p_0 = q_0 = r_0 = \phi_0 = \psi_0 = 0$

$u_0 \neq 0$ $= V_c\cos\theta_0$, $w_0 \neq 0$ $= V_c\sin\theta_0$, $\theta_0 \neq 0$

前へ傾き、上下、前後へは移動している状態!!

並

① $\boxed{d_u u_0 = -mg\sin\theta_0}$ …①

$d_v v_0 = mg\cos\theta_0\sin\phi_0 = 0$ ok. $\phi_0 = 0$, $v_0 = 0$

$\boxed{d_w w_0 = mg\cos\theta_0}\cos\phi_0$ ($\cos\phi_0 = 1$)

~~u_0が求まる~~ …②

$u_0 = V_c\cos\theta_0$
$w_0 = V_c\sin\theta_0$

同じ

回転

$\tau_{\phi 0} = 0$
$\tau_{\theta 0} = 0$
$\tau_{\psi 0} = 0$

右行一

$0 = 0$
$0 = 0$
$0 = 0$

$u_0 = V_c\cos\theta_0$
$w_0 = V_c\sin\theta_0$

水平

$V_c = u_0\cos\theta_0 + w_0\sin\theta_0$

$0 = \cancel{u_0 \theta} = 0$

$0 = -u_0\sin\theta_0 + w_0\cos\theta_0$

$u_0\sin\theta_0 = w_0\cos\theta_0$

$V_c\cos\theta_0 = u_0\cos^2\theta_0 + w_0\sin\theta_0\cos\theta_0$

$= u_0\cos^2\theta_0 + u_0\sin^2\theta$

$= u_0$!!

$(\Delta p+p_0)(\Delta V+V_0)$

$(p_0)\Delta V + \Delta p(V_0)$

$u_0,\ w_0,\ \theta_0$

$$\Delta\dot{u} = -g\sin(\underbrace{\theta_0+\Delta\theta}_{\sin\theta_0\cos\Delta\theta+\cos\theta_0\sin\Delta\theta}) - \left[\Delta q(w_0+\Delta w) - \Delta r(\underbrace{v_0}_{0}+\Delta v)\right] - \frac{d_u}{m}(u_0+\Delta u)$$

$$= -g\left[(\cos\theta_0)(\Delta\theta) + \boxed{\sin\theta_0\underbrace{\cos\Delta\theta}_{1}}\right] - w_0\Delta q$$

線形化

つり合いでは $d_u u_0 = -mg\sin\theta_0$ で消える (*)

$$\boxed{\Delta\dot{u} = -g\underset{s}{\cos\theta_0}\,\Delta\theta - w_0\Delta q - \frac{d}{m}\Delta u}$$

$$\Delta\dot{v} = g\underbrace{\cos(\theta_0+\Delta\theta)}_{\cos\theta_0\underbrace{\cos\Delta\theta}_{1}-\sin\theta_0\underbrace{\sin\Delta\theta}_{\Delta\theta}}\underbrace{\sin(\phi_0+\Delta\phi)}_{\Delta\phi} - (\Delta r(u_0+\Delta u) - \Delta p(w_0+\Delta w)) - \frac{d}{m}(\overset{0}{v_0}+\Delta v)$$

$$\boxed{\Delta\dot{v} = g\cos\theta_0(\Delta\phi) - u_0\Delta r + w_0\Delta p - \frac{d}{m}\Delta v}$$

$$\Delta\dot{w} = -\frac{T_0+\Delta T}{m} + g\underbrace{\cos(\theta_0+\Delta\theta)}_{\cos\theta_0\cos\Delta\theta-\sin\theta_0\sin\Delta\theta \;\to\; -\sin\theta_0\boxed{\Delta\theta}}\underset{(1)}{\cos(\phi_0+\Delta\phi)} - (\underbrace{\Delta v\Delta p}_{0} - \Delta q(\overset{0}{u_0}+\Delta u)) - \frac{d}{m}(w_0+\Delta w)$$

$=$

(*) 消える

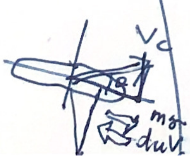
$$\boxed{\Delta\dot{w} = -g\sin\theta_0(\Delta\theta) + u_0\Delta q - \frac{1}{m}\Delta T - \frac{d_w}{m}\Delta w}$$

(*) V_cが決まると、θ_0も決まる (図)の拡張でつり合う

$$d_u\overbrace{\boxed{V_c\cos\theta_0}}^{u_0} = -\boxed{mg\sin\theta_0} \qquad d_w\overbrace{\boxed{V_c\sin\theta_0}}^{w_0} = +mg\cos\theta_0$$

①,②

$$-\tan\theta_0 = \frac{d_u V_c}{mg}$$



回転. $I_x \dot{p} = (\tau_\phi - qr(I_z - I_y)) \rightarrow \boxed{I_x \Delta\dot{p} = \Delta\tau_\phi}$

（つり合い $\tau_{\phi_0} = q_0 r_0 (I_z - I_y)$ ）.

$I_y \dot{q} = (\tau_\theta - rp(I_x - I_z)) \rightarrow \boxed{I_y \Delta\dot{q} = \Delta\tau_\theta}$

$qr - q_0 r_0$

$= (q_0 + \Delta q)(r_0 + \Delta r) - q_0 r_0$

$= \Delta q r_0 + \Delta r q_0$

（つり合い $\tau_{\theta_0} = r_0 p_0 (I_x - I_z)$ ）

$I_z \dot{r} = (\tau_\psi - pq(I_y - I_x)) \rightarrow \boxed{I_z \Delta\dot{r} = \Delta\tau_\psi}$

（つり合い $\tau_{\psi_0} = p_0 q_0 (I_y - I_x)$ ）

オイラー $\dot{\phi} = p + q\sin\phi\tan\theta + r\cos\phi\tan\theta$

$\Delta\dot{\phi} = \underset{\text{top}}{p_0} + (q_0 + \Delta q)(\sin(\phi_0 + \Delta\phi))\tan(\theta_0 + \Delta\theta) + (r_0 + \Delta r)\cos(\phi_0 + \Delta\phi)\tan(\theta_0 + \Delta\theta)$

$= \Delta p + \underbrace{\Delta q \cdot \Delta\phi}_{\text{小さい}} \tan(\theta + \Delta\theta) + \Delta r \tan(\theta_0 + \Delta\theta)$

（つり合い $\cancel{p_0} + \cancel{q_0}\sin\phi_0 \tan\theta_0 + \cancel{r_0}\cos\phi_0 \tan\theta_0 = 0$ ）

$$\boxed{\Delta\dot{\phi} = \Delta p + (\tan\theta_0)\Delta r}$$

$\dot{\theta} = \cos\phi\, q - \sin\phi$

つり合い $\cos\phi_0\, q_0 = \sin\phi_0\, r_0$

$\Delta\dot{\theta} = \cos(\phi_0 + \Delta\phi)(q_0 + \Delta q) - \sin(\phi_0 + \Delta\phi)(r_0 + \Delta r)$

$$\boxed{\Delta\dot{\theta} = \Delta q - \underbrace{\Delta\phi\Delta r}_{=0} = \Delta q}$$

$\dot{\psi} = \frac{\sin\phi}{\cos\theta} q + \frac{\cos\phi}{\cos\theta} r$

$\Delta\dot{\psi} = \frac{\sin(\phi_0 + \Delta\phi)}{\cos(\theta_0 + \Delta\theta)}(q_0 + \Delta q) + \frac{\cos(\phi_0 + \Delta\phi)}{\cos(\theta_0 + \Delta\theta)}(r_0 + \Delta r)$

$\Delta\dot{\psi} = \frac{\Delta\phi\Delta q}{\cos\theta_0} + \frac{1}{\cos\theta_0}\Delta r$.

$$\boxed{\Delta\dot{\psi} = \frac{1}{\cos\theta_0}\Delta r}$$