$E x_1' = F$

$$X_1 = \begin{bmatrix} \zeta \\ V_\zeta \\ \eta \\ V_\eta \\ \alpha \\ \omega \end{bmatrix} \begin{array}{l} \text{surge position} \\ \text{surge velocity} \\ \text{heave position} \\ \text{heave velocity} \\ \text{pitch position} \\ \text{pitch velocity} \end{array}$$

consider 3-DOFs and respect velocity.

$\zeta' = V_\zeta$

$\eta' = V_\eta$

$$1 \cdot \zeta' = V_\zeta$$

$$M_x \cdot V_\zeta' + \omega' \cdot M_d \cos\alpha = Q_\zeta + M_d\, \omega^2 \sin\alpha$$

$$1 \cdot \eta' = V_\eta$$

$$M_y \cdot V_\eta' + \omega' \cdot M_d \sin\alpha = Q_\eta - M_d\, \omega^2 \cos\alpha$$

$$1 \cdot \alpha' = \omega$$

$$M_d \cos\alpha \cdot V_\zeta' + M_d \sin\alpha \cdot V_\eta' + J_{TOT} \cdot \omega' = Q_\alpha$$

Tle forces consider:

Weight Q^{we}

Buoyancy Q^b

tie rod Q^t

win

Samplification

1) Only 2D has been considered

2) The system is rigid

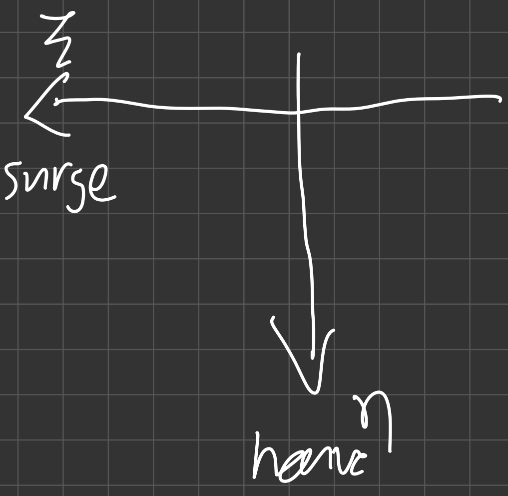
3) Wind thrust through 1-D aproach

The system is divided to three components

Nacelle N

floater and tower S

Blade P

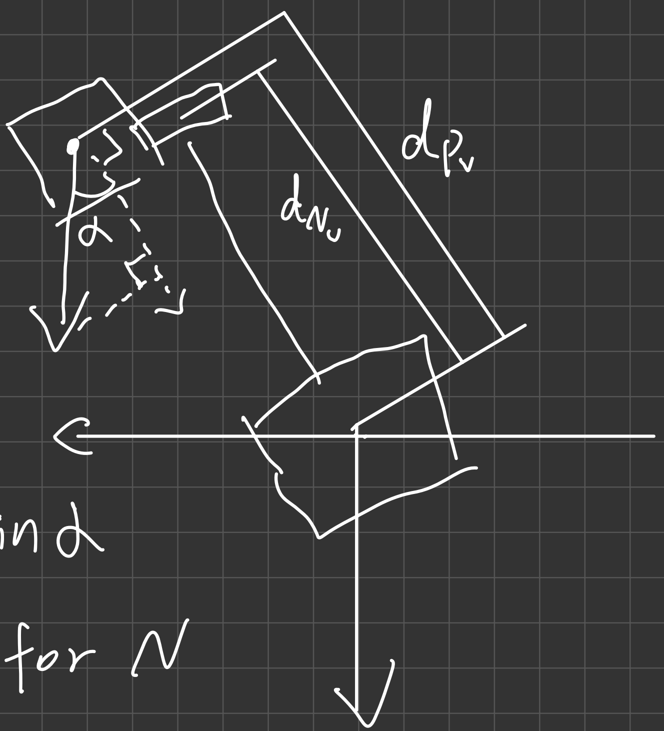


weight

$$Q^{we}_{\xi} = 0$$

$$Q^{we}_{\eta} = (M_N + M_P + M_S) g$$

$$Q^{we}_{\alpha}$$



$$\sin\alpha = \frac{Q^{we}_{\alpha P}}{M_P g}$$

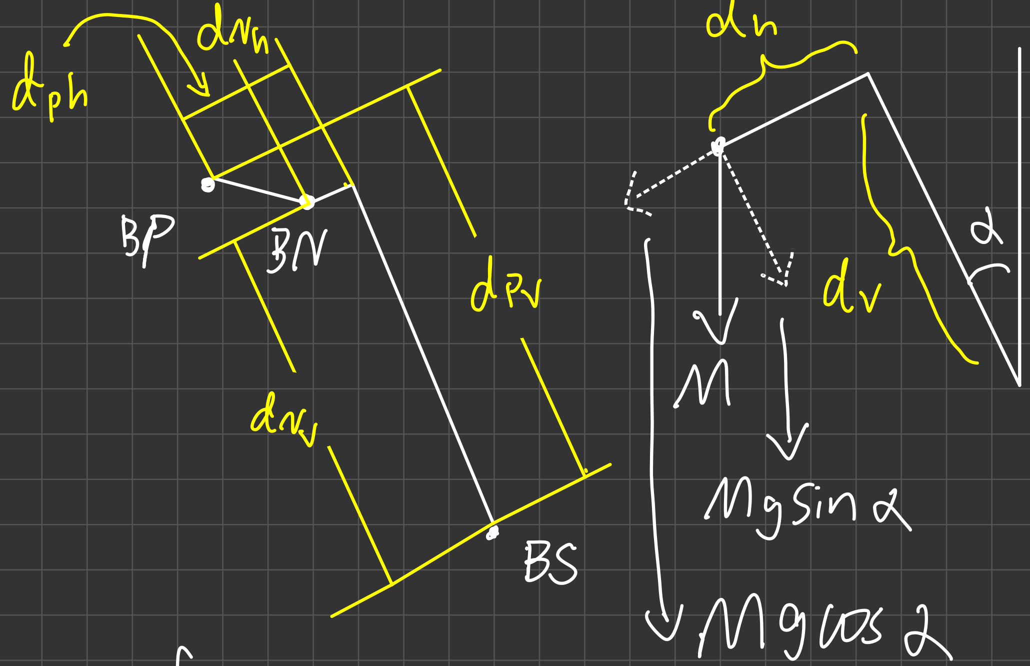
$$Q^{we}_{\alpha P} = M_P g \sin\alpha$$

Same analysis for N

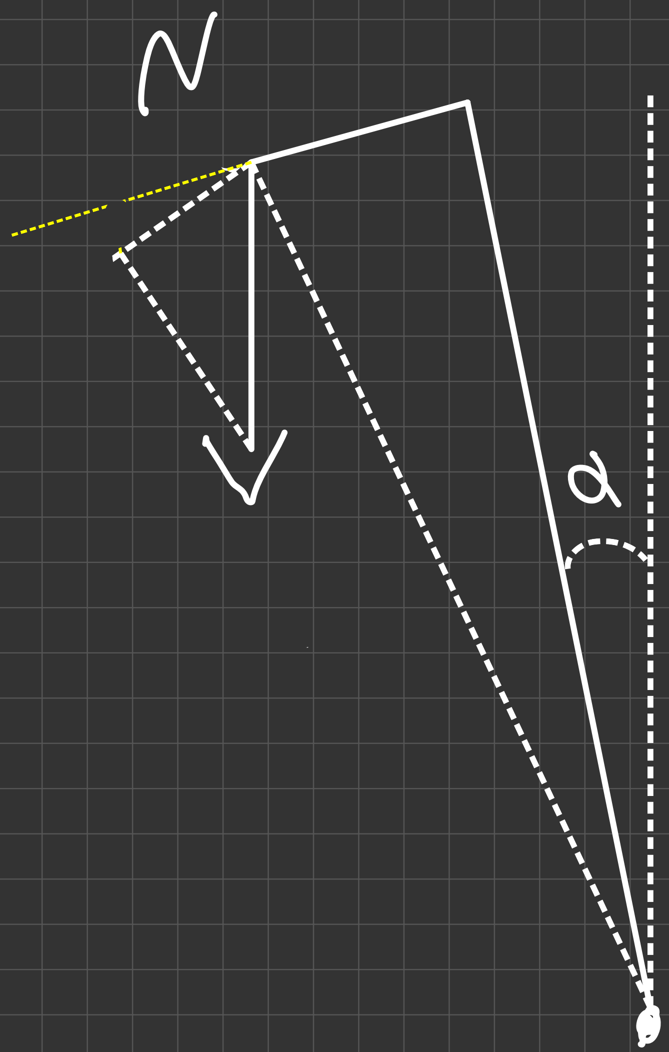
$$Q^{we}_{\alpha N} = M_N g \sin\alpha$$

$$Q^{we}_{\alpha_{Np}} = (M_N + M_p)\sin\alpha\, g$$

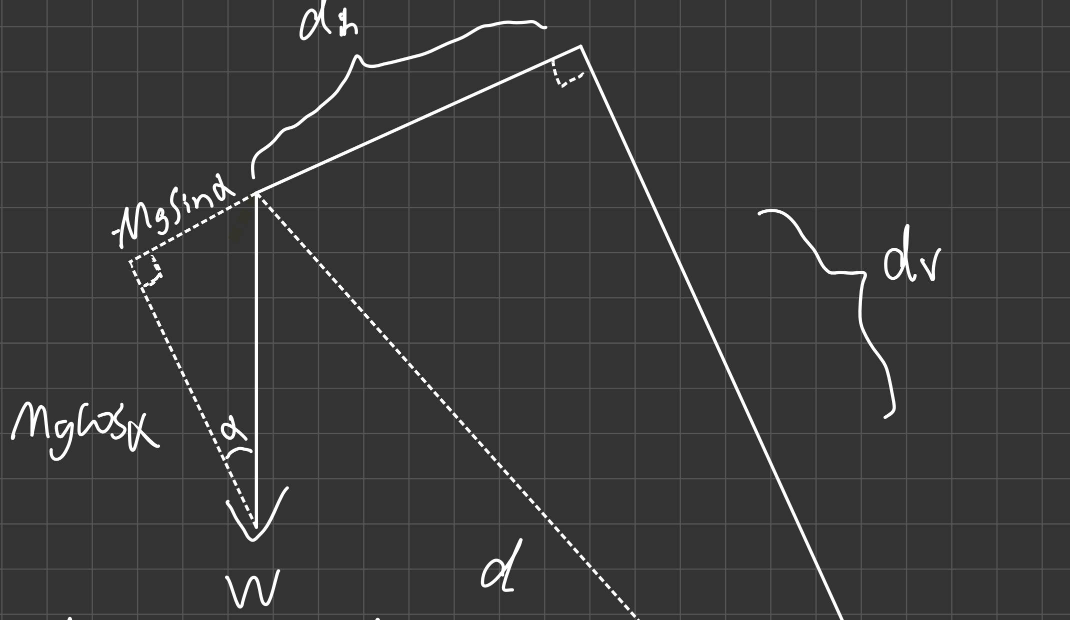
$$Q^{we}_{\alpha} = M_N d_{N_v} \sin\alpha\, g + M_p d_{p_v} \sin\alpha\, g$$



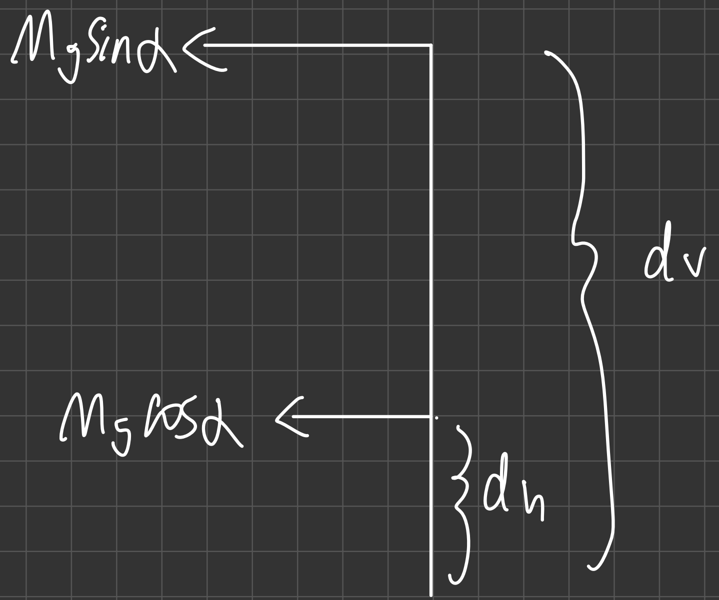
Q^{we}_{α} is the sum of torque due to pitch



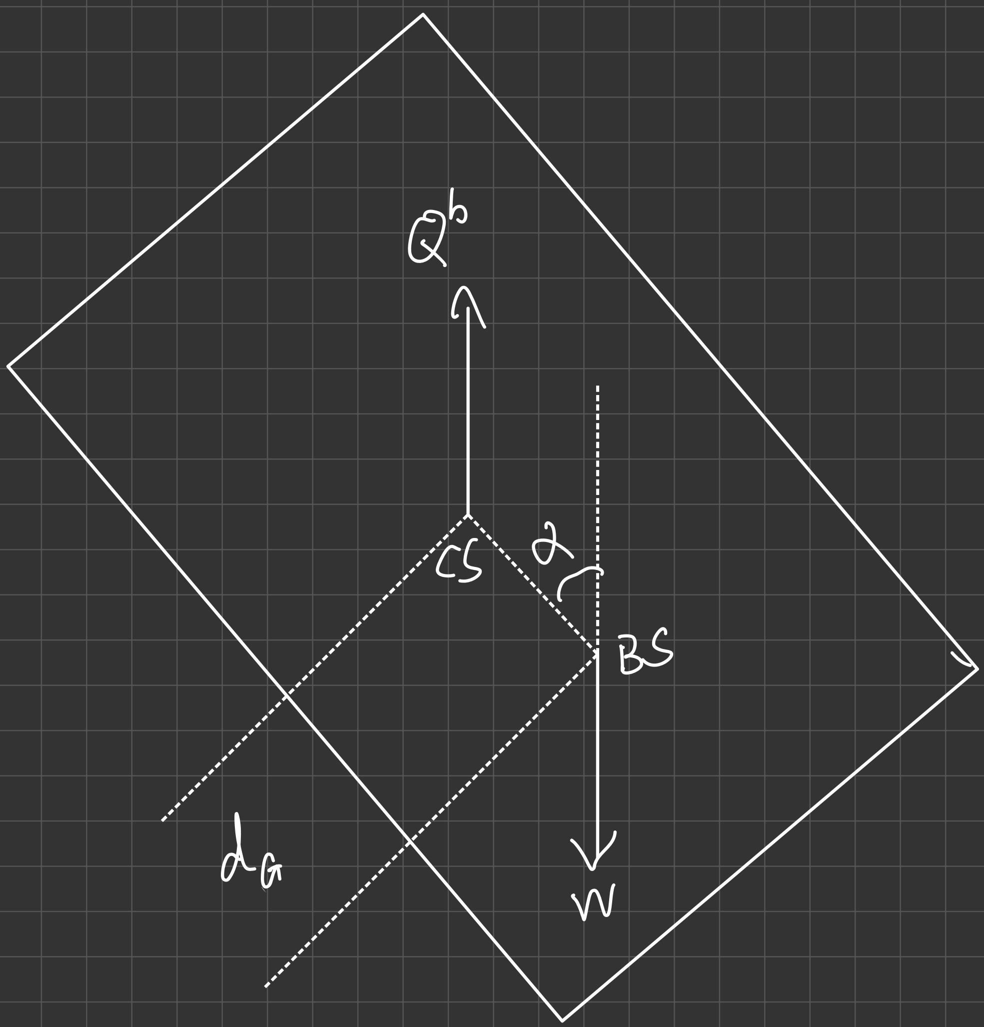
Weight torque

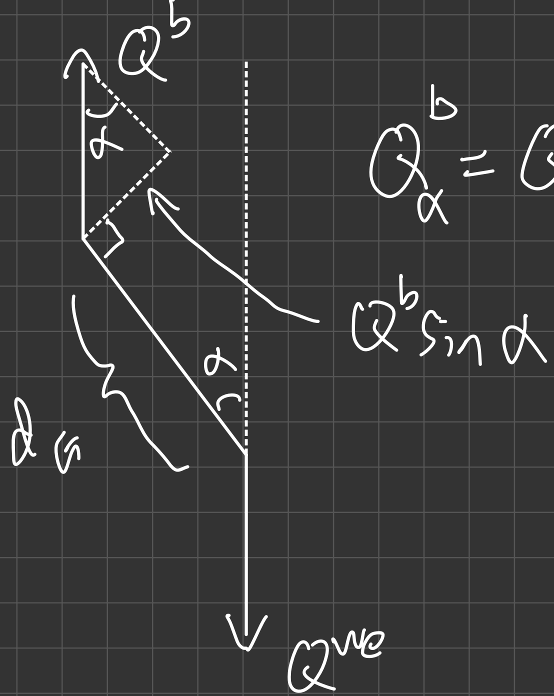


$$Mg\sin\alpha\, d_v + Mg\cos\alpha\, d_h$$
$$= Mg(\sin\alpha\, d_v + \cos\alpha\, d_h)$$



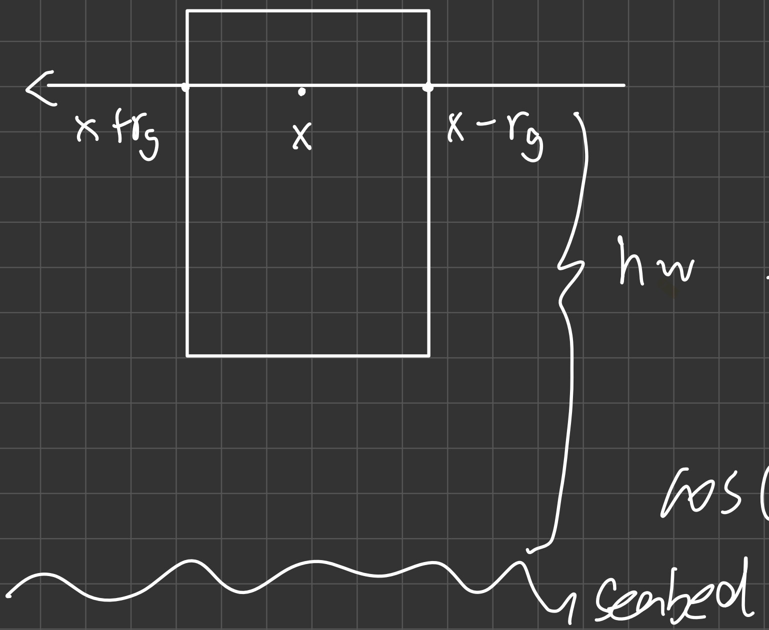
Buoyancy torque





$$Q^b_\alpha = Q^b_\eta \cdot \sin\alpha \, d_G$$

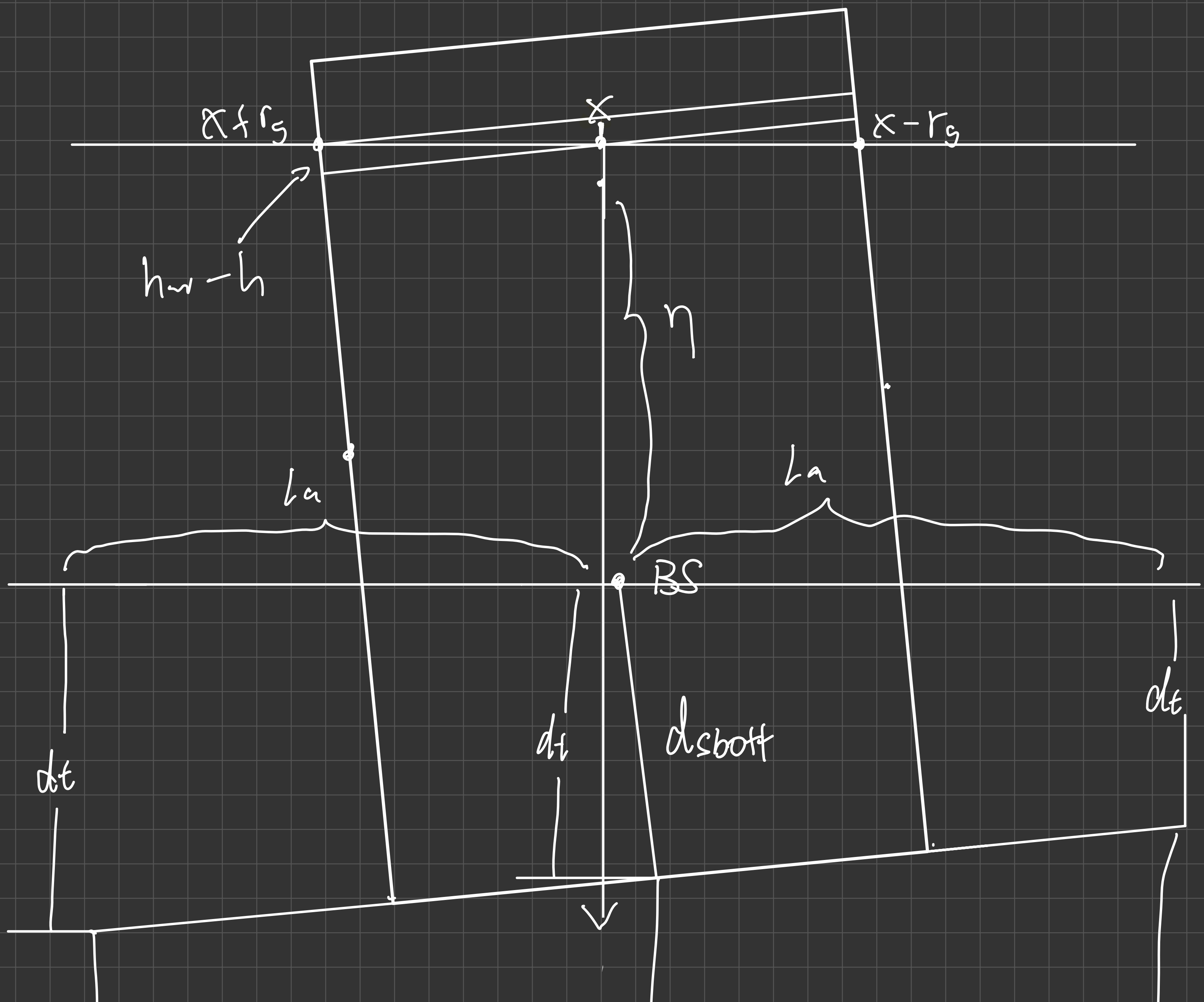
Approximate V_g

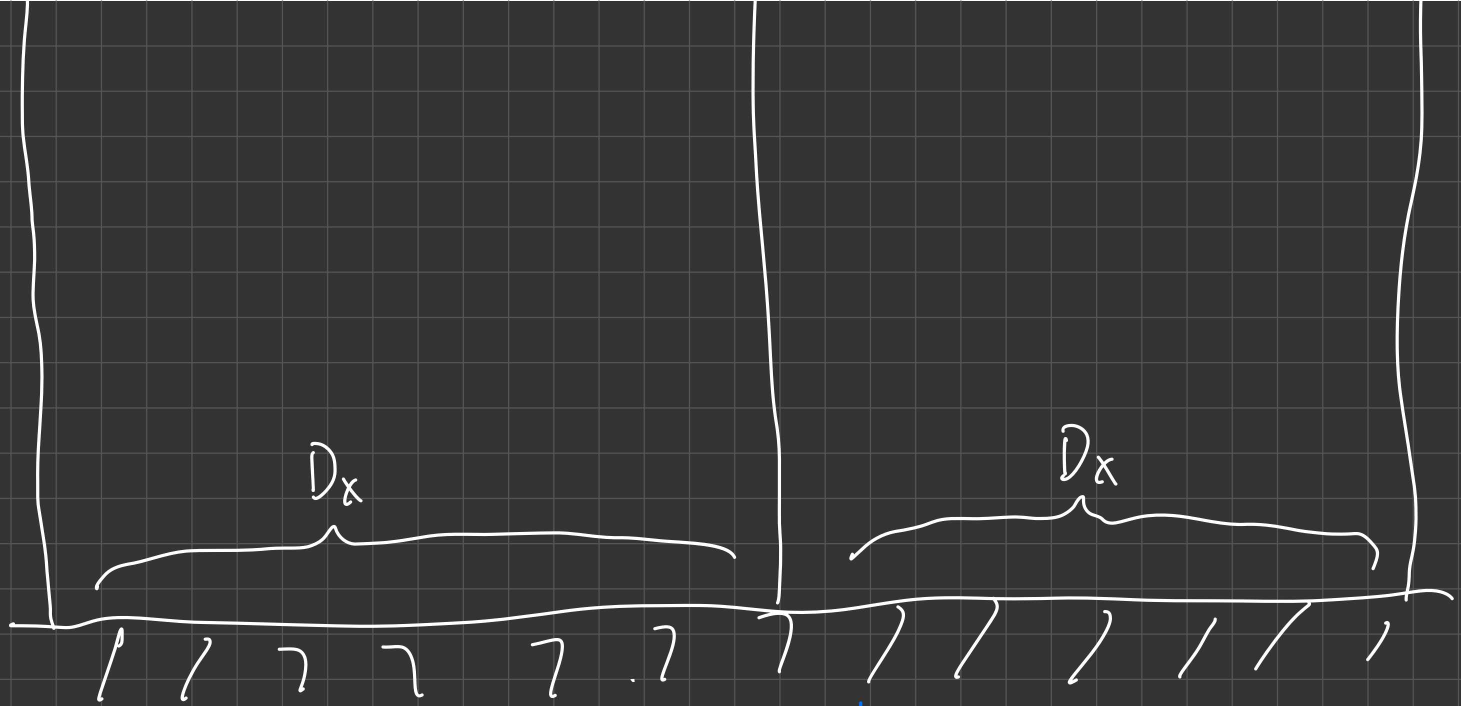


water surface
(Assume flat and horizontal)

h_w — Average of $x+r_g$, x, $x-r_g$

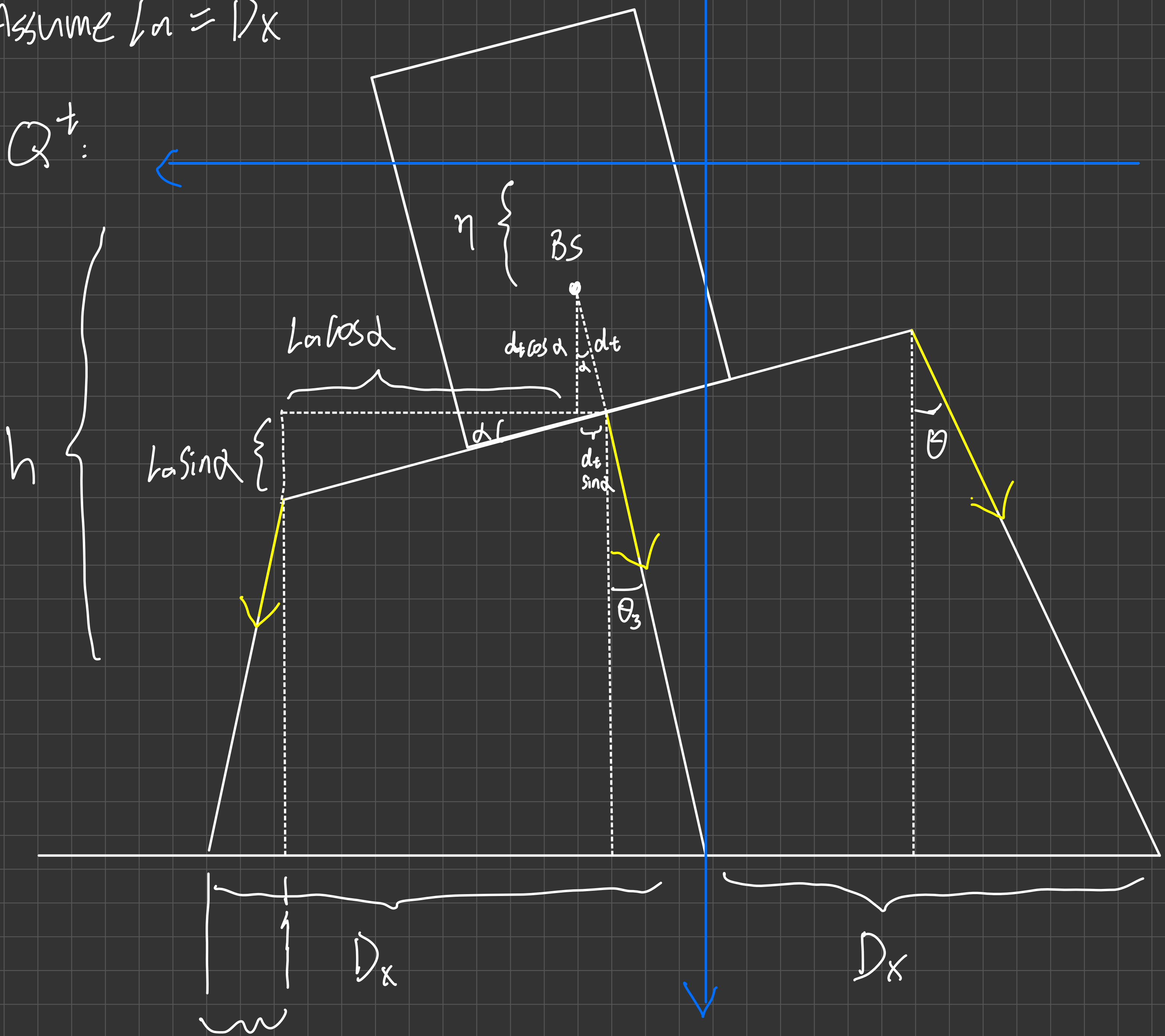
$\cos(\alpha) \simeq 1$ (small pich angle)



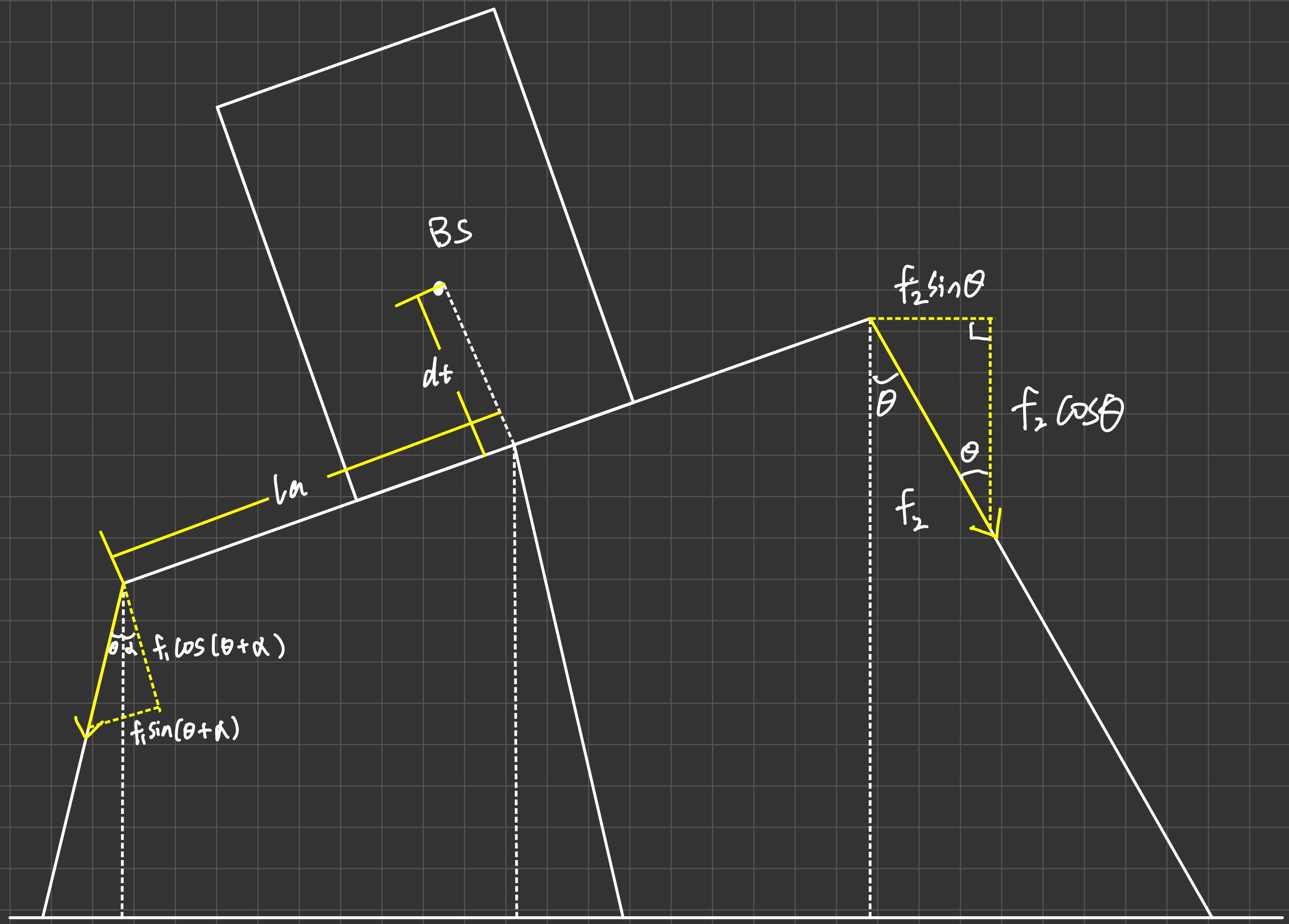


Assume $L_a = D_x$

Q^t:



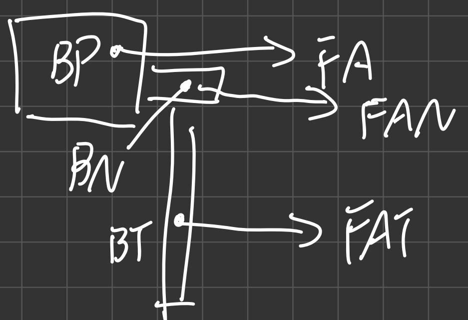
$D_x - \xi - L_a \cos\alpha + d_t \sin\alpha$



Torque of f_1: $Q^t_{\alpha f_1} = f_1\cos(\theta+\alpha)\cdot l_a - f_1\sin(\theta+\alpha)d_t$

because those two torques are opposite direction

Wind Force



work done

$$1 \cdot \xi' = V_\xi$$

$$M_x \cdot V_\xi' + \omega' \cdot M_d \cos\alpha = Q_\xi + M_d \omega^2 \sin\alpha$$

$$1 \cdot \eta' = V_\eta$$

$$M_y \cdot V_\eta' + \omega' \cdot M_d \sin\alpha = Q_\eta - M_d \omega^2 \cos\alpha$$

$$1 \cdot \alpha' = \omega$$

$$M_d \cos\alpha \cdot V_\xi' + M_d \sin\alpha \cdot V_\eta' + J_{TOT} \cdot \omega' = Q_\alpha$$

$$\xi' = V$$

$$\begin{bmatrix} \xi \\ \eta \\ \alpha \end{bmatrix}$$

$$\xi' - V_\xi = 0$$

$$\xi' -$$

$$M_x \cdot \xi'' + 0 \cdot \eta'' + M_d \cos\alpha \cdot \alpha'' = Q_\xi + M_d \omega^2 \sin\alpha$$

$$0 \cdot \xi'' + M_y \eta'' + M_d \sin\alpha \; \alpha'' = Q_\eta - M_d \omega^2 \cos\alpha$$

$$M_d \cos\alpha \; \xi'' + M_\alpha \sin\alpha \cdot \eta'' + J_{TOT} \alpha'' = Q_\alpha$$

$$\begin{bmatrix} M_x & 0 & M_d \cos\alpha \\ 0 & M_y & M_d \sin\alpha \\ M_d \cos\alpha & M_\alpha \sin\alpha & J_{TOT} \end{bmatrix} \begin{bmatrix} \xi'' \\ \eta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} Q_\xi + M_d \omega^2 \sin\alpha \\ Q_\eta - M_d \omega^2 \cos\alpha \\ Q_\alpha \end{bmatrix}$$

$$J_R \, \alpha_R'' = T_A - T_E$$

work done by weight — Work done by buoyancy — work done by tie rods

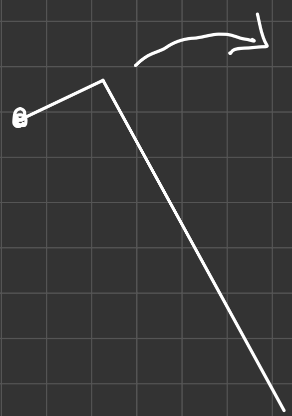
$$\left.\begin{aligned} &Q^w_\xi \cdot \xi + Q^b_\xi \, \xi + Q^t_\xi \, \xi \\ &Q^w_\eta \cdot \eta + Q^b_\eta \cdot \eta + Q^t_\eta \cdot \eta \\ &Q^w_\alpha \cdot \alpha + Q^b_\alpha \cdot \alpha + Q^t_\alpha \cdot \alpha \end{aligned}\right\} \text{work done by weight, buoyancy, tie rods}$$

we have Q_ξ

Q_η

Q_α

$$E_k = \frac{1}{2}(M_s + m_x)(\xi')^2 + \frac{1}{2}(M_s + m_y)(\eta')^2 + \frac{1}{2}M_N V_N^2 + \frac{1}{2}M_P V_P^2 + \frac{1}{2}(J_s + J_N + J_P)(\alpha')^2$$



Forces considered in R_{int}

weight, buoyancy, tension in the mooring lines

$$Q_\xi^w = 0$$

$$Q_\eta^{we} = (M_N + M_p + M_s)g$$

does not depend on any state

$$Q_\alpha^{we} =$$

States : $D = \begin{bmatrix} \xi \\ \eta \\ \alpha \\ \alpha_R \end{bmatrix}$ surge position, heave position, pitch position, rotor position

$$R_{int} = \begin{bmatrix} Q_\xi^w + Q_\xi^b + Q_\xi^t \\ Q_\eta^w + Q_\eta^b + Q_\eta^t \\ Q_\alpha^w + Q_\alpha^b + Q_\alpha^t \\ 0 \end{bmatrix}$$

$$V_{in} = V_w + V_\xi + d_p \omega \cos \alpha$$

$$\tilde{J}_R \alpha_R'' = \frac{P_A}{\alpha_R'} - \tilde{T}_E$$

$$\tilde{F}A = \frac{1}{2}\rho A(V_{in}^2 - V_{out}^2) + \Delta FA$$

$$FAN = \frac{1}{2}\rho C_{dN} A_N \cos(\alpha)$$

$$M_x = M_s + M_N + M_p + m_x$$

$$M_y = M_s + M_N + M_p + m_y$$

$$J_{TOT} = J_s + J_N + J_P + M_N d_N^2 + M_P d_P^2$$

$$M_x\, \xi''$$

$$M_y\, \eta''$$

$$J_{TOT}\, \alpha''$$

$$\begin{bmatrix} M_x & 0 & 0 \\ 0 & M_y & 0 \\ 0 & 0 & J_{TOT} \end{bmatrix} \begin{bmatrix} \xi'' \\ \eta'' \\ \alpha'' \end{bmatrix} + \begin{bmatrix} Q_\xi^w + Q_\xi^b + Q_\xi^t \\ Q_\eta^w + Q_\eta^b + Q_\eta^t \\ Q_\alpha^w + Q_\alpha^b + Q_\alpha^t \end{bmatrix}$$

$$= \begin{bmatrix} Q_\xi^{wi} + Q_\xi^h + Q_\xi^{wa} \\ Q_\eta^{wi} + Q_\eta^h + Q_\eta^{wa} \\ Q_\alpha^{wi} + Q_\alpha^h + Q_\alpha^{wa} \end{bmatrix}$$

$$\tilde{J}_R \omega_R' = \frac{1}{2\omega_R}\rho A V_{in}^3 C_p(\lambda, \beta) - \tilde{T}_E$$

$$V_{in} = V_w + \xi' + d_p \alpha' \cos\alpha$$