MODULE II : MANEUVERABILITY

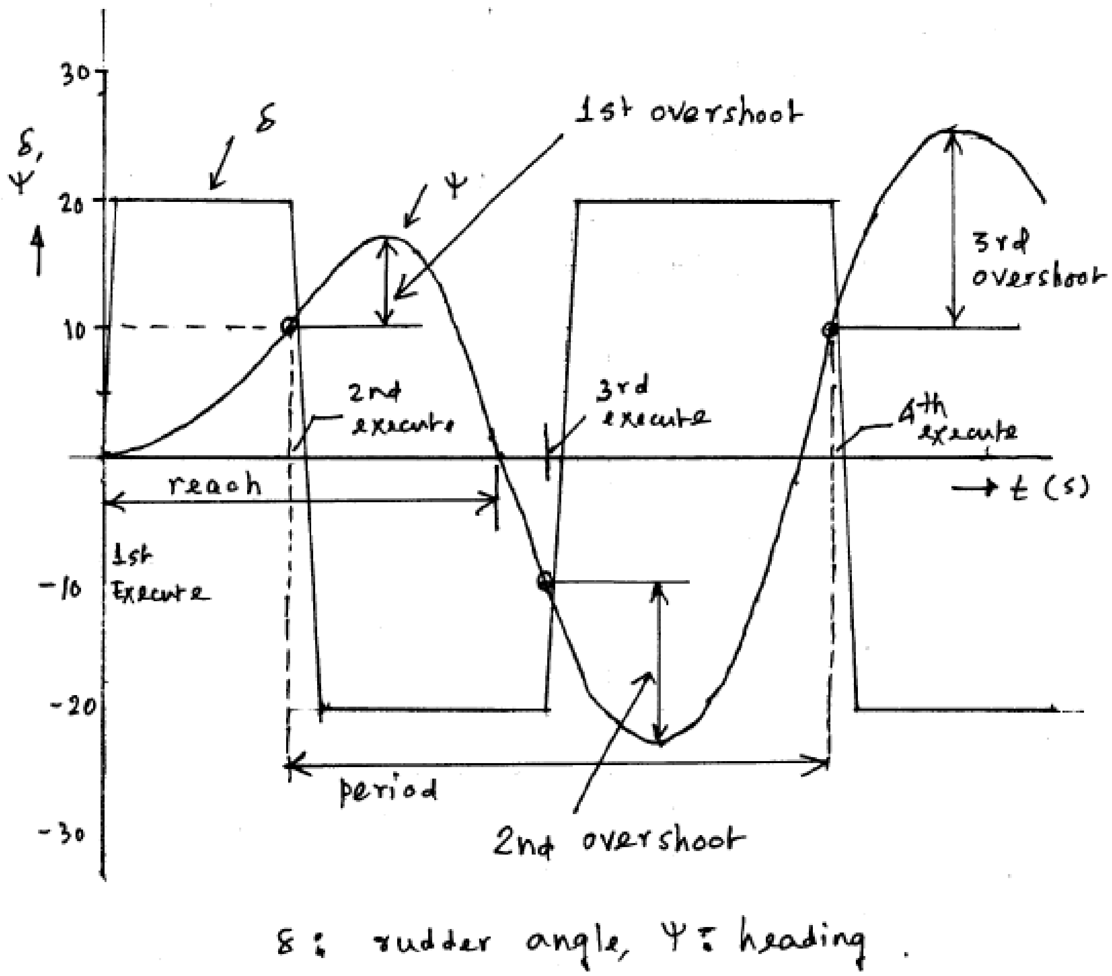
Topic : Definitive Maneuvers

Question 1

Draw a schematic diagram of a 20/10 zigzag maneuver and identify all the terms.

Answer:

The figure is shown below and the terms like (time of) 1^{st},2^{nd},3^{rd} executes, (time to) reach, period, 1^{st} and 2^{nd} overshoot etc. are explained on the diagram.



Question 2

(i) The sway and yaw maneuvering equations with rudder working are as follows:

$$-Y_v v + (m - Y_{\dot v})\dot v - (Y_r - mU)r - Y_{\dot r}\dot r = Y_\delta \delta$$
$$-N_v v - N_{\dot v}\dot v - N_r r + (I_Z - N_{\dot r})\dot r = N_\delta \delta$$

From this, show that the steady turning radius for a given ship at a given rudder angle is independent of forward speed but its yaw rate is in proportion to forward speed.

(ii) For a ship of L =110m, B=18m, T=4.1m, C_B=0.68, the hydrodynamic and rudder derivatives are as follows:

$Y_v^{'} = -9.65\times10^{-3}$; $Y_r^{'} = 2.14\times10^{-3}$; $N_v^{'} = -2.57\times10^{-3}$; $N_r^{'} = -1.44\times10^{-3}$
$Y_\delta^{'} = -1.0\times10^{-3}$; $N_\delta^{'} = 0.5\times10^{-3}$

Find its turning radius, drift angle and yaw rate for 16 knots at 35 deg. rudder.

Answer:

(i)

During steady turning phase, the time derivatives are all zero, and therefore the sway and yaw equations reduces to (obtained by making $\dot v = \dot r = 0$) :

$$-Y_v v - (Y_r - mU)r = Y_\delta \delta$$
$$-N_v v - N_r r = N_\delta \delta$$

In non-dimensional form:

$$-Y_v^{'} v^{'} - (Y_r^{'} - m^{'})r^{'} = Y_\delta^{'} \delta$$
$$-N_v^{'} v^{'} - N_r^{'} r^{'} = N_\delta^{'} \delta$$

From this we get by solving for $v^{'}$ and $r^{'}$:

$$v^{'} = \delta\left[\frac{N_\delta^{'}(Y_r^{'} - m^{'}) - Y_\delta^{'} N_r^{'}}{Y_v^{'} N_r^{'} - N_v^{'}(Y_r^{'} - m^{'})}\right], \qquad r^{'} = \delta\left[\frac{N_v^{'} Y_\delta^{'} - Y_v^{'} N_\delta^{'}}{Y_v^{'} N_r^{'} - N_v^{'}(Y_r^{'} - m^{'})}\right]$$

We have (from definition of non-dimensionalization), $r^{'} = rL/V$. Also, $V = rR$.

Thus, $r^{'} = rL/V = rL/rR = L/R$

We then get,

$$r = r'\frac{V}{L} = \delta\frac{V}{L}\left[\frac{N_v'Y_\delta' - Y_v'N_\delta'}{Y_v'N_r' - N_v'(Y_r' - m')}\right]; \quad \frac{R}{L} = \frac{1}{r'} = \frac{1}{\delta}\left[\frac{Y_v'N_r' - N_v'(Y_r' - m')}{N_v'Y_\delta' - Y_v'N_\delta'}\right]$$

This shows that for a given ship, yaw rate $r \propto V, \delta$, and the turning radius $R \propto \frac{1}{\delta}$ but independent of V.

From the definition of non-dimensional sway, we have $v' = \frac{v}{V} = \frac{V\sin(-\beta)}{V} \approx -\beta$. Thus drift angle is given by $-v'$, the expression of which is given above. It is seen that drift angle is in proportion to δ but independent of V.

(ii)

Here $m' = \frac{m}{0.5\rho L^3} = \frac{\rho LBTC_B}{0.5\rho L^3} = \frac{2BTC_B}{L^2} = \frac{(2)(18)(4.1)(0.68)}{180^2} = 3.098\times10^{-3}$

Turning radius

$$R = \frac{L}{\delta}\left[\frac{Y_v'N_r' - N_v'(Y_r' - m')}{N_v'Y_\delta' - Y_v'N_\delta'}\right] = \frac{110}{35\times\pi/180}\left[\frac{(-9.65)(-1.44) - (-2.57)(2.14 - 3.098)}{(-2.57)(-1) - (-9.65)(0.5)}\right]$$
$$= 279\ m$$

Yaw rate

$$r = \delta\frac{V}{L}\left[\frac{N_v'Y_\delta' - Y_v'N_\delta'}{Y_v'N_r' - N_v'(Y_r' - m')}\right] = 1.69 \text{ deg/sec}$$

Drift angle

$$\beta = -\delta\left[\frac{N_\delta'(Y_r' - m') - Y_\delta'N_r'}{Y_v'N_r' - N_v'(Y_r' - m')}\right] = 9.61 \text{ deg}$$

Question 3

(i)
Find an approximate expression for heel angle during steady turn.

(ii)
A vessel turns in a radius of 300 m. at a speed of 16 knots under the action of rudder force of 2 MN. If the draft of the ship if 8m, KG is 9m and GM is 3m, find the approximate agle of heel during the steady turn

Answer:

(i)

During steady turn, let F_h and F_r are the hull and rudder forces respectively. Referring to the figure below, by equating forces, we have $F_h - F_r = \frac{\Delta V^2}{Rg}$ where Δ is mass, R is turning radius, and V is speed during turn.

If F_h and F_r acts at the points H and E respectively as shown in the diagram, the heeling moment is given by

$$
\begin{aligned}
&(F_h - F_r)(KG) + F_r(KH) - F_h(KE) \\
&= (F_h - F_r)(KG - KE) + F_r(KH - KE) \\
&= (F_h - F_r)(GE) - F_r(EH)
\end{aligned}
$$

(K represent point on keel)

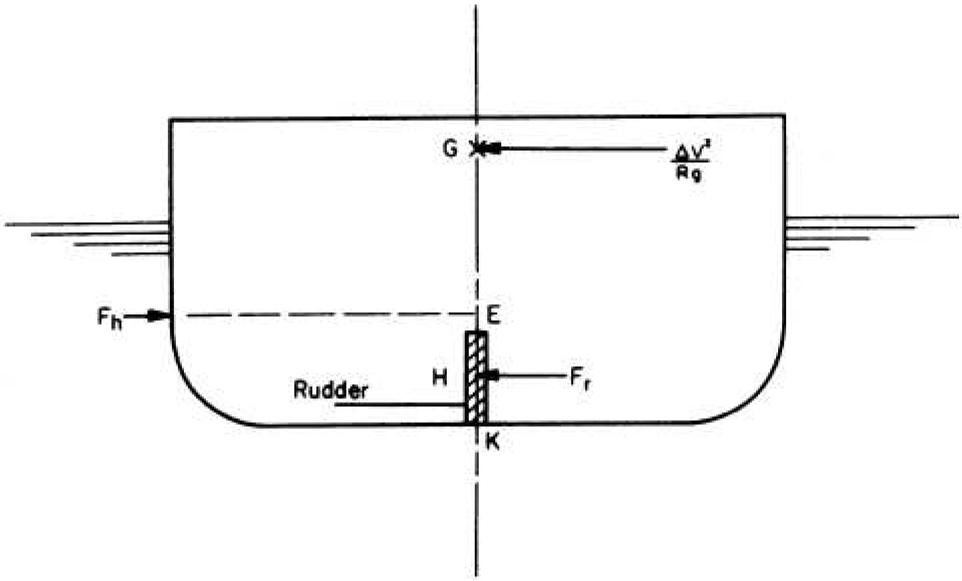
For most ships, both E and H are approximately same and at the half draft level. With this approximation, heeling moment becomes $(F_h - F_r)(GE)$

If the heel angle is α, we have

$$\Delta GM \sin\alpha = (F_h - F_r)(GE) = \frac{\Delta V^2}{Rg}(GE)$$

Thus for small α for which $\sin\alpha \approx \alpha$, we get the heel angle as:

$$\alpha = \frac{V^2}{Rg}\frac{GE}{GM}$$



(ii)

For this problem, $V = 16$ knots, and $R = 450$ m.

Assuming that the rudder force acts at half draft level, we have $GE = KG - T/2 = 9 - 8/2 = 5$ m

Thus, $\alpha = \dfrac{(16 \times 0.5144)^2}{(300)(9.8)} \dfrac{5}{3} = 0.0384\, rad$ = 2.2 deg.