MODULE II : MANEUVERABILITY

Topic: Motion Stability, Equations of Motion and Hydrodynamic Derivatives

Question 1

Describe by suitable sketches different types of motion stability for a surface ship

Answer:

Motion stability refers to the ship's behavior after a momentary disturbance is applied to the vehicle in steady forward motion.

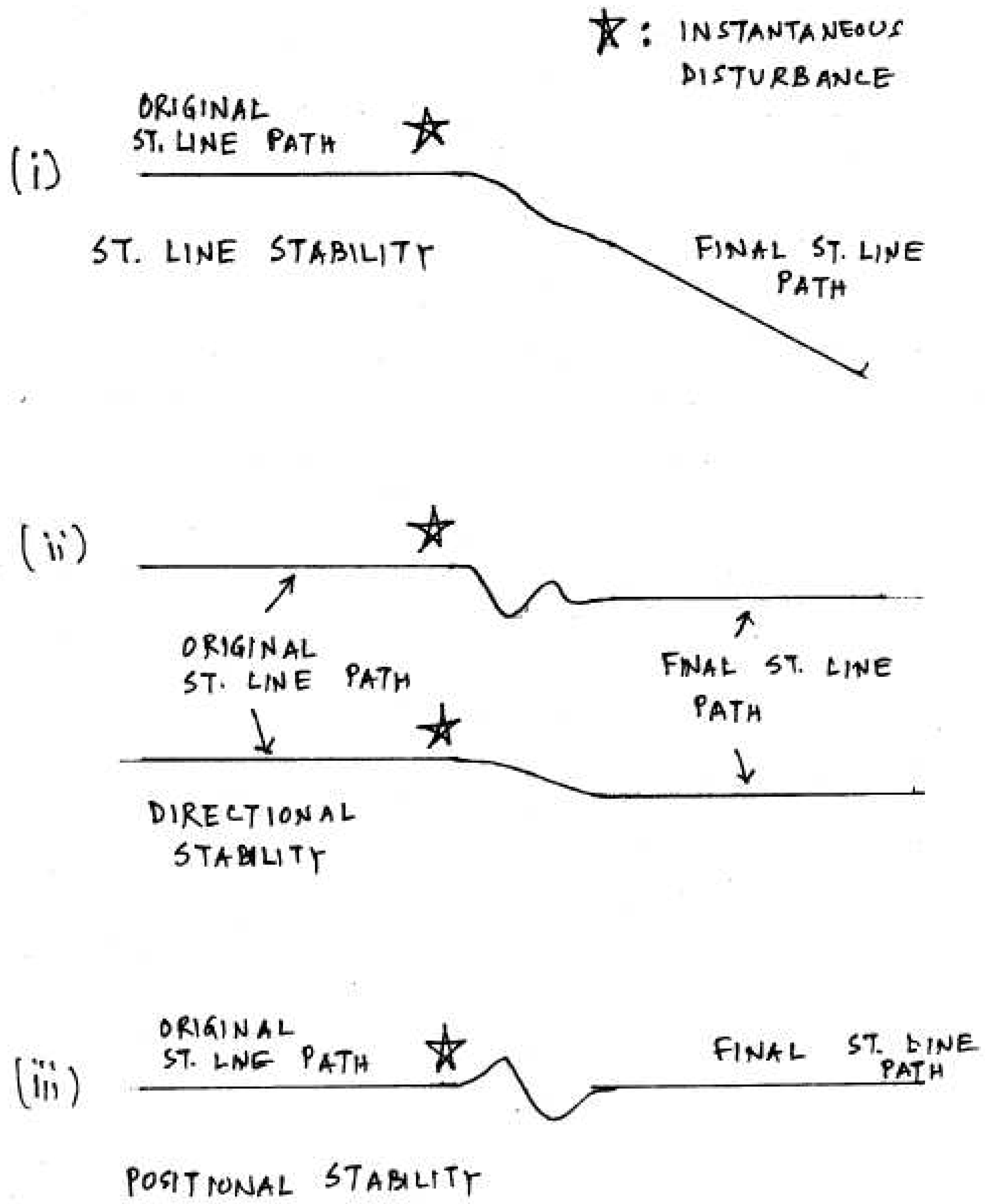
There are 3 types of motions stability:

i. Straight line stability : this is the ships ability to resume a straight-line path without application of control surface forces. This means, if the ship takes a straight-line path after the disturbance is removed, then it is said to possess straight-line stability.

ii. Directional stability: this is the ship's ability to resume a straight line path having the same direction as it had before the disturbance. There can be two possible paths during the disturbance phase: either it can be oscillatory or non-oscillatory.

iii. Positional stability: this is the ship's ability to resume a straight line path having the same direction and position it had before the disturbance. Here by position we mean that it follows essentially the same straight line path it had before the disturbance.

These are illustrated in the diagram below.


☆ : INSTANTANEOUS DISTURBANCE
(i)
ORIGINAL ST. LINE PATH
FINAL ST. LINE PATH
ST. LINE STABILITY
(ii)
ORIGINAL ST. LINE PATH
FINAL ST. LINE PATH
DIRECTIONAL STABILITY
(iii)
ORIGINAL ST. LINE PATH
FINAL ST. LINE PATH
POSITIONAL STABILITY

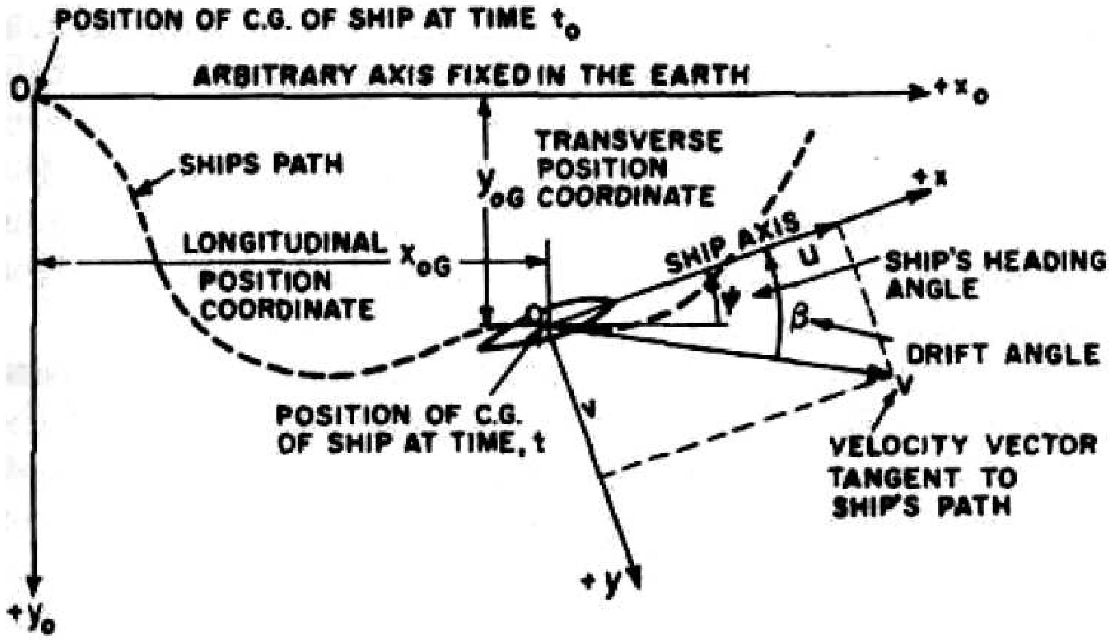
Question 2

By means of a suitable sketch, explain the coordinate system and the different motion and force parameters used in studying ship maneuver in calm water.

Answer

In order to study ship maneuver in calm water in horizontal plane, an inertial coordinate system OX_0Y_0 arbitrarily fixed in earth, and a body-fixed system Gxy are used with origin usually fixed at the CG of the body (strictly, this is a point on the mean water surface vertically above/below CG). The position of the ship is then given by X_{0G} and Y_{0G} while its orientation or heading ψ (which is also referred to as yaw angle) is given by the angle between the longitudinal body-axis with the inertial OX_0 axis. The ship's velocity V is resolved into components u and v along the body axes Gx and Gy respectively. The angle that V makes with the body's longitudinal axis Gx is known as the drift angle β.

An illustration of the various terms are shown in the figure below.



Question 3

Briefly describe what is meant by hydrodynamic derivatives. Identify the important linear hydrodynamic derivatives that arise in the study of maneuverability and discuss their relative magnitudes.

Answer:

Hydrodynamic derivatives are essentially derivatives of hydrodynamic forces and moments against the motion parameters. Thus if A represents hydrodynamic forces/moments and α represents a velocity parameter, then the derivatives $\frac{\partial A}{\partial \alpha}, \frac{\partial^2 A}{\partial \alpha^2}$ etc. are called the hydrodynamic derivatives. Forces/moments and velocities/accelerations are related through Newton's equation of motion and one influences the other. The importance of the hydrodynamic derivatives terms arise from the fact that the nature of the various hydrodynamic forces/moments and the motions parameters are related through these terms.

For a ship in horizontal plane motions, the important forces and moments are sway force Y and yaw moment N. The important motion parameters are sway and yaw velocities and accelerations $v, \dot{v}, \dot{\psi}, \ddot{\psi}$. Thus the important linear derivatives are: $Y_v, N_v, Y_{\dot{v}}, N_{\dot{v}}, Y_{\dot{\psi}}, N_{\dot{\psi}}, Y_{\ddot{\psi}}, N_{\ddot{\psi}}$. Their relative magnitudes are as shown below:

$Y_{\dot{v}}$	:	large negative
Y_v	:	large negative
$N_{\dot{v}}$	:	small, positive or negative
N_v	:	small, positive or negative
$Y_{\ddot{\psi}} \equiv Y_{\dot{r}}$	:	small, positive or negative
$Y_{\dot{\psi}} \equiv Y_r$	:	small, positive or negative
$N_{\ddot{\psi}} \equiv N_{\dot{r}}$	:	large negative
$N_{\dot{\psi}} \equiv N_r$	:	large negative

Question 4

Two designs possess the following values of derivatives:

Design	$Y_v^{'}$	$N_v^{'}$	$Y_r^{'}$	$N_r^{'}$	$m^{'}$
A	-0.36	-0.07	0.06	-0.07	0.12
B	-0.26	-0.10	0.01	-0.03	0.10

Comment on the straight-line motion stability of the two designs.
Assuming both designs are 100m long, how far are the neutral points ahead of CG?

Answer:

For the ship to possess straight-line motion stability, the following criterion must be met:

$$\frac{N_r^{'}}{Y_r^{'}-m} > \frac{N_v^{'}}{Y_v^{'}}$$

or equivalently the stability index must be positive:

$$c \equiv N_r^{'}Y_v^{'} - N_v^{'}(Y_r^{'} - m^{'}) > 0$$

For design A, c = (-0.07)(-0.36) - (-0.07)(0.06-0.12)=0.0252 - 0.0042=+0.0021

For design B, c =(-0.03)((-0.26) – (-0.10)(0.01-0.10)=0.0078 – 0.009 = -0.0012

Thus we see that design B does not possess straight-line stability while design A has straight-line stability.

The distance of neutral point ahead of CG is given by $(N_v^{'} / Y_v^{'})L$.
Thus for L=100m., the distance of neutral point for design A and B are respectively (100)(-0.07/-0.36)=19.44m and (100)(-0.10/-0.26)=38.46m.

Question 5

The hydrodynamic derivatives for a 180m. long ship without a skeg are:

$Y_v^{'} = -0.0116$ $N_v^{'} = -0.00264$
$Y_r^{'} = -0.00298$ $N_r^{'} = -0.00166$
$m^{'} = 0.00798$

When a skeg is added, $Y_v^{'}$ and $N_v^{'}$ become -0.0050 and 0.0 respectively, Show that the ship without the skeg is unstable but addition of the skeg makes it stable. Determine the distance of the neutral point for the two cases, and find the relative distance the neutral point has shifted aft due to addition of the skeg.

Answer:

The stability index is :

$$c \equiv N_r^{'}Y_v^{'} - N_v^{'}(Y_r^{'} - m^{'})$$

Without the skeg,
c =(-0.00166)(-0.0116) – (-0.00264)(-0.00298-0.00798)= -9.68×10^{-6} 10(-6) < 0

With the skeg, c = (-0.00166)(-0.0050) - (0.0)(-0.00298-0.00798) = 8.3×10^{-6} 8.3 > 0

Thus the ship without the skeg is unstable and addition of the skeg makes it stable.

Neutral point ahead of CG:

Without the skeg: $(N_v^{'} / Y_v^{'})L$ =(-0.00264)/(-0.0116)(180) = +40.96m
With the skeg : $(N_v^{'} / Y_v^{'})L$ =(0)/(-0.0050)(180) = 0m

Thus we see that addition of skeg brings the neutral point (40.96-0)=40.96 m or 40.96/180=22.75% of length towards aft, which makes the ship stable.