CONFIDENTIAL

UNIVERSITI KUALA LUMPUR
Malaysian Institute of Marine Engineering Technology

FINAL EXAMINATION
OCTOBER 2025 SEMESTER SESSION

SUBJECT CODE	:	**LNB31003**
SUBJECT TITLE	:	**SEAKEEPING AND MANOUVERING**
PROGRAMME NAME (FOR MPU: PROGRAMME LEVEL)	:	**BET (NAVAL ARCHITECTURE AND SHIPBUILDING) WITH HONOURS**
TIME / DURATION	:	**09.00 AM - 12.00 PM (3 HOURS)**
DATE	:	**27 JANUARY 2026**

INSTRUCTIONS TO CANDIDATES

1. Please read **CAREFULLY** the instructions given in the question paper.
2. This question paper has information printed on both sides of the paper.
3. This question paper consists of **TWO (2)** section; Section A and Section B.
4. Answer **ALL** question in Section A. For Section B, answer **THREE (3)** questions with at least one (1) question from question 4 or question 5.
5. Please write your answers on this answer booklet provided.
6. Answer **ALL** questions in English language **ONLY**.
7. Answer should be written in blue or black ink except for sketching, graphic and illustration.
8. Formula sheet, added mass coefficient and graph paper are appended.

THERE ARE 6 PAGES OF QUESTIONS, EXCLUDING THIS COVER PAGE.

SECTION A (Total: 40 marks)

INSTRUCTION: Answer ALL questions.
Please use the answer booklet provided.

Question 1

Naval Architecture engineer is tasked with analyzing the maneuvering characteristics of a new seagoing vessel design. To do this, a 1:100 scale model is tested in a towing tank filled with fresh water. The objective is to apply fundamental principles of hydrodynamics and scaling laws to analyze the experimental data and predict the full-scale vessel's behavior. The table below presents the experimental data for sway force and yaw moment in relation to varying sway velocities.

Sway velocity, V(m/s)	-0.4	-0.3	-0.2	-0.1	0	0.1	0.2	0.3	0.4
Sway Force, Y(KN)	102	76	51	25	0	-25	-50	-77	-101
Yaw Moment, N(KN.m)	31	23	16	7.5	0	-7.5	-15.5	-22	-32

(a) Analyze the provided data to plot the relationship between sway velocity, sway force, and yaw moment. Using principles of hydrodynamics, estimate the linear hydrodynamic derivatives (Yv and Nv) and explain how they relate to the ship's lateral stability. (PLO1, SP3, SK3) (10 marks)

(b) Based on the provided model test data and applying the principles of scaling and dynamic similarity, determine the magnitude of the linear derivatives Yv and Nv for the full-scale vessel at the same Froude number. Justify your scaling methodology and critically evaluate its potential limitations and inaccuracies. (PLO2, SP3, SK4) (10 marks)

Question 2

(a) The zig-zag test is a standard maneuver used to evaluate a ship's course-keeping and turning ability. It's an essential part of the sea trial process, providing data on the vessel's response to rudder commands. The test involves a series of alternating rudder commands at a specific angle, and the resulting ship heading is recorded. The analysis of this test requires an in-depth understanding of the dynamics of ship motion.

i. Sketch and label the key components of a zig-zag maneuver. Using fundamental engineering principles, describe the essential criteria that must be achieved during the test to assess a ship's stability and course-keeping ability. (PLO1, SP3, SK3) (6 marks)

ii. Describe and illustrate with sketches two distinct methods used to assess the directional stability of a vessel. Explain the engineering fundamentals behind each method, and critically evaluate the type of stability information each test provides. (PLO1, SP3, SK3) (8 marks)

(b) Describe the application of a Planar Motion Mechanism (PMM) for experimentally determining the hydrodynamic derivatives Yv and Nv. Critically analyze the process by which the measured forces and moments on the oscillating ship model are used to extract these specific derivatives. (PLO2, SP3, SK4) (6 marks)

SECTION B (Total: 60 marks)

INSTRUCTION: Answer only THREE (3) questions.
Please use the answer booklet provided.

Question 3

(a) An ocean engineer must possess specialist knowledge of wave theory to accurately analyze how waves propagate and interact with marine structures. This requires a deep understanding of fundamental wave equations, such as the dispersion relation, which links wave frequency, wave number, and water depth. These equations are not just theoretical; they are essential for solving real-world engineering problems. (PLO1, SP3, SK4)

i. Using your knowledge of wave theory, show how the wave dispersion relation, ω2=gktanh(kd), simplifies to c=g/ω in deep water. (5 marks)

ii. The horizontal particle velocity in a wave is given by the formula:

$$\underline{u} = \frac{\partial \phi}{\partial x} = \frac{gak}{\omega} \frac{\cosh k(z+d)}{\cosh kd} \sin(kx - \omega t)$$

Simplify this formula for a shallow water scenario, and explain what happens to the particle's velocity, $\underline{u}$ as the water gets shallower and shallower. (7 marks)

(b) For a wave group with a length of 300 m, containing individual waves of 30 m in length: (PLO4, SP3, SK8)

i. Investigate the relationship between the component wave velocity and the group velocity for deep water waves. Using this knowledge, calculate the time taken for a component wave to travel the length of the group. (5 marks)

ii. Subsequently, calculate how far the group of waves would move forward during this time. Justify your calculations by relevant technical source or principle. (3 marks)

Question 4

An ocean engineer must possess a fundamental understanding of hydrodynamic properties to accurately predict a vessel's motion in waves. A key aspect of this is the concept of added mass, which describes the inertial resistance a fluid provides to an accelerating body. When a ship or its model heaves, it accelerates the volume of surrounding water along with it. This added mass of water increases the effective mass of the vessel, significantly influencing its natural period of oscillation and its response to wave forces. A thorough analysis of this phenomenon requires applying fundamental engineering principles to experimental data, such as the specific particulars and sectional data recorded from a model test that have been provided below:

- Length of model, L = 3.132 m
- Max. beam, B = 0.548 m
- Draught, T = 0.208 m
- Density of water ρ =1000 kg/m^3
- Wave length = ship length = 3.132 m
- Model speed, u = 1.1611 m/s
- Displacement, Δ = 267.00 kg
- Direction of ship travel, μ = 180° (i.e. head sea)
- LCG = at amidship

Stn	Bn (m)	Tn (m)	Sn (m^2)
0	0.000	0.208	0.000
5	0.545	0.208	0.103
10	0.548	0.208	0.114
15	0.545	0.208	0.103
20	0.000	0.208	0.000

(a) Using the provided sectional data and specialist knowledge of added mass coefficients (Use the added mass coefficient charts available as per attached), analyze and calculate the added mass for heaving in terms of the model mass. Show all steps and explain clear connection between the sectional data, the added mass coefficients, and the final calculation. (PLO1, SP3, SK3) (10 marks)

(b) The model is now subjected to waves with a heading angle (μ) of 120 ° and wave amplitude, ζ_a = 0.06 m, analyze the provided data to first determine the non-dimensional amplitude for the heaving force, f_o. Subsequently, calculate the dimensional exciting force for the heaving motion, F_o. (PLO2, SP3, SK4)

$$F = F_o \cos \omega_e t \ \underline{and}\ f_o = \frac{F_o}{(\rho g \zeta_a . L . B)} \text{ (Nondimensional form)}$$

$$f_o = \frac{2}{LB}\int_{-L/2}^{L/2} y_{(x)} \cos(kx \cos\mu) dx$$

(10 marks)

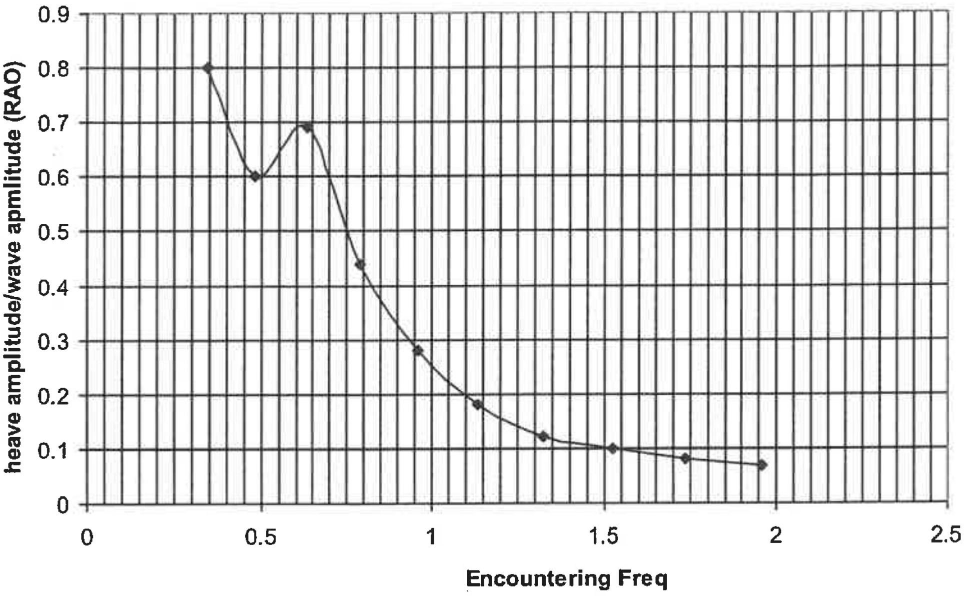
Question 5

Periodic waves or real-world ocean environments are composed of a multitude of wave frequencies and amplitudes. Spectral analysis provides a powerful tool to represent this randomness and to predict a vessel's response by linking the energy distribution of the waves to the ship motion. The following questions requires you to apply this fundamental knowledge to analyse a given sea spectrum and evaluate its implications for a vessel seakeeping performance.

A naval architect is performing a problem analysis on the seakeeping performance of a vessel in irregular waves. The task requires specialist knowledge of spectral analysis to evaluate the ship behavior. The vessel is traveling at 10 knots in head seas, and the sea spectrum, S(ω), for this wave environment is provided in the table.

ω	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
S(ω)	0.2	2.0	4.05	4.3	3.4	2.3	1.5	1.0	0.7	0.5

If the encountering frequency is given by $\omega_E = \omega_w\left(1 - \frac{\omega_w V_S}{g}\cos\mu\right)$ and the Response Amplitude Operator (RAO) values of the vessel can be obtained from the Graph 5.1 below:



Graph 5.1: Response Amplitude Operator (RAO) for vessel heave motion

Hence, conduct the following calculations

a) Using your knowledge of engineering fundamentals and spectral analysis, calculate the heave response spectrum for the vessel by applying the provided sea spectrum data and the vessel's Response Amplitude Operator (RAO) values. (PLO1, SP3, SK3)

(10 marks)

b) (i) Plot a graph of the heave response spectrum against the encountering frequency, ωe, to visually represent the vessel's motion characteristics in the given seaway. Critically analyze the plot to identify the dominant frequencies of motion and their implications for the vessel's performance. (PLO2, SP3, SK4) (4 marks)

(ii) Calculate the moment of the response spectrum, m_R which is the area under the curve and its significant response. Explain the physical significance of these calculated values and how they are used to evaluate the vessel's seakeeping performance. (PLO2, SP3, SK4) (6 marks)

Question 6

(a) Marine engineers must apply wave theory to design safe structures. The wave dispersion relation is a core principle that describes how a wave properties, such as wavelength, are fundamentally altered by water depth. The following problem asks you to use this knowledge to analyze how water depth influences wavelength for a given wave period.

Using the dispersion relations, determine the wavelength (λ), of a wave with a period (T) of 10 seconds under two distinct water depth scenarios:

(i) A depth of 2000 m

(ii) A depth of 1 m

Assume water depth for shallow water is considered from *2m* and below. (PLO1, SP3, SK3)

(6 marks)

(b) Based on the provided velocity potential for deep water waves, derive the formula for the kinetic energy per unit area of the water surface which is equal to ¼ $\rho g a^2$. Where for a fluid element of mass $\rho.dx.dz$:

$$\text{K.E. of element} = \frac{1}{2}(\rho.dx.dz)(\underline{u}^2 + \underline{w}^2)$$

where u and w are the horizontal and vertical velocity components. For deep water, the velocity potential is given as;

$$\phi_\infty = -\frac{ga}{\omega}.e^{kz}\cos(kx - \omega t)$$

You may use trigonometric identities $\sin^2\theta + \cos^2\theta = 1$ to solve your derivation. (PLO2, SP3,SK4)

(14 marks)

END OF EXAMINATION PAPER

FORMULA SHEET

Properties of Harmonic Waves in Deep Water

Surface profile (i.e. elevation of line of equal pressure at z = 0),

$\zeta = \zeta_a \cos(kx - \omega t)$

Wave velocity or celerity,

$$V_w = \frac{L_w}{T_w} = \frac{g}{\omega_w} = \left(\frac{gT^2{}_w}{2\pi}\right)$$

Wavelength, $L_w = \frac{2\pi V^2{}_w}{g} = \frac{2\pi g}{\omega_w^2} = \frac{gT_w{}^2}{2\pi}$

Wave Number,

$$k = \frac{2\pi}{L_w} = \frac{\omega_w{}^2}{g} = \frac{g}{V_w^2} = \frac{4\pi^2}{gT_w^2}$$

Wave Period, $T_w = \left(\frac{2\pi L_w}{g}\right)^{\frac{1}{2}}$

Energy per unit wave Surface, $E = \frac{1}{2}\rho\zeta_a^2$

Properties of Harmonic Waves in water of any depth

Elevation of lines of Equal Pressure,

$$\zeta = \zeta_a \frac{\sinh k(-z+d)}{\sinh kd}\cos(kx - \omega t)$$

Surface profile (i.e. elevation of line of equal pressure at z = 0),

$\zeta = \zeta_a \cos(kx - \omega t)$

Horizontal water velocity,

$$u = \zeta_a V_w k \frac{\cosh k(-z+d)}{\sinh kd}\cos(kx - \omega t)$$

Vertical water velocity,

$$w = \zeta_a V_w k \left(\frac{\sinh k(-z+d)}{\sinh kd}\right)\sin(kx - \omega t)$$

Wave Velocity or celerity,

$$V_w = \left(\frac{gL_w}{2\pi}\tanh kd\right)^{\frac{1}{2}}$$

Note: for shallow water ($d \langle \frac{L_w}{20}$),

$V = \sqrt{gd}$

Velocity Potential

The mathematical expression for ϕ (velocity potential) satisfying the boundary conditions :

$$\phi_d = -\frac{g.a}{\omega}.\frac{\cosh k(z+d)}{\cosh kd}.\cos(kx - \omega t)$$

Wave Relationships

$$c = \frac{\lambda}{T} = \sqrt{\frac{g}{k}\tanh\ kd}$$

$$\therefore \lambda = T.\sqrt{\frac{g}{k}\tanh\ kd}$$

$$= T.\sqrt{\frac{g}{2\pi}\lambda\ \tanh\left(\frac{2\pi d}{\lambda}\right)}$$

$$= T.\sqrt{\lambda}\sqrt{\frac{g}{2\pi}\tanh\left(\frac{2\pi d}{\lambda}\right)}$$

$$\therefore \sqrt{\lambda} = T.\sqrt{\frac{g}{2\pi}\tanh\left(\frac{2\pi d}{\lambda}\right)}$$

$$\therefore \lambda = T^2.\frac{g}{2\pi}\tanh\left(\frac{2\pi.d}{\lambda}\right)$$

Encountering Frequency

$$\omega_E = \omega_w \left(1 - \frac{\omega_W V_S}{g}\cos\mu\right)$$

Heaving Motion

For the steady condition the amplitude of the forced heaving motion z_a is given by:

$z_a = z_{st}.\ \mu_z$

Where, z_{st} = static heaving amplitude = $\frac{F_o}{c}$

μ_z = magnification factor = $\frac{z_a}{z_{st}}$

$$\mu_z = \frac{1}{\sqrt{(1-\Lambda^2)^2 + 4k^2\Lambda^2}}$$

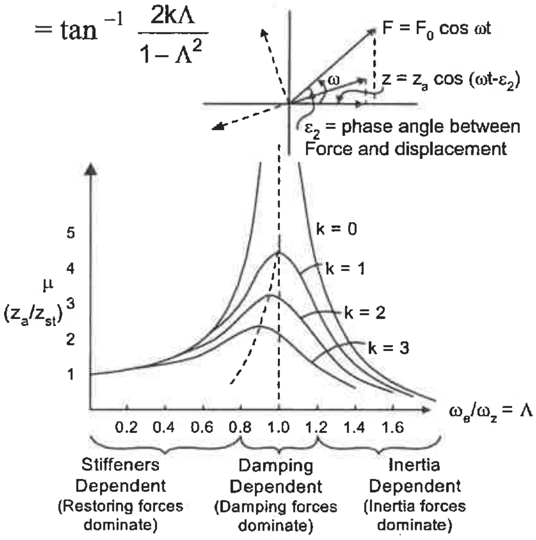
k = non-dimensional damping factor

$$= \frac{v}{\omega_z}$$

and $v = \frac{b}{2(m + a_z)}$, $\omega_z = \sqrt{\frac{c}{(m + a_z)}}$

ϵ_z = phase angle between the exciting force and the motion

$$= \tan^{-1}\frac{2k\Lambda}{1-\Lambda^2}$$



Magnification Factor vs Tuning Factor

Where Λ = tuning factor

$$= \frac{\text{Freq. of encounter}}{\text{Nat. freq.}}$$

$$= \frac{\omega_e}{\omega_z}$$

Added Mass, Damping, Restoring Coefficient and Exciting Forces for Heaving Motions

where $B_n = 2r$ and a_n = added mass of ship section

$$C = \frac{a_n}{\rho\pi\frac{B_n^2}{8}} \quad \text{or} \quad a_n = C.\frac{\rho\pi B_n^2}{8}$$

C for Lewis-form section is obtained from graph provided. as a function of the (draught/beam) ratio and the area coeff. of the section as well as a function of circular frequency of oscillation.

Area coeff. of section,

$$\beta_n = \frac{\text{Section Area}}{B_n \times T_n} = \frac{S_n}{B_n \times T_n}$$

<u>Damping, b</u>

The damping coeff., b can be calculates similar to the case of added mass.

Damping coeff. per unit length, b_n =

$$\frac{\rho.g^2\bar{A}^2}{\omega_e^3}$$

<u>Restoring coefficient, C</u>

$$C = \rho g A_W$$

$$= \rho.g.L.B.C_W$$

Where C_W is waterplane area coeff.

<u>Exciting Force</u>

F = $F_o.\cos\omega_e t$

and $f_o = \frac{F_o}{(\rho g \zeta_a.L.B}$ (Nondimensional form)

$$f_o = \frac{2}{LB}\int_{-L/2}^{L/2} y_{(x)}\cos(kx\cos\mu)dx$$

Pitching Motion

$\theta_a = \theta_{st}.\ \mu_\theta$

Where, θ_{st} = static pitch amplitude $= \frac{M_o}{c}$

μ_θ = magnification factor $= \frac{\theta_a}{\theta_{st}}$

$$\mu_\theta = \frac{1}{\sqrt{(1-\Lambda^2)^2 + 4k^2\Lambda^2}}$$

k = non-dimensional damping factor

$= \frac{\nu}{\omega_\theta}$

The solution of the equation of motion is

$$\theta = B\, e^{-\nu t} \sin(\omega_d.t + \gamma) + C \sin(\omega_e t - \epsilon_2)$$

which, for a steady-state condition (when the first term dies out with time t), is

$\theta = \theta_a \sin(\omega_e.t - \epsilon_2)$ since $C = \theta_a$

or

$$\theta = \frac{\theta_{st}}{\sqrt{(1-\Lambda^2)^2 + 4k^2\Lambda^2}} \sin(\omega_e t - \epsilon_2)$$

ϵ_2 = phase angle between the exciting force and the motion $= \tan^{-1} \frac{2k\Lambda}{1-\Lambda^2}$

The phase angle bet. wave motion and pitching motion,

$$\epsilon = \epsilon_1 + \epsilon_2$$

Virtual Mass Moment of Inertia, Damping, Restoring Coefficient and Exciting Moment

Virtual Mass Moment of Inertia, a

$$a = (m + \delta m) \times k_{yy}^2$$

$$= \frac{\Delta'}{g}.k_{yy}^2$$

Damping, b.

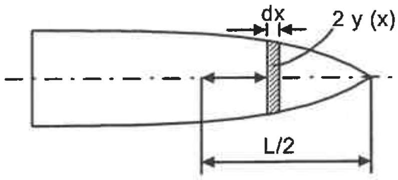
$$b'_{pitch} = \frac{b.\sqrt{gL}}{\Delta_B L^2}$$

Normally,

$$b'_{pitch} = \frac{b}{\rho.\nabla.(L/4)^2\sqrt{g/L}}$$

Where,
$\Delta = \rho\nabla = kg$
$L = m$
$g = m/s^2$

Restoring Moment Coefficient, c



Restoring Moment

$$= c\theta = \rho.g.\theta.\int_{-L/2}^{L/2} x^2.2y_{(x)}.dx$$

$$= \rho.g.\theta.I_y$$

$$c = \Delta_B.GM_L$$

Exciting Moment for Pitching, M_θ

$$M_o = 2\rho.g.\zeta_a \int_{-L/2}^{L/2} y_{(x)}.x.\sin(kx.\cos\mu).dx$$

Non-dimensional amplitude of pitching moment,

$$f_o = \frac{M_o}{\frac{1}{2}.\rho.g.\zeta_a.B.L^2}$$

$$= \frac{4}{B.L^2}\int_{-L/2}^{L/2} y_{(x)}.x.\sin(kx\cos\mu).dx$$

Rolling Motion

Amplitude of roll motion

$\phi_a = \mu_\theta \times \phi_{st}$

Virtual mass moment of Inertia

$$I_v = M.k_{xx}^2 + \delta I_{xx}$$

$$= (\Delta + \delta\Delta)\ k_{xx}^2$$

Restoring moment coefficient

$c = \Delta g GM_T$

Tuning factor

$$\Lambda = \frac{\omega_e}{\omega_\phi}$$

The damping factor is $\kappa = \dfrac{\upsilon}{\omega_\phi}$ where

$$\upsilon = \frac{b}{2a}$$

Static roll deflection

$$\phi_{st} = \frac{M_o}{c}$$

$$\mu_\theta = magnification\ factor = \frac{\phi_a}{\phi_{st}}$$

$$\mu_\theta = \frac{1}{\sqrt{\left(1-\Lambda^2\right)^2 + 4\kappa^2\Lambda^2}}$$

Motion In Irregular Waves

For heave response;

$$m_o = \frac{1}{3} \text{ x C.I. x } \Sigma f(S_R(\omega_E))$$

$$\overline{H}_1 = 2.50\ m_o^{1/2}$$

$$\overline{H}_{1/3} = 4.00\ m_o^{1/2}$$

$$\overline{H}_{1/10} = 5.10\ m_o^{1/2}$$

$$\text{RAO} = \frac{\text{Heave Amplitude}}{\text{Wave Amplitude}}$$

For roll response;

$$(\phi)_1 = 1.253\ m_o^{1/2}$$

$$(\phi)_{1/3} = 2.00\ m_o^{1/2}$$

$$(\phi)_{1/10} = 2.545\ m_o^{1/2}$$

$$RAO = \frac{Roll\ \ Amplitude}{Wave\ \ Amplitude}$$

Manoeuvrability - Notation Of Force And Moment Derivatives

The following standard notation is used:

e.g. $\dfrac{\partial Y}{\partial v} = Y_v,\ \dfrac{\partial N}{\partial \dot{\psi}} = N_{\dot{\psi}},\ \dfrac{\partial N}{\partial \delta_R} = N_{\delta R}$

etc.

Also, for planar motions, $\dot{\psi} \equiv r\ \ and\ \ \ddot{\psi} \equiv \dot{r}$

Non-dimensional derivatives:

$$m' = \frac{m}{\frac{\rho}{2}L^3};\ v' = \frac{v}{U};\ \dot{v}' = \frac{\dot{v}L}{U^2};\ \ x'_G = \frac{x_G}{L}$$

$$I'_z = \frac{I_z}{\frac{\rho}{2}L^5};\ r' = \frac{rL}{U};\ \dot{r}' = \frac{\dot{r}L^2}{U^2}$$

$$Y'_v = \frac{Y_v}{\frac{\rho}{2}L^2U};\ Y'_r = \frac{Y_r}{\frac{\rho}{2}L^3.U};\ N'_v = \frac{N_v}{\frac{\rho}{2}L^3.U};\ N'_r = \frac{N_r}{\frac{\rho}{2}L^4.U}$$

$$Y'_{\dot{v}} = \frac{Y_{\dot{v}}}{\frac{\rho}{2}L^3U};\ Y'_{\dot{r}} = \frac{Y_{\dot{r}}}{\frac{\rho}{2}L^4.U};\ N'_{\dot{v}} = \frac{N_{\dot{v}}}{\frac{\rho}{2}L^4.U};\ N'_{\dot{r}} = \frac{N_{\dot{r}}}{\frac{\rho}{2}L^5}$$

$$Y'_{\delta R} = \frac{Y_{\delta R}}{\frac{\rho}{2}L^2U^2};\ N'_{\delta R} = \frac{N_{\delta R}}{\frac{\rho}{2}L^3.U^2}$$

The Stability Criterion

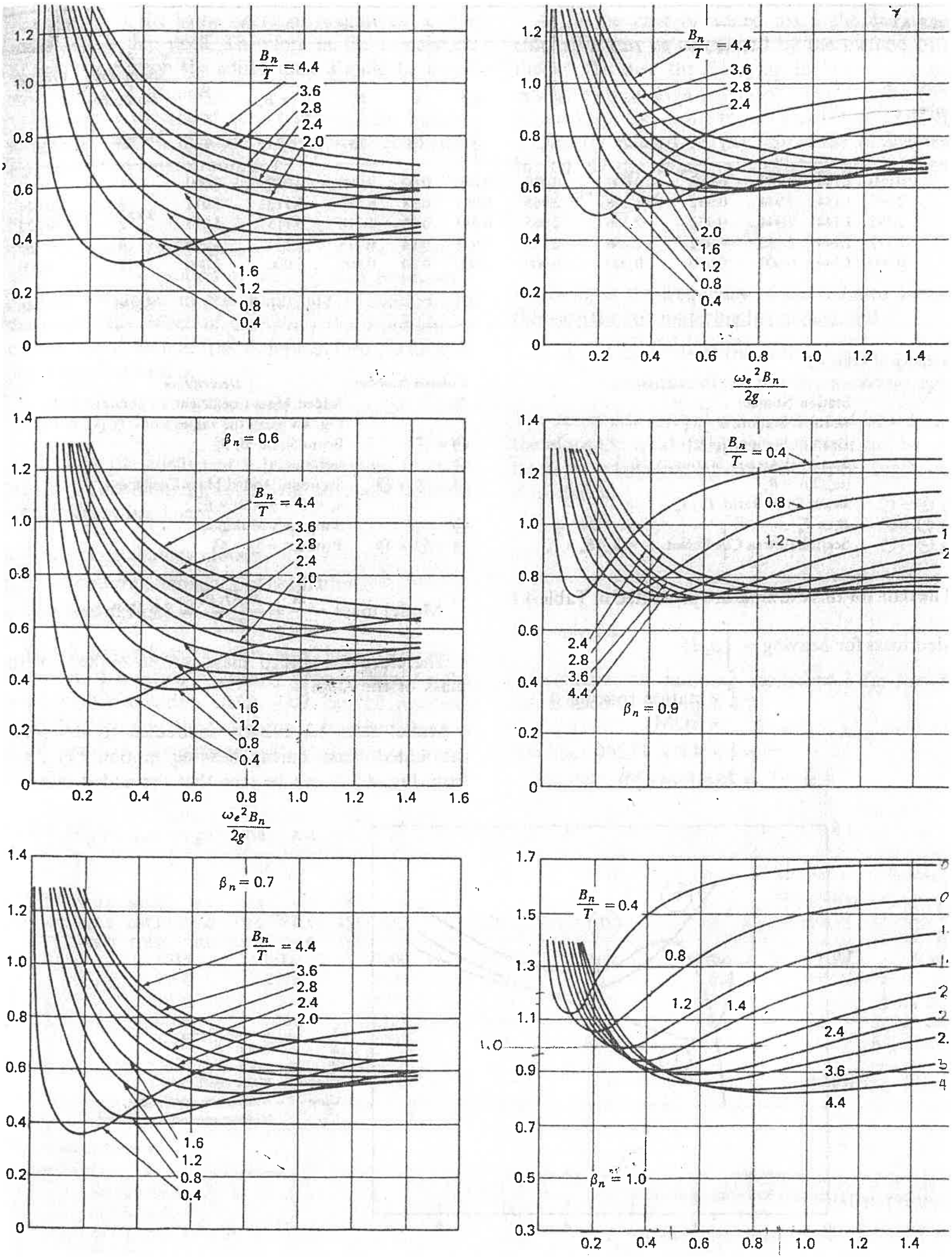
For directional stability,

$Y'_v N'_r - \left(Y'_r - m'\right)N'_v > 0$ (Non-dimensionalised form)

OR

$Y_v\ \left(N_r - m x_G u\right)$ - $N_v\ (Y_r - mu) > 0$

(Origin is not at cg)



$\frac{B_n}{T} = 4.4$
3.6
2.8
2.4
2.0
1.6
1.2
0.8
0.4
$\frac{\omega_e^2 B_n}{2g}$
$\beta_n = 0.6$
$\beta_n = 0.9$
$\frac{B_n}{T} = 0.4$
1.2
$\beta_n = 0.7$
1.4
3.6
4.4
$\beta_n = 1.0$