Appendix E

ANSWERS TO QUESTIONS IN APPENDIX E

The following answers are to questions posed in the book *Introduction to Naval Architecture* (2013), 5th edition, Elsevier (ISBN 978-0-08-098237-3).

For numeric/algebraic questions, the answer is given in full. For the more discursive questions, a number of bullet points are given to indicate the main issues that should be addressed in answering the question. Although grouped by chapters, additional matter relevant to the answers may be found in other chapters of the book. Also, the student should be encouraged to carry out additional research to provide more up-to-date, or more complete, information than that which can be contained in a single volume.

CHAPTER 2. DEFINITION AND REGULATION

Question 1. How is the overall geometry of a ship defined? How are the coefficients of fineness related?

Answer 1.

The answer should include the following:

- Principal dimensions of length beam, draught and freeboard.
- Camber, flare, tumble home.
- Definitions of the coefficients of fineness.
- The table of offsets.
- Differentiate between external and moulded dimensions.
- Show that $C_B = C_P \times C_M$.

Question 2. Discuss the various displacements and tonnages used to define the overall size of a ship. Why are freeboard and reserve of buoyancy important?

Answer 2.

The answer should include the following:

- Displacement, deadweight, lightweight and cargo deadweight.
- Gross and net tonnage.
- Panama and Suez Canal tonnages.
- IMO's International Convention on Tonnage Measurement of Ships.
- The Load Line Regulations.
- Ability to sustain some flooding without capsizing or plunging.

Question 3. Discuss the various international and national bodies linked to shipping and their roles.

Answer 3.

The answer should include the following:

- The International Maritime Organisation, with SOLAS and MARPOL.
- Classification Societies. Classing of ships and retention of class through surveys.
- The International Association of Classification Societies (IACS)
- Port control organisation.
- Maritime and Coastguard Agency.
- Accident investigation.

Question 4. A ship floating freely in saltwater is 150 m long, 22 m beam and 9 m draught and has a mass displacement of 24,000 tonnes. The midship's wetted area is 180 m^2. Find the block, prismatic and midship area coefficients.

Answer 4.

Since the ship is in saltwater, the volume of displacement is

$$24,000/1.025 = 23,415 \text{ m}^3$$

Hence: Block coefficient $= 23,415/(150 \times 22 \times 9) = 0.788$
Prismatic coefficient $= 23,415/(180 \times 150) = 0.867$
Midship area coefficient $= 180/(22 \times 9) = 0.909$

Question 5. A circular cylinder 100 m long and 7 m diameter floats with its axis in the waterline. Find its mass in tonnes in saltwater. How much must the mass be reduced to float with its axis in the waterline in freshwater?

Answer 5.

The volume of displaced water $= (\pi/2)(3.5)^2 \times 100 = 1924.23 \text{ m}^3$
Mass in saltwater $= 1924.23 \times 1.025 = 1972$ tonnes
Mass to be removed $= 1924.23 \times 0.025 = 48$ tonnes

CHAPTER 3. SHIP FORM CALCULATIONS

Question 1. What do you understand by approximate integration? Discuss the various rules used in simple naval architectural calculations and how they are used.

Answer 1.

The answer should include the following:

- Trapezoidal rule.
- Simpson's rules.
- Tchebycheff rules.
- Gauss rules

- Use of tabular solutions for areas, volumes and their first and second moments.
- Use of spreadsheets.

Question 2. Show that Simpson's 1,4,1 rule is accurate for defining the area under a curve defined by the equation $y = a + bx + cx^2 + dx^3$, between $x = -h$ to $x = h$.

Answer 2.

There are three ordinates, at values of x given by $-h$, 0 and $+h$. Let these be y_1, y_2 and y_3, respectively.

Then by definition:

$$y_1 = a - bh + ch^2 - dh^3$$
$$y_2 = a$$
$$y_3 = a + bh + ch^2 + dh^3$$

By integration:

The area under the curve $= \Sigma y\, dx = \Sigma[a + bx + cx^2 + dx^3]dx$
$= [ax + (1/2)bx^2 + (1/3)cx^3 + (1/4)dx^4]$ evaluated between $-h$ and $+h$
$= 2ah + (2/3)ch^3$

This is the value obtained by applying the 1, 4, 1 rule.

Question 3. Find the area of the waterplane defined by the following half ordinates (in metres) which are 16 m apart:

2.50, 11.00, 20.50, 27.00, 29.50, 29.00, 25.00, 18.00, 7.00.

Answer 3.

Create a table in which the half ordinates are multiplied by Simpson multipliers and then summated.

Half Ord (m)	Simpson Multiplier	Function (*A*)
2.50	1	2.50
11.00	4	44.00
20.50	2	41.00
27.00	4	108.00
29.50	2	59.00
29.00	4	116.00
25.00	2	50.00
18.00	4	72.00
7.00	1	7.00
Total		**499.50**

Then the total area $= 2 \times (16/3) \times 499.5 = 5328\ m^2$.

Question 4. The half ordinates (m) of a section of a ship at waterlines which are 1.5 m apart are, reading from the design waterplane down:

33.45, 33.30.32.55, 30.90, 25.80 and 12.00.

At the turn of bilge, midway between the last two half ordinates, an extra half ordinate is 19.80 m.

Find the area of the section up to the design waterplane and the height of the centroid of area above the keel.

Answer 4.

Draw up a table using all the half ordinates and adjusting the Simpson multipliers to allow for the spacing in way of the turn of bilge.

Half Ordinate	Simpson Multiplier	Function (*A*)	Lever from Keel	Function (*M*)
33.45	1	33.45	7.5	250.88
33.30	4	133.20	6.0	799.20
32.55	2	65.10	4.5	292.95
30.90	4	123.60	3.0	370.80
25.80	1.5	38.70	1.5	58.05
19.80	2	39.60	0.75	29.70
12.00	0.5	6.00	0	0.00
Total		**439.65**		**1802.03**

Note: In the table above the actual distances of the half ordinates from the keel have been used as levers. It is usually simpler to use nominal distances of 1, 2, 3, etc. and then multiply by the actual distance (e.g. using what may be termed a 'lever factor') in calculating the moment.

Using the total from the table:

$$\text{Total area} = 2 \times (1.5/3) \times 439.65 = 439.65 \text{ m}^2$$

$$\text{Total moment} = 2 \times (1.5/3) \times 1802.03 = 1802.03 \text{ m}^3$$

$$\text{Distance of centroid of area from the keel} = 1802.03/439.65 = 4.10 \text{ m}$$

Note: It is not necessary to work out the actual moment. The distance of the centroid will be given by dividing the $F(M)$ by $F(A)$ and multiplying by the 'lever factor' which in this case is unity.

Question 5. The half ordinates (m) of a waterplane, which are 6 m apart, are given by:

11.16, 24.84, 39.42, 47.52, 40.23, 26.46, 13.23.

Calculate, and compare the areas of the waterplane as given by the Simpson's 1,4,1 rule, the 1,3,3,1 rule and the trapezoidal rule.

Answer 5.

For the trapezoidal rule, the areas between adjacent ordinates will be half their sum multiplied by their distance apart. The 'multipliers' now become 1, 2, 2, 2, . . ., 2, 1. Now construct a table as below:

Half ord.	SM	$F(A)$	SM	$F(A)$	Multiplier	$F(4)$
11.16	1	11.16	1	11.16	1	11.16
24.84	4	99.36	3	74.52	2	49.68
39.42	2	78.84	3	118.26	2	78.84
47.52	4	190.08	2	95.04	2	95.04
40.23	2	80.46	3	120.69	2	80.46
26.46	4	105.84	3	79.38	2	52.92
13.23	1	13.23	1	13.23	1	13.23
Total		**578.97**		**512.28**		**381.33**

Applying the various rules:

By 1,4,1 rule, area = (2/3) × 6 × 578.97 = 2315.88 m^2.
By 1,3,3,1 rule, area = 2 × (3/8) × 6 × 512.28 = 2305.26 m^2.
By trapezoidal rule, area = 2 × (6/2) × 381.33 = 2287.98 m^2.

Assuming the 1,4,1 rule is accurate:

The 1,3,3,1 rule underestimates by 10.62 m^2 = 0.46%.
The trapezoidal rule underestimates by 27.90 m^2 = 1.20%.

It should be noted that it is to be expected that usually trapezoidal rule will underestimate waterplane areas because of their curvature.

Question 6. A three-dimensional body 54 m long has regularly spaced sectional areas (m^2) of:

1.13, 2.50, 4.49, 6.40, 9.92, 14.52, 20.35, 26.18, 29.62, 29.59, 27.07, 21.48, 15.19, 10.08, 6.83, 4.48, 3.13, 2.47 and 0.00.

Calculate the volume of the body and the distance of its centroid of volume from the centre of length.

Answer 6.

Since there are 19 areas given and the total length is 54 m, the distance of the sections apart is 3 m.

Now construct a table as below, noting that:

- The Simpson multipliers have been halved to simplify the arithmetic. The final volume must be doubled to allow for this.

- Levers used are 1, 2, 3, etc. The moments obtained must be tripled to allow for the 3 m separation. They are taken from the midpoint which again simplifies the arithmetic.

Area	SM	*F* (Vol)	Lever	*F* (Moment)
1.13	0.5	0.57	9	5.13
2.50	2	5.00	8	40.00
4.49	1	4.49	7	31.43
6.40	2	12.80	6	76.80
9.92	1	9.92	5	49.60
14.52	2	29.04	4	116.16
20.35	1	20.35	3	61.05
26.18	2	52.36	2	104.72
29.62	1	29.62	1	29.62
29.59	2	59.18	0	0.00
27.07	1	27.07	−1	− 27.07
21.48	2	42.96	−2	− 85.92
15.19	1	15.19	−3	− 45.57
10.08	2	20.16	−4	− 80.64
6.83	1	6.83	−5	− 34.15
4.48	2	8.96	−6	− 53.76
3.13	1	3.13	−7	− 21.91
2.47	2	4.94	−8	− 39.52
0.00	0.5	0.00	−9	− 0.00
Total		**380.57**		**125.97**

The total volume $= 2 \times (1/3) \times 3 \times 380.57 = 761.14\ m^3$.

Note: In this case, 2 is the doubling because the Simpson multipliers were halved. The areas are the full areas of cross section so there is no need to multiply by two for two sides of the body.

Centroid of volume forward of midpoint $= 3 \times 125.97/380.57 = 0.99$ m.

Question 7. Find the area, tonnes per centimetre, centre of flotation and the transverse inertia of the waterplane defined by the following half ordinates (m) which are 15 m apart.

0.26, 2.99, 8.32, 12.87, 16.38, 17.55, 17.94, 17.81, 16.64, 13.78, 8.32, 2.47, 0.26.

If the displacement is 70,000 tonnes, what is the value of BM?

Answer 7.

Construct a table as below:

Half Ordinate, y	SM	$F(4)$	Lever	$F(M)$	y^3	SM	$F(I)$
0.26	1	0.26	6	1.56	0	1	0
2.99	4	11.96	5	59.80	27	4	107
8.32	2	16.64	4	66.56	576	2	1152
12.87	4	51.48	3	154.44	2132	4	8527
16.38	2	32.76	2	65.52	4395	2	8790
17.55	4	70.20	1	70.20	5405	4	21622
17.94	2	35.88	0	0.00	5774	2	11548
17.81	4	71.24	−1	− 71.24	5649	4	22597
16.64	2	33.28	−2	− 66.56	4607	2	9215
13.78	4	55.12	−3	−165.36	2617	4	10467
8.32	2	16.64	−4	− 66.56	576	2	1152
2.47	4	9.88	−5	− 49.40	15	4	60
0.26	1	0.26	−6	− 1.56	0	1	0
Total		**405.60**		**− 2.60**			**95236**

Using the summations from the table:

Area of waterplane = $2 \times (1/3) \times 15 \times 405.60 = 4056\ \text{m}^2$.
Tonnes per centimetre = $4056 \times 1.025/100 = 41.5$ tonnes/cm.
CF aft of amidships = $15 \times 2.60/405.6 = 0.096$ m.
Transverse inertia of waterplane = $2 \times (1/3) \times (1/3) \times 15 \times 95{,}236 = 317{,}450\ \text{m}^4$.
A displacement of 70,000 tonnes corresponds to $70{,}000/1.025 = 68{,}300\ \text{m}^3$.
Hence BM = $I/V = 317{,}450/68{,}300 = 4.65$ m.

Question 8. A homogeneous log of square cross section, side 1 m, and 6 m long is floating in a position of stable equilibrium. The log's density is half that of the water in which it is floating. Find the longitudinal metacentric height.

Answer 8.

It is necessary to check transverse stability first to establish the attitude at which the log will float. Symmetry shows that there are only two possible positions of stable equilibrium:

1. with one of the sides of the square cross section horizontal;

2. with a diagonal of the square horizontal.

Taking 1, draught = 0.5 m and KB = 0.25 m:

$$\begin{aligned} \mathrm{BM} &= I/V = (1/12)\,(1)^3 \times 6/(0.5 \times 1.0 \times 6) = 0.1667\ \mathrm{m} \\ \mathrm{KM} &= \mathrm{KB} + \mathrm{BM} = 0.4167\ \mathrm{m} \end{aligned}$$

But KG for the homogeneous log will be 0.5 m; i.e. GM is negative and the log will not be stable in this position.

Checking on the case with the diagonal horizontal:

The diagonal is $(2)^{1/2} = 1.414$ m
$\mathrm{KB} = (1/3)\ 1.414 = 0.471$ m
$\mathrm{BM} = I/V = [(1/12)\,(1.414)^3 \times 6]/[0.5 \times 1.0 \times 6] = 1.414/3 = 0.471$

Note: We can use the simpler expression for V which is constant.

In this case:

$$\mathrm{KM} = \mathrm{KB} + \mathrm{BM} = 0.942\ \mathrm{m}$$

But KG = (1/2) 1.414 = 0.707, and GM is positive and the log will float stably.

Turning now to the longitudinal inertia:

$$I_{\mathrm{L}} = (1/12)\,(6)^3(1.414)$$

$$\mathrm{BM_L} = I_{\mathrm{L}}/V = [(1/12)\,(6)^3(1.414)]/[0.5 \times 1.0 \times 6] = 8.484\ \mathrm{m}$$

$$\mathrm{KB} = (1/3)1.414 = 0.471\ \mathrm{m\ and\ KG} = (1/2)1.414 = 0.707$$

$$\mathrm{GM_L} = \mathrm{KB} + \mathrm{BM_L} - \mathrm{KG} = 0.471 + 8.484 - 0.707 = 8.248\ \mathrm{m}$$

CHAPTER 4. FLOTATION

Question 1. What do you understand by equilibrium? For a ship being heeled to small angles, what do you understand by stability? What do you understand by the term metacentre? What is the significance of the positions of the centre of gravity and the metacentre in relation to stability?

Answer 1.

The answer should include the following:

- Ship is in equilibrium if the forces and moments acting on it balance out. It will remain in the same position until disturbed.
- Concept of the ship remaining at the heel angle when the disturbing moment is removed or reducing or increasing that angle.
- Neutral, positive and negative stability.
- The metacentre (M) is the point through which successive lines of buoyancy act. For small angles, it is effectively a fixed point on the ship's centreline.

- Positive stability if M is above G and so on.
- Metacentric height (GM) is the measure used to define initial stability.

Question 2. A rectangular box of length, L, beam, B, and depth, D, floats at a uniform draught, T. Deduce expressions for KB, BM and KM in terms of the principal dimensions. If the beam is 9 m, what must be the draught for the metacentre to lie in the waterplane?

Answer 2.

Being rectangular, KB = T/2

$$\mathrm{BM} = I/V = [(1/12)(B)^3 L]/LBT = B^2/12T$$
$$\mathrm{KM} = \mathrm{KB} + \mathrm{BM} = T/2 + B^2/12T$$

If $B = 9$ m, then KM = $T/2 + 81/12T$.
For M to lie in the waterplane, KM = T.
That is,

$$T = T/2 + 81/12T$$

giving $T^2 = 81/6$ and $T = 3.674$ m.

Question 3. A uniform body of regular triangular cross section of length, L, base, B, and height, H, floats apex down. If its density is half that of the water in which it is floating, find expressions for KB, BM and KM in terms of B and H.

Answer 3.

At a draught T, the beam on the waterline will be BT/H.
Since the density is half that of the water, T must satisfy the relationship:

$$(BT/H)(T/2) = (1/2)(BH/2), \quad \text{hence } T^2 = H^2/2,\ T = 0.707H$$

Beam at the waterline = $0.707B$.

$$\mathrm{KB} = (2/3)T = 0.471H$$
$$\mathrm{BM} = I/V = (1/12)(0.707B)^3 L/[(1/2)T(0.707B)L = B^2/12(0.707H)$$

Question 4. Describe an easy way to establish whether a complex three-dimensional fitting is made of brass, lead or steel.

Answer 4.

The fitting can be weighed in air and in freshwater. The difference in the two weights will be the weight of the volume of freshwater equal to the volume of the fitting. Dividing the weight in air by the volume gives the density of the material of which the fitting is made. Hence which material used can be ascertained.

Note: This is in essence the reasoning reportedly used by Archimedes to solve a problem and caused him to spring out of his bath shouting ‘Eureka’.

Question 5. A small craft is floating in an enclosed dock. Then:

1. Two bulks of timber floating in the dock are lifted on to the craft.
2. A large stone in the craft is dumped into the dock.

State whether the water depth in the dock will increase, decrease or remain the same in each case. Does your answer depend upon the density of the water?

Answer 5.

In case 1, the bulks of timber are initially displacing their own weight of water. When lifted into the craft, the craft will sink lower until its extra buoyancy equals the weight of the timber. The net effect will be no change in the depth of water in the dock.

In case 2, the removal of the stone from the craft reduces the craft's displacement by the weight of the stone. When placed in the dock water, the stone displaces its own volume of water. This will be less than the reduction in displacement of the craft. Hence the level of water in the dock will reduce.

These answers are unaffected by the density of water in the dock.

Question 6. A ship of 100 m length floats in seawater at a draught of 4 m forward and 4.73 m aft. Data for the ship is:

Tonnes per centimetre = 12.
Centre of flotation is 4.1 m aft of amidships.
Moment to change trim 1 m = 3700 tonnes m/m.

Where should a weight, of 50 tonnes, be added to bring the ship to a level keel? What is the new level draught?

Answer 6.

Since we are not told otherwise we must assume that the TPC, CF and MCT remain unchanged for the changes of draught involved.
Trim must be changed by 0.73 m, by trimming by the bow.
Moment required = $0.73 \times 3700 = 2701$ tonnes m.

The added weight must create this moment about the CF. It must, therefore, be placed a distance y forward of the CF, where

$$50\,(y + 4.1) = 2701$$

and hence

$$y = 49.92 \text{ m}$$

For constant displacement, the ship trims about the CF. Hence:

Old draught at the CF = $4.00 + (0.73)[(50 + 4.1)/100] = 4.395$ m.
Sinkage due to the added weight = $50/1200 = 0.042$ m.
Hence the new level draught = $4.395 + 0.042 = 4.437$ m.

CHAPTER 5. STABILITY

Question 1. When and why is an inclining experiment carried out? Discuss how it is carried out and the steps taken to ensure accurate results.

Answer 1.

The answer should include the following:

- Carried out near completion of ship's build.
- To ascertain the displacement and the position of the centre of gravity for the ship as inclined and hence in the light and other ship conditions.
- Ship has known weights arranged equally on the port and starboard sides of the upper deck. Half the weights on one side moved through a measured distance to the other side.
- Then second half of weights moved. Weights returned to original position and the other weights moved in sequence.
- Inclination of ship measured by a long pendulum (or, preferably, two) after each weight shift.
- Draughts and water density recorded at various depths and positions round the ship.
- Ship as complete as possible with minimum of extraneous equipment on board.
- All weights to come off, and go on, to create the light ship state are noted – weight and position.
- All tanks pressed full or empty to minimise free surface effects.
- Good weather conditions.
- Ship held very lightly by cables. Access brow lifted clear.
- Minimum personnel on board. These to return to defined positions for each pendulum reading.

Question 2. A ship of 11,500 tonnes is inclined using four groups of weights, each group of 20 tonnes separated by 12 m across the upper deck. The weights are moved in sequence, leading to the following deflections of a pendulum 6 m long. Each weight movement is 12 m transversely.

Weight Moved (tonnes)	Movement	Pendulum Reading (m)
20	P to S	0.13 to S
20	P to S	0.25 to S
40	S to P	0.01 to S
20	S to P	0.11 to P
20	S to P	0.23 to P
40	P to S	0.01 to S

Comment upon the readings and deduce the metacentric height as inclined.

Answer 2.

It appears from the readings that some additional weight (enough to cause a pendulum deflection of 0.01 m) has moved to starboard during the first weight movement and has not subsequently returned.

The mean pendulum deflection is 0.12 m for 240 tonnes m moment.
Angular movement (φ) for each weight transfer = 0.12/6 = 0.02 rad.
Now $W \cdot \mathrm{GM} \cdot \Phi$ = Moment causing heel.
Hence GM = 240/(11,500 × 0.02) = 1.04 m.
This is the metacentric height as inclined.

Question 3. Show the position of the metacentre for a right cylinder of circular cross section, floating with its axis horizontal will be at the centre of the circular cross section whatever the draught. Use this fact to show that the centroid of a semicircle of diameter d is $2d/3\pi$ from the diameter.

Answer 3.

The metacentre for a circular cylinder, floating as described is at the centre of the circle.

With the cylinder floating with a draught $d/2$, the transverse inertia of the waterplane is given by

$$\mathrm{I} = (1/12)d^3L$$

where L is the cylinder length, and the volume of displacement = $(1/2)\pi(d/2)^2L$.

$$\mathrm{BM} = I/V = 2d/3\pi$$

Question 4. A waterplane is defined by the following half ordinates, spaced 6 m apart:

0.12, 2.25, 4.35, 6.30, 7.98, 9.27, 10.20, 10.80, 11.10, 11.19, 11.19, 11.19, 11.19, 11.16, 11.13, 11.04, 10.74, 10.02, 8.64, 6.51, 3.45.

If the ship's displacement is 14,540 tonnes in saltwater, find:

1. The waterplane area.
2. The longitudinal position of the centre of flotation.
3. $\mathrm{BM_T}$
4. $\mathrm{BM_L}$

Answer 4.

Draw up a table as below:

Half Ordinate	SM	$F(A)$	Lever	$F(M)$	Lever	$F(I)$	Cube Ordinate	$F(I_T)$
0.12	1	0.12	10	1.20	10	12	0	0
2.25	4	9.00	9	81.00	9	729	11	44
4.35	2	8.70	8	69.60	8	557	82	164
6.30	4	25.20	7	176.40	7	1235	250	1000
7.98	2	15.96	6	95.76	6	575	508	1016
9.27	4	37.08	5	185.40	5	927	797	3188
10.20	2	20.40	4	81.60	4	326	1061	2122
10.80	4	43.20	3	129.60	3	389	1260	5040
11.10	2	22.20	2	44.40	2	89	1368	2736
11.19	4	44.76	1	44.76	1	45	1401	5604
11.19	2	22.38	0	0.00	0	0	1401	2802
11.19	4	44.76	−1	− 44.76	−1	45	1401	5604
11.19	2	22.38	−2	− 44.76	−2	90	1401	2802
11.16	4	44.64	−3	− 133.92	−3	402	1390	5560
11.13	2	22.26	−4	− 89.04	−4	356	1379	2758
11.04	4	44.16	−5	− 220.80	−5	1104	1346	5384
10.74	2	21.48	−6	− 128.88	−6	773	1239	2478
10.02	4	40.08	−7	− 280.56	−7	1964	1006	4024
8.64	2	17.28	−8	− 138.24	−8	1106	645	1290
6.51	4	26.04	−9	− 234.36	−9	2109	276	1104
3.45	1	3.45	−10	− 34.50	−10	345	41	41
		535.53		− 440.10		13,176		54,761

If displacement is 14,540 tonnes, the volume of displacement is

$$V = 14,540/1.025 = 14,185\ \text{m}^3$$

Using the summations from the table:

Total waterplane area = 2 × (1/3) × 6 × 535.53 = 2142.12 m^2.
Distance of CF aft of the mid-ordinate = 6 × 440.10/535.53 = 4.93 m
Transverse I = 2 × (1/3) × (1/3) × 6 × 54,761 = 73,015 m^4.
Transverse BM = I/V = 73,015/14,185 = 5.15 m.

Longitudinal inertia about amidships = $2 \times (1/3) \times 6 \times 6 \times 6 \times 13{,}176 = 1{,}897{,}344\ m^4$.
Longitudinal inertia about the CF = $1{,}897{,}344 - 2142 \times 4.93 \times 4.93 = 1{,}845{,}280\ m^4$.
Longitudinal BM = 1,845,280/14,185 = 130 m.

Question 5. The half ordinates defining a ship's waterplane, reading from forward, are:

0.12, 6.36, 12.96, 18.00, 21.12, 22.20, 22.08, 21.00, 18.36, 12.96, 4.56.

The ordinates are 30 m apart and there is an additional (total) area aft of the last ordinate of 78 m^2, with its centroid 4.8 m aft of the last ordinate.

Find:

1. The total waterplane area.
2. The position of the centre of flotation.
3. The longitudinal inertia about the CF.

Answer 5.

Draw up a table as below:

Half Ordinate	SM	$F(A)$	Lever	$F(M)$	Lever	$F(I)$
0.12	1	0.12	5	0.60	5	3.0
6.36	4	25.44	4	101.76	4	407.0
12.96	2	25.92	3	77.76	3	233.3
18.00	4	72.00	2	144.00	2	288.0
21.12	2	42.24	1	42.24	1	42.2
22.20	4	88.80	0	0.00	0	0.0
22.08	2	44.16	−1	− 44.16	−1	44.2
21.00	4	84.00	−2	− 168.00	−2	336.0
18.36	2	36.72	−3	− 110.16	−3	330.5
12.96	4	51.84	−4	− 207.36	−4	829.4
4.56	1	4.56	−5	− 22.80	−5	114.0
		475.80		− 186.12		2627.6

Using the summations from the table:

The main waterplane area = $2 \times (1/3) \times 30 \times 475.8 = 9516\ m^2$.
To this must be added the extra 78 m^2 aft of the last ordinate giving a total area of 9594 m^2.
The moment aft of the main body of the waterplane = $2 \times (1/3) \times 30 \times 30 \times 186.12\ m^3 = 111{,}672\ m^3$.

The moment of the additional area aft = $78 \times (150 + 4.8) = 12{,}074\ \mathrm{m}^3$.
Giving a total moment aft = $123{,}746\ \mathrm{m}^3$.
CF aft of mid-ordinate = $123{,}746/9594 = 12.90$ m.
Longitudinal inertia of main waterplane about amidships = $2 \times (1/3) \times 30 \times 30 \times 30 \times 2627.6 = 47{,}297{,}000\ \mathrm{m}^4$.
Additional I due to area aft = $78 \times (154.8)^2 = 1{,}869{,}000\ \mathrm{m}^4$.
Total longitudinal inertia = $49{,}166{,}000\ \mathrm{m}^4$.
Inertia about the CF = $49{,}166{,}000 - 9594 \times 12.90 \times 12.90 = 47{,}569{,}000\ \mathrm{m}^4$.

Question 6. How is a ship's stability at large angles measured? Why are *cross curves* used? What do you understand by an angle of loll?

Answer 6.

The answer should include the following:

- Above about 10° of heel, the concept of a fixed metacentre breaks down.
- As a ship is heeled, the righting moment is given by the product of the buoyancy force and its perpendicular distance from the centre of gravity. That is, righting moment = W · GZ.
- GZ is plotted against the angle of heel to give the curve of statical stability. From this curve can be found the maximum sustained heeling moment the ship can withstand and the range of stability.
- It is difficult to determine accurately the heeled waterline for a given displacement. Instead curves are produced of SZ (where S is a convenient point on the centreline) against displacement for a range of angles of heel. For a given displacement and knowing the position of G relative to S, GZ curves can be derived for that displacement.
- A ship which is slightly unstable in the upright state may acquire positive stability at a small angle. This angle is known as an angle of loll.
- A ship with an angle of loll will not remain upright but will, under the action of wind and waves, 'flop' from one side to another.

Question 7. What effects do liquid free surfaces in a ship have on its stability? Can other cargoes present similar effects?

Answer 7.

The answer should include the following:

- A sketch showing a tank with a free surface.
- As ship heels the liquid surface takes up a new horizontal position. Some liquid will move towards the heeled side producing a destabilising effect.
- Proof that the reduction in effective GM is $\rho i/V$, where ρ is the fluid density, i is the inertia of the free surface and V is the ship's volume of displacement.

- Since i is proportional to the cube of the fluid surface's width, the free surface effect can be significantly reduced by fore and aft subdivision.
- Cargoes which can move as a ship heels can have the same effect. Grain is one such cargo. Other cargoes are subject to liquefaction under some conditions.

Question 8. Why does a ship need stability? What factors are usually considered in setting standards?

Answer 8.

The answer should include the following:

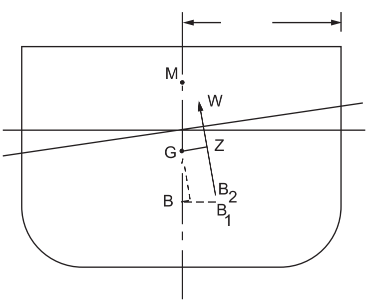
- A ship will not float upright unless it is stable in that position. Account must be taken of all possible loading conditions.
- It should not heel too much in winds and be able to absorb the energy of wind gusts.
- It must be able to withstand the action of waves without rolling to undue amplitudes.
- It should not heel too much when turning under the action of the rudder.
- Ship must be able to accept some flooding without capsizing or plunging.
- It must not heel too much when unloading. That is, as the cranes swing round to drop cargo on the dockside.
- Passenger carrying ships must allow for the fact that in some circumstances most of the passengers may crowd to one side of the ship.

Question 9. A ship with vertical sides in way of the waterline is said to be wall sided. Show for such a vessel that for inclinations, φ, within the range of wall-sidedness:

$$GZ = \sin\varphi[GM + ½BM \tan^2 \varphi]$$

Answer 9.

When inclined, the immersed and emerged wedges will be right angled triangles.



Referring to the figure, the centre of buoyancy movement can be regarded as made up of BB_1 parallel to the original waterplane and B_1B_2 at right angles to it.

It follows that:

$$\begin{aligned} BB_1 &= (1/V)\Sigma(y/2)(y \tan \varphi)(4y/3)dL = (2/3V)\Sigma y^3 \tan \varphi \, dL \\ &= (I/V)\tan \varphi = BM \tan \varphi \end{aligned}$$

where the summation is over the length of the waterplane.

$$\begin{aligned} B_1B_2 &= (1/V)\Sigma(y/2)(y \tan \varphi)[(2/3)y \tan \varphi]dL = ½BM \tan^2\varphi \\ GZ &= BB_1 \cos \varphi + B_1B_2 \sin \varphi - BG \sin \varphi \\ &= BM[\tan \varphi \cos \varphi + ½\tan^2 \varphi \sin \varphi] - (BM - GM) \sin \varphi \\ &= BM \sin \varphi + ½BM \tan^2 \varphi \sin \varphi - BM \sin \varphi + GM \sin \varphi \\ &= \sin \varphi[GM + ½BM \tan^2 \varphi] \end{aligned}$$

Question 10. Show that a wall-sided ship with an initial metacentric height, GM, which is negative will loll to an angle, **y**, such that

$$\tan \mathbf{y} = + [2GM/BM]^{05}$$

or

$$-[2GM/BM]^{05}$$

Answer 10.

For a wall-sided vessel:

$$GZ = \sin \varphi[GM + ½BM \tan^2 \varphi]$$

When the vessel is lolling, GZ is zero; therefore:

$$GZ = \sin \varphi[GM + ½BM \tan^2 \varphi]$$

To satisfy this equation, either

$$\sin \varphi = 0 \quad \text{or} \quad GM + ½BM \tan^2 \varphi = 0$$

The first solution is the case with the ship upright, but in this condition GM is negative so it is an unstable situation and the vessel will not stay upright.

To satisfy the second condition, the angle of heel, γ, is such that

$$\tan^2 \gamma = -2GM/BM$$

Since GM is negative, the right-hand side is positive and the equation leads to

$$\tan \gamma = + [2GM/BM]^{0.5}$$

or

$$-[2GM/BM]^{0.5}$$

Question 11. A ship of 10,000 tonnes has cross curves of stability which give, for that displacement, SZ values of:

φ (degree)	15	30	45	60	75	90
SZ (m)	0.85	1.84	2.82	2.80	2.06	1.14

If the pole S is 0.5 m below G:

1. Find the corresponding values of GZ.
2. Plot the GZ curve.
3. Find the angle and value of the maximum GZ.
4. Find the angle of vanishing stability.

Answer 11.

In this case GZ = SZ − 0.5 sin φ, hence construct a table as below:

φ (degree)	15	30	45	60	75	90
SZ (m)	0.85	1.84	2.82	2.80	2.06	1.14
0.5 sin φ	0.13	0.25	0.35	0.43	0.48	0.50
GZ (m)	0.72	1.59	2.47	2.37	1.58	0.64

Plotting the GZ curve:

1. Angle of maximum GZ = approximately 51°.
2. Value of GZ max = approximately 2.55.
3. Angle of vanishing stability = approximately 95°.

Question 12. A ship of 12,000 tonnes has cross curves of stability which give, for that displacement, SZ values of:

φ (degree)	15	30	45	60	75	90
SZ (m)	0.68	1.64	2.58	2.86	2.72	2.20

If the pole S is 0.65 m below G:

1. Find the corresponding values of GZ.
2. Plot the GZ curve.
3. Find the angle and value of the maximum GZ.
4. Find the angle of vanishing stability.
5. The dynamical stability up to 60°.

Answer 12.

In this case GZ = SZ − 0.65 sin φ, hence construct a table as below:

φ (degree)	15	30	45	60	75	90
SZ (m)	0.68	1.64	2.58	2.86	2.72	2.20
0.65 sin φ	0.17	0.33	0.46	0.56	0.63	0.65
GZ (m)	0.51	1.31	2.12	2.30	2.09	1.55

Plotting the GZ curve:

1. Angle of maximum GZ = approximately 58°.
2. Value of GZ max = approximately 2.31.
3. Angle of vanishing stability = approximately 114°.

The dynamical stability up to 60° is given by the product of the displacement and the area under the GZ curve up to that angle. Use Simpson's rule to obtain the area.

Angle, φ	GZ (m)	Simpson Multiplier	Function (A)
0	0	1	0
15	.51	4	2.04
30	1.31	2	2.62
45	2.12	4	8.48
60	2.30	1	2.30
Total			**15.44**

Hence area under the GZ curve = (1/3)(15/57.3)(15.44) = 1.347 m rad.

Hence dynamical stability up to 60° = 12,000 × 1.347 = 16,170 tonnes m.

Question 13. Outline the latest IMO probabilistic method for assessing damage stability.

Answer 13.

The answer should include the following:

- Margin line no longer used. Instead down flooding and progression of flooding is allowed for.
- The assessed (A) and required (R) subdivision indexes.
- Many more damage scenarios studied.

- Statistical data used to establish the probable location and extent of damage.
- Regulations still being developed.
- Special case of Ro−Ro ships.

Question 14. Discuss the special problems of Ro−Ro ships with large vehicle decks.

Answer 14.

The answer should include the following:

- Large free surfaces possible on the vehicle decks.
- The use of large bow (and stern doors) to ease loading and unloading creates potential problems in severe weather.
- The Stockholm agreement dealt with these vessels.
- Large open spaces mean that longitudinal strength requires special consideration.
- Danger of water entering the ship through damaged bow doors.
- Balance in design between rapid loading/unloading and attaining sufficient stability and strength.

CHAPTER 6. LAUNCHING, DOCKING AND GROUNDING

Question 1. Discuss the means of transferring ships from dry land to the sea on first build. Describe the slipway and the means of ensuring a successful conventional launch.

Answer 1.

The answer should include the following:

- Launching ways for end on and sideways launching.
- Building large ships in graving docks.
- Use of shiplifts.
- Setting up ship to transfer weight from the building blocks to the launch ways.
- Cradles supporting the two ends of the ship.
- Greasing of ways and experiments to determine its resistance to sliding.
- Means of arresting ship once launched.

Question 2. Discuss the calculations carried out to ensure a successful end on launch. What safety precautions are taken?

Answer 2.

The answer should include the following:

- Calculating, for a series of positions down the slipway, the buoyancy, weight (constant) and their moments about the fore poppet and after the end of the ways.
- Establishing whether the ship will float off, or drop off, the end of the ways. For the latter check that the depth of water is adequate.
- Finding the maximum force on the fore poppet as the ship pivots about it. Ensuring the poppet and ship are strong enough.
- Strength checked for longitudinal bending, bearing in mind that the structure may be incomplete at launch.
- Providing means of absorbing the energy of launch and bringing the ship to rest quickly. Water brakes and the use of drag chains.
- Checks on the sliding resistance of the grease used.
- Picking suitable tide and wind conditions.

Question 3. Discuss the docking process and the precautions taken to ensure a successful operation.

Answer 3.

The answer should include the following:

- Preparing the dock blocks, shores, etc. Using the ship's docking plan and the plan of the dock.
- Trimming vessel so that keel is almost parallel with the top of the dock blocks.
- Picking a suitable tide. Avoiding excessive wind.
- Marking dock so that ship is positioned accurately lengthwise and transversely in the dock.
- Carrying out a stability check as the ship touches the blocks and before the shores can be driven home.
- Connecting up the necessary shore supplies and means of access.

CHAPTER 7. RESISTANCE

Question 1. Name two key relationships between the physical quantities that are important in a study of the resistance of ships. Why is each important?

Answer 1.

The answer should include the following:

- Froude number. Important for wave-making resistance, particularly at higher speeds. Comparisons of model and full scale results made at the same value of Froude number.
- Concept of corresponding Froude number.
- Reynolds' number. Important for frictional resistance. Important at lower speeds.

Question 2. Discuss the various types of resistance encountered by a ship. How can they be reduced? What is their relative importance at different speed regimes?

Answer 2.

The answer should include the following:

- Wave-making resistance. High speed. Use of fine forms forward and bulbous bows.
- Frictional resistance. Relatively more important at lower speeds. Reduce wetted surface area. Keep the underwater hull clean and free of fouling.
- Eddy making resistance. Avoid sudden charges in direction of the fluid flow.
- Appendage resistance. Avoid protrusions from the ship. For essential appendages, use streamlined shapes (e.g. rudders) and align with the general direction of flow (e.g. shaft brackets).
- Wind resistance. Depends upon the relative speed of the ship to the air. In a head wind resistance will become large. Streamline the above water hull and the superstructure.

Question 3. Discuss how ship model data can be used to determine ship resistance.

Answer 3.

The answer should include the following:

- Obtain total model resistance by running a model at the corresponding Froude number.
- Calculate model frictional resistance.
- Subtract frictional from total to give the residuary resistance.
- Scale residuary resistance to the ship value in the ratio of the ship to model displacements.
- Add frictional resistance calculated for the ship.
- Add allowances for appendage and wind resistances.

Question 4. How are the following used?

1. The ITTC correlation line?
2. Methodical series?

Answer 4.

The answer should include the following:

- ITTC line is based on a lot of model and ship data enabling the skin friction resistance of ship and model to be compared. Term correlation is used in preference to skin friction as it is recognised that the line, although mainly influenced by skin friction, includes the affects of other factors.
- Generally adopted enabling good comparison of data from different sources.
- Methodical (or standard) series are model results for models based on a type ship and in which parameters are varied in a systematic way. This enables the influence of small changes in form parameters, for instance, to be assessed for the type ship form.
- Methodical series have been carried out by the major hydrodynamic research organisations.

Question 5. What do you understand by roughness? How does it come about? How is it measured? How can it be reduced?

Answer 5.

The answer should include the following:

- Concepts of laminar and turbulent flow.
- The boundary layer, increasing in thickness from the bow to the stern.
- Reynolds' number and early pipe experiments.
- Arises from irregularities on the wetted surface – plate overlaps, welding, pitting and plate waviness, marine growth.
- Measured by a roughness gauge giving the variation in surface elevation over a 50 mm length.
- To reduce:
  1. Ensure surface is as smooth as possible, as built.
  2. Preserve plating as it is fabricated to reduce initial corrosion.
  3. Use good anti-corrosion coatings to reduce corrosion in service. Possibly install a cathodic protection system.
  4. Reduce fouling by good outer bottom coatings and regular dockings.

Question 6. Describe a typical ship tank in which resistance experiments are carried out. How can model results be compared with full scale data? Why are special ship trials needed?

Answer 6.

The answer should include the following:

- A long narrow tank with carriage running on rails either side. Rails follow curvature of the earth.

- Model secured below the carriage through a dynamometer that measures the force needed to tow the model and allow some freedom of movement in heave and trim.
- Model run at the corresponding Froude number and resistance measured. Repeated over a range of speeds and displacement.
- Care needed to avoid currents in the tank.
- See answer to Question 3 for getting ship resistance.
- Ship is run over a measured distance to establish its speed at a known displacement, with a clean hull and in good weather conditions.
- From ship result and the corresponding prediction an overall factor of comparison can be obtained.
- Not possible to separate out resistance and differences in propulsion efficiency. This can only be done in special trials in which effectively the ship has its resistance measured directly as in Greyhound and Lucy Ashton trials.

CHAPTER 8. PROPULSION

Question 1. Discuss what you understand by the term 'effective power'. What are the factors affecting the overall propulsive efficiency?

Answer 1.

The answer should include the following:

- Effective power is that needed to overcome the resistance of the naked hull.
- Overall propulsive efficiency is the ratio of the effective power to the required shaft power.
- Factors involved, or hull efficiency elements (as defined in the text), are:
  - hull efficiency,
  - propulsive efficiency,
  - relative rotative efficiency,
  - shaft transmission efficiency,
  - appendage coefficient.

Question 2. Outline the simple momentum theory for a propulsor. Show that the ideal efficiency is related to the axial and rotational inflow factors.

Answer 2.

The answer should include the following:

- Application of Bernouilli's principle to the flow through the propulsor disc.

- Velocity through disc is $V(1 + a)$, where V is the speed of advance of prop and a is the axial inflow factor.
- Equate thrust to change of momentum.
- Equate work done by the thrust to the kinetic energy in the water.
- Show that final water velocity is bV, where $b = 2a$.
- Show ideal efficiency = $1/(1 + a)$.
- Mention that rotational inflow factor arises from rotation in the screw race and reduces efficiency still further.

Question 3. Discuss the physical features of a screw propeller and the blade section. How are the thrust and torque estimated?

Answer 3.

The answer should include the following:

- Concept of helicoidal surface.
- Pitch, rake, skew, blade outline.
- Blade sections; face; back; aerofoil sections; camber; thickness.
- Pitch ratio; blade area; handing of propellers.
- Flow around aerofoil section; circulation.
- Lift on blade element from blade section characteristics.
- Integration over blade surface to give thrust and torque.

Question 4. What do you understand by the term cavitation? Why is it important, how is it studied and how can it be reduced?

Answer 4.

The answer should include the following:

- Typical flow over an aerofoil section. Most of lift from suction.
- Formation of bubbles when pressure is reduced.
- Concept of a cavitation number.
- Likely at blade tips where velocity is high; at hub where angle of incidence is high.
- Reduces efficiency and can cause physical damage and noise.
- Studied in a cavitation tunnel where model propeller is run in water at reduced pressure. Cavitation viewing trials on ships.
- For a given thrust best results if the pressure distribution is more uniform. Tips are off-loaded, for instance.

Question 5. Discuss the various types of propulsive device used to propel marine vehicles.

Answer 5.

The answer should include the following, with a general discussion of each:

- Fixed pitch propellers.
- Controllable pitch propellers.

- Self-pitching propellers.
- Shrouded/ducted propellers.
- Pump jets.
- Contra-rotating propellers.
- Azimuthing propellers.
- Vertical axis propellers.
- Water jets.
- Surface piercing propellers.
- Paddle wheels.
- Wind using sails or rotors.

Question 6. Describe the use of a measured distance to determine a ship's speed accurately. What precautions are taken to achieve an accurate result?

Answer 6.

The answer should include the following:

- A sketch of a typical measured mile.
- Runs in two directions to eliminate tide effects.
- Runs at a series of steady power.
- Good weather conditions.
- Clean ship's bottom.
- Large turning circle at end of each run to ensure ship is up to speed as it enters the measured distance.
- Ship on correct heading. That is, on a course normal to the lines through the marker posts.
- Adequate water depth to avoid shallow water effects.
- Displacement must be accurately known.
- Apart from timing the ship over the distance measurements should be taken of shaft revolutions and, if possible, shaft thrust and torque.

CHAPTER 9. THE SHIP ENVIRONMENTS

Question 1. Discuss the features of the environment in which a ship operates that affect its design.

Answer 1.

The answer should include the following:

- **Temperature of air and water.** Air-conditioning systems, machinery output. Typical range of figures for design.
- **Icing conditions.** Ice on upperworks and rigging affects stability; ice on the water can be dangerous or inhibit movement.
- **Wind.** Can make steering difficult; affect on standard of stability. Beaufort scale and wind gradient above the water surface.

- **Waves.** Motions of ship; possible need to stabilise. Stability in waves. Loss of speed in waves.
- **Driving rain, sand and dust**. Abrasion of exposed surfaces; penetration of exposed equipment.

Question 2. Discuss the two 'standard' waves used in ship design. The sea surface usually looks completely irregular. How does the naval architect define such seas?

Answer 2.

The answer should include the following:

- The 'standard' waves are the sinusoidal and trochoidal waves. The first is used as the basic component from which an irregular sea is built up. The latter is used in longitudinal strength calculations.
- The irregular sea surface is considered as the sum of a large number of small amplitude sinusoidal waves. Such seas are categorised as long or short crested depending upon whether all the components are travelling in the same direction or not.
- The concept of an energy spectrum.
- The use of the area under the energy spectrum to obtain the significant wave height and the probabilities of exceeding certain wave amplitudes.
- The use of wave statistics to determine the waves a ship is likely to meet during service.
- Freak waves and how they arise.

Question 3. Discuss the international rules governing the pollution of the environment by ships. What steps can be taken by the naval architect to reduce or eliminate pollution?

Answer 3.

The answer should include the following:

- IMO and MARPOL. (The student should be encouraged to use the Internet to expand upon the information in the book.)
- Use of double hull tankers. Restrictions on cleaning tanks at sea.
- Control of hazardous substances.
- Control of any 'dumping' from the ship.
- Provision of waste treatment systems or holding tanks for short haul ships. Arranging heads, galleys, bathrooms, etc. to simplify piping to sewage treatment plants.
- Incinerators and crushing plant.
- Environmentally friendly paint systems.
- Treatment of ballast water.

Question 4. Discuss the important features of a ship's internal environment. Why are they important and how are they controlled?

Answer 4.

The answer should include the following:

- **Motions in a seaway.** Can cause nausea and sickness which are unpleasant and make the crew less efficient. Some tasks become more difficult physically.
- **Air quality.** Temperature and humidity need to be within limits for comfort of passengers and crew. Controlled by heating and air-conditioning systems. Levels of oxygen, carbon dioxide and other possible pollutants must be controlled. Usually achieved by introducing a percentage of fresh air into the ventilation system.
- The concept of effective temperature.
- **Vibration and noise.** Both are caused largely by the same sources – unbalanced machinery, misaligned shafts, water flow, flow of fluids in systems. Both are unpleasant and if the levels are high enough cause injury. Levels are controlled by reducing exciting forces, applying insulation and mountings to reduce transmission.
- **Shock.** Can arise in an accident or for enemy attack. Equipments must be robust and/or mounted to protect them against failure.
- **Illumination.** Controlled to provide efficient working conditions and, in passenger ships, to produce the desired mood.

Question 5. Discuss how noise is measured. How does it vary with distance from the source? How does it arise in a ship and why should it be reduced as much as possible? How can noise levels be reduced in critical areas?

Answer 5.

The answer should include the following:

- Sound intensity is expressed in decibels (dB), that is relative to a standard reference level.
- Noise level increases, or reduces, by 6 dB when the distance from the source is halved or doubled, respectively.
- To specify a noise requires the distribution of energy over the frequency range.
- Humans react differently to different frequency. They are more sensitive to high frequencies. To allow for this subjectivity noise levels can be quoted in dB(A) in which the energy at each frequency is modified by a weighting factor.
- Noise arises from machinery, propellers, fans, electrical transformers, the sea and from flow of fluids in pipes.
- Noise can be transmitted through structure and through the air.
- Mounting equipment and pipes can reduce noise through the supporting structure. Insulation can reduce transmission through surrounding cabinets and through bulkheads and decks.
- ‘Short circuits’ must be avoided.

- Active noise cancellation can be used where it is critical. System generates a noise of equivalent frequency and volume content but in anti-phase.

CHAPTER 10. SEAKEEPING

Question 1. What do you understand by the terms *simple harmonic motion*, *added mass*, *damping*, *tuning factor* and *magnification factor*?

Answer 1.

The answer should include the following:

- SHM occurs when a body, once displaced from a position of equilibrium, is acted upon by a restoring force proportional to the displacement.
- Motion characterised by its amplitude, A, and period, T, through an equation of the type:

$$\text{Displacement at time } t = A \sin[(k/M)^{0.5} t + \delta]$$

where M is the body's mass, k is the force per unit displacement and δ is a phase angle. The period of the motion is

$$T = 2\pi(M/k)^{0.5}$$

and its frequency $n = 1/T$.

- When the body reaches the equilibrium position, it overshoots and the restoring force then acts in the reverse direction. Such a motion would carry on indefinitely.
- In a real fluid, the movement of the body sets some of the surrounding fluid in motion. The effect is to increase the apparent mass of the body by an amount known as the added mass.
- The motion also creates forces opposing the motion and these are known as damping forces. They slow the motion and eventually bring it to rest.
- When a body is acted upon by an oscillating force, it responds in what is termed a forced oscillation. The tuning factor is the ratio of the applied force to the natural frequency of the system. Motion amplitudes become large when the tuning factor approaches unity.
- The magnification factor is the ratio of dynamic displacement to the static displacement, the latter being the displacement due a steady force, equal to the amplitude of the applied oscillating force.

Question 2. What are the main causes of vibration in ships? How can the levels of vibration be reduced?

Answer 2.

The answer should include the following:

- Need to distinguish between local and main hull vibrations.
- Main hull vibrations are caused by the sea and may be flexural (vertical or horizontal) or torsional. Depend upon the main hull structure and therefore difficult to change after design is finalised. Need to avoid natural hull periods becoming close to the wave periods likely to be encountered.
- Local vibrations are caused by machinery, propellers and rotating shafts.
- Need to balance all forces in reciprocating and rotary machinery.
- Balance the propeller and provide good flow into it.
- Allow good propeller clearance.
- Avoid resonance of components.
- Use isolating mounts to reduce transmission of vibration forces.
- Fit a vibration damper. This may be active but more usually passive.

Question 3. Show that in the case of undamped, small amplitude motion, a ship when heeled in still water, and released, will roll in simple harmonic motion, Deduce the period of roll. Repeat this for a ship heaving.

Answer 3.

1. **Rolling**

For a small angle of heel, φ, the restoring moment acting on the ship is

$$\Delta \mathrm{GM} \varphi$$

where Δ is the displacement.

This causes an angular acceleration, such that

$$(\Delta k^2/g)(\mathrm{d}^2\varphi/dt^2) = -\Delta \mathrm{GM} \varphi$$

where k is the radius of gyration.

That is the equation of motion is

$$\mathrm{d}^2\varphi/dt^2 + (g\mathrm{GM}/k^2)\varphi = 0$$

This is the standard equation for simple harmonic motion (SHM) with a period of

$$T_\varphi = 2\pi k/(g\mathrm{GM})^{0.5}$$

2. **Heaving**

In this case if the ship is pushed down a distance, z, in the water and released, the restoring force is

$$\rho g A_\mathrm{W} z$$

where A_W is the area of the waterplane.

The vertical acceleration is then given by

$$\Delta d^2z/dt^2 = -\rho g A_W z$$

The equation of motion, which again is that for SHM, is

$$d^2z/dt^2 + g\rho A_W z/\Delta = 0$$

The period is

$$T_{heave} = 2\pi(\Delta/\rho g A_W)^{0.5}$$

Question 4. Discuss how ship motion data can be presented, including the concepts of response amplitude operators and an energy spectrum.

Answer 4.

The answer should include the following:

- Need to present so that one set of results applies to geometrically similar ships and models.
- For speed the Froude number is used, or V^2/L.
- Translational movements, for moderate motions, are proportional to the linear dimension. The amplitudes of these motions (e.g. heave) are divided by wave height.
- Angular motions also divided by wave height as maximum wave slope is proportional to wave height. Data in waves which vary as ship length the angular motions will translate directly.
- All motion amplitudes vary linearly with wave height.
- Natural periods of motion vary as the square root of the linear dimension.
- Ordinates of curves of motion amplitude against motion period (both expressed non-dimensionally) are known as response amplitude operators (RAOs) or transfer functions.
- The wave system can be represented by an energy spectrum. If the ordinates of this are multiplied by the square of the corresponding RAO, an energy spectrum of motion is obtained.
- From the energy spectrum, the average and significant motion amplitudes can be deduced.

Question 5. Discuss the various factors that can affect a ship's performance in waves. How can some of these affects be minimised?

Answer 5.

The answer should include the following:

- Increased resistance will mean reduced speed for a given power.
- Master may reduce speed to reduce wetness or motions.

- Slamming can cause damage and may require a change of speed or course.
- The ship may become wet. That is, it may ship large quantities of spray or green seas, usually at the bow. Can cause damage to exposed equipment and make movement on deck hazardous. May be reduced by reduction in speed and change of course.
- Reduced efficiency of propeller due to non-uniform inflow conditions. In the extreme, the propeller can leave the water. Reduces speed and may damage the transmission system. Reduce speed or change course.
- Motions can degrade the performance of the crew. The tasks may become more physically demanding and the crew can become less able physically and mentally due to motion sickness.

Question 6. Discuss how the overall seakeeping performance of two different designs can be compared.

Answer 6.

The answer should include the following:

- Determine the pattern of use of the intended design. Areas of the world it is to operate through, and the times of year.
- Assess the probability of meeting various sea conditions and likely ship speed and direction.
- The probable ship condition, e.g. deep or light condition.
- Deduce the ship responses (including wetness, etc.) that are likely to be critical to its operations.
- For each set of sea conditions, assess the probability of the ship being limited in some way.
- Combining all probable seas, deduce overall probabilities of ship being limited.
- Assess the relative importance, to the owner, of each type of limitation.
- Obtain an overall ‘figure’ for comparison of designs. This may be the percentage of time in total during which its performance will be degraded in one way or another.

Question 7. Discuss the various ways in which seakeeping data can be acquired.

Answer 7.

The answer should include the following:

1. **Sea conditions.**
   - Ocean wave statistics are published. It has been shown that average conditions do change with time, e.g. the North Atlantic is becoming rougher.

- For specific trials, recording buoys can be used to record the waves in the area of the ship.
- Buoys, or fixed recorders, can record conditions in the approach to ports.

2. **Motions**.
   - RAOs can be found from model tests or by calculations.
   - Calculations are good except where motions are strongly non-linear.
   - Models can be tested in ship tanks (long narrow tanks) for head and following sea data.
   - Seakeeping basins (large areas of water) are needed for general model testing so that the model can travel at different directions to, and manoeuvre in, the wave system.
   - Waves may be regular or irregular, long or short crested.
   - Length of run is determined by the need to record a representative sample of the motions. Multiple runs are usually needed for accurate results.
   - Model must accurately reproduce the ship condition – draughts, displacement and moments of inertia.
   - Data can be telemetered ashore or recorded in the model, usually the former to reduce model weight.

Question 8. Discuss how a ship can be stabilised to reduce roll motions.

Answer 8.

The answer should include the following, with outline diagrams and a description of their operation:

- Passive and active systems.
- Bilge keels. Fitted at the turn of bilge to provide most leverage. Performance enhanced by forward ship speed.
- Fixed fins. Can be regarded as a variant on the bilge keel.
- Passive tanks. Can be effective even with the ship stationary.
- Active fins. Moved to oppose the rolling motion using a sensor. Fitted in pairs at the turn of bilge. May have flaps to improve efficiency by changing the aerofoil shape. Depend upon ship speed, the force generated being proportional to the square of the water speed.
- Active tank. Similar in action to the passive tank but can be 'tuned' to react to the motion frequency.

Question 9. Discuss, in general terms, the effect of ship form on seakeeping performance.

Answer 9.

The answer should include the following:

- Comment on difficulty of isolating the effect of a given change.

- Note that an improvement at one frequency may lead to poorer performance at another frequency.
- Importance of some frequency ranges, e.g. for human responses to motions.
- Increasing size usually reduces motions in a given sea state. Beware in case an increase in length, say, leads to resonance with the waves.
- Long length reduces chance of meeting waves long and high enough to cause problems.
- High freeboard reduces wetness.
- Flare forward can make the ship drier but may lead to more slamming forward.
- High length/draught ratio will reduce pitch and heave but increase chances of slamming.
- Bulbous bows help to reduce motions in short waves

Question 10. Discuss the reasons why a ship may experience very large rolling angles.

Answer 10.

The answer should include the following:

- Resonance with exciting waves in beam seas.
- Asymmetric resonance.
- Loss of transverse righting moment in waves.
- Roll experienced during broaching.
- Parametric rolling and the other hazards listed in the section titled ‘Hazards due to wave resonance effects’.
- Low damping of roll due to absence of bilge keels.

CHAPTER 11. VIBRATION, NOISE AND SHOCK

Question 1. Discuss the ways in which a ship’s structure may flex and vibrate. How can the levels of vibration experienced be reduced?

Answer 1.

- Main hull: Flexing in the vertical and horizontal planes; torsional vibration about a fore and aft axis.
- Local: Due mainly to forces imposed by equipment mounted on it or by responding to forces transmitted from adjacent structure.
- Balance machinery and propellers.
- Provide good clearances between propellers and the hull.
- Avoid resonance between exciting frequencies and frequencies of the structure.
- Use active or passive damping.

- Use vibration isolating mounts.
- Maintain equipment in good order – avoid bearing wear.

Question 2. Discuss the shock experienced by a ship due to an underwater explosion. How can the effects be mitigated?

Answer 2.

- Reference to Figure 11.3 of text.
- The migration of the bubble created by the explosion.
- The shock wave.
- Whipping.
- Use of shock mounts.
- Mounting sensitive equipment where the structure attenuates the shock wave.

CHAPTER 12. MANOEUVRING

Question 1. Discuss what you understand by directional stability and manoeuvring. How are these attributes provided in a ship?

Answer 1.

The answer should include the following:

- A ship is directionally stable if, having been disturbed from a straight course, it returns to a straight course (not the same direction) after the disturbing force is removed.
- A ship has good manoeuvrability when it responds positively and well to control surface movements and to changes in shaft revolutions.
- For good directional stability, the bow can be cut away under water and a skeg fitted aft.
- For manoeuvrability, rudders are provided aft, transverse thrusters are provided forward or aft, azimuthing propulsion pods are fitted, or a combination of these. For most ships rudders are used.
- A very directionally stable ship may be difficult to turn.
- A rudder can improve both directional stability and manoeuvrability.
- An autopilot is often fitted to reduce the load on the helmsman.
- Ships requiring to hold a precise position relative to the seabed are provided with a dynamic positioning system with an input from some external source such as a satellite guidance system. Such ships have a series of thrusters forward and aft.

Question 2. Describe a number of measures that can be used to define a ship's manoeuvring characteristics.

Answer 2.

The answer should include the following, illustrated with sketches such as those in the main text:

- The turning circle, describing the features of the circle such as advance, transfer and drift angle.
- Often an ability to respond quickly to rudder changes is more important than a tight turning circle.
- The zig-zag manoeuvre.
- The spiral manoeuvre explaining the differences to be expected between a directionally stable and unstable ship.
- The pull-out manoeuvre.
- The stopping distance. This may be very large for large bulk carriers and tankers.

Question 3. Describe, and sketch, a number of different types of rudder. How are rudder forces and torques on a conventional rudder calculated?

Answer 3.

The answer should include the following types of rudder, with a sketch of each:

- Spade.
- Balanced and semi-balanced.
- Active.
- Kitchen.
- Vertical axis.
- Cycloidal.

Rudder forces and torques are calculated by dividing the rudder into a number of strips, calculating the force on each strip based on aerodynamic data for the rudder section, and summating to give the total force and the position at which it acts.

CHAPTER 13. STRUCTURES

Question 1. Discuss how a ship structure may fail in service.

Answer 1.

The answer should include the following:

- **Failure** can be defined as occurring when the structure can no longer carry out its intended function.
- **Cracking.** The structure parts because it can no longer sustain the load imposed and fractures. Possibly because the material ultimate strength

has been exceeded, but, more likely, due to fatigue. Even if structure does not fracture it may leak.

- **Distortion.** The structure takes on permanent set due to the yield point being exceeded. Systems can no longer function efficiently.
- **Instability.** Very large deflections, the structure behaving like a crippled strut. That is, the structure buckles.

Question 2. Outline the simple standard method of assessing a ship's longitudinal strength. How are bending moments translated into hull stresses?

Answer 2.

The answer should include the following:

- Still water situation studied first and then the ship is balanced on a wave equal in length to the ship length. Two cases with the crest and then the trough amidships.
- Trochoidal wave form.
- Two cases – hogging and sagging. Sketch to illustrate.
- Weight and buoyancy distributions obtained and the shear force and bending moments derived.
- Obtain section modulus at critical sections including amidships. Calculate position of the section's neutral axis.
- Only continuous structure contributes to the section strength.
- How to deal with sections including two materials.
- Deriving stresses in deck and keel for the hogging and sagging conditions.
- Emphasise method is comparative only. Stress values calculated are not those to be expected in actual service.

Question 3. Discuss superstructures and their contribution to longitudinal strength.

Answer 3.

The answer should include the following:

- Superstructures are major discontinuities and need careful treatment.
- They can contribute to longitudinal strength, but care is needed to ensure they, themselves, are strong enough to take the strains imposed upon them.
- The working of the ship tends to peel the superstructure away from the main hull.
- Can be made more effective by making them longer and extending them the full width of the hull.
- Ends should be landed on transverse bulkheads.
- Superstructures often made of aluminium. Introduces possibility of differential corrosion. Fire risk as aluminium melts at lower temperature than steel.

- Avoid expansion joints as these can act as stress raisers.
- Ideally carry out a finite element analysis of the structure.

Question 4. Discuss the transverse strength of a ship, the loading and methods of calculation.

Answer 4.

The answer should include the following:

- Loads in a seaway can be calculated including the inertia and gravity forces.
- Tanks with liquids will introduce additional loads due to *sloshing*.
- Frames in way of the waterline will be subject to berthing forces. These can be reduced by suitable fendering.
- Other transverse 'racking' loads can arise when a ship is docked.
- Usual to consider first a transverse frame with the adjoining shell plating and progress to a complete section between two transverse bulkheads.
- Transverse bulkheads are important in resisting racking of the ship.
- Methods that can be used to evaluate transverse frames as frameworks are:
  1. energy methods,
  2. moment distribution,
  3. slope-deflection methods.

Question 5. Discuss fatigue, cracking and stress concentrations in relation to ship type structures.

Answer 5.

The answer should include the following:

- Fatigue is most common cause of failure.
- A fatigue fracture is usually smooth and stepped.
- S–N curves.
- Fatigue limit. Steel in corrosive environment has no fatigue limit.
- Using high tensile steel does not help as fatigue characteristics similar to mild steel. Danger of higher stresses if designer uses the higher UTS to reduce scantlings.
- Fatigue life depends upon stress level, structural continuity, weld geometry and imperfections.
- Designer uses data from laboratory tests on typical welded joints.
- Cracks are bound to occur in ships. Not serious unless they extend.
- After crack initiation propagation is generally relatively slow unless the structure suffers from brittle fracture.

- To avoid brittle fracture use tough steels.
- Steels have a transition temperature above which fracture is ductile and below which it is brittle.
- A brittle steel is one with a relatively high transition temperature – above 0°C.
- Charpy and Crack Tip Opening (Displacement) tests are used to assess toughness. Charpy is simpler and most often quoted. Unfortunately it is not representative of the geometry of a structure which is important.
- Stress concentrations are a raising of the stress level locally above that generally in the surrounding material.
- Stress concentrations caused by holes and defects. In effect the stress lines are funnelled through a bottleneck.
- Openings in decks should have well rounded corners to reduce stress concentrations. They will often have thicker plating at the corners to reduce the stress level. Where several holes are cut along a deck, they should be carefully aligned.
- Structures will have built-in stresses due to manufacturing processes, especially welding.

Question 6. Discuss buckling and load shortening curves in relation to ships' structures.

Answer 6.

The answer should include the following:

- Buckling is due to the compressive loading exceeding a critical value.
- A simple strut is a good analogy and buckling strengths for these can be found using Euler's theories.
- Any initial out of straight of a strut affects its load bearing capacity. Rankine–Gordon theories.
- A stiffener, with some of the attached plating, can be regarded as a strut when loaded axially. The difficulty is assessing the end constraints which are important to the load the structure can take.
- In most ship structures, the buckling of one element throws more load on to surrounding structure. If this cannot withstand the extra load, there will be progressive failure.
- A ship structure includes many grillages made up of a number of stiffeners and associated plating. Experimental work enables a designer to determine the loads a grillage can take before and after yield is initiated. These loads are shown in load shortening curves.
- These curves allow a more efficient lighter structure to be designed than if the yield stress was not allowed to be exceeded.

CHAPTER 14. SHIP DESIGN

Question 1. How would you expect a good set of ship requirements to be set out? What would you expect them to cover?

Answer 1.

The answer should include the following:

- A good set of requirements would set out the operational needs of the owner, clearly and unambiguously.
- They would leave the designer to decide how best these operational needs can be met.
- They would cover items to be carried, capacity, speed, intended routes, ports to be used and any company rules or standards to be incorporated into the design. Any cost limitations to be spelt out.
- Standards to be followed – international, national and owner's.

Question 2. What factors should be taken into account in assessing the cost of a ship? How can different design solutions be compared?

Answer 2.

The answer should include the following:

- Costs of ownership must include acquisition and operational costs.
- The earnings of the ship are set against the costs.
- Cost elements include design, production, trials, through life maintenance and operations. Operational costs will include crew wages, fuel, port dues, insurance and general running costs.
- Depreciation is a factor if the ship is intended to be sold after a few years.
- For comparisons all costs, present and future, must be brought to a common base.
- The concept of net present value is often adopted, using discounted cash flow methods.
- The higher the net present value the 'better' the design from the economic point of view.

Question 3. Describe the design process and discuss the various phases of design?

Answer 3.

The answer should include the following:

- The process is iterative. One way of describing it is as a design spiral.
- The initial phase is explorative, with many different ways, some possibly rather novel, of meeting the requirements being explored.

- Having found the broad design features the next phase is to develop the concept to the point of establishing feasibility and an estimate of cost.
- The next phase develops the ideas up to the detail where a contract to build can be negotiated and a firm price established.
- The detailed design produced by the builder in response to the contract design and supporting specifications.
- Producing information needed for operating the ship.

Question 4. Discuss the impact of computers upon the design, build and operation of ships.

Answer 4.

The answer should include the following:

- In design more design options can be studied and in greater depth, more quickly and at an earlier stage.
- More detailed calculations are possible, e.g. finite element analyses in structural design, enabling departures from previous practice to be adopted with greater assurance of success.
- There is less possibility of introducing errors due to data being incorrectly transcribed.
- Information can be passed to the builder electronically, again reducing the chance of errors.
- Electronic methods can be used to control cutting and welding processes, leading to greater accuracy of assembly and less built-in stress.
- Simulations can be used to aid an owner in envisioning the way the ship will look, in studying emergency escape arrangements and in training operating personnel.
- Better control of logistic support both during build and operation.
- Greater assistance to the master in running the ship.

Question 5. Describe how a formal safety assessment can be conducted.

Answer 5.

The answer should include the following:

- Safety embraces not only the hardware but also policies of the organisation.
- Identification of all practical hazards, using knowledge of the design, operational areas and previous experience.
- Establish the risk of each hazard, the risk being a combination of its likely occurrence and the consequences.
- Consider how the risk can be eliminated or reduced.
- Carry out cost–benefit analyses to judge economic consequences of various options.

- Produce plans for dealing with incidents including escape and rescue if relevant.
- Issue information and set up procedures as a means of managing safety.
- Arrange for safety audits.

Question 6. How can ship design be approached in a methodical manner?

Answer 6.

The answer should include the following:

- Treat the ship as having three basic functions supported by capabilities and attributes.
- Base new ship on type ship or synthesise from elements required to create the required capabilities.
- Establish how equipment and systems fitted in the ship contribute to the capabilities, etc. Produce dependency diagrams.
- Use the dependency relationships to investigate availability and vulnerability.
- Assess attributes such as stability, strength and powering, etc. at regular intervals with the outputs of each modifying the others as necessary.
- Maintain a master definition of the ship's configuration as the design develops, allowing only authorised people to alter decisions already made.
- The above is likely to be achieved by using a CAD system.

CHAPTER 15. SHIP TYPES

Question 1. Discuss the various types of merchant ship. Discuss how container ships were evolved and the advantages they possess over general cargo carriers.

Answer 1.

The answer should include the following:

- General cargo ships including reefers.
- Container ships.
- Bulk carriers; dry cargo (grain, ore); tankers (crude oil, product carriers, chemical carriers, liquefied gas).
- Passenger ships.
- Tugs.

Container ships:

- Evolved as part of an integrated road, rail and sea transport system.
- Restrictions may be imposed by heights of bridges, widths of roads, etc.
- Required development of specialist ports and handling equipment.

- Greater security of cargo.
- More rapid turn round in port giving increased usage rates.
- Less manpower required.
- Containers can create special 'climates' for sensitive cargo – refrigerated, freezer and inert atmosphere.

Question 2. Discuss the various types of fast craft with their advantages and disadvantages. Indicate typical uses to which each type is put. How would you go about comparing the relative merits of several types?

Answer 2.

The answer, for types of craft, should include the following:

- **Catamarans.** Good stability, large deck space. Used in fast ferries and increasingly proposed for the high-speed carriage of goods.
- **Trimarans (and the pentamarans as a derivative).** Good stability, high speed on relatively low powers, large deck areas, good seakeeping. Proposed for frigates, aircraft carriers, high-speed transports.
- **Hydrofoil craft.** Reduced resistance at speed due to the hull being lifted clear of the water. Can contour waves by sensing waves and adjusting foils to ride over them. Used for many years in high-speed ferries, usually on medium length routes. Foils may be active (the foil lift is changed by changing the profile of the foil) or passive (the foils adjust their lift as the craft rides higher in the water).
- **High-speed monohulls which may be round bilge or hard chine.** The former preferred at moderate speed and for good seakeeping. The latter for good stability at higher speeds. Used for many recreational purposes and for service type boats.
- **Surface effect ships.** The weight is supported completely or partly on a cushion of air. Reduced power, through reduced wave-making at high speed. The true cushion craft is amphibious. Used for commercial ferries and in the military, for landing troops and material across a beach.
- **RIBS.** High speed, lightweight. Easily transported and used for a wide range of coastguard and military applications.

For comparing different types:

- Very difficult as each type has advantages in some situations and disadvantages in others.
- Simple comparisons using the same displacement, or the same length, say, can be very misleading.
- Best way is to produce an optimum design for each type against a specific mission profile.

- Select the type that meets the requirement most closely, or most economically.

Question 3. Discuss the various types of tug and their main design features.

Answer 3.

The answer should include:
Tugs can be classified according to:

- Where they are used (harbour, coastal, ocean going).
- The type of propulsion (conventional, stern drive, tractor).
- The use to which they are mainly put (harbour assistance, ocean tow, salvage, escort).

In slowing a ship, the main component of force the tug exerts is due to the lift generated by the flow of water round its hull. The tug's own propulsors are used to hold it at an angle of attack to the water flow.

The main attribute usually quoted for a tug is its bollard pull. That is, the pull it can exert at zero speed. Tug must also be efficient when running free and must be able to get close to the ship it is assisting.

Question 4. Discuss the types of passenger vessel now in use.

Answer 4.

The answer should include the following:

- **Small ferries.** Often these are high-speed craft of various types. May operate on canals or rivers or be capable of open water passage.
- **Ro–Ro ships taking passengers, cars and lorries.** These have access ramps at the bow and stern to facilitate loading and unloading. Stability must allow for the possibility of water getting on the vehicle deck.
- **Cruise ships.** These vary enormously in size. The largest can carry several thousand passengers. Good entertainment and other leisure facilities. High standards of accommodation.
- **Passenger ships** bring into play extensive requirements for safety of passengers and crews.

Question 5. Discuss a number of warship types. Give their main functions. Discuss in more detail the design and use of destroyers and frigates.

Answer 5.

The answer should include the following:
Main features of warships include:

- Weapons to attack an enemy and to defend oneself. Guns, missiles, mines, torpedoes.

- Sensors to detect an enemy and to control the weapons. Sonar for underwater, radar for above water.
- Decoys to seduce enemy weapons.
- Low signatures to make it difficult for the enemy to detect and for weapons to lock on to their target. That is, stealth through low acoustic, radar cross section, infrared, magnetic or pressure signatures.
- Good communications to exchange information and data with the rest of the task force.
- Ability to continue functioning after damage by the enemy.

The main types of warship include:

- Carriers
- Guided missile cruisers
- Destroyers and frigates
- Submarines
- Mine countermeasures craft
- Patrol craft.

Destroyers and frigates tend to be general purpose craft able to protect a task force, or a convoy, from submarine, aircraft or surface attack. To do this they:

- Must be high speed for manoeuvring and investigating contacts.
- Have a good set of sensors and weapons for dealing with each type of threat.
- Sacrifice protection for the other desired attributes.
- Have a good range but rely on replenishment at sea for longer operations.
- Often operate at some distance from the main elements of the task force to give early warning of attack and provide an early layer of defence. They are an integral part of the layered defence of the force.
- Need good seakeeping characteristics to enable them to keep up with heavier units in rough weather.

Question 6. What are the main features of submarines that distinguish them from surface ships?

Answer 6.

The answer should include the following:

- Ability to operate in three dimensions under water. They use ballast tanks for submerging and surfacing and hydroplanes in addition to rudders for manoeuvring.
- A propulsion system (nuclear or fuel cell) that can operate both above and under water. Or two systems are provided – typically diesels for the surface and electric motors when submerged.

- Stability must be studied for the surface and submerged conditions and in the transition from one to the other, which may be the critical case.
- A strong pressure hull to withstand the very high pressures at their operational depths. Usually the pressure hull is circular in cross section with domed ends.
- Weapons capable of being fired when submerged.
- Need for a comprehensive air treatment system to keep the internal atmosphere pure and free from odours.
- Systems to enable the crew to escape, or be rescued, when the submarine is lying disabled on the seabed.