Ship Stability at the Operational Level

Edition 3

Capt. Harry Subramaniam

Ship Stability at the operational level

NUTSHELL SERIES
BOOK 4

BY

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DEDICATION

Mrs Vijaya Harry
11th April '26 - 11th Jan '09
Founder, Vijaya Publications

Dedicated to my mother, without whose patient and constant encouragement, this book would not have been possible.

About the Author
Capt H SUBRAMANIAM

Born in Sept. 1942, Harry Subramaniam was educated in the Lawrence School, Lovedale, one of the best schools in India. He passed out of the Training Ship Dufferin in 1960 winning several prizes. He has about ten years of sea experience including Command of merchant ships. He has over fifty years of teaching experience at maritime training institutions and has thus been associated with all the four great nautical training institutions in Indian history - he was a cadet on T.S. Dufferin, the last Captain Superintendent of T.S. Rajendra, the first Captain Superintendent of T.S. Chanakya and Principal of L.B.S. College. He retired from Govt service in September 2002 after 34 glorious years including 12 years as head of maritime training institutions.

He then sailed in command again for six months to satisfy himself that he was also a practising Master, not merely a teaching Master! He has over three years of experience in making blended learning programmes with Executive Shipmanagement Co Singapore and ADU Academy in India. He is now a nautical training consultant in Mumbai.

His achievements/distinctions include:

• Extra Master Certificate (UK).

• External Examiner of Masters & Mates for over forty years.

• The Chief Examiner of Extra Masters of India.

• Leader of the Indian delegation to the IMO on two occasions.

• Nautical Assessor in a formal investigation into a major ship collision.

• ‘Man of the year Award’ in 2001 by Sailor Today magazine for his ‘Conception and implementation of INDoS (Indian National database of Seafarers)’.

• ‘Lifetime Achievement Award’ in 2002 by Marine World magazine.

• ‘Literary Distinction Award’ by Marex Bulletin in 2006.

• ‘Lifetime contribution to Maritime Training Award’ by GlobalMet in 2007.

• ‘Individual Innovation Award 2007’ by Sailor Today Magazine for the manner in which he conducted India’s first Maritime Quiz for Seafarers.

• ‘Outstanding Contribution to Maritime Education & Training Award’ by the Govt. of India on National Maritime Day 2013.

• Chairman of the Nautical Institute, India (West) Branch.

• Master (Chairman) of the Company of Master Mariners of India. His qualifications, experience and devotion to teaching enable him to put each subject in a 'Nutshell'. All his eight books in the Nutshell Series have been great successes.

FOREWORD

Capt. R.D. Kohli 13th September 1981
Extra Master,
Executive Director, Shipping Corporation of India Ltd.,
Chairman of the Council, The institute of Marine Technologists,
Master of the Company of Master Mariners of India,
President, Dufferin Rajendra Ex Cadets Association,
Vice Chairman, Narottom Morarjee Institute of Shipping.

I have known Capt. Subramaniam for over ten years – a young enthusiastic mercantile marine officer with a dynamic personality, always giving the impression that he wants to accomplish more.

When he suddenly appeared at my office, I was surprised – a professor wanting to see me! After presenting me with a copy of his latest book ‘Shipborne Radar’ he said ‘Sir, would you please write the foreword to my book on stability?’ I was taken aback by this unusual request, more so when he went on to say that he had particularly decided, five years ago, to request me to write the foreword to his book on stability, even before he wrote the books on Navigation, Meteorology, and Radar.

This set me thinking about my first voyage. I was a cadet fresh out of the training ship ‘Dufferin’ and the passage, trans-Atlantic in winter. The ship rolled very heavily, often as much as 35°, creaking and moaning. Crashing sounds were frequently heard as various objects in the cabins broke loose, answering the call of gravity along the highly inclined plane. I thoroughly enjoyed myself in blissful ignorance of terms in stability such as stiff and tender ships, free surface effect, angle of vanishing stability and progressive flooding. I shudder to think what I would feel, if I was in the same circumstances today, realising the implications of such a situation.

Capt. Subramaniam has attempted, and I would say succeeded, in combining the theory and practical application of stability. The book closely follows the best approach. Starting from the very basics, or ‘beginning at the very beginning’, the book brings the student steadily up to the required level in such a manner that he can study it by himself, whilst out at sea, hardly needing any other assistance.

I have specifically avoided indulging in paraphrasing about the biography of the author. He has by now become well established by his "Nutshell Series".

I understand that Capt. Subramaniam plans to include the more complex topics on this subject in his next books 'Ship Stability II' & 'Ship Stability III' in the near future. I wish him all success.

(R.D. Kohli)

PREFACE TO THIS E - BOOK

This is the third edition of this book. Some minor cosmetic improvements have been made throughout to the second edition to make it suitable for this E-Book. Answers are now given under each question instead of the end of the book.

May 2019

PREFACE TO THE RENAMED 2nd EDITION

In this book, now renamed 'Ship Stability at the Operational Level', formerly called 'Ship Stability I', ten chapters have been added, by transferring them down from "Ship Stability II", to cover the syllabuses for:

1) Navigational Watchkeeping Officer.

2) The BSc (Nautical Science) degree courses of the University of Mumbai;

3) The BSc (Nautical Science) degree courses of the Indian Maritime University;

4) The BSc (Nautical Technology) degree courses of the University of Mumbai;

5) The one-year Diploma in Nautical Science (DNS) course of the Indian Maritime University.

I was pleasantly surprised when many Marine Engineers said that they found the Stability books in the Nutshell Series very useful.

Bombay 13th Sep 2011 (H. SUBRAMANIAM)

Contents

1. DENSITY & RELATIVE DENSITY

Density of a substance is its mass per unit volume.

Density = Mass / Volume

where mass is in tonnes (t), volume is in cubic metres (m^3) and density is in tonnes per cubic metre (tm^{-3}).

Though mass may be expressed in kilograms (kg) & density in kilograms per cubic metre (kgm^{-3}), the use of tonnes is more convenient in stability. The density of fresh water is 1 tm^{-3}.

Relative density of a substance is the number of times the substance is heavier than fresh water. Being a ratio, RD has no units.

$$RD = \frac{\text{Mass of any volume of substance}}{\text{Mass of an equal volume of FW}}$$

Considering a volume of $1m^3$,

$$\text{RD of substance} = \frac{\text{Density of substance}}{\text{Density of fresh water}}$$

Since the density of fresh water is 1 tm^{-3}, RD of a substance is numerically equal to its density, if density is expressed in tm^{-3}.

Some typical values are given below:

	Density	RD
Fresh water	1.000 tm^{-3}	1.000
Salt water	1.025 tm^{-3}	1.025
Fuel oil	0.950 tm^{-3}	0.950
Diesel oil	0.880 tm^{-3}	0.880
Dock water	1.015 tm^{-3}	1.015

Example 1

A tank has a volume of 400 m^3. Find how many tonnes of SW (density 1.025 tm^{-3}) it can hold.

Mass of SW= Volume x density = 400 x 1.025 = 410 t

Answer: The tank can hold 410 t of SW.

Example 2

A tank can hold 320 tonnes of SW. Find how many tonnes of oil of RD 0.8 it can hold.

Mass of SW = Volume of SW x density of SW

320 = V x 1.025

V = 320 / 1.025

Volume of tank = 320 / 1.025 m^3

Mass of oil = Volume of oil x density of oil

= (320 / 1.025) x 0.8 = 249.8 t

Answer: The tank can hold 249.8 tonnes of oil.

Example 3

A cylindrical tank is 10 metres high and has a radius of 3 metres. If it is filled to an ullage of 2 metres, with oil of RD 0.7, find the mass of oil.

Mass of oil = Volume of oil x density of oil

= ((22 / 7)x 3 x 3 x 8) 0.7 = 158.4 t **Answer**

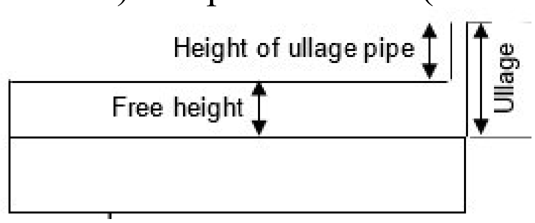
Example 4

A rectangular tank measuring 20 m x 10 m x 10 m has an ullage pipe extending to 0.5 m above the tank top. If the tank is 98% full of FW, find the mass of FW and state the ullage.

Volume of FW = (98 / 100) (20 x 10 x 10) m^3

Mass of FW = Volume of FW x density of FW = (98 / 100) (20 x 10 x 10) x 1 = 1960 t.

Depth of FW= (98 / 100) x depth of tank = (98 / 100) x 10 = 9.8 m



Free height inside tank = 10 - 9.8 = 0.2 m

Height of ullage pipe above tank top = <u>0.5</u> m

Ullage = 0.7 m

Answer: Mass of FW 1960 tonnes, ullage 0.7 metres.

Example 5

A rectangular tank is 20 m x 20 m x 12 m. Find how many tonnes of oil of RD 0.8 it can hold, if 2% of the volume <u>of the tank</u> is to be left for expansion. State also, the ullage on loading.

Volume of tank = 20 x 20 x 12 = 4800 m^3

Volume of tank = Volume of oil + Free space

4800 = V + (2% of 4800) = V + 96

V = 4704 m^3

Mass of oil = Volume of oil x density of oil

= 4704 x 0.8 = 3763.2 t

Depth of oil = 98% depth of tank

= 98% of 12 = 11.76m

Ullage = 12 - 11.76 = 0.24 m

Answer: Mass of oil = 3763.2 t, ullage = 0.24 m.

Example 6

In worked example 5, if it was required to leave 2% of the volume <u>of oil loaded</u> for expansion, find the mass of oil and the ullage on loading.

Volume of tank = Volume of oil + Free space

4800 = V + (2% of V) = 1.02 V

V = 4705.88 m^3

Mass of oil = Volume of oil x density of oil

= 4705.88 x 0.8 = 3764.7 t

Depth of oil = Volume of oil / Tank surface area

= (4705.88 / (20 x 20)) = 11.765 m

Ullage = tank depth - oil depth

= 12 - 11.765 = 0.235 m

Answer: Mass of oil 3764.7 t, ullage 0.235 m.

Exercise 1

Density and relative density

1. A rectangular tank measures 16 m x I5 m x 6 m. How many tonnes of oil of RD 0.78 can it hold?

(Answer: 1123.2 t).

2. A cylindrical tank of diameter 8 m is 10 m high. 400 t of oil of RD 0.9 is poured into it. Find the ullage, assuming π to be 3.1416.

(Answer: 1.158 m).

3. A tank of 2400 m^3 volume and 12 m depth, has vertical sides and horizontal bottom. Find how many tonnes of oil of RD 0.7 it can hold, allowing 2% of the volume of the tank for expansion. State the ullage on loading.

(Answer: 1646.4 t; 0.24 m).

4. A tank 10 m deep has vertical sides. Its bottom consists of a triangle 12 m x 12 m x 10 m. Find the mass of oil (of RD 0.8) to be loaded, allowing 3% of the volume of oil loaded for expansion. State the ullage on completion of loading.

(Answer: 423.6 t; 0.291 m).

5. A rectangular tank measuring 25 m x 12 m x 8 m has an ullage pipe projecting 0.3 m above the tank top. Find the SW mass in the tank if ullage is 3.3 m.

(Answer: 1537.5 t).

6. A rectangular tank measures 30 m x 16 m x 14 m. It has an ullage pipe projecting 0.5 m above its top. Oil of RD 0.78 is to be loaded. The pipeline leading from the refinery to the ship is 10 km long and 40 cm in diameter. At the time of completion, all the oil in the pipeline must be taken. Find at what ullage the valve at the refinery end must be shut so that the final ullage in the ship's tank would be 0.78 m. State also, the mass of oil loaded finally. (Assume π to be 3.1416).

(Answer: 3.398 m; 5136.8 t).

7. A tank with a horizontal base and vertical sides is 10 m deep and has a rectangular trunkway 1 m high. The volume of the tank alone is 8000 m^3 and that of the trunkway 500 m^3. Find the ullage when 5320 t of vegetable oil of RD 0.7 is loaded.

(Answer: 1.5 m).

8. A rectangular tank has a total depth of 21 m and a volume of 20600 m^3, which includes a trunkway of depth 1 m and volume 600 m^3. Find the ullage when 16320 t of oil of RD 0.8 is loaded.

(Answer: 0.333 m).

9. A rectangular tank has a total depth of 10.5 m and volume 8200 m^3, which includes a trunkway of depth 0.5 m and volume 200 m^3. Find the mass of oil of RD 0.8 loaded and the ullage, if 2% of the volume of the tank is left for expansion.

(Answer: 6428.8 t; 0.41 m).

10. A rectangular tank has a total depth of 21 m and volume 10250 m^3 that includes a trunkway of depth 1 m and volume 250 m^3. Oil of RD 0.9 is to be loaded leaving 3%, of the volume of oil loaded, for expansion. Find the mass of oil to be loaded and the final ullage.

(Answer: 8956.3 t; 1.097 m).

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2. WATER PRESsURE

Pressure is the load per unit area.

At any point in a liquid, pressure acts in all directions and is expressed in tonnes per square metre (tm^{-2}). It may, if desired, be expressed in kilo-Newtons per square metre ($kN\ m^{-2}$) where 1 tonne per square metre = 9.81 kilo-Newtons per square metre OR in bars, where 1 bar = 10.2 tonnes per square metre.

At any point in a liquid,

Pressure = depth x density

$tm^{-2} = m \times tm^{-3}$

Thrust is the total pressure exerted on a given surface. Thrust is expressed in tonnes (t) but may, if desired, be expressed in kilo-Newtons (kN) where 1 tonne = 9.81 kN.

Thrust = pressure x area

$t = tm^{-2} \times m^2$

Example 1

Find the thrust on a keel plate 10 m x 2 m when the draft of the ship is 5 m in salt water.

Pressure = depth x density = 5 x 1.025 = 5.125 tm^{-2}

Thrust = pressure x area = 5.125 x 10 x 2 = 102.5 t

Answer: Thrust on keel plate = 102.5 tonnes.

Example 2

A tank has a rectangular bulkhead 20 m wide and 10 m high. Find the thrust experienced by the bulkhead when the tank is full of oil of RD 0.9.

Note: For calculating the thrust on a vertical surface, the pressure is taken at the geometric centre of the immersed part of the surface and multiplied by the immersed area.

Pressure = depth x density = 5 x 0.9 = 4.5 tm^{-2}

Thrust = pressure x area = 4.5 x 20 x 10 = 900 t

Answer: Thrust on bulkhead = 900 tonnes.

Example 3

A lock gate is 30 m wide and 10 m high. The water inside the lock is 7 m deep and of RD 1.005 and that outside is 5 m deep and of RD 1.025. Find the resultant thrust and the direction in which it acts.

Considering the water inside,

Pressure = depth x density

=(7/ 2) x 1.005 = 3.5175 tm^{-2}

Thrust = pressure x area

= 3.5175 x 30 x 7 = 738.675 t

Considering the water outside

Pressure = depth x density

=(5/ 2) x 1.025 = 2.5625 tm^{-2}

Thrust = pressure x area

= 2.5625 x 30 x 5 = 384.375 t

Thrust outwards = 738.675 t _

Thrust inwards = 384.375 t

Answer: Resultant thrust = 354.3 t outwards.

Example 4

A deep tank 10 m wide and10 m deep has a rectangular manhole (1.2 m x 0.6 m) at its forward end. The longer sides of the manhole are horizontal and its lower edge is 0.7 m from the bottom of the tank. Find the total pressure experienced by the manhole cover when the tank is full of oil of RD 0.8 to an ullage of I m.

Depth of tank	=	10 m
Ullage	=	1 m
Depth of oil	=	9 m
Height of C	=	1 m
Depth of C	=	8 m

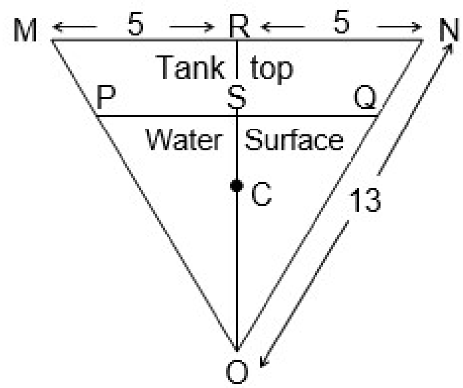
Pressure at C = depth x density = 8 x 0.8 = 6.4 tm^{-2}

Thrust = pressure x area = 6.4 x 1.2 x 0.6 = 4.608 t

Answer: Total pressure on manhole = 4.608 tonnes.

Example 5

A collision bulkhead is in the form of a triangle 10 m x 13 m x 13 m. Find the thrust experienced by it when saltwater is run into the forepeak tank to 9 m sounding.



In triangle ORN,

$OR^2 = ON^2 - RN^2 = 13^2 - 5^2 = 144$

OR = 12 m = Depth of the tank

Triangles OSQ and ORN are similar.

(SQ / RN) = (OS / OR) or SQ = (5 x 9) / 12 = 3.75 m

Area of triangle OPQ = ½ (PQ . OS) = SQ . OS

$= 3.75 \times 9 = 33.75\ m^2$

Area of immersed part of bulkhead = $33.75\ m^2$

Depth of C below water line = (1 x 9) / 3= 3 m

Pressure at C = depth x density

$= 3 \times 1.025 = 3.075\ tm^{-2}$

Thrust = pressure x area = 3.075 x 33.75 = 103.781 t

Answer: Thrust on bulkhead = 103.781 tonnes.

Example 6

A double bottom tank measures 20 m x 20 m x 1 m. Its air pipe extends 12 m above its top. Find the thrust on the tank top when it is pressed up with salt water.

Pressure at tank top = depth x density

$= 12 \times 1.025 = 12.3\ tm^{-2}$

Thrust on tank top = pressure x area

= 12.3 x 20 x 20 = 4920 t

Answer: Thrust on tank top = 4920 tonnes.

Exercise 2

Water pressure 2m

1. Find the thrust experienced by a flat keel plate10 m x m when the draft is 8 m in SW.

(Answer: 164 t).

2. A box-shaped vessel 150 m x 20 m x 12 m is afloat in DW of RD 1.010 at an even keel draft of 10 m. Find the total water pressure exerted on the hull.

(Answer: 47470 t - two sides 15150 t; two ends 2020 t; keel 30300 t).

3. A submarine has a surface area of 650 m^2 and can withstand a total water pressure of 1332500 t. Find at what approximate SW depth she would collapse.

(Answer: 2000 m).

4. A rectangular lock gate 40 m wide and 20 m high has water of RD 1.010 12 m deep on one side and later of RD 1.020 11 m deep on the other. Find the resultant thrust experienced and the direction in which it acts.

(Answer: 440.4 t towards the shallower side).

5. A rectangular lock gate 36 m wide and 20 m high has FW on one side to a depth of 16 m. Find what depth of SW on the other side will equalise the thrust.

(Answer: 15.804 m).

6. A collision bulkhead is triangular. Its maximum breadth is 12 m and its height 15 m. Find the thrust experienced by it if the forepeak tank is pressed up to a head of 3 m of SW.

(Answer: 738 t).

7. A collision bulkhead is triangular shaped, having a breadth of 14 m at the tank top and a height of 12 m. As a result of a collision, the forepeak tank gets ruptured and SW enters the tank to a sounding of 9 m. Calculate the thrust on the bulkhead.

(Answer: 145.3 t).

8. A tank has a triangular bulkhead, apex upwards. Its base is 14 m and its sides, 15 m each. It has a circular inspection hole of radius 0.5 m. The centre of the manhole is 0.8 m above the base and 1.6 from one corner. Find the thrust on the manhole cover when the tank contains oil of RD 0.95 to a sounding of 10 m. (Assume π to be 3.1416).

(Answer: 6.864 t).

9. A rectangular deep tank is 22 m x 20 m x 10 m. Above the crown of the tank is a rectangular trunkway 0.2 m high, 5 m long and 4 m wide. Find the thrust on the tank lid when the tank is pressed up with

SW to a head of 2.64 m above the crown of the tank.

(Answer: 50.02 t).

10. A double bottom tank measures 25 m x 20 m x 2 m. Find the thrust on the tank top when pressed up to a head of 16 m of SW. Also find the resultant thrust on the tank bottom, and the direction that it acts, if the ship's draft in SW is 10 m.

(Answer: 8200 t outwards).

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3. FLOTATION

Archimedes' Principle states that when a body is wholly or partially immersed in a fluid, it suffers an apparent loss of weight that is equal to the weight of fluid displaced.

Since the word fluid includes both, liquids and gases, and the fact that merchant ships are only expected to be partially immersed in water, a modified version of Archimedes' Principle may be called the Principle of flotation.

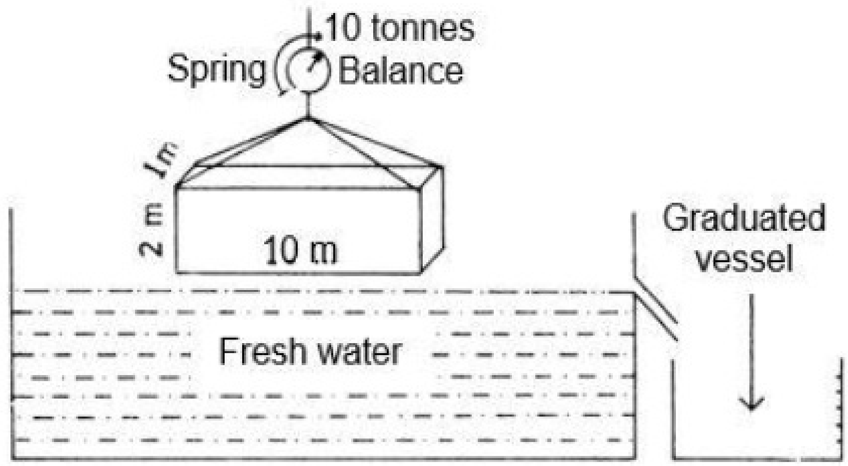
Principle of flotation: When a body is floating in a liquid, the weight of liquid displaced equals to the weight of the body.

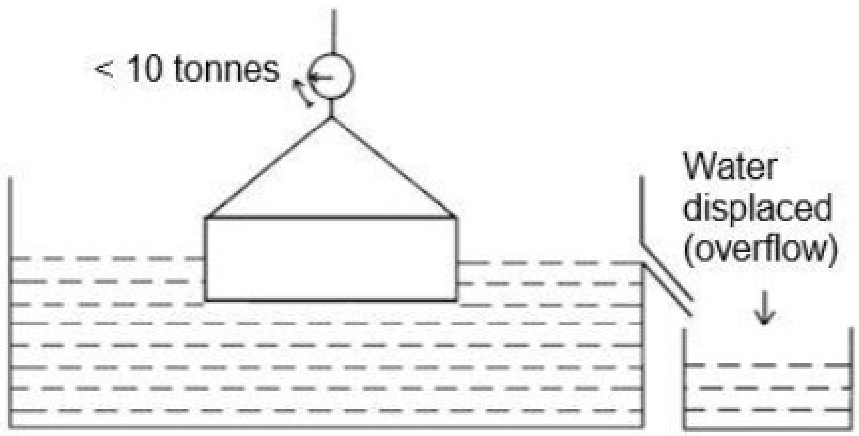
Experimental explanation

Consider a rectangular watertight box 10 m x 1 m x 2 m, weighing 10 t. If this was lifted by a crane and gradually lowered into a pool full of FW, the volume of water displaced can be collected and measured.

It will be noticed that as the box is lowered more and more into the water, the load registered by the spring balance becomes less and less. Consider the case when the draft becomes 0.1 m. The underwater volume of the box is then 1.0 m^3 i.e. the volume of water displaced (overflow) is 1.0 m^3. The weight of water displaced, or *displacement*, is 1 t. So, the apparent loss of weight, or *buoyancy*, experienced by the box is 1 t.

The spring balance now shows a reading of only 9 t whereas it showed 10 t before the box reached the water surface. Similarly, when the draft becomes 0.2 m, the displacement (or buoyancy) is 2 t and the load registered by the spring balance is 8 t.





The following would be the results, in a tabular form:

Draft in m	Volume of Displacement in m^3	Displacement or buoyancy in tonnes	Load in tonnes registered by spring balance
0.0	0.0	0.0	10
0.05	0.5	0.5	9.5
0.1	1	1	9
0.2	2	2	8
0.4	4	4	6
0.6	6	6	4
0.8	8	8	2
1.0	10	10	0

At a draft of 1.0 m, it is noted that the spring balance registers zero indicating that the buoyancy equals to the weight so that the body is now floating freely.

From the foregoing it is clear that:

(i) The volume of water displaced is the underwater volume of the ship.

(ii) Buoyancy or displacement is the upward thrust experienced by the ship. When the ship is floating freely, its displacement (or buoyancy) equals to its weight. The weight of the ship is therefore referred to as displacement (W).

W = Vol of water displaced x density of water displaced

OR

W = Underwater vol of ship x density of water displaced

While doing stability calculations, density should preferably be in tm^{-3}, volume in m^3 & displacement in t.

Example 1

A homogeneous rectangular log 6 m x 1 m x 0.8 m floats in SW at a draft of 0.5 m, with its largest face parallel to the water. Find its mass.

W = u/w volume x density of water displaced

W = 6 x 1 x 0.5 x 1.025 = 3.075 t

Since the log is floating freely, its displacement and mass are equal.

Answer: Mass of log = 3.075 tonnes.

Example 2

A homogeneous rectangular log 6 m x 1.5 m x 1 m has RD 0.7. Find its draft in FW. (Assume that the log will float with its largest face parallel to the water).

Mass of log = Volume x density

= 6 x 1.5 x 1 x 0.7

= 6.3 t

When floating freely, mass= displacement.

W = u/w volume x density of water displaced

6.3 = 6 x 1.5 x d x 1

d = 0.7 m

Answer: Draft in FW = 0.7 metres.

Example 3

A homogeneous log of 0.5 m square section has RD 0.8. Find its draft in water of RD 1.02, assuming that it will float with one face horizontal.

Let the length of the log be L metres.

Mass of log = Volume x density

= L x 0.5 x 0.5 x 0.8 tonnes

W = u/w volume x density of water displaced

W = L x B x d x 1.02

= L x 0.5 x d x 1.02 tonnes

When floating freely, displacement = mass

L x 0.5 x d x 1.02 = L x 0.5 x 0.5 x 0.8

d = (0.5 x 0.8) / 1.02 = 0.392 m

Answer: Draft of log = 0.392 metres.

Example 4

A hollow, plastic cylinder of 1 m diameter and 10 m length floats in FW at a draft of 0.2 m, with its axis horizontal. Find its mass.

OA = OB = OC = 0.5 m radius

CD = 0.2 m draft

OD= OC - CD = 0.3 m

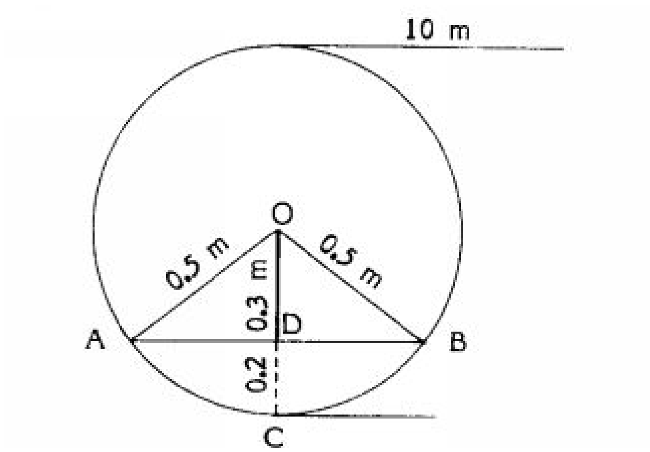
In triangle ODB,

$DB^2 = OB^2 – OD^2 = 0.5^2 – 0.3^2 = 0.16$

DB = 0.4 m

Sin BOD = 0.4 x 2 = 0.8

Angle BOD = 53.13° & angle AOB = 106.26°



Area of segment AOBC / Area of circle = AOB / 360°

Area of segment AOBC = (πr^2 x AOB) / 360°

= (3.1416 x 0.5^2 x 106.26) / 360

= 0.232 m^2

Area of triangle AOB = ½ (0.8 X 0.3) = 0.120 m^2

Area of segment ABC = 0.232 – 0.120 =0.112 m^2

Underwater volume = 0.112 x 10 = 1.12 m^3

W = u/w volume x density of water displaced

W = 1.12 x 1 = 1.12 t

Answer: Mass of cylinder = 1.12 tonnes.

Example 5

A cylindrical drum of radius 40 cm & height 2 m weighs 200 kg. Lead pellets are put in it until it floats with its axis vertical, at a draft of 1.4 m in SW. Find the mass of lead pellets in it, in kilogrammes.

W = u/v volume x density of water displaced

W= $\pi r^2 d$ x 1.025 = 3.1416 x .4 x .4 x 1.4 x 1.025

W = 0.7213 t

Total mass of drum and lead = 0.7213 t

Mass of drum = 0.2000 t

Mass of lead = 0.5213 t

Answer: Mass of lead pellets = 521.3 kg.

Example 6

A rectangular lidless box 6 m x 2 m x 1.5 m floats in water of RD 1.005 at a draft of 0.6 m. Find the maximum mass of iron that can be sinking it, when it is floating in SW.

W = u/w volume x density of water displaced

Maximum W = 6 x 2 x 1.5 x 1.025 = 18.450 t

Present W = 6 x 2 x 0.5 x 1.005 = 7.236 t

Difference of displacement = 11.214 t

Answer: In SW, it can hold 11.214 tonnes of iron.

Example 7

A rectangular barge 10 m x 5 m x 4 m, floating in SW at a draft of 2 m, is being lifted out of the water by a heavy-lift crane. Find the load taken by the crane when the draft becomes 1.2 m.

W = u/w volume x density of water displaced.

W at 2.0 m draft = 10 x 5 x 2.0 x 1.025 = 102.5 t

W at 1.2 m draft = 10 x 5 x 1.2 x 1.025 = 61.5 t

Load taken by crane = difference = 41.0 t

Exercise 3
Flotation

1. A rectangular log of wood 8 m long, 2 m wide and 2 m high floats in FW at a draft of 1.6 m with one face horizontal. Find its mass and RD.

(Answer: 25.6 t; 0.8).

2. A rectangular log of wood 5 m x 1.6 m x 1.0 m weighs 6 t and floats with its larger face horizontal. Find its draft in SW and its RD.

(Answer: 0.732 m; 0.75).

3. A rectangular log 3 m broad and 2 m high floats with its breadth horizontal. If the density of the log is 0.7 tm^{-3}, find its draft in water of RD 1.01.

(Answer: 1.386 m).

4. A cylinder 2 m in diameter and 10 m long floats in FW, with its axis horizontal, at a draft of 0.6 m. Find its mass.

(Answer: 7.92 t).

5. A barge of triangular cross section is 20 m long, 12 m wide and 6 m deep. It floats in SW at a draft of 4 m. Find its displacement.

(Answer: 328 t).

6. A cylindrical drum of 1.2 m diameter and 2 m height floats with its axis vertical in water of RD 1.016 at a draft of 1.4 m. Find the maximum mass of lead shots that can be put in it without sinking it.

(Answer: 0.689 t).

7. A rectangular barge 10 m long and 5 m wide, floating in SW at a draft of 3 m, is being lifted out of the water by a heavy-lift crane. Find the load on the crane when the draft has reduced to 1 m.

(Answer: 102.5 t).

8. A rectangular box 2.4 m long, 1.2 m wide and 0.8 m high, floats in water of RD 1.012 at an even keel draft of 0.2 m. Find the maximum mass of SW that can be poured into it without sinking it.

(Answer: 1.749 t).

9. A box-shaped vessel of 18450 t displacement is 150 m long and 20 m wide. Find its draft in SW.

(Answer: 6 m).

10. A box-shaped vessel 120 m long and 15 m wide is floating in DW of RD 1.005 at a draft of 5 m. If her maximum permissible draft in SW is 6 m, find how much cargo she can now load.

(Answer: 2025 t).

4. SOME IMPORTANT TERMS

Displacement is commonly used to denote the mass of a ship in tonnes. Technically, it is the mass of water displaced by a ship and, when floating freely, the mass of water displaced equals to the mass of the ship, as explained in Chapter 3.

Light displacement is the mass of the empty ship without any cargo, fuel, lubricating oil, ballast water, fresh and feed water in tanks, consumable stores, or passengers and crew and their effects.

Load displacement is the total mass of the ship when she is floating in salt water with her summer loadline at the water surface.

Present displacement is the mass of the ship at present. It is the sum of the light displacement of the ship and everything on board at present.

Deadweight (DWT) of a ship is the total mass of cargo, fuel, freshwater, etc., that a ship can carry, when she is floating in salt water with her summer loadline at the water surface.

DWT of ship = load displacement - light displacement

Deadweight aboard is the total mass of cargo, fuel, ballast, fresh water, etc, on board at present.

DWT aboard = present displacement - light displacement

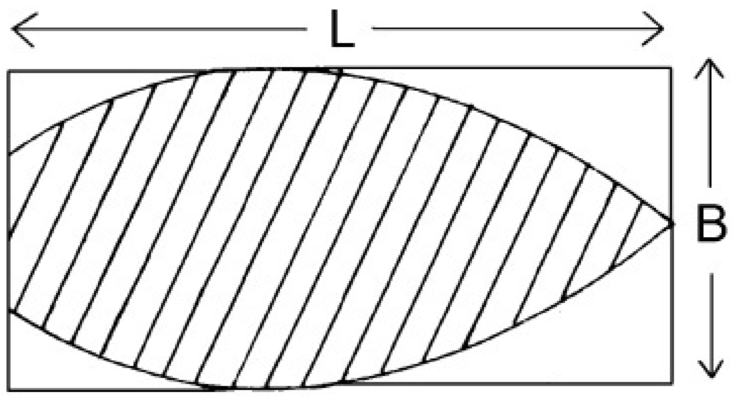
Deadweight available is the total mass of cargo, fuel, fresh water, etc., that can be put on the ship at present to bring her summer loadline to the water surface in salt water.

DWT available = load displ - present displ.

Waterplane coefficient (Cw), or coefficient of fineness of the water-plane area, is the ratio of the area of the water-plane to the area of a rectangle having the same length and maximum breadth.

$$C_W = \text{Area of water-plane} / (L \times B)$$

$$\text{Area of water-plane} = L \times B \times Cw$$

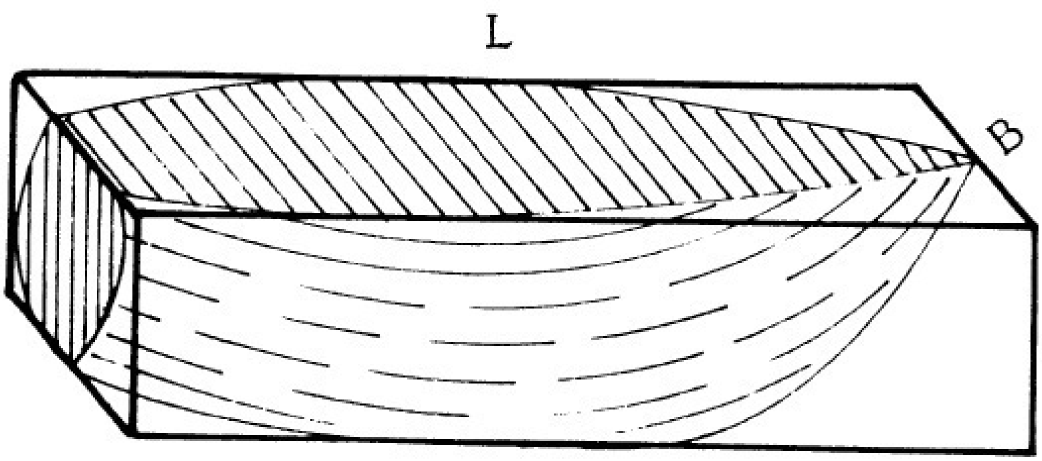


Block coefficient (C_b), or coefficient of fineness of displacement, at any draft is the ratio of the underwater volume of the ship at that draft to a rectangular box having the same extreme dimensions.

$$C_b = \text{Underwater volume} / (L \times B \times d)$$
$$\text{Underwater volume} = L \times B \times d \times C_b$$

The term block coefficient may also be used with respect to a tank in which case it would be the ratio of the volume of the tank to the volume of a rectangular box having the same extreme dimensions as the tank.

$$C_b \text{ of tank} = \text{Volume of tank} / (L \times B \times D)$$
$$\text{Volume of tank} = L \times B \times D \times C_b$$



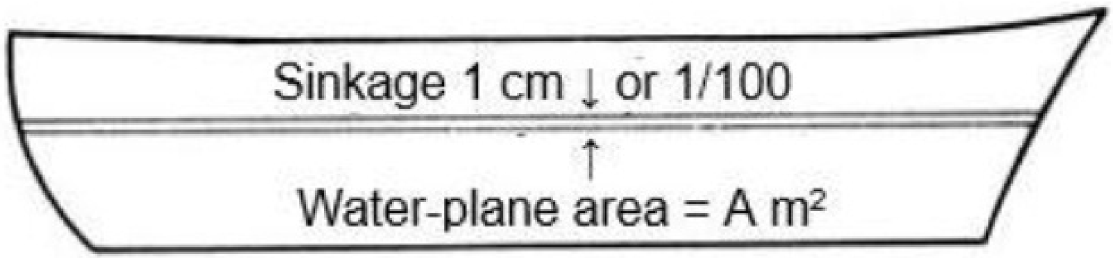
Reserve buoyancy (RB) is the volume of the enclosed spaces above the waterline. It maybe expressed as a volume in m^3 or as a percentage of the total volume of the ship.

RB = Total volume - underwater volume

RB % = (Above water vol / Total vol) x 100

Reserve buoyancy is so called because, though it is not displacing any water at that time, it is available for displacement if weights are added or if bilging takes place. Bilging is the accidental entry of water into a compartment, due to underwater damage, and is discussed in 'Ship Stability at the Management Level'.

Tonnes per centimetre (TPC) is the number of tonnes required to cause the ship to sink or rise by one centimetre. In SI units TPC is indicated as tcm^{-1}.



Considering 1 cm sinkage

Increase in underwater volume =A (1/ 100) m^3

Increase in W = (A / 100) x density of water displaced

Or TPC = (A / 100) x density of water displaced

TPC in SW = (A / 100) x 1.025

TPC in FW = (A / 100) x 1.000 = (A / 100)

TPC in DW RD 1.017 = (A /100) x 1.017 = 1.017A / 100

In the foregoing formulae, the area of the water-plane of a ship-shape has been considered constant since the sinkage or rise being considered is only 1 cm. However, the area of the water-plane of a ship-shape usually increases as draft increases. Hence, its TPC also increases as draft increases. In view of this, calculations involving TPC should generally be confined to small values of sinkage or rise, say less than about 20 cm, in the case of ship-shapes. Other-wise, the accuracy of the calculation will tend to suffer.

In the case of a box-shaped vessel, the area of the water-plane is the same at all drafts and hence its TPC does not change with draft.

Example 1

A box-shaped vessel is 120 m long and 16 m wide and has a load draft of 8 m. If the present draft is 6 m, find the DWT available.

W = u/w volume x density of water displaced

Load W	= 120 x 16 x 8 x 1.025 =	15744 t
Present W	= 120 x 16 x 6 x 1,025 =	11808 t
DWT available	= difference =	3936 t

Example 2

The length and breadth of the water-plane of a ship are 100 m and 12 m. If the coefficient of fineness of the water-plane is 0.7, find the TPC in SW and in FW.

Water-plane area = L x B x C_W

= 100 x 12 x 0.7 = 840 m^2

TPC = (A/100) x density of water

In SW, TPC = (840/100) x 1.025

= 8.610 t cm^{-1} **Answer**

In FW, TPC = (840/100) x 1

= 8.400 t cm^{-1} **Answer**

Example 3

A ship floating in DW of RD 1.010 at a draft of 5 m, is 90 m long and 10 m wide at the water-line. If the block coefficient is 0.72 and the light displacement is 1200 t, find the DWT aboard.

W = u/w volume x density of water displaced

W = u/w volume x density of water displaced

Present W	= 90 x 10 x 5 x 0.72 x 1.010
	= 3272.4 t
Light W	= 1200.0 t
DWT aboard	= 2072.4 t **Answer**

Example 4

A box-shaped vessel is 120 m long, 14 m wide and 12 m high. If the displacement is 13776 t, find the reserve buoyancy % in SW.

W = u/w volume x density of water displaced

13776 = V x 1.025 OR V = 13776/1.025 = 13440 m^3

Total volume = 120 x 14 x 12 = 20160 m^3

RB = Total vol – U/W vol = 20160 – 13440 = 6720 m^3

RB % = (RB / Total vol) x 100

=(6720 / 20160) x 100 = 33.333 %

Example 5

A ship is floating in FW at a draft of 6.8 m. If the maximum FW draft is 7.0 m, and the SW TPC is 40, find the DWT available.

SW TPC = (A / 100) x 1.025

OR A = (40 x 100) / 1.025 = 39.024 m^2

FW TPC = (A / 100) = (3902.4 / 100)

= 39.024 t cm^{-1}

Sinkage required = 7.0 – 6.8 = 0.2 m = 20 cm.

Cargo to load = Sinkage x TPC = 780.48 t **Answer**

Exercise 4

Displacement, DWT, RB, TPC, etc.

1. A box-shaped vessel 120 m long and 15 m wide has light draft of 4 m & load draft of 9.8 m in SW. Find: light displacement, Ioad displacement & DWT. (Answer: 7380 t; 18081 t; 10701 t).

2. A box-shaped vessel 100 m long and 14 m wide is floating in SW at a draft of 7.6 m. The light draft is 3.6 m and load draft 8.5 m. Find the present displacement, DWT aboard and DWT available. (Answer: 10906 t; 5740 t; 1291.5 t).

3. A ship is 200 m long and 20 m wide at the waterline. If the coefficient of fineness of the water-plane is 0.8, find the TPC in SW, in FW & DW of RD 1.015. (Answer: 32.8 tcm^{-1}; 32.0 tcm^{-1}; 32.48 tcm^{-1}).

4. A double bottom tank 20 m x 10.5 m x 1.0 m has a block coefficient of 0.82. Calculate how much fuel oil of RD 0.95 it can hold. (Answer: 163.59 t).

5. A ship floating in SW at a draft of 8 m is 110 m long and 14 wide at the waterline. If the block coefficient is 0.72, find the displacement. If the load displacement is 12000 t, find the DWT available. (Answer: 9092.16 t; 2907.84 t).

6. A ship displacing 14000 t is 160 m long and 20 m wide at the waterline. If it is floating in SW at 6.1 m draft, find its block coefficient. (Answer: 0.7).

7. A box-shaped vessel 18 m x 5 m x 2 m floats in SW at 1.4 m draft. Calculate the RB%. (Answer: 30%).

8. A box-shaped vessel displacing 2000 t is 50 m x 10 m x 7 m. Find the RB% in FW. (Answer: 42.857%).

9. A ship's SW TPC is 30. Find its TPC in FW & in DW of RD 1.018. (Answer: 29.268 tcm-1; 29.795 tcm-1).

10. A ship is afloat at 8.2 m draft in DW of RD 1.010. If the TPC in SW is 40, find how much cargo can be loaded to bring the draft in the same DW to 8.4 m. (Answer: 788.3 t).

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5. EFFECT OF DENSITY ON DRAFT & DISPLACEMENT

Part I: When displacement is constant

When a ship goes from SW to FW, the draft would increase and vice versa. This can be illustrated by a simple example. Consider a ship of 10000 tonnes displacement.

W = u/w volume x density of water displaced

In salt water

$$10000 = V_{SW} \text{ X } 1.025$$

$$\text{or } V_{SW} = 10000 / 1.025 = 9756 \text{ m}^3$$

$$\text{Underwater volume in SW} = 9756 \text{ m}^3$$

In fresh water

$$10000 = V_{FW} \text{ X } 1$$

$$\text{or } V_{FW} = 10000 \text{ m}^3$$

$$\text{Underwater volume in FW} = 10000 \text{ m}^3$$

From the foregoing example it is clear that when a ship goes from SW to FW the underwater volume (and hence the draft) increases, and vice versa, though the displacement is constant.

FRESH WATER ALLOWANCE

FWA is the increase in draft when a ship goes from SW to FW and vice versa.

$$\text{FWA} = \text{W} / 40 \text{ TPC}$$

Where

W is the displacement of the ship in salt water,
expressed in tonnes.

TPC is the tonnes per centimetre immersion in salt water.

FWA is the fresh water allowance in centimetres.

FWA of a ship usually increases as draft increases. This is because W depends on underwater volume whereas TPC depends on waterplane area. As draft increases, both W and TPC increase but W increases at a faster rate. Hence FWA, as calculated by the foregoing formula, also increases as draft increases. The following table is taken from the hydrostatic particulars of an actual ship in service.

The FWA calculated, by the foregoing formula, for the summer load condition is called the FWA of the ship. This FWA is mentioned in the loadline certificate and is considered constant for those loadlines marked on the ship's sides - T, S, W and WNA. These marks are explained later in this chapter. When a ship is loading down to her marks in FW, she can immerse her loadline by the FWA of the ship so that when she goes to SW, she would rise to her appropriate loadline.

If it is desired to find the FW draft of the ship when she is not immersed up to the loadline marked on the ship's sides, the FWA must be calculated by the formula and added to the SW draft of the ship at that time.

Draft m	W t	TPC t cm^{-1}	$\frac{W}{40\ TPC}$	=	FWA Cm
3.000	5478	20.90	$\frac{5478}{40 \times 20.90}$	=	6.6
5.000	9788	22.08	$\frac{9788}{40 \times 22.08}$	=	11.1
7.000	14299	22.95	$\frac{14299}{40 \times 22.95}$	=	15.6
9.000	19051	24.14	$\frac{19051}{40 \times 24.14}$	=	19.7
9.233 (load draft)	19617	24.28	$\frac{19617}{40 \times 24.28}$	=	20.2

DOCK WATER ALLOWANCE

DWA is the increase in draft when a ship goes from saltwater to dockwater, and vice versa, where the dockwater is neither fresh nor salt i.e., RD between 1 and 1.025. When loading in a dock, the ship can immerse her loadline by the DWA so that when she goes to sea, she would rise to her appropriate loadline.

When a ship goes from SW to FW (change of RD of .025) she increases her draft by FWA. So, for any change of RD between 1.025 and 1.000, linear interpolation may be done. For example:

	Change of RD	Change of Draft
SW 1.025 to FW 1.000	0.025	FWA
SW 1.025 to DW 1.017	0.008	$\frac{0.008 \times FWA}{0.025}$
SW 1.025 to DW 1.020	0.005	$\frac{0.005 \times FWA}{0.025}$
FW 1.000 to DW 1.016	0.016	$\frac{0.016 \times FWA}{0.025}$
DW 1.017 to DW 1.005	0.012	$\frac{0.012 \times FWA}{0.025}$

From the foregoing example, it is clear that:

Change of draft = (change of RD / 0.025) x FWA.

The change of draft, so obtained, would be in the same units as the FWA - mm, cm or m.

This formula holds good for any change of RD. However, when the change of draft is calculated between SW and DW, it is called DWA. The term dock water is used here only symbolically to represent water whose RD is between 1.000 and 1.025 and, for stability purposes, includes the water of rivers, harbours, etc., even though they may not have enclosed docks.

Part II: When draft is constant

When a ship floats at the same draft, on different occasions, in water of different RD, the displacement each time would be different. This is illustrated by a simple example.

Suppose the underwater volume of a certain ship at 7 m draft is 14000 m^3.

In SW, draft 7m,W = 14000 x 1.025 = 14350 t.

In FW, draft 7m,W = 14000 x 1.000 = 14000 t.

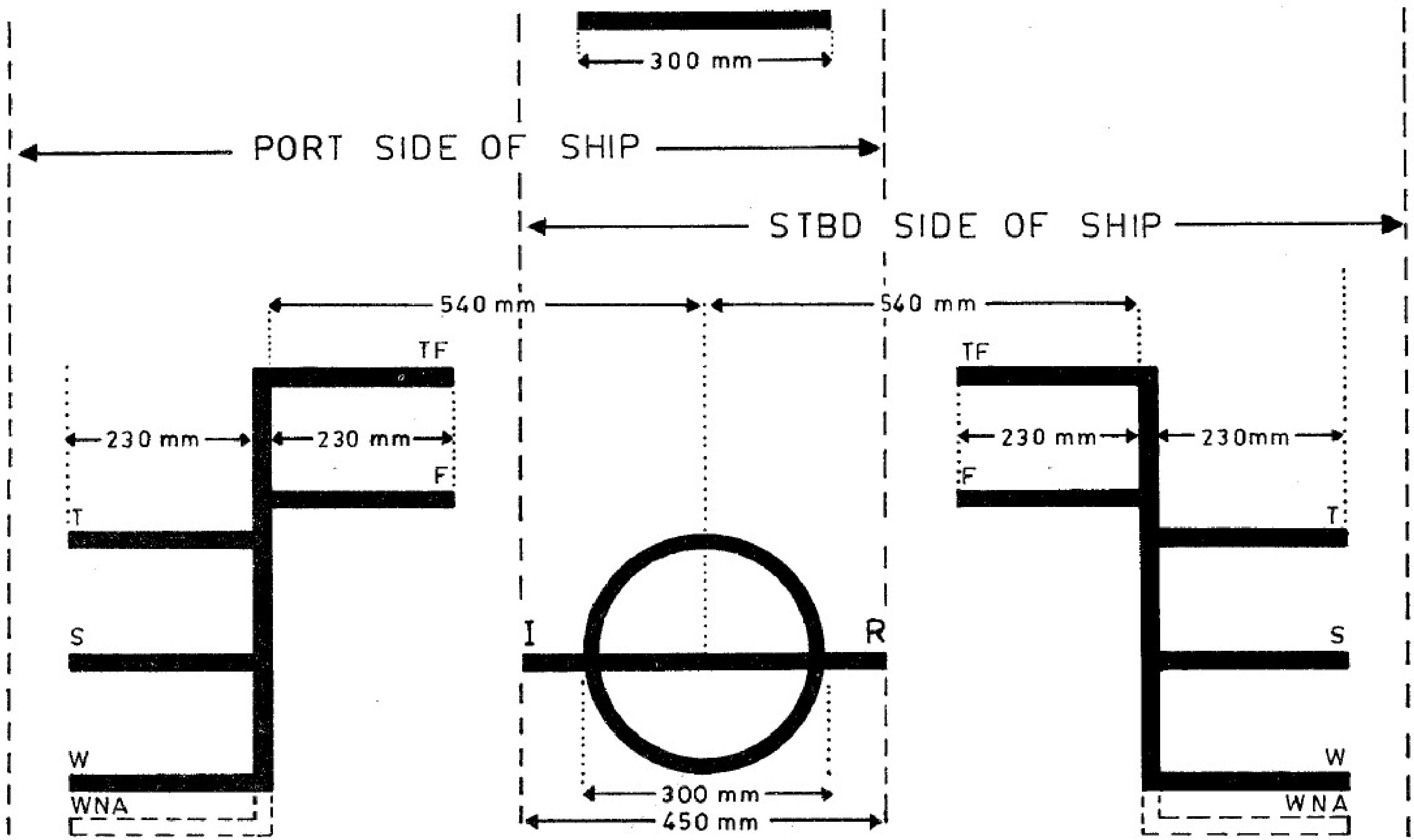
RD 1.01, draft 7m,W = 14000 x 1.010 = 14140 t.

RD 1.02, draft 7m,W = 14000 x 1.020 = 14280 t.

LOADLINES OF SHIPS

The accompanying diagram shows the port and starboard side loadlines of a cargo ship. To see the port side loadlines, cover up the right 1/3 of the sketch. To see the starboard side loadlines, cover up the left 1/3 of the sketch. The WNA loadline has been included in dotted lines as it is only required by vessels less than 100 metres in length, trading in the North Atlantic during the winter season. The exact limits and dates of the winter zone in the North Atlantic are given in the Loadline Rules.

All the lines are 25 mm thick, are cut into the shell plating and are painted white or yellow on a dark background or black on a light background. The upper edge of each loadline indicates its exact level.



300 mm
PORT SIDE OF SHIP
STBD SIDE OF SHIP
540 mm
540 mm
TF
F
T
S
W
WNA
230 mm
230 mm
I
R
300 mm
450 mm
TF
F
230 mm
230mm
T
S
W
WNA

The top of the deck line indicates where the top of the freeboard deck would meet the outer side of the shell plating, if produced. Directly below the deck line is the Plimsoll mark (or loadline disc) and the vertical distance between them is called the Statutory Summer Freeboard. The centre of the loadline disc is at the middle of the **upper edge** of its 25 mm thick, painted, diametric line. The deck line and the Plimsoll mark are situated exactly amidships.

Exactly 540 mm forward of the disc is a vertical line 25mm thick with horizontal lines, measuring 230 mm x 25 mm, on each side of it. On its forward side the lines are marked S, T and W (also WNA if applicable). The lines on the after side are marked F and TF.

The upper edge of the line marked S is in line with the horizontal line of the Plimsoll mark. In summer zones, the ship can load up to this line in salt water. The vertical distance between the upper edges of S and T (and also between S and W) is 1/48 of the summer draft of the vessel. The dates and limits of winter, summer and tropical zones are given in the loadline rules. The WNA mark, if applicable, if situated exactly 50 mm below the W mark (measured between their upper edges).

The vertical distance between the upper edges of the lines marked S and F, and also between T and TF, is the FWA of the ship.

Example 1

A ship's load displacement is 16000 t and TPC is 20. If she is in DW of RD 1.010, find by how much she may immerse her loadline so that she will not be overloaded when she goes to sea.

FWA = W /(40.TPC) =16000 / (40 x 20) = 20 cm

DWA = ((1.025 – dd) / 0.025)FWA

= ((1.025 – 1.010) / 0.025) 20 = 12 cm

Hence, ship can immerse her SW loadline by 12 cm.

Example 2

A vessel of FWA 200 mm goes from water of RD 1.018 to water of RD 1.006. Find the change in draft and state whether it will be sinkage or rise.

Change of draft = Change of RD / 0.025 x FWA

= ((1.018 – 1.016) / 0.025)x 200 = 96 mm.

Since the RD of water has decreased the draft will increase. Hence, the vessel will sink by 96 mm.

Example 3

A box-shaped vessel 24 x 5 x 3 m has an even keel draft of 1.2 m in DW of RD 1.009. Calculate the draft in DW of RD 1.019.

W = u/w volume x density of water displaced.

In DW RD 1.009, W = 24 x 5 x 1.2 x 1.009

In DW RD 1.019, W = 24 x 5 x d x 1.019

Since displacement is constant,

24 x 5 x d x 1.019 = 24 x 5 x 1.2 x 1.009

d = 1.2 x 1.009 / 1.019 = 1.188 m

Hence, draft in DW of RD 1.019 = 1.188 m.

Note: This problem could also be worked by calculating the displacement, SW TPC, FWA and then the change of draft, all by various formulae. However, such a method would be unduly tedious.

Example 4

A box-shaped vessel 20 x 6 x 4.5 floats in DW of RD 1.010 at a draft of 2.4 m. Calculate the percentage reserve buoyancy in DW of RD 1.020.

W = u/w volume x density of water displaced.

In DW RD 1.010, W = 20 x 6 x 2.4 x 1.010

In DW RD 1.020, W = V x 1.020

Since displacement is constant,

V x 1.020 = 20 x 6 x 2.4 x 1.010

V = 285.176 m^3

Total volume = 20 x 6 x 4.5 = 540 m^3

Above water volume = Total volume - u/w volume

= 540 – 285.176 = 254.824 m^3

RB% = (Above water volume / Total volume) x 100 = (254.824 / 540) x 100 = 47.19 %

Hence, RB% in DW of RD 1.020 = 47.19 %

Example 5

A vessel displaces 5000 t at a certain draft in DW of RD 1.018. Find her displacement when floating at the same draft in DW of RD 1.012.

W = u/w volume x density of water displaced.

In DW RD 1.018,

5000 = V x 1.018 or V = 5000 / 1.018= 4911.591 m^3

Hence, u/w vol of ship at that draft = 4911.591 m^3

In DW RD 1.012,

W = 4911.591 x 1.012 = 4970.53 t = 4971 t

Displacement in DW of RD 1.012 = 4971 tonnes.

Example 6

A vessel displaces 16000 t at her summer load draft in SW. If she is now floating in DW of RD 1.015 with her summer loadline on the water, calculate how much DWT is available.

W = u/w volume x density of water displaced

At Summer load draft, 16000 = V x 1.025

or V = 16000 / 1.025 = 15609.756 m^3

Hence, underwater volume of ship at summer draft = 15609.756 m^3

Present displacement =15609.756 x 1.015 = 15843.9 t

DWT available = Maximum W – present W
= 16000 – 15843.9 = 156.1 t.

Example 7

A vessel is in SW with her summer loadline 60 mm above the water on the port side and 10 mm above the water on the starboard side. Find the DWT available, if her TPC is 40.

Obviously, the vessel is listed to starboard. Since both, port and starboard loadlines are of **same** name (above water), mean distance from water will be half the **sum** of the distances.

Mean distance of loadline = (60 + 10) / 2 = 35 mm

Hence, when upright, loadlines will be 3.5 cm above water.

DWT available = Sinkage x TPC = 3.5 x 40 = 140 t.

Example 8

A vessel is in SW with her port summer loadline 80 mm below water and her starboard, 200 m above. Find the DWT available if TPC is 30.

Obviously, the vessel is listed to port. Since the loadline on one side is above the water and the other, below the water (**different** names), the mean distance of the loadline from the water will be half the **difference** between the distances. The name (above or below) of the mean distance will be the same as that of the larger of the two distances.

Mean distance of loadline = (200 - 80) / 2 = 60 mm = 6 cm.

Hence, when upright, loadline will be 6 cm above water.

DWT available = Sinkage x TPC = 6 x 30 = 180 t.

Example 9

A vessel floats in DW RD 1.016 with her winter loadline 100 mm below water on the port side and 180 mm below water on the starboard side. If her FWA is 200 mm, TPC is 24 and summer load draft is 9.6 m, find DWT available.

Port winter loadline is 100 mm below water

Stbd winter loadline is 180 mm below water

Mean dist from water = ½(180+100) = 140 mm below.

Hence, when upright, winter loadline will be 14 cm below water.

Dist W to S = (1/48) x Summer draft = (9.6/48) = 0.2 m = 20 cm

Hence, distance from present waterline to S = 20 – 14 = 6 cm

DWA = (1.025 - 1.016) / 0.025 x FWA = (0.009 / 0.025) x 200 = 72 mm

Hence, total sinkage permissible = 6 + 7.2 = 13.2 cm.

TPC = (A/ 100) x density of water

Note: TPC given is always SW TPC unless specifically stated otherwise.

In SW, 24 = (A/100) x 1.025 or (A/100) = 24/1.025)

In DW, TPC = (A / 100) x 1.016 = (24 / 1.025) x 1.016 = 23.79 tcm^{-1}

DWT available = sinkage x TPC = 13.2 x 23.79 = 314 t.

Example 10

A vessel arrives at port X at the mouth of a river. Her displacement is 12000 t and arrival draft 5.77 m in RD 1.020. She is to cross a bar upriver before entering port Y. The depth at the bar is 6.0 m and RD 1.005. If her TPC is 25, find the minimum quantity of cargo to off-load at port X so that she may cross the bar with an under-keel clearance of 0.5 m.

FWA = W / (40 x TPC) =12000 / (40 x 25) = 12 cm

Change of draft = (Change of RD/0.025) x FW = ((1.020 – 1.005) / 0.025) x 12 = 7.2 cm = 0.072 m.

Depth of water over bar	=	6.000 m
Under-keel clearance	=	0.500 m
Max draft to arrive at bar	=	5.500 m
Change of draft due to RD	=	0.072 m
Max draft on dep port X	=	5.428 m
Draft on arrival port X	=	5.770 m
Required mean rise at port X	=	0.342 m
Required mean rise at port X	=	34.2 cm

TPC at Port X = (25 / 1.025) x 1.020 = 24.88 tcm^{-1}

Cargo to discharge = rise x TPC = 34.2 x 24.88

= 850.9 t

Cargo to discharge at port X = 851 t **Answer.**

Note: The TPC given is always the SW TPC unless clearly stated otherwise. The TPC used in the final stage of this problem is the TPC at RD 1.020 because the cargo lightening operation is being carried out at port X whose RD is 1.020. This is purely of academic interest because any cargo calculation involving TPC is approximate only. If the SW TPC was used in this problem, the answer would be only 4 tonnes different. In actual practice at sea, the displacement of the ship at the required draft of 5.5 m in RD 1.005 would be found using the hydrostatic particulars of the ship and that, subtracted from the present displacement, would give the quantity of cargo to off-load at port X. This is explained later in Chapter 17.

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Exercise 5

Effect of density and draft on displacement

1. A ship of 16000 t displacement and TPC 20 is afloat in SW at 8.0 m draft. Find the draft in FW. (Answer: 8.2 m).
2. A ship goes from water of RD 1.008 to SW. Find the change in draft if her FWA is 180 mm. State whether it would be sinkage or rise. (Answer: 12.2 cm rise).
3. A vessel goes from water of RD 1.010 to FW. If her FWA is 160 mm, state whether she would sink or rise and by how much. (Answer: 6.4 cm sinkage).
4. A ship of FWA 175 mm goes from water of RD 1.006 to water of RD 1.018. Find the amount of sinkage or rise. (Answer: 8.4 cm rise).

5. A ship's stability data book indicates that her load displacement is 18000 t and TPC is 25. If she is now loading in DW of RD 1.018, by how much may her loadline be immersed so that she would not be overloaded? (Answer: 5.0 cm).
6. A box-shaped vessel 20 x 4 x 2 m has a mean draft of 1.05 m in SW. Calculate her draft in DW of RD 1.012. (Answer: 1.063 m).
7. A box-shaped vessel 18 x 5 x 2 m floats in DW of RD 1.000 at a draft of 1.4 m. Calculate the % reserve buoyancy when she enters SW. (Answer: 31.71%).
8.The hydrostatic particulars of a ship indicate that her displacement in SW at a draft of 5 m is 3000 t. Find her displacement when afloat at 5 m draft in water of RD 1.018. (Answer: 2979.5 t).
9. A vessel displaces 4500 t of FW at a certain draft. Find her displacement at the same draft in water of RD 1.020. (Answer: 4590 t).
10. A ship 100 m long and 20 m wide, having block coefficient of 0.8, floats in SW at a mean draft of 8.0 m. Calculate the difference in displacement when floating at the same draft in FW. (Answer: 320 t).
11. A vessel displaces 14500 tonnes, if floating in SW up to her winter loadline. If she is in a dock of RD 1.010, with her winter load-line on the surface of the water, find how much cargo she can load, so that she would float at her winter loadline in SW. Answer: 212.2 t).
12. A vessel of 12000 t displacement arrives at the mouth of a river, drawing 10.0 m in SW. How much cargo must she discharge so that her draft in an upriver port of RD 1.012 would be 10.0 m? (Answer: 152.2 t).
13. A vessel floating in DW of RD 1.005 has the upper edge of her summer loadline in the waterline to starboard and 50 mm above the waterline to port. If her FWA is 180 mm and TPC is 24, find the amount of cargo that the vessel can load to bring her to her permissible draft. (Answer: 397.7 t).
14. A vessel is floating at 7.8 m draft in DW of RD 1.010. TPC is 18 and FWA is 250 mm. The maximum permissible draft in SW is 8.0 m. Find the DWT available. (Answer: 620.8 t).
15. A vessel's statutory freeboard is 2.0 m. She is loading in DW of RD 1.015 and her freeboard is 2.1 m. TPC = 24, FWA = 200 mm. Find the DWT available. (Answer: 427.8 t).

16. A vessel is lying in a river berth of density 1.010 tonnes per m^3, with her summer loadline 20 mm above the water on the starboard side and 50 mm above the water on the port side. Find how much cargo she can load to bring her to her summer loadline in SW, if her summer displacement is 15000 tonnes and TPC is 25. (Answer: 307.9 t).
17. A vessel is floating in dock water of RD 1.005 with her starboard WNA mark 30 mm below, and her port WNA mark 60 mm below the water line. If her summer SW draught is 8.4 m, TPC is 30 and FWA is 160 mm, calculate how much cargo can be loaded to bring the vessel to her summer draught in SW. (Answer: 906 t).
18. A vessel is loading in a SW dock and is lying with her starboard Winter loadline 60 mm above and her port Winter loadline 20 mm below the surface of water. If her summer draught in SW is 7.2 m and TPC is 20, find how many tonnes of cargo the vessel can load to bring her down to her Tropical loadline in SW. (Answer: 640 t).
19. From the following details, calculate the DWT available: - Present freeboards: port 3.0 m, stbd 2.9 m, in water of RD 1.020. FWA 200 mm. TPC 30. Statutory summer freeboard 28 m. (Answer: 567.2 t).
20. From the following information, calculate the DWT available up to the Tropical loadline in SW:

Present freeboards: port 1.68 m, stbd 1.79 m in water of RD 1.017. Tropical SW freeboard: 1.63 m. Tropical SW draft: 9.6 m. FWA: 150 mm. TPC: 20.4. (Answer: 309.7 t).

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6. CENTRE OF GRAVITY

The centre of gravity (G or COG) of a ship is that point through which the force of gravity may be considered to act vertically downwards with a force equal to the weight of the ship.

The position of the COG of a ship is indicated by its distance in metres from three reference lines:

(i) Its height above the keel. This distance is referred to as KG where 'K' represents the keel. KG affects the stability of the ship.

(ii) Its distance from the after perpendicular. This distance is referred to as AG where 'A' represents the after perpendicular of the ship. AG affects the trim of the ship.

Note: The after perpendicular 'A' of a ship is the after part of the stern post. If the vessel does not have a stern post, then it is the axis of the rudderstock.

Some shipyards use amidships (H) for reference instead of the after perpendicular 'A'. The distance of the COG is then referred to as HG, in this book, but then it must be stated whether the COG is forward or abaft amidships each time. HG affects the ship's trim.

Note: Amidships is taken to be the vertical line drawn at right angles to the keel, midway between the forward and after perpendiculars.

(iii) Its distance from the centre line of the ship. This distance causes the ship to list. Since mariners like to keep their ship upright at all times, this distance should preferably be zero.

The position of the COG of a ship depends on the distribution of weights on board and not on total weight.

When a weight is added (loaded), the COG of the ship moves directly towards the COG of the added weight.

When a weight is removed (discharged), the COG of the ship moves directly away from the COG of the removed weight.

When a weight already on board is shifted, the COG of the ship moves in a direction parallel to that moved by the weight.

The foregoing statements are illustrated by the following figures wherein G is the COG of the ship before loading/discharging/shifting and G_1 is the COG of the ship after the loading/ discharging/shifting is completed.

The distance through which the COG would move is given by the following formula:

$$GG_1 = wd / W$$

Wherein,

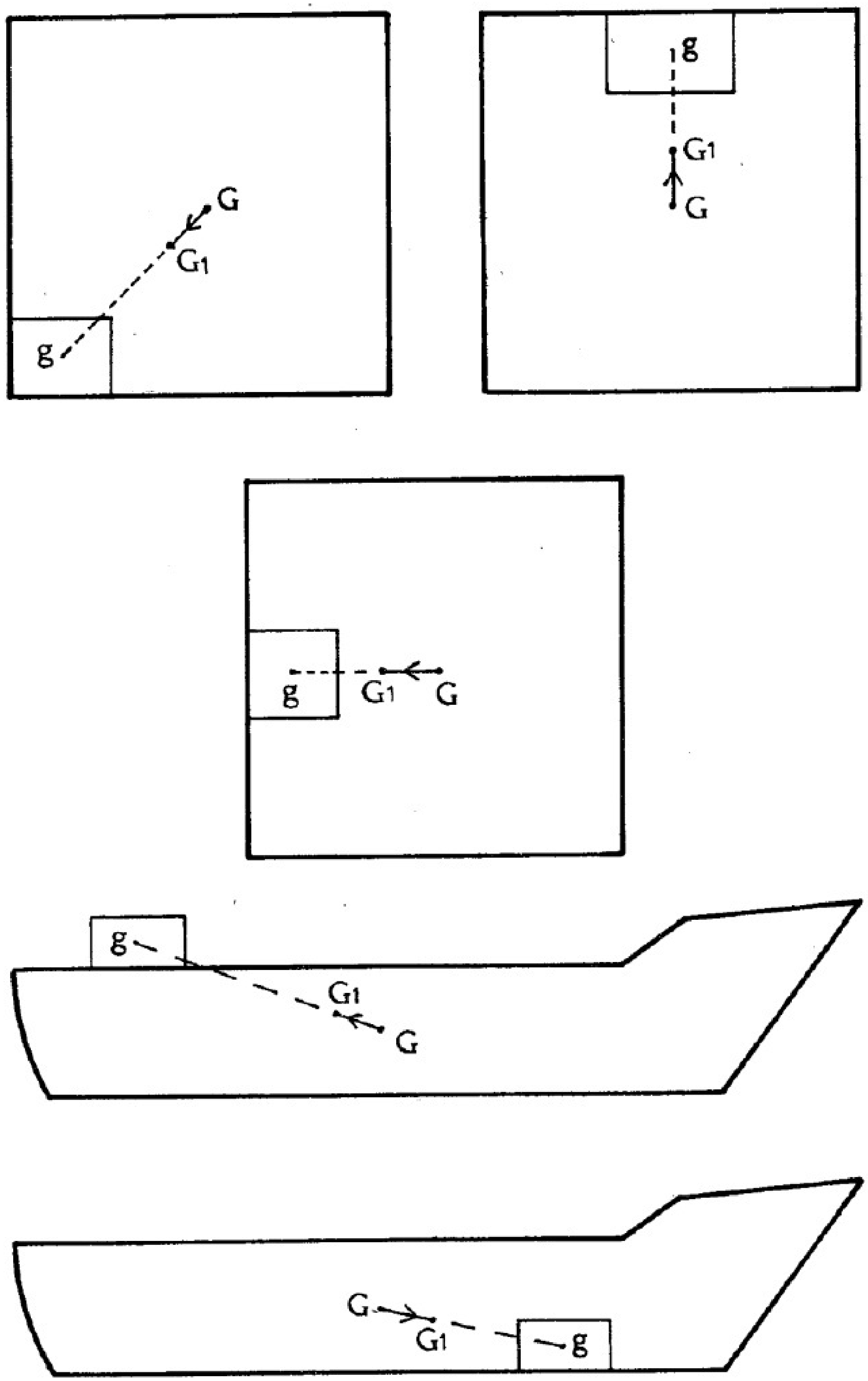
GG_1 is the shift of COG of ship in metres.

w is the weight loaded/discharged/shifted in tonnes.

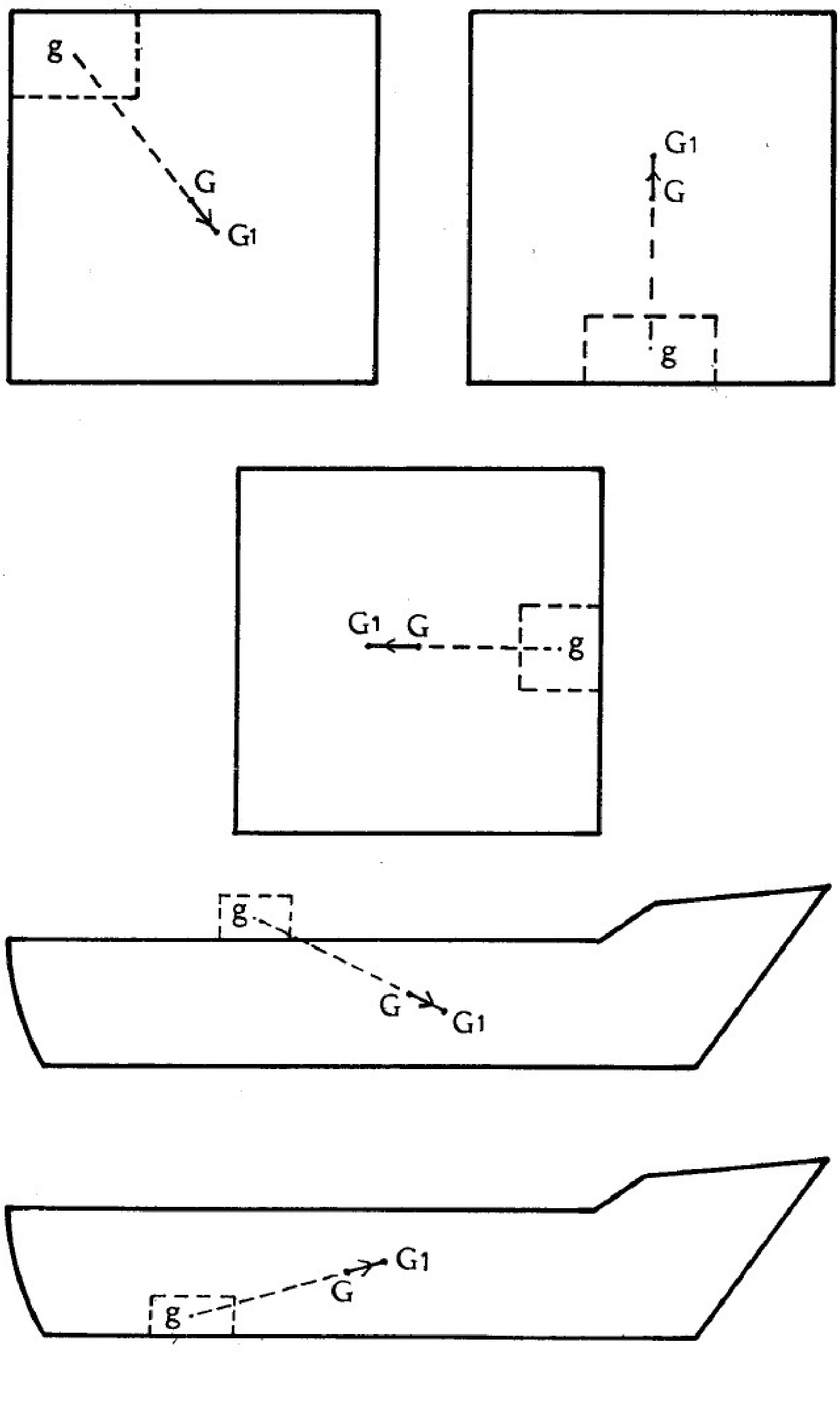
W is the final displacement of ship in tonnes. i.e., after the weight has been loaded/discharged/shifted.

d When loading/discharging, d is the distance in metres between the COG of the ship and the COG of the weight. When shifting a weight, d is the distance moved by the weight.

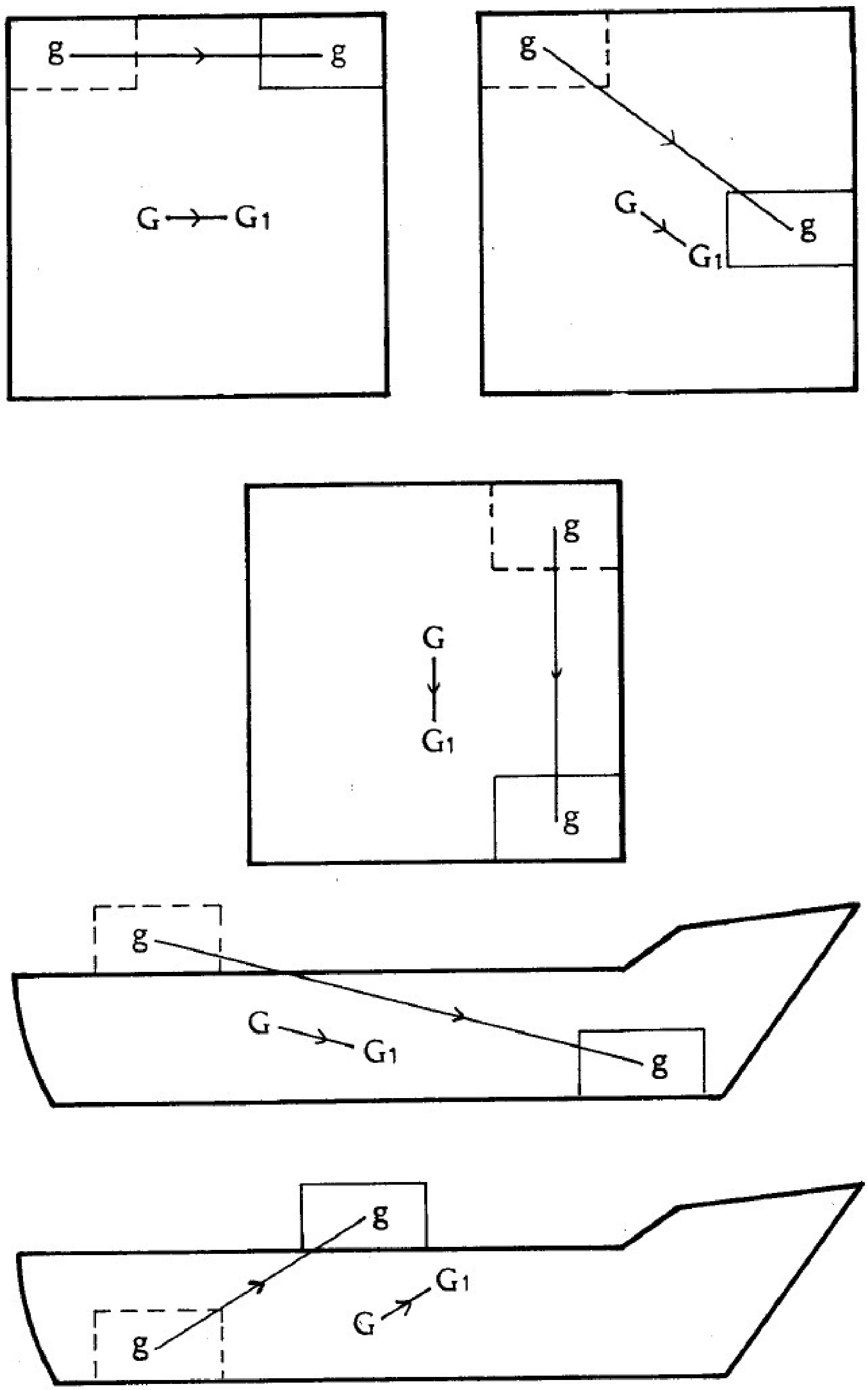
Effect of adding a weight



Effect of removing a weight



Effect of shifting a weight



In stability calculations, the vertical, longitudinal and transverse movements of the COG of the ship are calculated separately. In other words, the actual movement of COG is split into its three components and each component is calculated separately, as shown in subsequent chapters.

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7. FINAL KG

Part I: Considering a single weight only:

When loading, discharging or shifting a single weight, the vertical shift of the COG of a ship is given by the formula:

$$GG_1 = wd / W$$

Wherein,

GG_1 : **Vertical** shift of COG of ship in metres.

w : Weight loaded/discharged/shifted in tonnes.

W: **Final** displacement of ship in tonnes.

d: When loading or discharging, 'd' is the **vertical** distance between the COG of the ship and
the COG of the weight. When shifting a weight
already on board, 'd' is the **vertical** distance
moved by the weight.

Example 1

In a vessel of 12000 t displacement, KG 9 m, 200 t of cargo was shifted from the upper deck (KG 12 m) to the lower hold (KG 2 m). Find the new KG.

KG of cargo while on UD = 12 m
KG of cargo when in LH = 2 m
Hence d (downwards) = 10 m

$$GG_1\downarrow = \frac{wd}{W} = \frac{200 \times 10}{12000} = 0.167 \text{ m}$$

Original KG = 9.000 m
$GG_1\downarrow$ = 0.167 m
KG_1 or new KG = 8.833 m **Answer**

Example 2

In a vessel of 7850 t displacement, KG 8.4 m, 150 t of cargo is loaded on the UD (KG 10 m). Find the final KG.

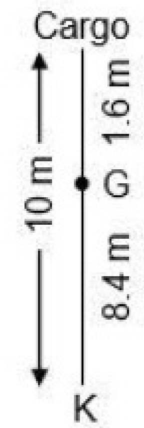
Final W = 7850 + 150 = 8000 t

w = 150 t, d = 1.6 m

$$GG_1 = \frac{wd}{W} = \frac{150 \times 1.6}{8000} = 0.03 \text{ m}$$

Since the cargo was loaded above the COG of the ship, GG_1 will be upwards.

Original KG	= 8.400 m
$GG_1\uparrow$	= 0.030 m
KG_1 or new KG	= 8.430 m **Answer**



Example 3

In a ship of 12300 t displacement, KG 10 m, 300 t of cargo was discharged from the lower hold (KG 2 m). Find the final KG.

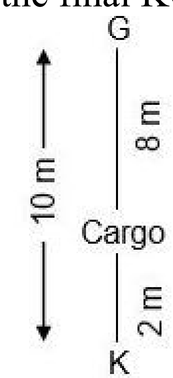
Final W = 12300 - 300 = 12000 t.

w = 300 t, d = 8 m

$$GG_1 = \frac{wd}{W} = \frac{300 \times 8}{12000} = 0.2 \text{ m}$$

Since cargo was discharged from below the COG of ship, GG1 will be upwards.

Original KG	= 10.0 m
$GG_1\uparrow$	= 0.2 m
KG_1 or new KG	= 10.2 m **Answer**



Example 4

On a vessel of 6000 t displacement, KG 7.4 m, how many tonnes of cargo may be discharged from the LH (KG 2.0 m) in order to have a final KG of 8.0 m?

Old KG	= 7.4 m	Original W	= 6000 t
New KG	= 8.0 m	Discharged	= w
$GG_1\uparrow$	= 0.6 m	Final W	= 6000 - w

$$GG_1 = \frac{wd}{W} \text{ or } 0.6 = \frac{w(5.4)}{6000 - w} \text{ or } w = 600 \text{ t}$$

Hence, cargo to discharge = 600 tonnes **Answer**

Example 5

A vessel of 11000 t displacement has KG 6.3 m. A jumbo derrick is used to shift a weight of 250 t from the lower hold (KG 3 m) to the UD

(KG 8.5 m). The head of the derrick is 19.5 m above the keel. Find the KG of the ship:

(a) When the weight is hanging by the derrick and

(b) When the shifting is over.

This problem is to be worked in two stages.

Stage 1: As soon as the weight is lifted off the tank top, the COG of the weight shifts from the LH to the derrick head.

KG of weight when in Lower Hold = 3.0 m
Height of derrick head above keel = 19.5 m
Hence, d = 16.5 m

$$GG_1\uparrow = \frac{wd}{W} = \frac{250 \times 16.5}{11000} = 0.375 \text{ m}$$

Original KG = 6.300 m
$GG_1\uparrow$ = 0.375 m
KG_1 or new KG = 6.675 m **Answer (a)**

Stage 2: As soon as the weight is placed on the UD, the COG of the weight shifts from the derrick head to the UD.

Height of derrick head above keel = 19.5 m
KG of weight when on UD = 8.5 m
Hence, d = 11.0 m

$$GG_1\downarrow = \frac{wd}{W} = \frac{250 \times 11}{11000} = 0.250 \text{ m}$$

New KG (end of stage 1) = 6.675 m
$GG_1\downarrow$ = 0.250 m
Final KG (end of stage 2) = 6.425 m **Answer (b)**

Example 6

A vessel of 6000 t displacement, KG 7.1 m, loads a heavy lift weighing 150 t by her jumbo derrick whose head is 16 m above the keel. If the weight is placed on the tween deck (KG 8 m) find:

(a)KG when the weight is hanging 1 m above the TD &

(b)KG when the loading is over.

Stage 1: As soon as the jumbo derrick takes the heavy lift off the wharf, the COG of the weight acts on the derrick head - equivalent to loading the weight 16 m above the keel. The height of the weight above the deck is of no importance.

Final W = 6000 + 50 = 6150 t
d = 16 – 7.1 = 8.9 m

$$GG_1\uparrow = \frac{wd}{W} = \frac{150 \times 8.9}{6150} = 0.217 \text{ m}$$

Original KG = 7.100 m
$GG_1\uparrow$ = <u>0.217</u> m
KG_1 or new KG = 7.317 m **Answer (a)**.

Stage 2: As soon as the weight is placed on the TD, the COG of the heavy lift shifts from the derrick head (KG 16 m) to the TD (KG 8 m). i.e., d =16 - 8 = 8 m downwards.

$$GG_1\downarrow = \frac{wd}{W} = \frac{150 \times 8}{6150} = 0.195 \text{ m}$$

New KG (at end of stage 1) = 7.317 m
$GG_1\downarrow$ = <u>0.195</u> m
Final KG (at end of stage 2) = 7.122 m **Answer (b).**

Exercise 6
Final KG by GG_1 formula

1. A ship of 8800 tonnes displacement and KG 6.2 m loads 200 tonnes of cargo in the LH, 1.7 m above the keel. Find the final KG.

(Answer: 6.1 m).

2. 600 tonnes of cargo was discharged from a vessel from the upper deck 11 m above the keel. If the original KG and displacement were 6 m and 12600 tonnes, calculate the final KG.

(Answer: 5.75 m).

3. In a vessel of 9900 tonnes displacement and KG 4 m, a heavy lift of 100 tonnes is loaded on the UD (KG 15 m). Find the final KG.

(Answer: 4.11 m).

4. 500 tonnes of cargo was discharged from the lower hold (KG 3 m) of a vessel whose displacement and KG before discharging were 11500 tonnes & 6.3 m. Find the final KG.

(Answer: 6.45 m).

5. 500 t of cargo was shifted 15 m downwards in a ship displacing 10000 t. Find the effect it has on the ship's KG and state whether KG increases or decreases.

(Answer: Decrease by 0.75 m).

6. In a ship of 9000 t displacement, KG 10.5 m, 300 t of cargo was shifted from the LH (KG 2.5 m) to the UD (KG 11.5 m). Find the resultant KG of the ship.

(Answer: 10.8 m).

7. In a vessel of 9009 tonnes displacement, KG 8.7 m, how many tonnes of cargo can be loaded on the UD (KG 15 m) so that the final KG becomes 9 m?

(Answer: 450.45 t).

8. A heavy lift derrick, whose head is 20 m above the keel, is to shift a locomotive weighing 300 tonnes from the UD (KG 8 m) to the LH (KG 2 m). If the displacement and initial KG of the vessel were 12000 tonnes & 7.6 m, find the KG of the vessel (a) when the derrick has taken the weight off the UD (b) after shifting.

(Answer: (a) 7.9 m (b) 7.45 m).

9. On a ship of 4,950 t displacement, KG 9.2 m, the ship's jumbo derrick is used to load a weight of 50 t, from the wharf, on to the UD (KG 8 m). If the head of the derrick is 25 m above the keel, calculate the KG of the ship (a) when the weight is hanging by the derrick on the centre line but 2 m above the UD and (b) after loading.

(Answer: (a) 9.358 m (b) 9.188 m).

10. A ship's derrick, whose head is 22 m above the keel, is used to discharge a weight of 20 t (KG 5 m), lying on the centre line. If the ship's displacement and KG before discharging were 6000 t and 8 m, calculate the KG (a) when the derrick lifts the weight and (b) after discharging.

(Answer: (a) 8.057 m (b) 8.010 m).

Part II: Considering several weights

The GG_1 formula, which seems adequate when considering a single weight at a time, becomes impracticable for general use of ships because several weights are loaded, discharged and/or shifted, at a time. In such cases, the calculation of final KG is done by taking moments about the keel.

The initial moment of the weight of the ship about its keel plus the moments about keel of all weights loaded minus the moments about keel of all weights discharged gives the final moment. This final moment about keel divided by the final displacement of the ship gives the final KG. In cases where weights have been shifted vertically, the weight multiplied by the vertical distance shifted gives the change in moment, to be added if the shift is upwards; to be subtracted if the shift is downwards.

Calculation of final KG, by taking moments about keel, can be done even when only a single weight is loaded, discharged or shifted.

Example 7

On a ship of 10000 tonnes displacement, KG 7.75 m, the following changes took place:

1000 t of cargo discharged from No. 2 LH, KG 4.0 m.

2000 t of cargo discharged from UD, KG 9.8 m.

500 t of FW taken into peak tanks, KG 6.5 m.

500 t of fuel oil taken into No. 4 DBT, KG 0.5 m.

500 t of cargo shifted from No. 2 TD to No.2 LH, through a vertical distance of 8 m.

Find the final KG of the ship.

Remarks	Weight (t)		KG (m)	Moment by keel (tm)	
	Loaded	Disch		Loaded	Disch
Ship	10000	-	7.75	77500	
2LHCargo	-	1000	4.0	-	4000
UD Cargo	-	2000	9.8	-	19600
Peaks FW	500	-	6.5	3250	-
HFO 4DBT	500	-	0.5	250	-
Total	11000	3000		81000	23600
	3000			23600	
Final W =	8000			57400	
500 t shifted 8 m down (-)				4000	
Final moment =				53400	

Final KG = Final moment / Final W

= 53400 / 8000 = 6.675 m.

Exercise 7

Final KG by moments about keel

1. A ship displacing 2000 t, KG 4.2 m, loads cargo of 300 t (KG 2.0 m), 200 t (KG 3.2 m) & bunkers of 500 t (KG 1.0 m). Find final KG.

(Answer: 3.380 m).

2. A ship displacing 3000 t, KG 3.9 m, loads: 200 t in No.1 LH (KG 3.0 m), 300 t on deck (KG 6.4 m), 150 t in No.3 TD (KG 5.2 m) and

350 t in No.4 LH (KG 4.0 m). Find the final KG.

(Answer: 4.100 m).

3. A ship of load displacement 10000 t, KG 6.0 m, discharges cargo of 250 t (KG 3.0 m) and 150 t (KG 4.0 m). Find the final KG.

(Answer: 6.109 m).

4. A ship of W 12000 t, KG 4.3 m, discharges: 200 t from No.1 LH (KG 2.6 m), 250 t from No.2 TD (KG 3.4 m), 1000 t from No.3 LH (KG 4 m) & 550 t from UD (KG 8 m). Find final KG.

(Answer: 4.183 m).

5. Ship of 2000 t displacement and KG 3.66 m loads 1500 t (KG 5.5 m), 3500 t (KG 4.60 m), and takes 1520 t of bunkers (KG 0.60 m). She discharges 2000 t cargo (KG 2.44 m) and consumes 900 t of bunkers (KG 0.40 m). Find KG.

(Answer: 4.865 m).

6. A ship of 3200 t displacement, KG 6.2 m, loads 5200 t of cargo (KG 4.8 m). Find the amount of deck cargo (KG 10.4 m) that can be loaded so that the final KG shall be 6.0 m.

(Answer: 1272.7 t).

7. A ship of 2600 t displacement, KG 4.88 m, loads 4600 t of homogeneous cargo (KG 5.0 m). Find how much deck cargo (KG 10 m) may be loaded to obtain a final KG of 5.11 m.

(Answer: 225.8 t).

8. A heavy-lift derrick is used to discharge a 100 t package from a ship of displacement 8000 t, KG 8.2 m. If the KG of the weight while on board is 3 m and if the derrick head is 25 m above the keel, find the KG of the ship (a) while discharging (b) after discharging.

(Answer: (a) 8.475 m (b) 8.266 m).

9. On a ship displacing 15000 t KG 7.9 m, a weight of 200 t is loaded on the UD (KG 12 m) using the ship's Stulken derrick whose head is 30 m above the keel. Find the ship's KG (a) while loading & (b) after loading.

(Answer: (a) 8.191 m (b) 7.954 m).

10. On a ship displacing 11000 t, KG 7.2 m, a shore crane shifts a 180 t heavy-lift from the UD (KG 12 m) to the LH (KG 3 m). Find ship's KG (a) during & (b) after shifting.

(Answer: (a) 7.120m (b) 7.053 m).

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8. CENTRE OF BOUYANCY

The centre of buoyancy (B or COB) of a ship is that point through which the force of buoyancy may be considered to act vertically upwards, with a force equal to the weight of water displaced by the ship. It is the geometric centre of the water displaced i.e. the geometric centre of the underwater volume of the ship.

The position of the COB of a ship is indicated by:-

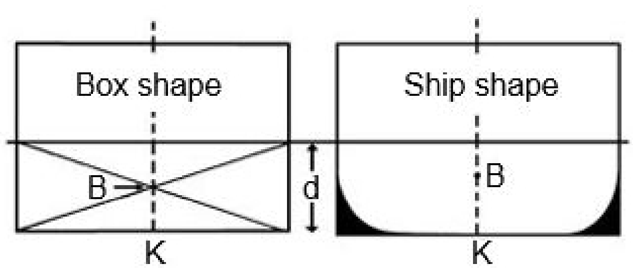
(i) Its height above the keel, called KB.

(ii) Its distance from the after perpendicular of the ship, called AB. Some shipyards use amidships (H) for reference instead of the after perpendicular (A). The distance of the COB is then referred to as HB, in this book, but then it must be stated whether the COB is forward or abaft amidships in each case.

Note: Definitions of the after perpendicular and amid-ships are given earlier, in chapter 6.

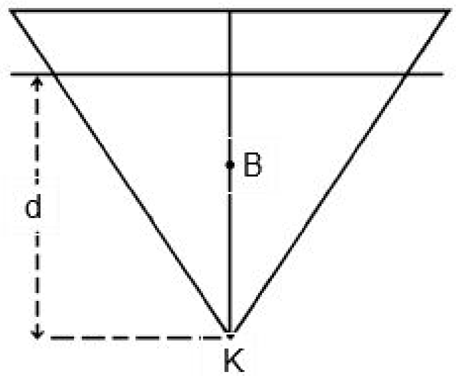
Both KB and AB depend on the shape and volume of the underwater portion of the hull and are therefore dependent on the ship's draft. KB and AB (or HB) are given in the hydrostatic particulars of the ship in the form of curves or tables against draft. Further explanation of the use of AB is given under the heading 'Trim' later in this book in chapters 27 and 28.

The KB of a box-shaped vessel would be exactly half the draft, if the vessel is upright and on an even keel. The KB of a **ship-shape** will, however, be a little greater than half draft, as illustrated by the following figures:



From the above figure, it is obvious that if the shaded part of the box-shaped figure is removed, the figure becomes ship-shaped.

The KB of a ship-shape would, therefore, be about five to ten percent more than half its draft. KB of a triangular-shaped vessel would be two-thirds of its draft, when on an even keel and upright, as shown in the following figure:



Exercise 8

Centre of buoyancy

1. A box-shaped vessel displacing 1640 t is 50 m long, 10 m wide and 8 m high. Find her KB in SW, when on even keel and upright. (Answer: 1.6 m).

2. A box-shaped vessel 60 m x 10 m x 10 m floats in DW of RD 1.020 at an even keel draft of 6 m. Find her KB in DW of RD 1.004. (Answer: 3.048 m).

3. A triangular-shaped vessel displacing 650 t floats in DW RD 1.015. Her water plane is a rectangle 30 m x 8 m. Find her KB. (Answer: 3.558 m).

4. A triangular-shaped vessel floats in SW. Her water plane is a rectangle 40 m x 12 m. If her KB is 3.6 m, find her displacement. (Answer: 1328.4 t).

5. A homogeneous log of wood 3 m x 0.75 m x 0.75 m floats in SW with one face horizontal. If the RD of the log is 0.8 m, calculate the vertical distance between its COG and its COB. (Answer: 0.082 m).

6. A homogeneous log of wood of 0.5 m square section floats in water of RD 1.005 at a draft of 0.4 m with one of its faces horizontal. Find the vertical distance between its COG and its COB in water of RD 1.020. (Answer: 0.053 m).

7. A cylindrical drum of 0.8 m diameter and 1.5 m height weighs 10 kg. 490 kg of steel is put in it such that it floats with its axis vertical in FW. Find its KB. (Assume π to be 22/7). (Answer: 0.497 m).

8. A barge is prism-shaped such that its deck and keel are identical and parallel; its sides vertical. Its deck consists of three shapes - triangular bow of 12 m each side; rectangular mid-part 80 m long and 12 m wide; semi-circular stern of radius 6 m. If the light displacement of the barge is 500 t and it has 5000 t of cargo in it, find its KB when floating on an even keel in SW. (Assume $\pi$to be 3.142). (Answer: 2.487 m).

9. The deck and keel of a flat-bottomed barge are identical. Its sides are vertical. The deck consists of two sections - the bow is a triangle 12 m broad and measures 12 m in the fore and aft direction; the mid-body is a rectangle 50 m long and 12 m broad. If it is floating on an even keel in SW with a displacement of 3444 t, find the position of its COB with reference to the keel and with reference to its after end. (Answer: KB 2.5 m; AB 28.107 m).

10. A barge 45 m long has a uniform transverse cross-section throughout, which consists of a rectangle above a triangle. The rectangle is 8 m broad and 4 m high. The triangle is apex downward, 8 m broad and 3 m deep. If the displacement of the barge is 1620 t, find the position of its COB with reference to the keel and also with reference to the after end, if it is upright and on an even keel in FW. (Answer: KB 3.667 m; AB 22.5 m).

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9. TRANSVERSE STATICAL STABILITY

While studying statical stability it is important to distinguish between the two terms - list and heel.

List

List is the transverse inclination caused by unequal distribution of weights on either side of the centre line of the ship. In other words, list is caused when the COG of the ship is not on the centre line - an internal cause. A ship with a list will become upright only if the COG is brought to the centre line.

Heel

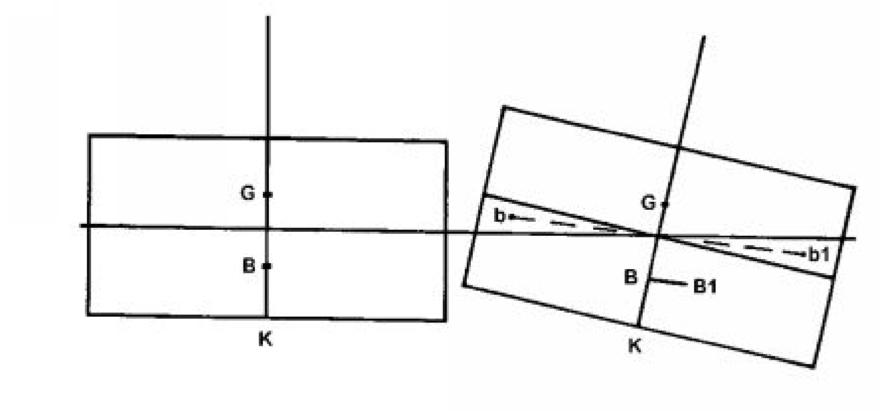
Heel is the transverse inclination of the ship caused by external forces such as wind, waves, centrifugal force during course alterations, over-tight moorings in port, etc. Since no transverse shift of weights has taken place on board, the position of the COG of the ship remains unaffected by heel.

Transverse Shift of B

When a ship is floating in still water, her COG and COB will be in a vertical line. The forces of gravity and buoyancy, being equal and opposite, will cancel each other out and the ship will be in static equilibrium.

When a ship is heeled over to one side, say to starboard, her underwater volume increases on the

starboard side and decreases on the portside. The COB, being the geometric centre of the underwater volume of the ship, will shift to the lower side (starboard side in this case), as shown in the following figure:-



In the foregoing figure:

b ~~**B**~~ is the geometric centre of the emerged wedge
(of the part that came out of the water due to heeling).
$\mathbf{b_1}$ is the geometric centre of the immersed wedge
(of the part that went underwater due to heeling).
B is the COB before heeling.
$\mathbf{B_1}$ is the COB after heeling.
$\mathbf{BB_1}$ is the shift of COB caused by heeling.

Note: BB_1 is parallel to bb_1. BB_1 is **not** parallel to the water line. BB_1 is **not** parallel to the keel. Angle GBB_1 is **not** a right angle.

Transverse metacentre (M)

When a vessel is heeled (inclined by an external force), the force of buoyancy, acting vertically upwards through the new position of COB, cuts the centre line of the ship at a point called the transverse metacentre (M). This is illustrated in the next figure.

The position of M is indicated by its height above the keel in metres (KM). KM increases as the angle of heel increases, until it reaches a maximum value at some large angle of heel. Thereafter, it decreases as angle of heel increases. However, over small angles of heel (say up to about 15°) the increase of KM is generally small. Hence, KM is considered constant for small angles of heel, for the sake of convenience in stability calculations, and is often termed initial KM.

KM is calculated by adding KB and BM, each of which is calculated separately. The initial KM is, therefore, a function of the draft of the vessel. On board a ship, the initial KM is obtained by consulting a table or graph, supplied by the shipyard, wherein KM is indicated against draft.

Metacentric height (GM)

It is the vertical distance between the centre of gravity and the metacentre. GM is termed positive when G is below M i.e., when KG is less than KM and negative when G is above M i.e., when KG is greater than KM. GM is illustrated in the next figure.

Over small angles of heel, wherein KM may be considered constant, GM also is considered constant and is referred to as initial GM.

Righting lever (GZ)

When a vessel is heeled (inclined by an external force), the force of buoyancy, acting vertically upwards through the new position of COB, becomes separated from the force of gravity, acting vertically downwards through the COG, by a horizontal distance called the righting lever (GZ) which is illustrated in the following figure.

GZ normally increases as angle of heel increases until it reaches a maximum value at some large angle of heel. Thereafter, GZ decreases as angle of heel increases.

For small angles of heel (up to about 15°), herein KM, and hence GM, may be considered constant,

$$GZ = GM \cdot \sin\theta$$

n which θ is the angle of heel and GM is the initial GM, as is apparent in the following figure.

For large angles of heel, GZ can be calculated by the wall-sided formula:

$$GZ = \sin\theta\,(GM + \tfrac{1}{2}\,BM\,\tan^2\theta)$$

This formula can be used whenever the ship's sides within the immersed wedge and the emerged wedge are parallel i.e., until the deck edge goes under water. θ is the angle of heel, GM the initial GM, and BM is the height of the initial metacentre above the COB before heeling, as shown in the following figure.

On board ships, the value of GZ can be obtained for various angles of heel by use of cross curves of stability (GZ curves or KN curves), supplied by the shipyard (as explained in chapters 23 and 24).

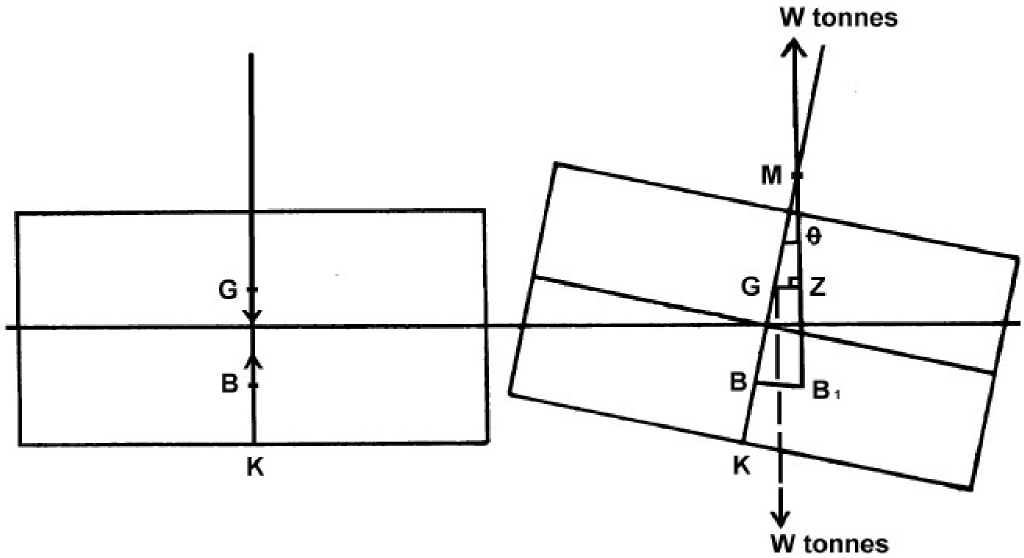


FIGURE ILLUSTRATING BM, KM, GM, GZ, etc.

K: Keel.

G: COG.

θ: Angle of heel.

B: COB before heeling.

B_1: COB after heeling.

BB_1: Shift of COB due to heel.

M: Transverse metacentre.

GM: Metacentric height.

GZ: Righting lever.

W: Displacement in tonnes.

W.GZ : Righting moment.

Righting moment

When a vessel is heeled (inclined by an external force), the forces of gravity and buoyancy, being equal and opposite, become separated by a horizontal distance called the righting lever and form a couple which tends to return the vessel to upright. The moment of this couple is a measure of the tendency of the vessel to return to upright and is hence called the righting moment or 'Moment of statical stability'.

RM = W.GZ for all angles of heel.

For small angles of heel, where GM may be considered constant, GZ = GM . Sin θ and hence:

RM = W.GM.Sin θ for small angles of heel.

Exercise 9
Moment of statical stability

1. A ship of 10000 t displacement has a GM of 0.4 m. Calculate the moment of statical stability when she is heeled by 5°. (Answer: 348.6 tm).
2. If a ship displacing 12000 t, heeled by 6°, has a righting lever of 0.1 m, find the moment of statical stability. If the KM is 8.2 m, find the KG. (Answer: 1200 tm; 7.243 m).
3. When a ship of 14000 t displacement is heeled by 8°, the moment of statical stability is 400 tm. If KG is 7.3 m, find KM. (Answer: 7.505 m).
4. A ship of 8000 t displacement has KB 3.5 m, KM 6.5 m, & KG 6 m. Find the moment of statical stability at 20° heel, assuming that the deck edge remains above water (i.e., ship is still wall-sided at that angle of heel). (Answer: GZ 0.239 m; RM 1912 tm).
5. A ship of 4000 t displacement has KG 5.1 m, KB 2.1 m, KM 5.5 m. Find the moment of statical stability when she heels 24°, assuming that she is wall-sided. (Answer: GZ 0.300 m; RM 1200 tm).

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10. EQUILIBRIUM OF SHIPS

Stable equilibrium

When a vessel is heeled (inclined by an external force), if she tends to come back to her original condition, she is said to be in stable equilibrium.

For a vessel to be stable, her GM must be positive i.e., KG must be less than KM, as shown in the following figures.

Note: As explained in Chapter 9, the position of COG remains unaffected by heel whereas the COB shifts to the lower side. The forces of gravity and buoyancy form a couple which tends to return the vessel to her original condition. A vessel with a list also may be stable.

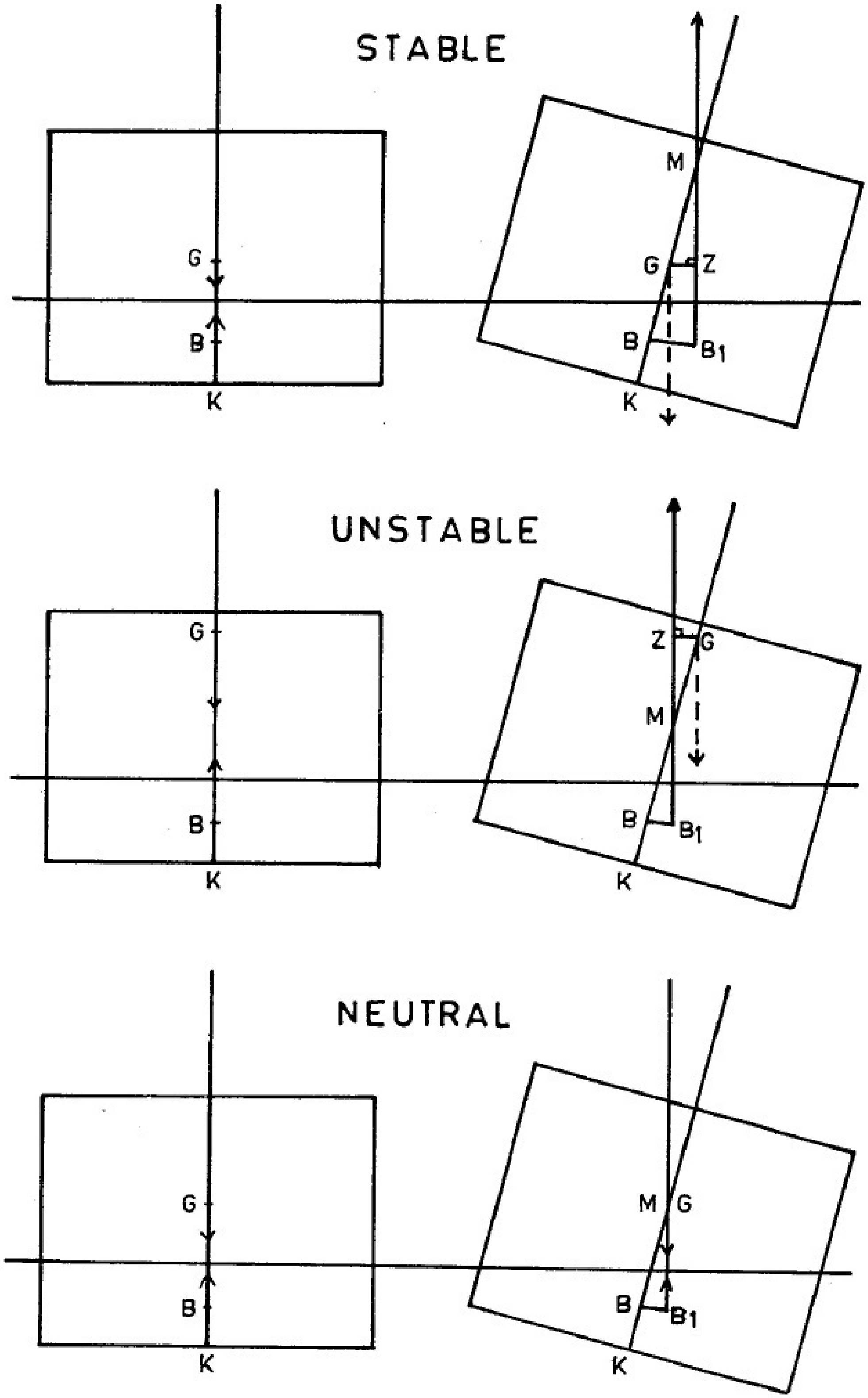
Unstable equilibrium

When a vessel is heeled (inclined by an external force), if she tends to continue heeling further, she is said to be in unstable equilibrium.

For a vessel to be unstable, her GM must be negative i.e., KG must be greater than KM, as shown in the following figures.

Note: As explained in earlier chapters, the COB shifts to the lower side. M is directly above B1. The forces of gravity and buoyancy form a couple but, G being higher than M, this couple tends to heel the vessel further. The moment of this couple is called a ‘negative righting moment’ or ‘upsetting moment’ or ‘capsizing moment’.

EQUILIBRIUM OF SHIPS



Neutral equilibrium

When a vessel is heeled (inclined by an external force), if she has no tendency to return to her original condition or to continue heeling further, she is said to be in neutral equilibrium.

For a vessel to be in neutral equilibrium, her GM must be zero i.e., KG equals to KM, as shown in the figure on the previous page.

Note: As explained in earlier chapters, the COB shifts to the lower side. M is directly above B1. Since G and M are coincident, no righting lever, and hence no righting moment, is formed. The vessel thus has no tendency to continue heeling further or to return to her original condition.

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11. MORE ABOUT UNSTABLE EQUILIBRIUM

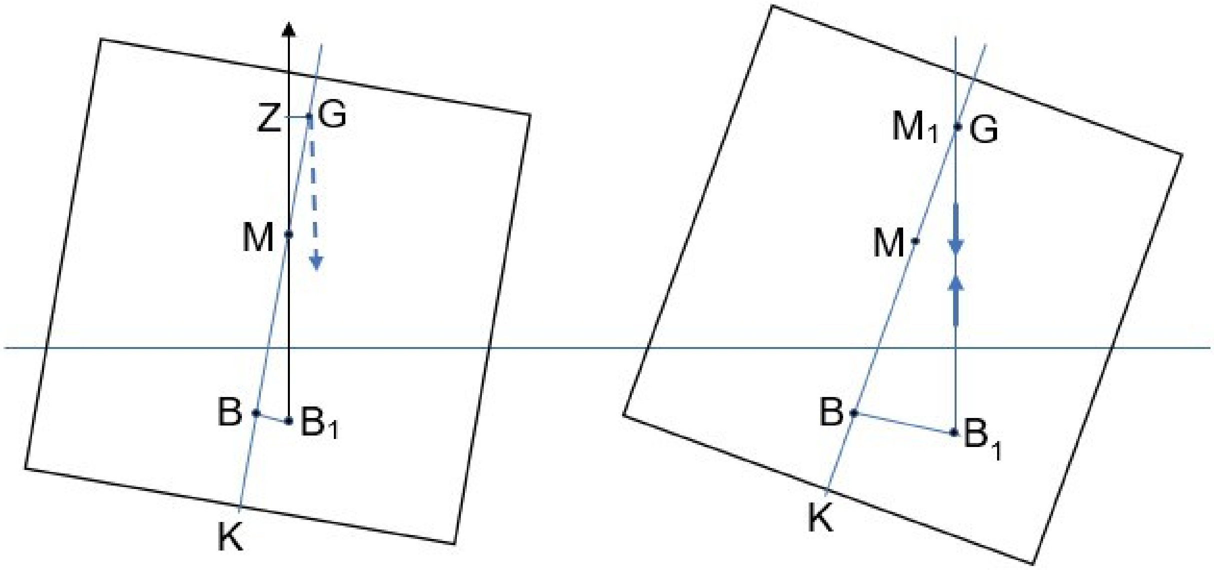
The impression obtained by reading about unstable equilibrium, in the previous chapter, would be that an unstable vessel would continue heeling more and more until she capsized. Though this could happen, this is not always the case.

Angle of loll

It was mentioned earlier, under the definition of metacentre, that KM increases as angle of heel increases until it reaches a maximum value at some large angle of heel. As an unstable vessel heels over more and more, it may happen that, at some angle of heel, KM increases sufficiently to equal to KG (see M_1 in the following figure). The vessel would then be in neutral equilibrium and the angle at which this happens is called the angle of loll.

In other words, when an unstable vessel heels over to progressively increasing angles of heel, it may happen that, at some angle of heel, the COB may come vertically below the COG. The vessel would then be in neutral equilibrium. The angle of heel at which this happens is called the angle of loll.

If any opening goes underwater, at this stage, progressive flooding would take place and the vessel would capsize. The angle of loll could be on either side of the vessel. If it is at the angle of loll to one side, and a wave was to roll her sufficiently to the other side, she would flop over to her angle of loll on the other side.



UNSTABLE VESSEL

HEELING OVER **AT ANGLE OF LOLL**

When at the angle of loll, if a wave causes the vessel to heel a little more, KM would increase and become more than KG. A small righting moment, so formed, would return the vessel to the angle of loll.

When at the angle of loll, if a wave causes the vessel to heel less, KM would decrease and become less than KG. A small capsizing moment, so formed, would return the vessel to the angle of loll.

The vessel at the angle of loll, therefore, appears to possess the characteristics of stable equilibrium.

Though the vessel appears to be temporarily safe, it must be emphasized here that the vessel at the angle of loll is in extremely precarious and dangerous situation – wrong action or no action on the part of the ship's staff would result in certain disaster.

The corrective action to be taken at the angle of loll is elaborated later, in chapter 21.

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12. FREE SURFACE EFFECT

When a vessel with a slack (partly full) tank rolls at sea, the liquid in the slack tank would move towards the lower side during each roll, thereby causing the angle of roll and the period of roll to increase. Because the vessel behaves as if her GM has been reduced, we say that a slack tank causes a virtual (imaginary) loss of GM. This called free surface effect (FSE).

The virtual loss of GM can be calculated quite easily and is called free surface correction (FSC). In order to indicate whether FSC has been applied or not, the GM before subtracting FSC is called ‘solid GM’ and after subtracting FSC it is called ‘Fluid GM’ or GM_F. In all stability calculations involving GM, it is fluid GM that is to be used.

FSC depends on the length and breadth (mainly breadth) of the slack tank. The quantity of liquid in the slack tank makes only a very small difference.

FSC can be calculated by the formula:

$$FSC = (i / V) \times (di / d_o)$$

Where: **i**: is the moment of inertia (or second moment of area) of the slack tank surface about its centre line, in m^4.

V: is the volume of displacement of the ship, in m^3.

di: is the density of liquid in the slack tank, in tm^{-3}.

d_o: is the density of water outside (in which the ship is floating), in tm^{-3}.

FSC: is the free surface correction in m, caused by this slack tank.

Since displacement = volume of displacement x density of water displaced, the denominator in the foregoing formula may be substituted by W, the displacement of the ship in tonnes. The formula then becomes.

$$FSC = i\ di / W$$

Since ‘i’ is in m^4 and ‘di’ is in tm^{-3}, ‘i di’ would be in tm and is hence called the free surface moment or FSM.

When several tanks are slack on a ship, the FSM of each tank is calculated separately and then added together to obtain the total FSM. This total FSM divided by the final W of the ship would give the total FSC of all the slack tanks.

On a ship, the 'i' of each tank about the tank's centre-line is readily available in the stability particulars supplied by the shipyard.

Example 1

Given the following particulars of a ship, calculate the fluid GM: W = 10000 t, KG = 9.0 m, KM = 9.8, moment of inertia of surface of tank about its centre line = 1242 m^4, RD of HFO in the tank = 0.95.

FSC = i di / W = (1242 x 0.95) / 10,000= 0.118 m

KM	=	9.800 m
KG	=	9.000 m
Solid GM	=	0.800 m
FSC	=	0.118 m
Fluid GM	=	0.682 m

Example 2

The stability particulars of a ship indicate that, for its present condition, the W = 5532 t, KM = 8.7 m, 'i' of No.3 DBT about its centre line = 1428 m^4. If No. 3 DBT is partly full of DO of RD 0.88, and the ship's KG is 8.5 m, calculate her fluid GM.

FSC = i di / W = 1428 x 0.88 / 5532 = 0.227 m

KM	=	8.700 m
KG	=	8.500 m
Solid GM	=	0.200 m
FSC	=	0.227 m
Fluid GM	=	-0.027 m

Note: Negative fluid GM means that ship is unstable.

Example 3

A vessel displacing 16635 t has KM 8.25 & KG 7.4 m. If the following tanks are slack, find the final fluid GM.

Tank	Contents	RD	'i'
No 1 DBT	SW	1.025	400 m^4
No 3 C	HFO	0.95	1200 m^4
No 4 S	HFO	0.95	270 m^4
No 5 P	DO	0.88	180 m^4
No 8 P	FW	1.00	25 m^4
No 8 S	FW	1.00	15 m^4

Working

Tank	Contents	$i \times d_i$	FSM tm
No 1 DBT	SW	400 x 1.025	410.0
No 3 C	HFO	1200 x 0.95	1140.0
No 4 S	HFO	270 x 0.95	256.5
No 5 P	DO	180 x 0.88	158.4
No 8 P	FW	25 x 1.00	25.0
No 8 S	FW	15 x 1.00	15.0
		Total FSM	2004.9

FSC = FSM / W = 2004.9 / 16635 = 0.121 m

KM	=	8.250 m
KG	=	7.400 m
Solid GM	=	0.850 m
FSC	=	0.121 m
Fluid GM	=	0.729 m

Example 4

On a vessel of 18000 t displacement KM 8.9 m, KG 8.3 m, a DB tank is partly full of FW. If the tank surface is rectangular, 20 m long and 18 m wide, calculate her fluid GM.

'i' of rectangular tank about its CL = lb^3 / 12 = 20 x 18^3 / 12 m^4

FSC = i di / W = (20 x 18^3) 1.0 / (12 x 18000) = 0.54 m

KM	=	8.90 m
KG	=	8.30 m
Solid GM	=	0.60 m
FSC	=	0.54 m
Fluid GM	=	0.06 m

Example 5

On a vessel of 5000 t displacement, KM 7.8 m, KG 7.0 m, No.2 port DB tank is partly full of FW. If this tank is 15 m long and 9 m broad, find the fluid GM.

'i' of rectangular tank about its CL = lb^3 / 12 = (l5 x 9^3)/ 12 m^4

FSC = i di / W = (15 x 9^3) 1.0 / (12 x 5000) = 0.182 m

KM	=	7.800 m
KG	=	7.000 m
Solid GM	=	0.800 m
FSC	=	0.182 m
Fluid GM	=	0.618 m

EFFECT OF TANK-BREADTH ON FSC

The breadth of a slack tank has an enormous effect on the FSC caused. This illustrated simply by worked examples 6, 7, 8 and 9.

Example 6

On a ship of W 10000 t, no: 3 DB tank is partly full of SW. If the tank is 20 m long and is 18 m wide from shipside to shipside, calculate the FSC caused.

FSC = i di / W = (lb^3 / 12) x (di / W) = (20 x 18^3 x 1.025) /(12 x 10000)= 0.996 m

Example 7

Same ship as example 6, except that No. 3 DB tank has a watertight centre girder dividing it into port and starboard tanks of equal breadth. Find the FSC when both, P & S tanks, are slack.

FSC No: 3S = i di / W = (lb^3 x di)/(12 x W) = 20 x 9^3 x 1.025 /(12 x 10000) = 0.1245

FSC for No: 3 P tank = 0.1245 m (tanks are identical)

Total FSC for No: 3 P & S tanks = 0.249 m

Example 8

Same ship as example 6, except that No 3 DB tank is divided into three watertight tanks – P, S & C – of equal breadth. Find the FSC when all three tanks are slack.

FSC No: 3P = i di / W = (lb^3 x di) / (12 x W) = 20 x 6^3 x 1.025 / (12 x 10000)= 0.0369m

Since all three tanks are identical:

FSC for No 3 Stbd tank	= 0.0369 m
FSC for No 3 Centre tank	= 0.0369 m
Total FSC for all 3 tanks	= 0.1107 m

Example 9

Same ship as example 6, except that No. 3 DB tank is divided into four identical watertight tanks – Port Outer, Port Inner, Stbd Inner, Stbd Outer. Find the FSC when all four tanks are slack.

FSC No: 3 PO = i di / W = (lb^3 / 12) x (di / W1) = (20 x 4.5^3 x 1.025) / (2 x 10000) = 0.01557 m

Since all four tanks are identical:
FSC for No 3 PI tank = 0.01557 m
FSC for No 3 SI tank = 0.01557 m
FSC for No 3 PO tank = 0.01557 m
FSC for No 3 SO tank = 0.01557 m
Total FSC for all 4 tanks = 0.06228 m

Analysis of results of examples 6, 7, 8 & 9

Sub-divisions	Total FSC
Single undivided DB tanks	0.996 m
Divided into 2 tanks of equal breadth, both slack	0.249 m
Divided into 3 tanks of equal breadth, all 3 slack	0.111 m
Divided into 4 tanks of equal breadth, all 4 slack	0.062 m

From the foregoing it is clear that when a tank is divided, in breadth, into a number of identical watertight compartments (n), the total FSC when all the compartments are slack is $1/n^2$ of the FSC that would have occurred if the slack tank was undivided.

This is elaborated below:

Example 6

Single undivided DB Tank FSC = 0.996 m

Example 7

n = 2, So FSC = 0.996 / n^2 = 0.996 / 4 = 0.249 m

Example 8

n = 3, So FSC = 0.996 / n^2 = 0.996 / 9 = 0.111 m

Example 9

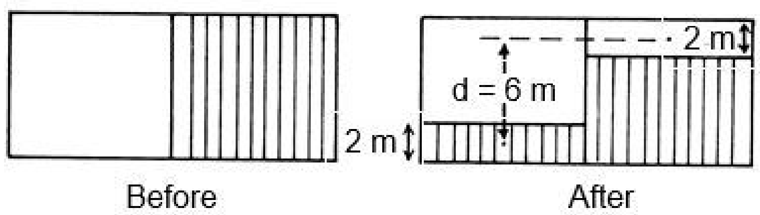
n = 4, So FSC = 0.996 / n^2 = 0.996 / 16 = 0.062 m

Note: The answers arrived at above are the same as the answers obtained in each example wherein the FSC was calculated separately for each compartment and then added together.

The effect of the breadth of a slack tank on the FSC is a very important factor to consider when deciding on the action to take when a ship has a very small, or negative, GM.

Example 10

A vessel of 10000 t displacement, KM 9.3 m, KG 7.3 m, has two rectangular, identical deeptanks, Port and Starboard, each 15 m long, 10 m wide and 8 m deep. The starboard deep tank is full of SW while the port deep tank is empty. Calculate the GM of the ship when one quarter of the water in the starboard deep tank is transferred to the port deep tank.



Mass of SW in tank = Volume of SW x density of SW = 15 x 10 x 8 x 1.025 = 1230 t

Mass of water transferred = ¼ (1230) = 307.5 t

$GG_1\downarrow$= dw / W = 6 x 307.5 / 10000 = 0.185 m

Old KG	=	7.300 m
$GG_1\downarrow$	=	0.185 m
New KG	=	7.115 m
KM	=	9.300 m
Solid GM	=	2.185 m

FSC for port tank = i di / W = (lb^3 x di)/ (12 x W) = (15 x 10^3 x 1.025) / (12 x 10000)

FSC for port tank	= 0.128 m
FSC for stbd tank	= 0.128 m
Total FSC for P & S	= 0.256 m

Alternate method:

FSC if tank is undivided = (LB^3 x di) / (12 x W) = (15 x 20^3 x 1.025) / (12 x 10000)= 1.025 m

FSC when n = 2, both sides slack = 1.025 x (1/ n^2) = 1.025 / 4 = 0.256 m

Solid GM	=	2.185 m
FSC	=	0.256 m
Fluid GM	=	1.929 m

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Exercise 10

Free surface effect

1. On a ship of W 5000 t, a tank is partly full of DO of RD 0.88. The moment of inertia of the tank about its centre line is 242 m^4. Find FSC. (Answer: 0.043 m).

2. If the tank in question 1 was partly full of SW instead of DO, find the FSC. (Answer:0.050 m).

3. On a ship of W 6000 t, KM 7.4 m, KG 6.6 m, a double bottom tank of 'i' 1200 m^4 is partly full of FW. Find the GM fluid. (Answer: 0.600 m).

4. Given the following details, find the GM fluid: W = 8800 t, tank of 'i' 1166 m^4 is partly full of HFO of RD 0.95, KM 10.1 m, KG 9.0 m. (Answer: 0.974 m).

5. On a vessel of W 16000 t, no: 4 port DB tank 20 m long and 8 m wide is partly full of DW ballast of RD 1.010. Find the FSC. (Answer: 0.054 m).

6. A vessel has a deeptank on the starboard side 12 m long 9 m wide which is partly full of coconut oil of RD 0.72. If W = 12000 t, KM = 9 m and KG = 8.5 m, find the GM fluid. (Answer: 0.456 m).

7. A vessel displacing 8000 t, has a rectangular deep tank 10 m long 8 m wide and 9 m deep full of SW. The KM is 7 m and KG 6.2 m. Find the GM when ⅓ of this tank is pumped out. **Note**: Since the dimensions of the tank are given, change of KG of tank due to change of sounding must be considered. (Answer: 0.785 m).

8. A ship of W 5000 t has a tank 16 m long, 10 m wide and 4 m deep which is empty. KM is 7.2 m and KG 7.0 m. Find the GM fluid if 400 t of oil of RD 0.95 is received in it. (See note under previous question). (Answer: 0.386 m).

9. A vessel has two deep tanks, P & S, each 12 m long, 5 m wide & 8 m deep. The port side is full of SW while the starboard side is empty. W = 9840 t, KM = 8.5 m, KG = 8.0 m. Find the GM fluid if SW is transferred from P to S until each tank has equal quantity of ballast. (Answer: 0.574 m).

10. Ship of W 10000 t, KM 9.9 m. Its present condition:

Tank	KG	i	Liquid	RD	Remarks
FP Tank	6.3	10	SW	1.025	Full
No 1 DBT	1.15	420	HFO	0.95	Slack
No 2 P	0.65	720	HFO	0.95	Slack
No 2 S	0.65	720	HFO	0.95	Empty
No 3 P	0.65	240	SW	1.025	Full
No 3 S	0.65	240	SW	1.025	Slack
No 3 C	0.60	1200	HFO	0.95	Full
No 4 P	0.70	300	FW	1.00	Slack
No 4 S	0.70	300	FW	1.00	Slack
No 5 P	0.85	180	DO	0.88	Slack
No 5 S	0.85	100	HFO	0.95	Full
AP Tank	8.80	20	SW	1.025	Empty

If final KG is 8.954 m, find final GM fluid. (Answer: 0.737 m).

11. Ship in question 10, transfers HFO from No: 1 DBT to No: 2 P such that No: 2 P becomes full, while No: 1 remains partly full. Find final GM fluid if the final KG is 8.950 m. (See following notes).

Note 1: It is not necessary to rework the entire problem. Just make the changes to the final part of the working of question 10, as shown here.

Note 2: Where a tank was originally slack but has now become full or empty, its FSM must be subtracted from the final FSM in question 10.

Note 3: When a tank was originally empty or full but has becomes slack, its FSM must be added to final FSM obtained in question 10. The fluid GM can now be computed as usual.

Final FSM in Question 10	2087.4 tm
No 2 DBT is now not slack	-684.0 tm
Final FSM for this question	1403.4 tm

(Answer: 0.810 m).

12. Vessel in the same condition as in question 10, transfers SW ballast from FP into No 3S & into AP, such that No 3S becomes full while FP & AP remain partly full. Find the GM fluid if final KG is 8.880 m. (Answer: 0.833 m).

13. Vessel in the same condition as in question 10, consumes the following while on passage:

Item	Weight	From
All the HFO	200 t	No: 1 DB
Half the HFO	100 t	No: 3 C
All the FW(total)	200 t	No 4 P & S

Find fluid GM on arrival next port.

Note 4: Find KG on arrival by taking moments about keel, as explained in chapter 7, and add an extra column for changes in FSM, as shown here.Bear in mind notes 1, 2 & 3, under question 11.

Remarks	Loaded (t)	Dischd (t)	KG (m)	Moment by K L (tm)	D (tm)	FSM (tm)
Ship in Q 10	10,000		8.954	89,540		2,087.4
No. 1 DB		200	1.150		230	-399.0
and so on.						

Note 5: When dealing with several tanks, as in a ship's calculation such as this, the change of KG of a tank due to change in its sounding may be ignored. This is the actual practice at sea.

For example: When ½ the HFO (i.e. 100 t) from No 3C is consumed, the moment of the discharged weight about keel would be 100 x 0.6 = 60 tm. (Answer: 0.285 m).

14. Vessel in the same the condition as in question 10, consumes the following on passage:

Item	Weight	From
All the HFO	150 t	No: 2 P DBT
Part HFO	50 t	No: 3 C DBT
All the FW (total)	100 t	No 4 S DBT

Find GM fluid on arrival port. (Answer: 0.458 m).

15. Vessel in the same condition as in question 10, loads 1000 t cargo in No: 2 LH KG 4 m; 2000 t cargo in No: 4 LH KG 5 m. Find final GM fluid, given that the final KM is 10.0 m. (Answer: 1.874 m).

16. A ship of 5000 t displacement has a DB tank 18 m long and 12 m wide, partly full of SW. Find the FSC in the following cases:

Note: Use of $1/n^2$ would be a very quick method.

(a)		If the tank is undivided. (Answer: 0.531 m)
(b)		If the tank is divided into identical P & S watertight divisions and
	(i)	Both sides are slack. (Answer: 0.133 m)
	(ii)	Only one side is slack. (Answer: 0.066 m)
(c)		If the tank is divided into P, S & C identical watertight divisions and
	(i)	All three of these are slack. (Answer: 0.059m)
	(ii)	Only two of these are slack. (Answer: 0.039m)
	(iii)	Only one of these is slack. (Answer: 0.020m)
(d)		If the tank is divided into four identical watertight divisions – Port inner, Port outer, Stbd inner, Stbd outer – and:
	(i)	All four of them are slack. (Answer: 0.033 m)
	(ii)	Any three of them are slack. (Answer 0.025m)
	(iii)	Any two of these are slack. (Answer: 0.017m)
	(iv)	Any one of these is slack. (Answer: 0.008 m)

17. A ship of 10000 t displacement has a FW DB tank which is 20 m long and divided into P, S and C watertight divisions. The P & S divisions are each 4 m wide, while the C division is 12 m wide. Calculate the FSC in the following cases:

Note: $1/n^2$ cannot be used here as the divisions are <u>not</u> identical.

(a) Only the port side tank is slack. (Answer 0.011m)

(b) Both P and S tanks are slack. (Answer: 0.021m).

(c) Only the centre tank is slack.(Answer: 0.288 m).

(d) All 3 tanks (PS&C), are slack. (Answer 0.309 m).

(e) If all the three divisions were not separate but formed one undivided tank 20 m broad. (Answer: 1.333 m).

18. A ship has a very small GM. It is decided to fill up SW ballast, one tank at a time, in six tanks:

Tank	i about tank's centre line (m^4)
No 1 DB	280
No 2 P or S	600
No 3 P or S	350
No 3 C	650

State the order in which the tanks must be filled to keep FSC at a minimum at all times.

(Answer: No: 1, No. 3 any one side, No. 3 other side, No. 2 any one side. No. 2 other side, No. 3 C).

19 .An unstable vessel is at her angle of loll. The following tanks are available for SW ballast:

Tank	i about tank's centre line(m^4)
No 1 DB	400
No 2 P	700
No 2 S	700
No 4 P	250
No 4 S	250
No 4 C	800

It is decided to ballast three tanks with SW, one at a time. What order should be followed to keep FSE minimum? (Answer: No: 4 wing tank on lower side, No: 4 wing tank on higher side, No: 1 DB tank).

20. A ship of W 8000 t, KM 7.9 m, KG 7.0 m, has a tank 15 m long & 12 m wide, partly full of HFO RD 0.95.

(a) Find the moment of statical stability at 6º heel.

(b) If the BM is 4.9 m, find the moment of statical stability at 20º heel if the ship is wall-sided.

(Answer:(a) 537.7 tm (b) GZ 0.331 m, RM 2648 tm).

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13. LIST

List is the transverse inclination caused when the COG of the ship is off the centre line.

For a ship to be in static equilibrium, the forces of buoyancy and gravity must cancel each other out. In other words, for a ship to be in static equilibrium:

(i) The force of buoyancy must equal the force of gravity and

(ii) The COB & COG of the ship must be in a vertical line, as shown in figure A.

If the COG is moved out of the centre line of the ship, due to asymmetrical loading or discharging or due to transverse shift of weights aboard as shown in figure B:

(i) The ship will sink or rise as necessary until the force of buoyancy equals the force of gravity and

(ii) The forces of buoyancy and gravity will form a couple which will cause the ship to incline until the COB comes vertically below the COG as illustrated in figure C.

In the following figures, GG_1 is the transverse shift of COG. The couple formed by the forces of gravity and buoyancy causes the ship to incline. As the ship inclines, the COB shifts to the lower side, as explained in chapter 9, and when it comes vertically under G_1, the ship would be in static equilibrium. The angle when this happens is the list - θ in figure C.

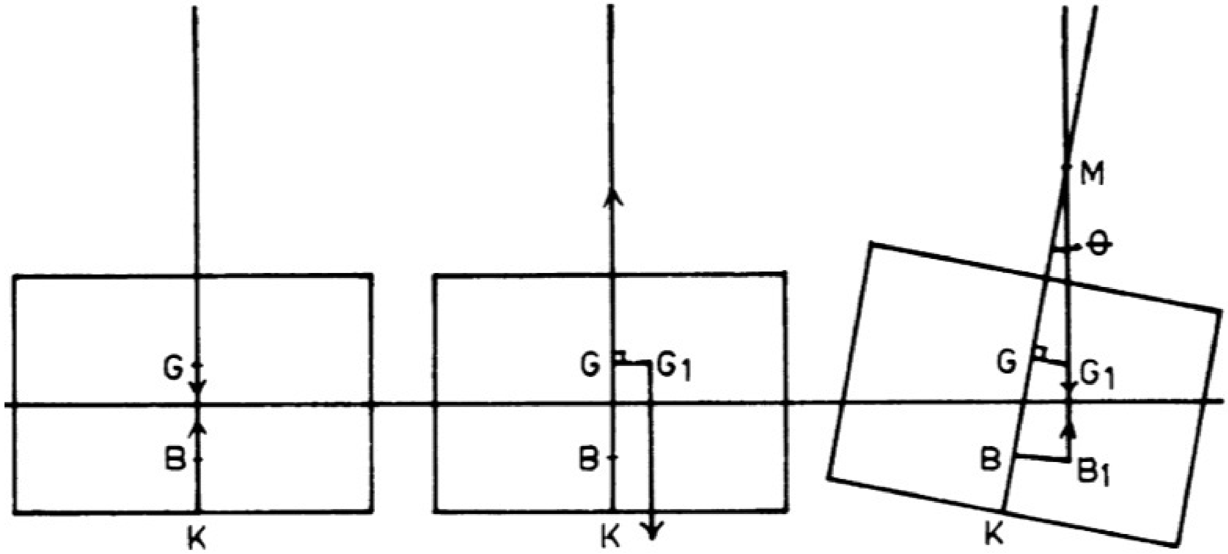


FIG. A FIG. B FIG. C

In right-angled triangle MGG_1

Tan θ = GG_1 / GM

where

θ is the angle of list.

GG_1 is the transverse shift of G.

GM is the fluid GM before listing.

Since GG_1 = dw / W , the formula becomes

Tan θ = dw / W.GM

where

θ is the angle of list.

dw is the final listing moment in tonne-metres.

W is the final displacement in tonnes.

GM is the final fluid GM in metres.

In order to calculate the angle of list systematically, the following order of work is suggested:

(i) Find the final listing moment (dw).

(ii) Find the final displacement (W).

(iii) Find the final fluid GM.

(iv) Apply the list formula Tan θ = dw / W.GM.

Example 1

On a ship of W 5000 t, GM 0.8 m, 40 t of cargo is shifted transversely by 10 m. Find the list.

Final listing moment = dw = 10 x 40 = 400 tm.

W & GM remain unchanged.

Tan θ = dw / W.GM = 400 / (5000 x 0.8) = 0.1

Hence, θ = 5.71° or 5° 43'.

Example 2

On a ship of W 8000 t, KG 7.0 m, KM 7.5 m, 100 t of cargo is loaded on the upper deck (KG 9.2 m) 2 m to port of the centre line. Find the list.

Final listing moment = dw = 2 x 100 = 200 tm to port

Final W = 8000 + 100 = 8100 t.

GG_1↑= wd / W = 100 x 2.2 / 8100= 0.027 m

KG	=	7.000 m
GG_1↑	=	0.027 m
Final KG	=	7.027 m
KM	=	7.500 m
Final GM	=	0.473 m

Tan θ = dw / W.GM = 200 / 8100 x 0.473 = 0.05220

Hence θ = 2.99° or 2° 59' to port

Example 3

A ship of W 10000 t, KM 7.0 m, KG 6.0 m works cargo as follows:

Loads 800 t in No 2 LH (KG 3.75) 4 m to P of the CL

Loads 600 t in No 4 LH (KG 6.0 m) 8 m to S of the CL

Discharges 400 t from upper deck (KG 10.0 m) 2 m to P of the CL.

If the FSM is 4400 tm, find the final list.

To find the FLM

Remarks	Weight (t)		dist off CL(m)	Listing mom (tm)	
	Loaded	Disch		Port	Stbd
Cargo 2 LH	800	-	4 m to P	3200	-
Cargo 4 LH	600	-	8 m to S	-	4800
Cargo UD	-	400	2 m to P	-	800
			Total	3200	5600
					-
					3200
				FLM =	2400

To find the final fluid GM

Remarks	Weight (t)		KG	Moment by keel (tm)	
	Loaded	Disch		Loaded	Disch
Ship	10,000	-	6.00	60,000	-
Cargo 2 LH	800	-	3.75	3,000	-
Cargo 4 LH	600	-	6.00	3,600	-
Cargo UD	-	400	10.00	-	4000
Total	11,400	400		66,600	4000
	- 400			- 4000	
Final	11,000		Final	62,600	

$$\text{Final KG} = \frac{62,600}{11,000} = 5,691 \text{ m}$$

Final KG = 62,600 / 11,000= 5,691 m

FSC = FSM / W = 4400 / 11000 = 0.4 m

To find the list

Tan θ = FLM / W.GM = 2400 / 11000 x 0.909 = 0.24002

Hence, θ = 13.5° or 13°30’ to stbd.

Example 4

A ship of W 8000 t, GM 0.6 m, is listed 5º to starboard. How much of HFO must be transferred from No 2 S to No 2 P to upright the vessel, if the centres of the tanks are 7 m apart?

Tan θ = dw / W.GM or dw = W.GM. Tanθ

Hence, dw = 8000 x 0.6 x Tan 5° = 420 tm 7w = 420 or w = 60 t

Example 5

A ship of 15000 t W, KM 9.0 m, KG 8.7 m is listed 10° to port. She now loads 150 t of cargo 7 m above the keel and 4 m to starboard of the centre line. Find the final list.

To find the initial listing moment

Tan θ = dw / W.GM or dw = W.GM. Tan θ

Hence, dw = 15000 x 0.3 x Tan 10° = 793.5 tm
Hence, initial listing moment or ILM = 793.5 tm to Port
To find final listing moment

LM caused now	=	150 x 4	=	600.0 tm to stbd.
ILM			=	793.5 tm to port.
FLM			=	193.5 tm to port.

To find final W & fluid GM
Final W = 15000 + 150 = 15150 t
$GG_1\downarrow$= dw / W = 1.7 x 150 / 15150 = 0.017 m

Original KG	=	8.700 m
$GG_1\downarrow$	=	0.017 m
Final KG	=	8.683 m
KM	=	9.000 m
Solid GM	=	0.317 m
FSC	=	0.000 m
Fluid GM	=	0.371 m

To find the list
Tan θ = FLM / W.GM =193.5 / 15150 x 0.317= 0.04029
Hence, θ = 2.31° or 2°18' to port.

Example 6

A ship of W 16000 t, KM 9.0 m, KG 8.0 m is listed 7° to starboard. It then works cargo as follows:
Loads 1600 t cargo KG 4.5 m, 5.0 m to port
Loads 1400 t cargo KG 8.0 m, 4.5 m to stbd.
Discharges 1000 t KG 6.5 m, 1.0 from stbd.
Find how many tonnes of ballast must be transferred transversely to upright the vessel, if the P & S tank centres are 10 m apart.
Note: The vessel is required to be upright. Hence FLM must be zero. Since final KG is not asked here, it need not be calculated.

To find the FLM
ILM = W.GM.Tan θ = 16000 x 1 x Tan 7° = 1964.6 tm.

Remarks	Weight (t) Loaded	Disch	Dist from CL	Listing mom (tm) Port	Stbd
ILM	-	-	-	-	1964.6
Cargo	1600	-	5 m to P	8000	-
Cargo	1400	-	4.5 m to S	-	6300.0
Cargo	-	1000	1 m from S	1000	
				9000	8264.6
				-8264.6	
			FLM	735.4	

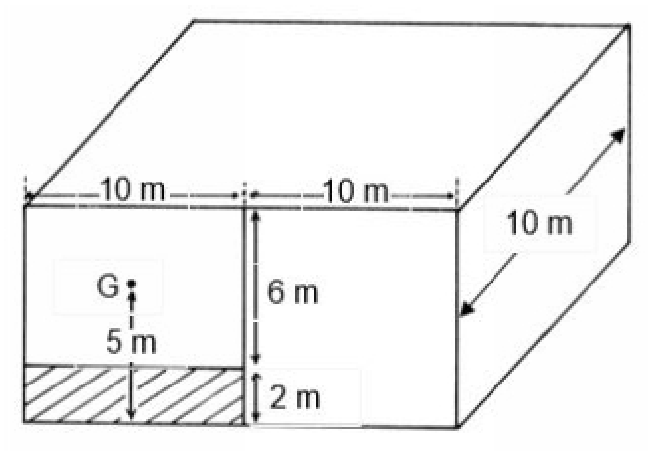
To upright vessel, required to cause a LM of 735.4 to starboard, by shifting ballast 10 m to port.

Hence, dw = 735.4 or 10 w = 735.4 or w = 73.54 t

Required to shift 73.5 t from P tank to S tank.

Example 7

A ship displacing 9000 t has KM 8.7 m, KG 7.2 m. She is now listed 8° to port. She has port and starboard deep tanks, each 10 m long, 10 m wide and 8 m deep. The port side deep tank, which was full of SW, is pumped out until its sounding is 2 m. If no other tanks on the ship are slack, find the final list.



To find the FLM

ILM = W. GM. Tan θ = 9000 x 1.5 x Tan 8° = 1897.3 tm to port

Weight of SW pumped out = 10 x 10 x 6 x 1.025 = 615 t

LM caused	=	615 x 5	=	3075.0 tm to stbd
ILM			=	1897.3 tm to port
FLM			=	1177.7 tm to stbd

To find the final fluid GM

(9000 x 7.2) – (615 x 5) = 8385 x Final KG

Final KG = 7.361 m

FSC = i di / W = (lb^3 / 12) x di / W = (10 x 10^3 x 1.025) /12 x 8385 = 0.102 m

KM	=	8.700 m
Final KG	=	7.361 m
Solid GM	=	1.339 m
FSC	=	0.102 m
Fluid GM	=	1.237 m

To find the list

Tan θ = FLM / W.GM =1177.7 / (8385 x 1.237) = 0.11354

Hence, θ = 6.48° or 6°29' to stbd

Example 8

A ship of 15000 t displacement, KM 8.6 m, KG 7.0 m, is to discharge a 100 t heavy lift from the centre line of No 2 LH (KG 2 m) by her jumbo derrick whose head is 20 m above the keel. The FSM (free surface moment) is 1000 tm. Find the list caused when the derrick swings the weight 14 m away from the centre line of the ship.

To find the FLM

FLM = dw = 14 x 100 = 1400 tm.

To find the final fluid GM

(When weight is hanging from derrick head)

GG_1↑= dw / W = (18 x 100) / 15000= 0.120 m

FSC = FSM / W = 1000 / 15000 = 0.067 m

Original KG	=	7.000 m
GG_1↑	=	0.120 m
New KG	=	7.120 m
KM	=	8.600 m
Solid GM	=	1.480 m
FSC	=	0.067 m
Fluid GM	=	1.413 m

To find the list

Tan θ = FLM / W.GM =1400/15000 x 1.413 = 0.06605

Hence θ = 3.78° or 3°47'

When the weight is hanging from the derrick with an outreach of 14 m, the list would be 3.78° or 3°47'.

Example 9

A ship of 8000 t displacement has a mean draft of 7.8 m and is to be loaded to a mean draft of 8.0 m. Her GM is 0.8 m and TPC is 20. She is listed 4° to starboard at present. How much cargo should be loaded into the port and starboard 'tween decks (centres 5 m & 6 m off the centre line respectively) for the ship to complete loading and finish upright?

Sinkage = 8.0 – 7.8 = 0.2 m = 20 cm

Can load = s x TPC = 20 x 20 = 400 t

ILM = W.GM. tan θ = 8000 x 0.8 x tan 4°

= 447.5 tm to stbd

Let the cargo to be loaded on the port side be x tonnes. Hence, the cargo to be loaded on the starboard side would be (400 – x) tonnes.

	Port	Stbd
ILM	-	447.5
Cargo on port side	5x	-
Cargo on stbd side	-	6(400-x)
Total	5x	447.5 + 6(400-x)

To finish upright, port LM = stbd LM.

Hence, 5 x = 447.5 + 6(400 – x)

Hence, x = 259 t (port side)

& (400 –x) = 141 t (stbd side).

Example 10

A ship of W 11000 t, KM 7.4 m, and KG 6.0 m is listed 4° to port. A heavy lift weighting 150 t is to be discharged from No 3 LH using the ship's jumbo derrick whose head is 23 m above the keel and whose heel is on the centre line. While in No 3 LH, the COG of the weight is 3 m above the keel and 5 m to port of the centre line. Find the list:

(i) As soon as the derrick lifts the load from the LH.

(ii) When the derrick has swung the load 15 m to starboard of the centre line.

(iii) After discharging the weight.

Tan θ = dw / W.GM or dw = W.GM.tan θ

Hence, ILM = 11000 x 1.4 x tan 4° = 1076.9 tm to port

Stage (i)

As soon as the derrick picks up the load, the COG of the weight shifts from LH (KG 3 m) to the derrick head (KG 23 m) i.e., d = 20 m upwards.

Since the GM changes, the list would change.

$GG_1\uparrow$= dw / W = (20 x 150) / 11000 = 0.273 m

Original GM	1.400 m
$GG_1\uparrow$	0.273 m
GM at stage (i)	1.127 m

Tan θ = LM / W.GM =1076.9 / (11000 x 1.127) = 0.08687

Hence, θ at stage (i) = 4.96° or 4° 58' to port.

Stage (ii)

When the derrick has swung out 15 m to S of the CL, the weight has travelled 20 m to S because it was originally lying 5 m to P of the CL.

LM caused = 20 x 150 = 3000.0 tm to stbd
ILM =1076.9 tm to port
FLM = 1923.1 tm to stbd

Tan θ = FLM / W.GM =1923.1 / 11000 x 1.127 = 0.15513

Hence, θ at stage (ii) = 8.82° or 8°49' to stbd.

Stage (iii)

As soon as the weight is discharged, the LM, GM and W change, causing the list to change.

Final W = 11000 – 150 = 10850 t

LM caused now = 15 x 150 = 2250.0 tm to port.
LM during stage (ii) = 1923.1 tm to stbd.
FLM = 326.9 tm to port.

KG of ship at stage (i) & (ii) = 06.273 m
Height of derrick head above keel = 23.000 m
d = 16.727 m

$$GG_1\downarrow = \frac{dw}{W} = \frac{16.727 \times 150}{10850} = 0.231 \text{ m}$$

GM during stages (i) & (ii) = 1.127 m
GM during stage (iii) = 1.358 m

Tan θ = FLM / W.GM = 326.9 / 10850 x 1.358 = 0.02219

Hence, Final θ = 1.27° or 1°16' to port

Exercise 11
List

1. On a ship of W 5000 t, GM 0.3 m, 20 t was shifted 5 m to port. Find the list. (Answer: 3.81° or 3° 49').

2. On a ship of W 8000 t, GM 2.0 m, if the following transverse shiftings were done, find the list:

200 t cargo shifted 4 m to stbd
100 t cargo shifted 2 m to port
100 t cargo shifted 4 m to port
50 t stores shifted 20 m to stbd

(Answer: 4.29° or 4° 17' to stbd).

3. If 200 t was shifted down by 10 m and to stbd by 5 m on a ship of W 10000 t, KG 7.0 m, KM 7.4 m, find the list. (Answer 9.46° or 9° 28' to stbd).

4. A quantity of grain estimated to be 100 t shifts transversely by 12 m and upwards by 1.5 m, on a ship of W 12000 t, GM 1.2 m. Find the list caused. (Answer: 4.81° or 4° 49').

5. A ship displaces 4950 t and has KG 4.85 m, KM 5.79 m. Cargo weighing 50 t is loaded 1.25 m above the keel and 4 m to port of the centre line. Find the list. (Answer: 2.35° or 2° 21' to port).

6. 100 t is discharged from a position 2.45 m above the keel and 6 m to port of the centre line of a ship of W 10000 t, KM 8.25 m, KG 7.45 m. Find the list. (Answer: 4.63° or 4° 38' to stbd).

7. A ship of 10000 t displacement, KG 8.3 m carries out the following cargo operations:

Qty (t)	Loaded or discharged	KG (m)	Distance off centre line
200	D	10.0	5 m port
800	D	2.3	4 m stbd
500	D	5.2	3 m port
250	L	8.0	Nil
250	L	12.0	Nil

If the final KM is 9.6 m, find the list. (Answer: 8.23° or 8° 14' to port).

8. A ship of W 9000 t, KG 8.3 m loads 600 t of cargo (KG 4.0 m, 3 m to port of the centre line) and discharges 400 t of cargo (KG 9.0 m, from 5 m to port of the centre line). 200 t of cargo is then shifted

upwards by 5 m and to starboard by 8 m. 300 t of cargo is then shifted 1 m downwards and 4 m to port. Find the list if the final KM is 8.95 m (Answer: 4.21° or 4° 13’ to stbd).

9. A ship of W 18000 t, KG 7.75 m, discharges 1500 t (6.0 m above the keel and 3 m port of the centre line) and loads 500 t (10 m above the keel and 4 m port of the centre line). Cargo was then shifted:

500 t upwards 2 m and to starboard 4 m;

800 t downwards 2 m and to port 3m.

If the final KM is 8.935 m, find the list. (Answer: 7.04° or 7° 03’ to stbd).

10. A ship listed 8° to port, displaces 12000 t and has KM 7.54 m KG 6.8 m. Find how many tonnes of SW ballast must be transferred from No 2 port DB tank to No 2 stbd DB tank, to upright in vessel, if the tank centres are 10 m apart. (Answer: 124.8 t).

11. A ship displacing 4000 t has GM 1.0 m (KM 10.0 m & KG 9.0 m) & is listed 10° to port. If 16000 t of cargo is now loaded on the CL and the final GM is 1.0 m (KM 9.0 m & KG 8.0 m), state whether the list would change. If yes, find the new list. (Answer: 2.02° or 2°01’ to port).

12. A ship of W 10000 t, GM 1.5 m, is listed 5° to stbd. If cargo is shifted vertically until her final GM is 0.5 m, state whether the list would change. If yes, find the new list. (Answer: 14.71° or 14° 42’ to stbd).

13. A ship of W 8500 t, KM 9.0 m, KG 8.3 m, is listed 8½° to stbd. Cargo was worked as follows:

200 t discharged KG 4 m from 5 m stbd of CL.

300 t discharged KG 5 m from 2 m port of CL

100 t loaded KG 2 m, 4 m to stbd of CL.

200 t shifted up by 2 m and port by 3 m.

If the final KM is 9.3 m, find the final list. (Answer: 2.56° or 2°33’ to stbd).

14. A ship of 15000 t displacement, KG 8.7 m, KM 9.5 m, is listed 10° to port. Cargo work carried out:

500 t loaded, KG 8.0 m, 5 m stbd of CL.

300 t discharged, KG 4.0 m, 4 port of CL.

Find the quantity of SW ballast that must be transferred transversely to bring the vessel upright, the tank centres being 12 m apart.

(Note: Since ship is to be upright, calculation of final KG or GM is not necessary here). (Answer: 132 t from stbd. to port).

15. A bulk carrier presently of 12250 t, KM 9.8 m, KG 9.0 m is listed 6½° to stbd. It then loads 1250 t of ore (KG 8 m, 2 m to stbd of CL) & discharges 250 t of ore (KG 2 m, 5 m from stbd of CL. 160 t of SW ballast is then transferred from the stbd shoulder tank to the port DB tank (vertically downwards by 9 m & transversely by 10 m). Find the final list, assuming FSM = 0 & final KM = 9.6 m. (Answer: 4.93° or 4°56' to stbd).

16. From a ship of W 8000 t, KM 8.6 m, KG 8.0 m, some deck cargo was washed overboard (KG 10 m, 8 m from the centre line). If the resultant list is 3°, find the quantity of cargo lost. (Answer: 31.7 t).

17. A ship of W 16000 t, KM 7.5 m, KG 6.0 m, TPC 25, is listed 3° to port. The mean draft is 8.6 m and it is to finish loading at 8.8 m. Spaces are available 5 m off the centre line, on either side. State how much cargo to stow on each side to finish upright. (Answer: Port side 124.2 t; Stbd side 375.8 t).

18. A ship displacing 12000 t has KM 9.0 m, KG 7.25 m. A 200 t heavy-lift is to be loaded by ship's jumbo whose head is 24 m above the keel. Find:

(i) The list when the derrick picks up the load from the wharf on the stbd side with an outreach of 15 m. (Answer: 9.46° or 9°28' to stbd).

(ii) The list when the weight is placed on the upper deck KG 10 m, 7 m to stbd of the centre line. (Answer: 3.85° or 3°51' to stbd).

19. A ship of W 10000 t, KM 7.3 m, KG 6.8 m, is listed 5° to port. A heavy-lift weighing 100 t, lying 6 m to port of the centre line and KG 10.0 m, is to be shifted to the lower hold KG 2.0 m on the centre line of the ship, by the ship's jumbo derrick whose head is 28 m above the keel. Find:

(i)The list as soon as the derrick takes the load. (Answer: 7.78° or 7°47' to port).

(ii) The list when the derrick swings the load to the centre line. (Answer: 2.91° or 2°55' to stbd).

(iii) The list after the shifting is over. (Answer: 1.61° or 1° 36' to stbd).

20. A ship of W 13000 t, KM 8.75 m, KG 8.0 m, has a list of 6° to starboard. A heavy-lift weighting 150 t, lying on the upper deck 9 m above the keel and 5 m to stbd of the centre line, is to be discharged

using the ship's jumbo derrick whose head is 22 m above the keel. Calculate:
(i) The list as soon as the load is taken by the derrick. (Answer: 7.48° or 7°29' to stbd).
(ii) When the load is hanging over the port side of the ship with an outreach of 10 m from the centre line. (Answer: 8.93° or 8°56' to port).
(iii) After discharging the heavy-lift. (Answer: 1.61° or 1° 36' to stbd).

21. A ship of 10000 t displacement is floating in SW and has KM of 10.8 m and KG of 9.0 m. She is listing 10° to stbd. She has two rectangular deep tanks, one on either side, each 12 m long, 12 m wide and 9 m deep. The stbd tank is full of FW

while the port one is empty. If FW is to be transferred from the stbd tank to the port one, find:
(i) The quantity of FW to transfer to bring the ship upright. (Answer: 264.5 t).
(ii) The list if one third of the original FW in the stbd tank is transferred to the port tank.
Note: Fluid GM should be used here. (Answer: 6.69° or 6°42' to port).

22. On a ship 8000 t displacement, 50 t is shifted transversely by 4 m. Find the list if the total FSM is 1216 tm, KM 7.0 m, KG 6.4 m. (Answer: 3.19° or 3°12').

23. A ship has W 10000 t, KM 7.8 m, KG 7.075 m, and is upright. No 3 P and S DB tanks are full of HFO RD 0.95. Each tank is rectangular, 15 m long, 12 m wide and 2 m deep. Calculate the list when HFO is consumed from No 3 S until the sounding is 1.2 m. (Answer: 10.69° or 10°41' to port).

24. A vessel displacing 9000 t has KM 8.02 m, KG 7.5 m, and is upright. She loads 250 t KG 12 m, 3 m to stbd of the centre line; loads 1000 t KG 3 m, 1 m to port of the centre line; discharges 250 t KG 8 m, 2 m to stbd of the centre line. 100 t of cargo is then shifted transversely 3 m to stbd. If the total FSM is 1200 tm, calculate the final list. (Answer: 3.43° or 3°26' to port).

25. A ship of W 14000 t, KM 9.0 m, KG 7.8 m, total FSM of 2100 tm, is listed 8° to port. How many tonnes of ballast must be shifted transversely by 10 m to upright the ship? (Answer: 206.6 t to stbd).

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14. STIFF AND TENDER VESSELS

	STIFF VESSEL	TENDER VESSEL
1.	A stiff vessel is one with an unduly large GM for her type, size and nature.	A tender vessel is one with a small GM for her type, size and nature.
	Note: Type refers to general cargo, bulker, tanker, etc., while nature refers to peculiarities of the vessel.	
2.	Angle and period of roll is small.	Angle and period of roll is large.
3.	Rolling is violent and irregular.	Rolling is smooth and regular.
4.	Uncomfortable for people on board because of jerky movements.	Less uncomfortable for people on board as movements are regular.
5.	Severe stresses set up on hull.	Less severe stresses set up on hull.
6.	General cargo likely to break loose due to jerky movements.	General cargo, once secured properly, is less likely to break loose.
7.	Bulk cargo less likely to shift as angle of roll is small.	Bulk cargo more likely to shift as angle of roll is large.

8.	No likelihood of vessel becoming unstable during passage owing to consumption of fuel and fresh water from DB tanks and due to FSE of tanks in use.	Likelihood of vessel becoming unstable during passage owing to consumption of fuel and fresh water from DB tanks and due to FSE of tanks in use.
9.	Greater ability to withstand loss of GM, if any, caused by bilging.	Less ability to withstand such loss of GM.
	Note: Bilging is the flooding of a compartment, as a result of damage, whereby water has free access in and out.	
10.	Greater ability to withstand transverse shift of cargo – list caused by such shift is small.	Less ability to withstand transverse shift of cargo – list caused by such shift is large.

Note: As explained in the previous chapter:

$$\text{Tan } \theta = dw / W.GM$$

It is obvious from the foregoing formula that the list caused varies inversely as the GM fluid. Considering identical circumstances, the list resulting from transverse shift of cargo will be less if the vessel is stiff and much more if the vessel is tender.

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15. STABILITY OF VESSELS WITH DECK CARGO OF TIMBER

A vessel with a considerable quantity of timber as deck cargo is likely to be tender at the commencement of the voyage itself, owing to the weight loaded so high up on the ship.

On passage, the GM will decrease further owing to the following reasons:-

1. Consumption of fuel oil and fresh water from double bottom tanks.
2. Free surface effect of tanks in use.
3. Absorption of water by the timber on deck.

This depends on:

(a) Type of wood – teak, oak, pine, etc.

(b) Nature of timber – logs, blocks, planks, boards etc., - the greater the surface area exposed, the greater the absorption.

(c) Age of timber – new timber would contain sap and hence not absorb much water whereas old timber would be dry and can absorb more.

(d) The amount of precipitation and spray experienced. In the case of spray, the absorption may be asymmetrical – more on the windward side than on the leeward side.

In view of the foregoing points, the amount of water absorbed is variable and though it can be as high as 30% of the weight of the timber, it is generally around 10 to 15% or so. This is equivalent to adding weight on deck, thereby causing a rise of the centre of gravity of the ship.

A vessel with a deck cargo of timber, therefore, becomes less and less stable, possibly unstable, during the passage. It may not be possible to increase the metacentric height before departure from the port, owing to lack of deadweight available – the vessel may already be down to her loadline.

In order to keep the vessel stable at all times, the following precautions should be taken:

i) Plan cargo stowage in lower holds and tweendecks in such a manner as to have as large a metacentric height as possible.

ii) Ensure that the number of slack tanks is kept to minimum and restricted to those tanks with minimum moment of inertia about the tank's centerline.

iii) During the passage, use fuel oil and fresh water first from the slack tanks until they are completely empty.

iv) During the passage, fill up adequate ballast tanks, one at a time, those with smallest 'i' first, as and when the fuel oil and fresh water tanks get empty, ensuring that the vessel does not get overloaded at any time.

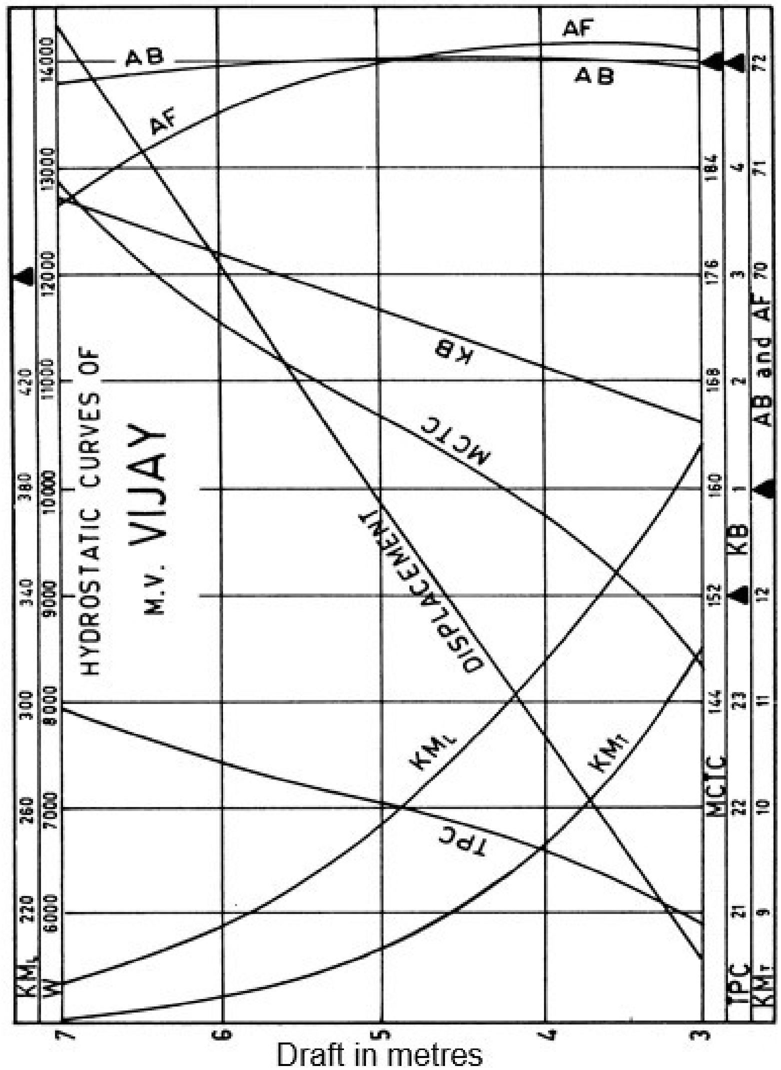
16. HYDROSTATIC CURVES

The hydrostatic particulars of a ship consist of displacement, deadweight, tonnes per centimetre (TPC), height of COB above keel (KB), distance of COB from after perpendicular (AB) or from amidships (HB), height of transverse metacentre above keel (KM_T), height of the longitudinal metacentre above keel (KM_L), distance of centre of flotation from after perpendicular (AF) or from amidships (HF) and moment to change trim by one centimetre (MCTC).

Since each of these values depends on the draft of the ship, the hydrostatic particulars are given by the shipyard in the form of curves or tables plotted or tabulated against draft.

The foregoing terms have all been explained in earlier chapters except for the last three - KM_L, AF (or HF) and MCTC. These will be explained in detail in subsequent chapters.

All the hydrostatic curves of a ship may be given, by the shipyard, on a single sheet of graph paper wherein draft may be indicated on the Y-axis and centimetres on the X-axis. For each curve, one centimetre on the X-axis represents a different value, as illustrated herein. Some shipyards include, on the same graph, curves of additional information which are dependant on draft, such as wetted surface area, midship area, block coefficient, water-plane area coefficient, etc.



In this chapter, the working will be confined to the construction of one curve at a time. Problems based on the hydrostatic particulars as a whole are included in the next chapter.

For examination purposes, when you construct graphs, bear in mind the following points:

(i) Use the largest scale that will comfortably fit on the paper you have.

(ii) Indicate clearly the scale chosen by you on each axis.

(iii) Draw the curves to scale on ordinary paper. It is not necessary to use graph paper.

(iv) You need to draw the graphs only within the given limits, for example: if the drafts are given between 2 m and 8 m, it is not normally necessary for you to show drafts less than 2 m or more than 8 m on the graph.

Example 1

Construct a displacement curve from the following information:

Draft (m)	2	3	4	5	6
Displ (t)	1400	3200	5050	7000	9000

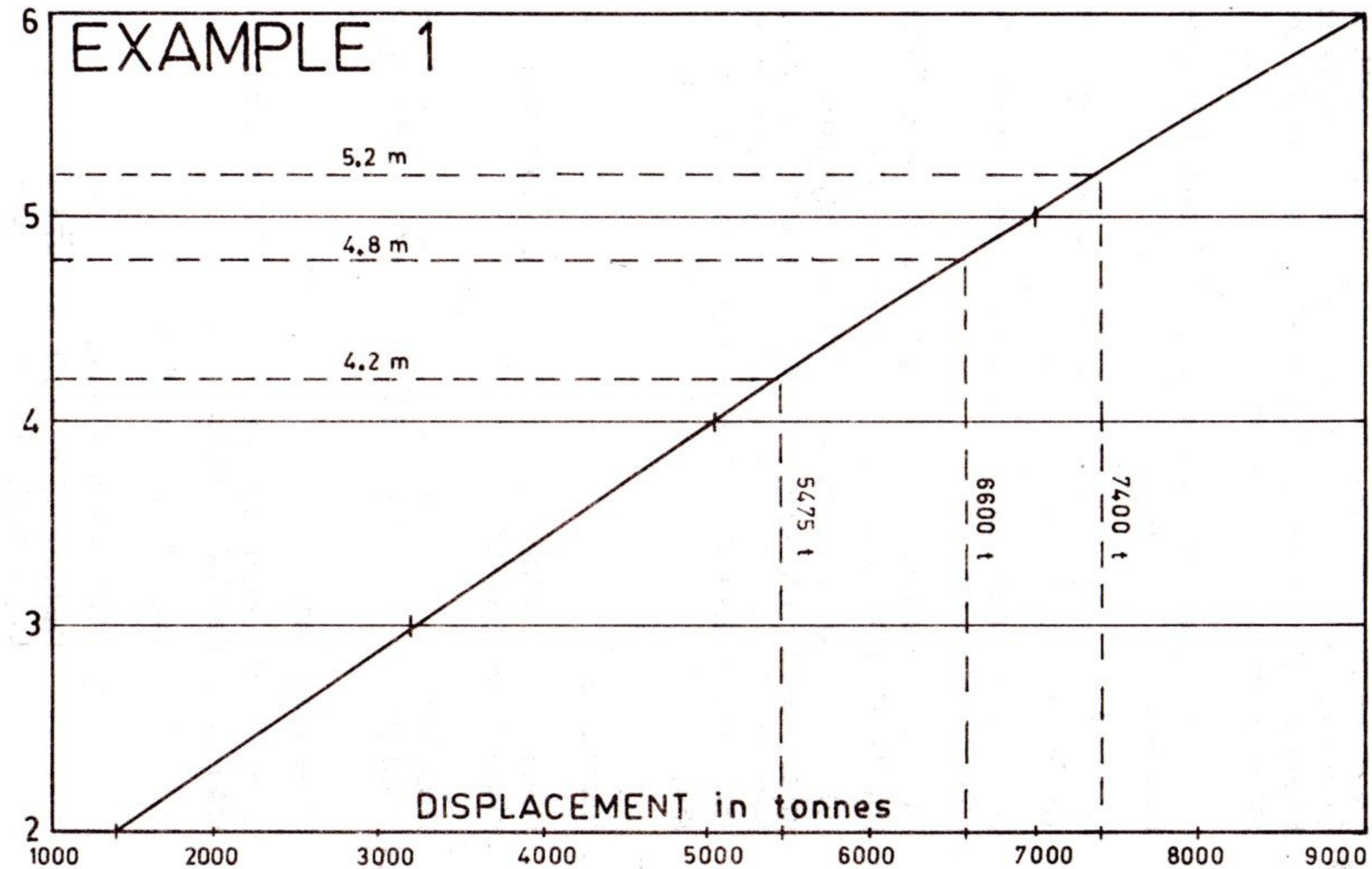
From your curve find:

(i) The DWT aboard at 4.2 m draft, if the ship's light displacement is 1300 t,

(ii) The TPC at 5 m draft.

Working:

Construct the curve as shown herein:


EXAMPLE 1
5,2 m
4,8 m
4,2 m
5475 t
6600 t
7400 t
DISPLACEMENT in tonnes
6
5
4
3
2
1000
2000
3000
4000
5000
6000
7000
8000
9000

Disp. at 4.2 m draft	=	5475 t
Light displacement	=	1300 t
DWT aboard ans (i)	=	4175 t

To find TPC:

Disp. at 5.2 m draft	=	7400 t
Disp. at 4.8 m draft	=	6600 t
40 cm draft change	=	800 t

1 cm draft change would cause 800/40 = 20 t
Hence, TPC at 5 m draft = 20.

Example 2

Construct a TPC curve from the following information:

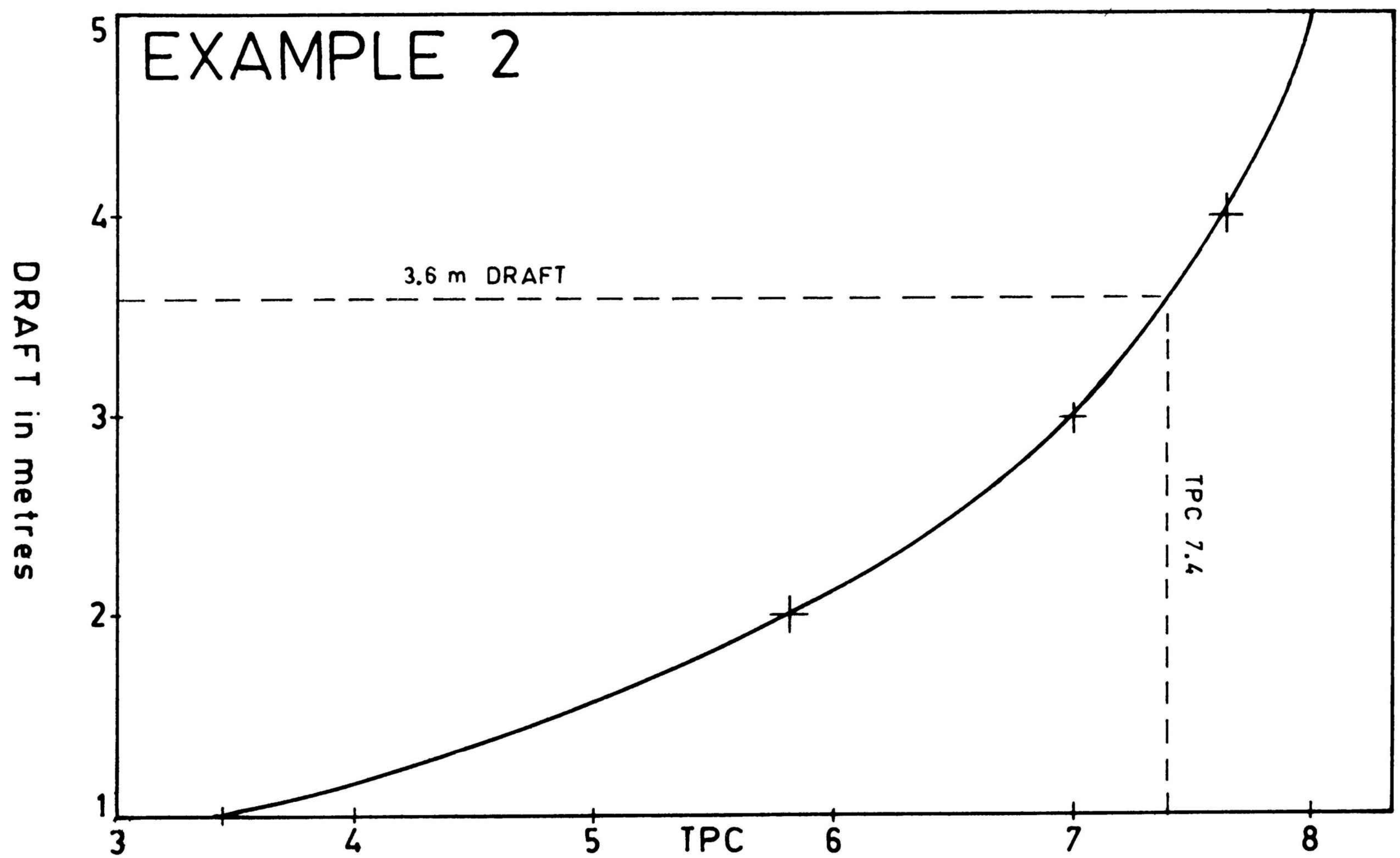
Draft	1	2	3	4	5
TPC	3.44	5.81	7.00	7.62	8.00

From your curve, find the area of the water plane at 3.6 m draft in SW.

Working:

Construct the TPC curve as shown on the next page.
From the curve, the TPC at 3.6 m draft = 7.4
Insert values in the formula: TPC = 1.025A/100
7.4 = 1.025A/100 = or A = 722 m^2

Hence, area of WP at 3.6 m draft = 722 m^2


EXAMPLE 2
3.6 m DRAFT
TPC 7.4
DRAFT in metres
TPC
1
2
3
4
5
3
4
5
6
7
8

Example 3

Construct a KB curve for a box-shaped vessel 150 m long, 18 m broad between 4 m and 9 m draft.

If the BM at 6 m draft is 4.5 m, and the KG of the vessel is 6.0 m, find the GM at that draft.

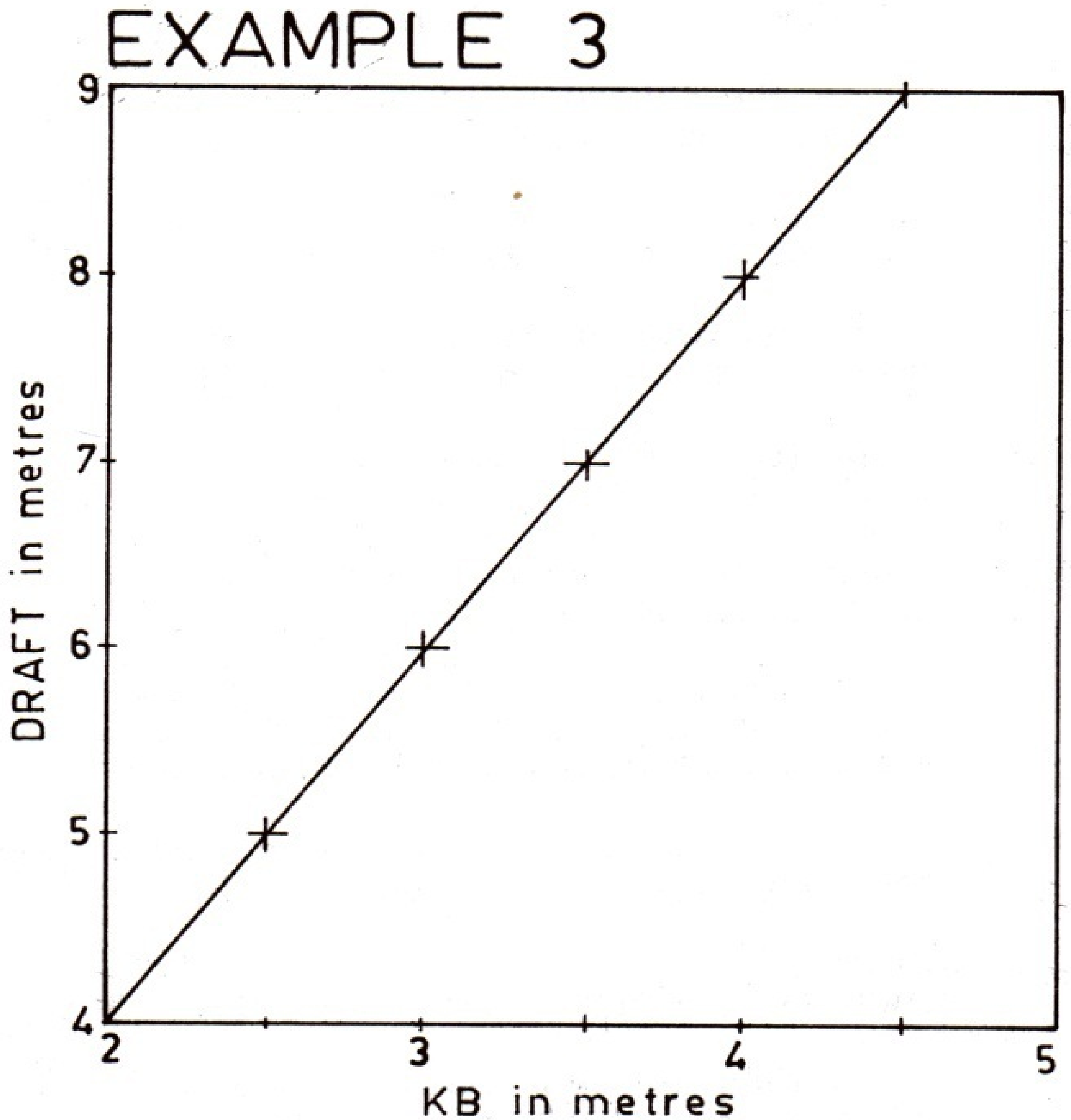
Working:

Since KB = ½ draft,

At 6 m draft KB	=	3.0 m
BM	=	4.5 m
KM	=	7.5 m
KG	=	6.0 m
GM	=	1.5 m

Data to construct the graph:

Draft (m)	KB (m)
4	2.0
5	2.5
6	3.0
7	3.5
8	4.0
9	4.5



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Exercise 12

Hydrostatic curves

1. Construct a displacement curve from the following information:-

Draft (m)	1	1.5	2	2.5	3
Disp (t)	330	1020	1950	2930	3850

From your graph, find:

(a) TPC at 2 m draft. (Answer: 19.5 tcm^{-1}).

(b) The draft when displacement is 3000 t. (Answer: 2.55 m).

2. Given the following information construct a displacement curve:-

Draft (m)	4	5	6	7	8
Disp (t)	7600	9800	12000	14300	16600

If the present draft is 5.4 m, and the load draft is 7.8 m, find the DWT available. (Answer: 5425 t).

3. Construct a displacement curve using the following data:

Disp (t)	770	1270	1800	2400	3100
Draft (m)	1	2	3	4	5

On arrival, the draft was 1.8 m. 2000 t of cargo was loaded and then 200 t of ballast was pumped out. Find the draft on sailing. (Answer: 4.85 m).

4. Construct a deadweight curve, given the following:

Draft (m)	2	3	4	5	6
DWT(t)	360	980	1680	2770	4080

(a) Find the DWT aboard at 4.75 m draft. (Answer: 2450 t).

(b) Find the TPC at 4 m draft. (Answer: 8.75 tcm^{-1})

(c) If the light displacement is 376 t, find the displacement at 5.4 m draft. (Answer: 3616 t).

5. Construct a TPC curve from the following:

Draft (m)	2	3	4	5	6	7
TPC	20.60	21.62	22.08	22.47	22.95	23.54

From your curve find the TPC at 6.6 m draft and at 3.3 m draft. (Answer: 23.26 tcm^{-1}, 21.78 tcm^{-1}).

6. Extract from a ship's hydrostatic particulars:

Draft (m)	1	2	3	4	5	6
TPC	58.90	62.30	63.0	64.60	65.32	65.86

a) Find the area of the water plane at 4.2 m draft. (Answer: 6317.1m^2).

b) At 4 m draft, the vessel loads 325 t of cargo. Find the new draft. (Answer: 4.054 m).

7. From the following information, construct a KB curve:

Draft (m)	1	2	3	4
KB (m)	0.667	1.333	2.0	2.667

If at 2.4 m draft the BM is 2.5 m, find the KM. (Answer: 4.100 m).

8. Construct a KB curve for a box-shaped vessel 50 m long and 12 m wide between the drafts of 1 m and 5 m. At 4 m draft the BM is 3 m. Find the KM. (Answer: 5.000 m).

9. From the following information, construct a KM_T curve:-

Draft (m)	2	4	6	8	10
KM_T (m)	16.0	9.86	8.44	8.25	8.62

From your graph, find:

(a) Find the minimum value of KM_T and the draft at which it occurs. (Answer: 8.2 m at 7.5 m draft).

(b) If the KG is 6.3 m, find the GM at 5.6 m draft. (Answer: 2.25 m).

10. Construct a KM_L curve of a ship having the following data:

Draft (m)	2	3	4	5	6	8	10
KM_L (m)	560	391	303	248	211	174	156

If the KG is 8 m, find the GM_L at 7 m draft. (Answer: 179 m).

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17. HYDROSTATIC TABLES

As mentioned in the previous chapter, the hydrostatic particulars of a ship may be given in the form of curves or tables plotted or tabulated against draft. Appendix I at the end of the book is the hydrostatic table of an imaginary general cargo ship M.V. 'VIJAY'. The following worked examples explain the use of hydrostatic tables. Extracts are given where necessary.

Example 1

Find the hydrostatic particulars of M.V. 'VIJAY' at a draft of 5.1 m in SW. (Extract given here).

DRAFT	W t in SW	TPC t cm-1	MCTC tm cm-1	AB m	AF m	KB m	KMT m	KML m
5.0	9891	22.06	165.7	72.014	71.913	2.685	8.686	254.3
5.2	10333	22.14	167.1	72.011	71.842	2.789	8.566	245.4

This is obtained by direct linear interpolation between the tabulated values against the drafts of 5.0 m and 5.2 m.

Required draft	=	5.100 m
Next below as per table	=	5.000 m
Difference from next below	=	0.100 m
Tabulated interval	=	0.200 m

	Draft	W	TPC	MCTC
Next below	5.0	9891	22.06	165.7
Next above	5.2	10333	22.14	167.1

From 5.0 to 5.2, tabular ratio for 5.1 m = 0.5

	Draft	W	TPC	MCTC
Tabular Difference	.2	442	.08	1.4
Interpolation ratio	x .5	x .5	x .5	x .5
Diff. from top line	.1	221	. 04	.7
Top line	5.0	9891	22.06	165.7
Next above	5.1	10112	22.10	166.4

	Draft	AB	AF	KB	KM_T	KM_L
Next below	5.0	72.014	71.913	2.685	8.686	254.3
Next above	5.2	72.011	71.842	2.789	8.566	245.4
Tab. Diff	.2	.003	.071	.104	.120	8.9
Int. ratio	x .5	x .5	x .5	x .5	x .5	x .5
Difference	.1	.002	.036	.052	.060	4.5
Top line	5.0	72.014	71.913	2.685	8.686	254.3
Reqd.Values	5.1	72.012	71.877	2.737	8.626	249.8

Note 1: W and KM_L may be worked to one decimal place and the others to three decimal places.

Note 2: In actual practice, the interpolation need not be shown so elaborately. Such interpolation may be done mentally, or in rough, or by a calculator and only the results shown.

Example 2

Find the hydrostatic particulars of M.V. 'VIJAY' at a displacement of 11762 t in SW. (Extract given here).

This is obtained by direct linear interpolation between the tabulated values against the SW displacements just below and just above the required value.

DRAFT	W t in SW	TPC t cm^{-1}	MCTC tm cm^{-1}	AB m	AF m	KB m	KM_T m	KM_L m
5.8	11672	22.37	171.3	71.977	71.586	3.102	8.298	223.0
6.0	12122	22.45	172.9	71.960	71.472	3.205	8.234	217.2

Required displacement	=	11762 t
Next below as per table	=	11672 t
Difference from next below	=	90 t
Tabulated interval	=	450 t

Interpolation ratio = 90 / 450 = 0.2

	W	Draft	TPC	MCTC
Next above	11672	5.8	22.37	171.3
Next below	12122	6.0	22.45	172.9
Tabular difference	450	0.2	.08	1.6
Interpolation ratio	x .2	x .2	x .2	x .2
Diff. from top line	90	.04	.016	.32
Top line	11672	5.80	22.370	171.3
Required values	11762	5.84	22.386	171.6

	W	AB	AF	KB	KM_T	KM_L
Next below	11672	71.977	71.586	3.102	8.298	223.0
Next above	12122	71.960	71.472	3.205	8.234	217.2
Tab. diff.	450	.017	.114	.103	.064	5.8
Int. ratio	x .2	x .2	x .2	x .2	x .2	x .2
Difference	90	.003	.023	.021	.013	1.2
Top line	11672	71.977	71.586	3.102	8.298	223.0
Required values	11762	71.974	71.563	3.123	8.285	221.8

Example 3

Find the displacement of m.v. 'VIJAY' when floating at a draft of 6.4 m in DW of RD 1.015.

From hydrostatic tables, 6.4 m SW draft, W = 13030 t.

At 6.4 m draft in SW, u/w volume = 13030/1.025 m^3

Hence, u/w vol of ship at 6.4 m draft in any water = 13030/1.025 m^3

At 6.4 m draft in DW RD 1.015,

W = (13030/1.025) 1.015 = 12902.9 t

Example 4

Find the draft of M.V. 'VIJAY' in DW of RD 1.010, at a displacement of 10650 tonnes.

Three methods of working this out are shown. The first one is more tedious but is very easy to understand. The second method is quicker to do, once the reasoning is understood. The third method is applicable only in this case, where displacement is given, and is hence not recommended for general use.

Alternative 1

Draft m	W in SW t	u/w vol m^3	W in DW of RD 1.010 t
5.2	10333	$\frac{10333}{1.025}$	$\frac{10333}{1.025} \times 1.010 = 10181.8$
5.4	10777	$\frac{10777}{1.025}$	$\frac{10777}{1.025} \times 1.010 = 10619.3$
5.6	11223	$\frac{11223}{1.025}$	$\frac{11223}{1.025} \times 1.010 = 11058.8$

The first two columns are taken from the hydrostatic table, while the next two are computed.

Interpolation is done between the first and last columns for the desired W of 10650 t in DW as shown here:

W in DW RD 1.010	Draft (m)
10619.3	5.400
11058.8	5.600
10650 t	5.414

Alternative 2

The underwater volume of a ship for a given draft is constant.

So at any draft,

W in SW x density of DW / 1.025 = W in DW (at same draft)

OR

W in SW = W in DW x 1.025 / density of DW (at same draft)

In this case,

W at same draft in SW = (10650 x 1.025) / 1.010 = 10808.2 t

Using the first two columns of the hydrostatic table, interpolate for W of 10808.2 t, as shown below:

W in SW (t)	Draft (m)
10777.0	5.400
11223.0	5.600
10808.2	5.414

Alternative 3

Entering the hydrostatic table with W of 10650 t, the draft and TPC, both for SW, can be obtained:

W	Draft (SW)	TPC (SW)
10333	5.2	22.14
10777	5.4	22.22
10650	5.343	22.197

FWA at 5.343 m SW draft = W / (40 TPC) = 10650 / (40 x 22.197) = 12 cm

DWA at 5.343 m SW draft= (1.025 – 1.010) / 0.025 x 12 = 7.2 cm = 0.072 m

SW draft for W 10650 t	= 5.343 m
DWA	= 0.072 m
DW draft for W 10650 t	= 5.415 m

Note: This method can be used only where W is given and draft in DW or FW is to be calculated. It cannot be used to find W accurately, given draft in DW or FW. This method is, therefore, not recommended for general use.

Example 5

Find the hydrostatic particulars of m.v. 'VIJAY' at 6.8 m draft in DW of RD 1.015.

From the hydrostatic table,

Draft	W in SW	TPC	MCTC	AB
6.8	13943	22.83	180.3	71.856
Draft	AF	KB	KM_T	KM_L
6.8	70.802	3.620	8.076	198.4

AB, AF, KB, KM_T and KM_L are functions of the ship's underwater volume and shape and are hence dependent on the draft only, not on the density of water displaced. Their values tabulated against draft hold good in any water, whether SW, FW or DW, for that draft.

However, W, TPC, and MCTC are functions of the draft and the density of water displaced. A correction would have to be applied, for the density of DW, to the tabulated values which are for SW.

Note: A simple thumb rule for quick thinking would be that, among all the hydrostatic particulars tabulated against draft, those given in metres hold good for that draft in water of any density whereas those given in other units (t, t cm^{-1}, tm cm^{-1}) are for SW and need correction for DW or FW.

As explained in detail in example 4, at any draft,

W in DW = (W in SW x density of DW) /1025 (at same draft)

At 6.8 m draft in DW, W = (13943 x 1.015) / 1.025 = 13807 t

The same correction for DW density must be applied to the tabulated TPC and MCTC. At 6.8 m draft in DW,

TPC= (22.83 x 1.015) / 1.025 = 22.607 t cm^{-1}

At 6.8 m draft in DW, MCTC = (180.3 x 1.015) / 1.025 = 178.541 tm cm^{-1}

Example 6

Find the hydrostatic particulars of M.V. 'VIJAY' at 12122 t displacement in FW. As explained in detail in example 4,

W in SW = (W in DW x 1.025) / density of DW (at same draft) = (12122 x 1.025) / 1= 12425 t.

Whereas the ship is displacing 12122 t of FW, it would displace 12425 t of SW at the same draft. The draft and the hydrostatic particulars may be interpolated for 12425 t of W in SW and the results obtained in two lots – the first lot requiring correction for density; the second lot being correct as it is.

At any draft, W in FW = (W in SW x 1) / 1.025

Hence, to convert SW W, TPC and MCTC to FW divide each by 1.025.

From hydrostatic table

	W	Draft	TPC	MCTC
In SW	12122	6.0	22.45	172.9
In SW	12575	6.2	22.54	174.6
In SW	12425	6.134	22.510	174.03
Corrn.	÷1.025		÷1.025	÷1.025
	12122	6.134	21.961	169.79

From hydrostatic table,

Draft	AB	AF	KB	KM_T	KM_L
6.000	71.856	70.802	3.620	8.076	198.4
6.200	71.939	71.329	3.309	8.180	211.6
6.134	71.946	71.376	3.275	8.198	213.4

These particulars, AB, AF, KB, KM_T and KM_L, hold good at 6.134 m draft in water of any density.

Example 7

M.V.'VIJAY', afloat at 3.8 m draft in SW, loads 3640 t of cargo and pumps out 810 t of ballast. Find the new draft.

From hydrostatic table, at 3.8 m draft W =	7277 t
Cargo loaded =	3640 t
	10917 t
Ballast out =	810 t
New W =	10107 t

Interpolating from hydrostatic table for W 10107 t,

W (t)	Draft (m)
9891	5.000
10333	5.200
10107	5.098

Example 8

Initial SW draft of M.V. 'VIJAY' was 5.4 m and the final SW draft was 4.7 m. Meanwhile 2000 t of ballast was pumped out. Find the amount of cargo worked.

From hydrostatic table, W at 5.4 m draft	=	10777 t
Ballast out	=	2000 t
W before cargo work	=	8777 t
From hydrostatic table, W at 4.7 m draft	=	9232 t
Hence, cargo loaded	=	455 t

Note: Though cargo work and deballasting may have been done simultaneously, it is easier to work it out as if the known quantity was handled first.

Example 9

M.V. 'VIJAY' arrives with a draft of 6.2 m in DW of RD 1.012. It is expected to load 2800 t of cargo and discharge 1098 t. Compute the ship's departure draft in (i) DW (ii) SW.

At 6.2 m draft

$$\text{W in DW} = \frac{\text{W in SW} \times 1.012}{1.025} = \frac{12575 \times 1.012}{1.025} = 12415.5 \text{ t}$$

Hence arrival W	=	12415.5 t
Cargo loaded	=	+2800.0 t
		15215.5 t
Cargo discharged	=	1098.0 t
Departure W	=	14117.5 t

From hydrostatic table,

W (t)	Draft (m)
13943 t	6.800 m
14402 t	7.000 m
14117.5 t	6.876 m

Hence, SW draft on departure = 6.876 m = answer (ii) To find the DW draft on departure, using hydrostatic table meant for SW, work as shown in example 4.

If draft is constant, u/w vol of a ship is also constant.

$$\frac{\text{W in SW}}{1.025} = \frac{\text{W in DW}}{\text{DW density}}$$

Hence, at same draft,

W in SW = (14117.5 x 1.025) / 1.012= 14298.9 t

If ship is displacing 14117.5 t of DW, she would displace 14298.9 t of SW, at same draft. So, entering the hydrostatic table with 14298.9 t, the draft can be obtained. This is the draft in DW at 14117.5 t W.

W (t)	Draft (m)
13943 t	6.800 m
14402 t	7.000 m
14298.9 t	6.955 m

Hence departure draft in

DW = 6.955 m answer (i)

in SW = 6.876 m answer (ii)

Example 10

On arrival port, M.V. 'VIJAY' had a draft of 6.6 m when RD was 1.010. On departure the draft and RD were 5.4 m and 1.020. Find the amount of cargo worked.

Arrival W	=	$\frac{13486 \times 1.010}{1.025}$	=	13288.6 t
Departure W	=	$\frac{10777 \times 1.020}{1.025}$	=	10724.4 t
Hence, cargo worked: discharged			=	2564.2 t

Exercise 13

Hydrostatic table

1. Find the hydrostatic particulars of M.V. 'VIJAY' at 4.72 m draft in SW. Answer:

Draft	RD	W	TPC	MCTC
4.72	1.025	9275.8	21.938	163.66
AB	AF	KB	KM_T	KM_L
72.016	71.987	2.535	8.894	268.0

2. Find the hydrostatic particulars of M.V. 'VIJAY' at a displacement of 7990 t in SW. Answer:

W	RD	Draft	TPC	MCTC
7990	1.025	4.130	21.665	158.972
AB	AF	KB	KM_T	KM_L
72.011	72.109	2.218	9.495	301.3

3. If the draft of M.V. 'VIJAY' is 5.0 m in DW of RD 1.005, find the displacement.

(Answer: 9698.0 t).

4. Find the displacement when M.V. 'VIJAY is at 5.63 m draft in water of RD 1.017.

(Answer: 11202.2 t).

5. Find the draft of M.V. 'VIJAY' when displacing 12650 t, in RD of DW is 1.009.

(Answer: 6.321 m).

6. At 10,000 t displacement, find the draft of M.V. 'VIJAY' in DW of RD 1.020.

(Answer: 5.071 m).

7. Find the hydrostatic particulars of M.V. 'VIJAY' at 5.0 m draft in DW of RD 1.015. Answer:

Draft	RD	W	TPC	MCTC
5.0	1.015	9794.50	21.845	164.083
AB	AF	KB	KM_T	KM_L
72.014	71.913	2.685	8.686	254.3

8. State the hydrostatic particulars of M.V. 'VIJAY' in FW at a draft of 6.1 m. Answer:

Draft	RD	W	TPC	MCTC
6.1	1.000	12047.3	21.946	169.512
AB	AF	KB	KM_T	KM_L
71.950	71.401	3.257	8.207	214.4

9. State the hydrostatic particulars of M.V. 'VIJAY' at 4.7 m draft in DW of RD 1.013. Answer:

Draft	RD	W	TPC	MCTC
4.7	1.013	9123.90	21.673	161.586
AB	AF	KB	KM_T	KM_L
72.017	71.992	2.525	8.910	269.0

10. Find the hydrostatic particulars of M.V. 'VIJAY' at 10,000 t displacement in FW. Answer:

W	RD	Draft	TPC	MCTC
10000	1.000	5.162	21.585	162.765
AB	AF	KB	KM_T	KM_L
72.012	71.855	2.769	8.589	247.1

11. M.V. 'VIJAY' is displacing 8576 t in DW of RD 1.018. State its hydrostatic particulars. Answer:

W	RD	Draft	TPC	MCTC
8576	1.018	4.427	21.663	160.386
AB	AF	KB	KM_T	KM_L
72.015	72.050	2.381	9.156	283.5

12. M.V. 'VIJAY' has a draft of 5.1 m in SW. It then loads 1800 t of cargo and takes on 400 t of bunkers and FW. Find its new draft.

(Answer: 6.084 m).

13. The arrival and departure drafts of M.V. 'VIJAY' were 4.6 m and 5.0 m in SW. In port, 1500 t of bunkers and FW was received. Find the amount of cargo worked and whether the cargo was loaded or discharged.

(Answer: 622 t discharged).

14. M.V. 'VIJAY' at 4.0 m draft in SW loads 5000 t of cargo and pumps out 800 t of ballast. Find its final draft.

(Answer: 5.905 m).

15. Initial draft of M.V. ‘VIJAY’ in DW of RD 1.010 is 5.3 m. She then loads 2500 t of cargo. Find its final draft (i) in the same dock. (ii) in SW.

(Answer: (i) 6.427 m (ii) 6.343 m).

16. M.V. ‘VIJAY’ is afloat in DW of RD 1.017 at 5.6 m draft. How much cargo can be loaded so that its draft will be 6.4 m in SW?

(Answer: 1894.6 t).

17. M.V. ‘VIJAY’ arrives outside a river port at a SW draft of 6.0 m. It is to cross a 5.4 m deep bar in the river RD 1.015. Find the minimum cargo to discharge into lighters, to cross the bar with an under-keel clearance of 0.4 m.

(Answer: 2327.5 t).

18. M.V. ‘VIJAY’ arrives at the port of Kochi (India) at 4.9 m draft in RD 1.006. On departure the draft was found to be 6.0 m – hydrometer reading 1.018. While in port, 2 heavy lifts weighting 200 t each were discharged. Find the amount of general cargo worked.

(Answer: Loaded 2947.5 t).

19. M.V. ‘VIJAY’ leaves Mumbai at 6.8 m draft in SW, bound for Kolkata. The owners want to know what would be the SW and the FW draft on arrival at the Kolkata pilot station. Can you calculate & give them the answer? Steaming time six days, consuming 20 t of fuel and 15 t of FW per day.

(Answer: 6.708 m, 6.858 m).

20. M.V. ’VIJAY’ is expected to arrive at a river port at a FW draft not exceeding 6.3 m. It is at present in DW of RD 1.020 at 5.4 m draft. Find the maximum amount of cargo that may be loaded at present, if the steaming time to the river port is eight days, daily consumption of fuel being 14 t and FW 16 t.

(Answer: 2005.8 t).

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18. HYDROSTATIC DRAFT

Hydrostatic draft (abbreviated in this book as hydraft) is the draft at the centre of flotation (COF or F). COF is the geometric centre of the waterplane area of the ship. It is the point about which she would pivot, when her trim is changed due to shifting a weight in the fore and aft direction, loading or discharging cargo. Hence COF is also called the tipping centre. The position of COF is given in the hydrostatic particulars of the ship by its distance forward of the after perpendicular (AF) or by its distance forward or abaft amidships (HF).

Trim is the difference between the drafts forward and aft.

The mean draft, or draft amidships, is the arithmetic mean of the draft forward and draft aft. In this book, H is the vertical axis through amidships.

Importance of hydrostatic draft is as follows:

Imagine a ship floating at an even keel draft of 6.0 m. This means that its draft at FP is 6.0 m and at AP also is 6.0 m. Draft at H (mean draft) and draft at F (hydraft) will both be 6.0 m. If the COF is situated amidships i.e., if F and H were coincident, the ship would pivot about F and the change of drafts at the forward and after perpendiculars would be the same in value but opposite in sign, as shown in figure 1.

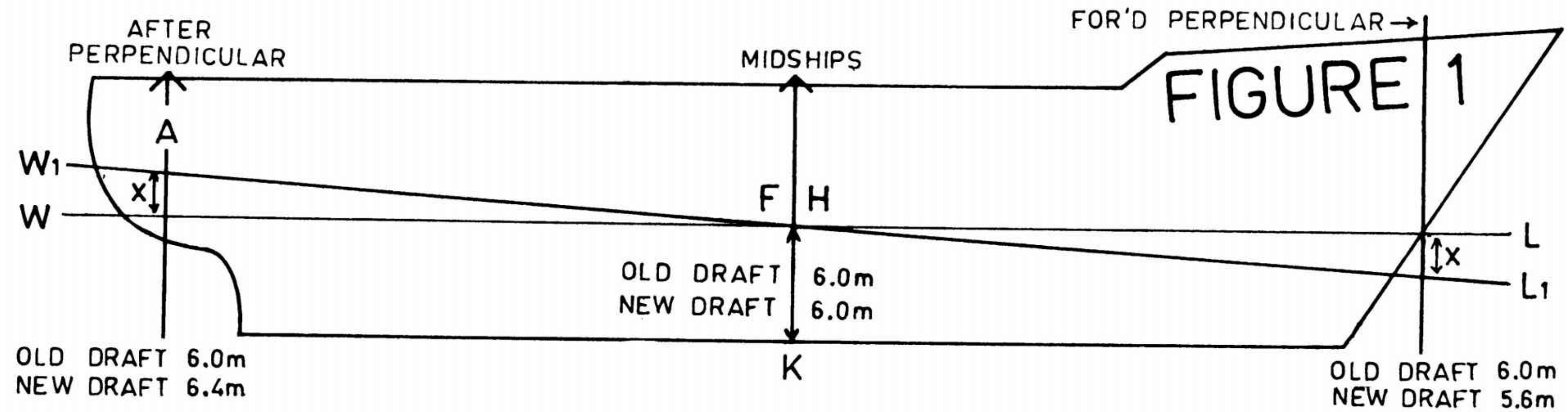
FIGURE 1
AFTER PERPENDICULAR
MIDSHIPS
FOR'D PERPENDICULAR →
A
W1
W
x
F
H
L
L1
K
OLD DRAFT 6.0m
NEW DRAFT 6.0m
OLD DRAFT 6.0m
NEW DRAFT 6.4m
OLD DRAFT 6.0m
NEW DRAFT 5.6m

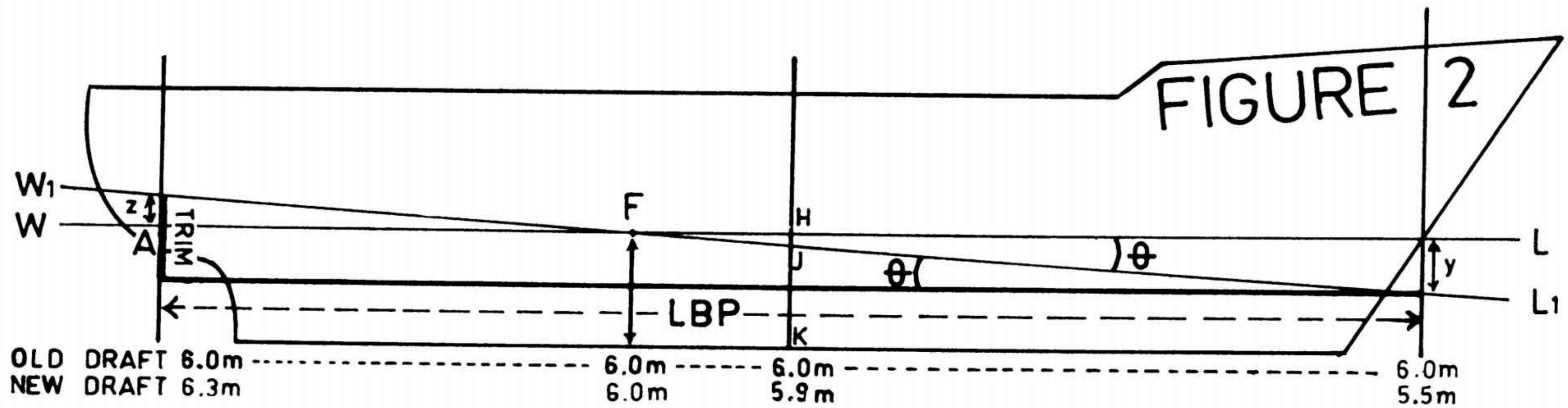
FIGURE 2
W1
W
z
A
TRIM
F
H
J
K
θ
y
L
L1
LBP
OLD DRAFT 6.0m
NEW DRAFT 6.3m
6.0m
6.0m
6.0m
5.9m
6.0m
5.5m

In figure 1, WL is the waterline before, & W_1L_1 the waterline after, the shifting of cargo towards aft. Because COF is amidships, the decrease in draft fwd and the increase in draft aft are equal, indicated by x in figure 1. The trim caused would then be 2x. The drafts before and after shifting of cargo are also indicated at the bottom of the figure at the fwd perpendicular, the after perpendicular and amidships (mean draft). When the COF is amidships, mean draft and hydrostatic draft are the same.

If the COF is situated abaft amidships, as shown in figure 2, the change of drafts fwd and aft would not only be opposite in sign (decrease fwd and increase aft in this case) but would also be of different values – greater change fwd and smaller change aft – indicated by y & z respectively in figure 2.

In figure 2, WL & W_1L_1 are the waterlines before and after shifting of cargo towards aft. The trim caused is y+z. The drafts before and after shifting cargo are indicated at each of four points – fwd, aft, midships (mean) and at F. It may be noted that before, the drafts were 6.0 m all over but after shifting of cargo, the mean (midships) draft in 5.9 m in this case whereas the hydrostatic draft remains unaltered at 6.0 m.

Referring to figure 2 and omitting any specific numerals, in right angled triangle FHJ,

$$HJ / HF = \tan\theta$$

But Tan θ also = Trim / LBP

$$\text{So } HJ / HF = \text{Trim} / \text{LBP}$$

or

$$HJ = HF \times \text{Trim} / \text{LBP}$$

Hence, correction to apply to mean draft to obtain hydrostatic draft = HF x Trim / LBP

This correction is positive when COF is abaft midships <u>and</u> the vessel is trimmed by the stern.

If the vessel was now trimmed by the head, by shifting cargo forward, the correction to apply to mean draft to obtain hydrostatic draft would be negative as illustrated by figure 3.

Similar simple illustrations can be made, where F is forward of midships, to show that:

Correction to apply to mean draft to obtain hydrostatic draft = HF x trim / LBP (see figure 4)

This correction is positive when HF and trim are of same name (both aft or both fwd) and negative when they are of contrary names (one fwd and other aft).

Note: HF is the distance of COF from amidships and is convenient to use if the ship's hydrostatic table indicates longitudinal distance from amidships (H).

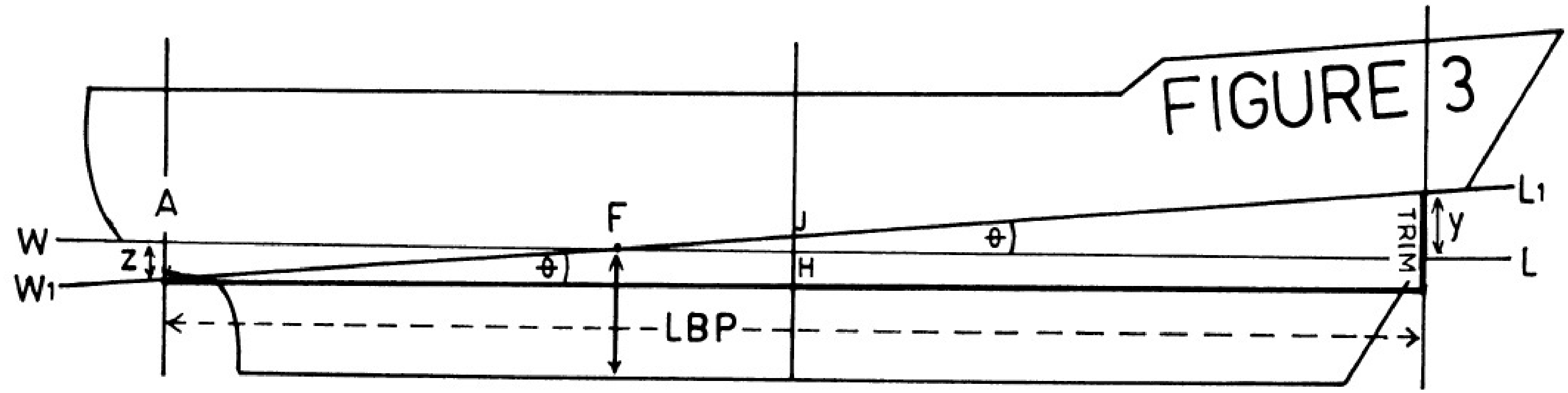
FIGURE 3
A
F
J
H
W
W1
L1
L
z
y
θ
θ
TRIM
LBP

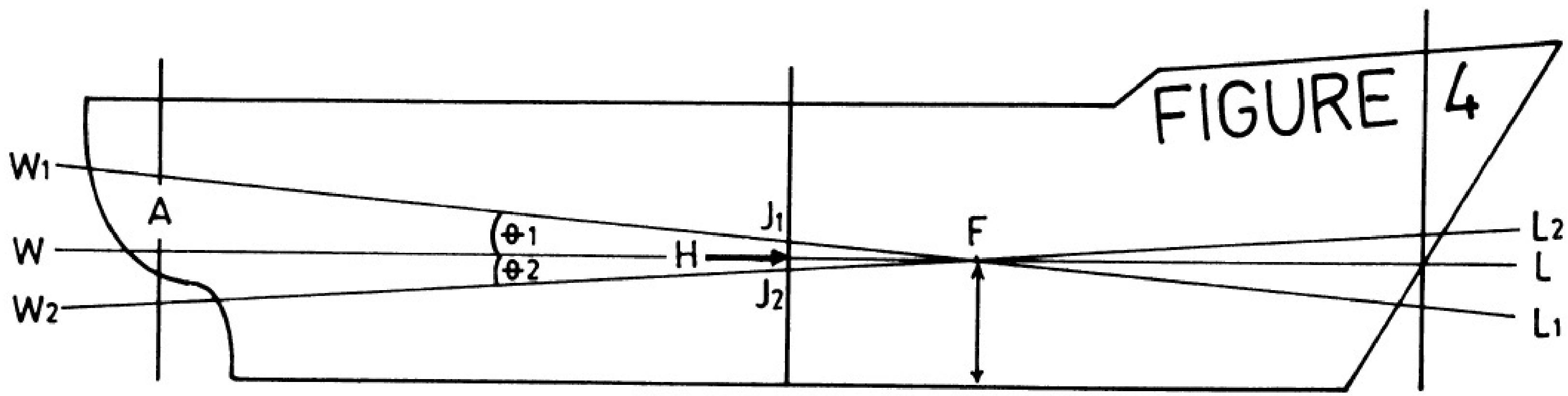
FIGURE 4
A
W1
W
W2
J1
J2
H
F
θ1
θ2
L2
L
L1

Hydrostatic draft may also be obtained by applying a correction to the aft draft of the ship. Referring to figures 2 & 3, it may be seen that the correction to apply to the aft draft to obtain hydrostatic draft is z, to be subtracted when the ship is trimmed by the stern and added when trimmed by the head.

$$z / AF = Trim / LBP \text{ (since both = Tan } \theta \text{)}$$

Hence, z = AF x Trim / LBP

Hence, correction to apply to after draft to obtain hydrostatic draft = AF x Trim / LBP

This correction is negative when the vessel is trimmed by the stern and positive when trimmed by the head.

Note: AF is the distance of the COF from the after perpendicular of the ship and is convenient to use when the ship's hydrostatic table indicates longitudinal distances from the after perpendicular (A).

Example 1

A ship is floating at a draft of 4.9 m fwd & 6.3 m aft. LBP is 120 m. If COF is 2 m abaft midships (HF 2 m aft or AF 58 m), calculate the hydrostatic draft.

Fwd	4.9	Fwd	4.9
Aft	6.3	Aft	6.3
Mean	5.6	Trim	1.4 m by stern

Corrn to mean draft = (HF x Trim) / LBP= (2 x 1.4) / 120 = 0.023 m

Since HF and trim are of same name (both aft), this correction is positive.

Mean draft	5.600 m
Correction	+0.023 m
Hydraft	5.623 m answer

OR

Correction to aft draft = (AF x Trim) / LBP = (58 x 1.4) / 120 = 0.677

Since trim is by stern, this correction is negative.

Aft draft	6.300 m
Correction	- 0.677 m
Hydraft	5.623 m answer

Example 2

Find the hydrostatic draft given the following particulars. Draft fwd 6.8 m, aft 5.0 m, COF 3 m aft of midships (i.e., HF 3 m aft or AF 60 m), LBP 126 m.

Fwd	6.8 m	Fwd	6.8 m
Aft	5.0 m	Aft	5.0 m
Mean	5.9 m	Trim	1.8 m by head

Corrn to mean draft = (HF x Trim) / LBP = (3 x 1.8) / 126 = 0.043 m
Since HF and trim are of contrary names, this correction is negative.

Mean draft	5.900 m
Correction	- 0.043 m
Hydraft	5.857 m answer

OR

Corrn to aft draft = (AF x Trim) / LBP = (60 x 1.8) / 126 = 0.857 m
Since trim is by head, this correction is positive.

Aft draft	5.000 m
Correction	+ 0.857 m
Hydraft	5.857 m answer

Example 3

M.V. 'VIJAY' is floating in SW at 5.0 m fwd and 7.0 m aft. Find its hydrostatic draft, using the hydrostatic table given in Appendix 1.

Fwd	5.0 m	Fwd	5.0 m
Aft	7.0 m	Aft	7.0 m
Mean	5.9 m	Trim	2.0 m by stern

For mean draft of 6.0 m, AF = 71.472 m
Corrn to aft draft = (AF x Trim) / LBP = (71.472 x 2) / 140 = 1.021 m
Since trim is by stern, this correction is negative.

Aft draft	7.000 m
Correction	- 1.021 m
Hydraft	5.979 m answer

HF in this case is 1.472 m fwd
Corrn to mean draft = (HF x Trim) / LBP = (1.472 x 2) / 140 = 0.021
Since the trim and HF are of contrary names, this correction is negative.

Mean draft	6.000 m
Correction	- 0.021 m
Hydraft	5.979 m answer

Example 4

Find the hydrostatic draft of M.V. 'VIJAY' when at 4.9 m fwd draft and 5.5 m aft draft in DW of RD 1.010.

Fwd	4.9 m	Fwd	4.9 m
Aft	5.5 m	Aft	5.5 m
Mean	5.2 m	Trim	0.6 m by stern

From the hydrostatic table, AF is 71.842 m at 5.2 m draft in water of any density.

Corrn to aft draft = (AF x Trim) / LBP = (71.842 x 0.6) / 140 = 0.308

Since trim is by stern, this correction is negative.

Aft draft	5.500 m
Correction	- 0.308 m
Hydraft	5.192 m answer

Note: This may also be worked using HF as illustrated in earlier examples.

Exercise 14

Hydrostatic draft

1. Drafts fwd 6.6 m, aft 8.6 m; COF 2 m fwd of midships; LBP 100 m. Find hydrostatic draft.

(Answer: 7.560 m).

2. Given the following particulars, find the hydrostatic draft in DW of RD 1.016: Drafts fwd 4.9 m, aft 4.3 m; HF 3.0 m fwd; LBP 120 m.

(Answer: 4.615 m).

3. A vessel is floating in FW at drafts of 8.0 m fwd and 12.0 m aft. If its HF is 2.5 aft and LBP is 200 m, calculate its hydrostatic draft.

(Answer: 10.050 m).

4. Drafts fwd 9.6 m, aft 8.2 in SW; COF 1.8 m abaft midships; LBP 180 m. Find its hydraft.

(Answer: 8.886 m).

5. A ship is floating in water of RD 1.012 at drafts of 7.2 m fwd and 8.8 m aft. Find its hydraft if the COF is amidships.

(Answer: 8.000 m).

6. A ship of LBP 176 m is floating in FW at a draft of 12.6 m fwd and 12.6 m aft. If its COF is 3 m fwd of amidships, find its hydrostatic draft.

(Answer: 12.600 m).

7. Drafts in FW, fwd 6.6 m aft 8.4 m, LBP 200 m; AF 96 m. Find hydrostatic draft.

(Answer: 7.536 m).

8. M.V. 'VIJAY' is floating in DW of RD 1.020
at drafts of 4.2 m fwd and 6.0 m aft. Find its hydrostatic draft.

(Answer: 5.076 m).

9. M.V. 'VIJAY' is afloat in DW of RD 1.015 at 5.0 m fwd and 7.0 m aft. Find its hydraft in SW.

Note: Find hydraft in DW and then compute hydraft in SW.

(Answer: 5.927 m).

10. M.V. 'VIJAY' is afloat at drafts of 6.2 m fwd and 7.8 m aft in FW. Find its present displacement. If the departure draft in SW is not to exceed 7.0 m state how much cargo she may load.

(Answer: 14035.0 t, 367.0 t).

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19. CALCULATION OF BM AND KM; KM CURVES

The transverse BM, also referred to as BM_T, is the vertical distance between the COB and the transverse metacentre, M or M_T, and is calculated by the formula:

$$BM = I / V$$

Where

I is the moment of inertia, or the second moment, of the water- plane area about the centre line of the ship, expressed in m^4.

V is the volume of displacement in m^3.

BM so obtained, would be in metres.

Rectangular water-planes:

The moment of inertia of a rectangle about its centre line (I or I *CL) is given by the formula:

$I = LB^3 / 12$. So, for a rectangular water-plane:

$$BM = I /V = LB^3/12V$$

Note: The vessel need NOT be box-shaped for its waterplane to be rectangular.

For a box-shaped vessel, V = L x B x d.

$BM = I /V = LB^3/12V = LB^3/12LBd = B^2/12d$.

For a triangular shaped vessel V = LBd/2

$BM = I /V = LB^3/12(LBd/2) = B^2/6d$.

Note: Though the vessel is triangular shaped, the water-plane is a rectangle. B is the breadth of the water-plane.

Shipshapes

The moment of inertia of the water-plane area of a ship about its centre line can be calculated by using Simpson's Rules as illustrated in the next chapter. The I, thus calculated, divided by V would give the BM or BM_T.

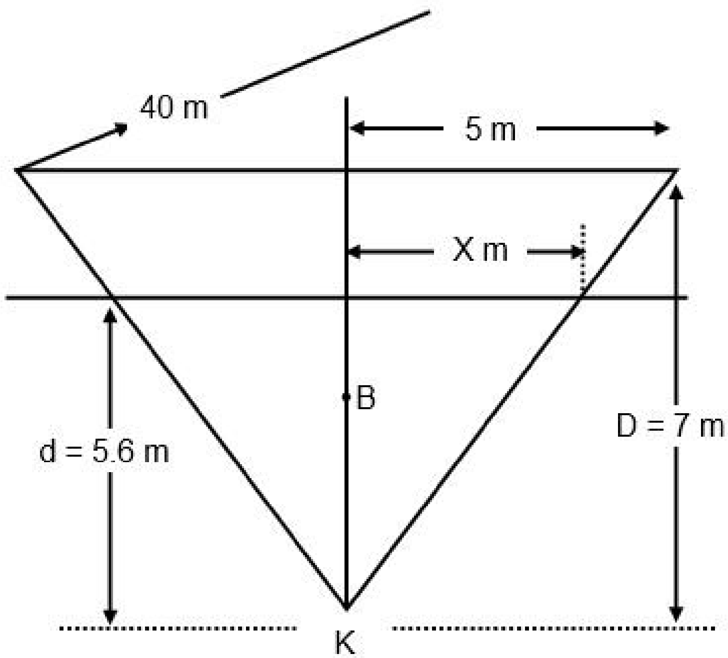
Example 1

Find the GM of a box-shaped vessel 20 x 6 x 5 m, if draft = 3 m and KG = 1.8 m.

KB = draft/2 = 3/2 .... = 1.5 m
BM = $B^2/12d$ = (6 x 6) ÷ (12 x 3) = 1.0 m
KM = KB + BM .... = 2.5 m
GM = KM – KG = 2.5 – 1.8 = 0.7 m answer.

Example 2

A vessel has the form of a triangular prism of length 40 m, breadth 10 m and depth 7 m. Find the KM at 5.6 m draft.

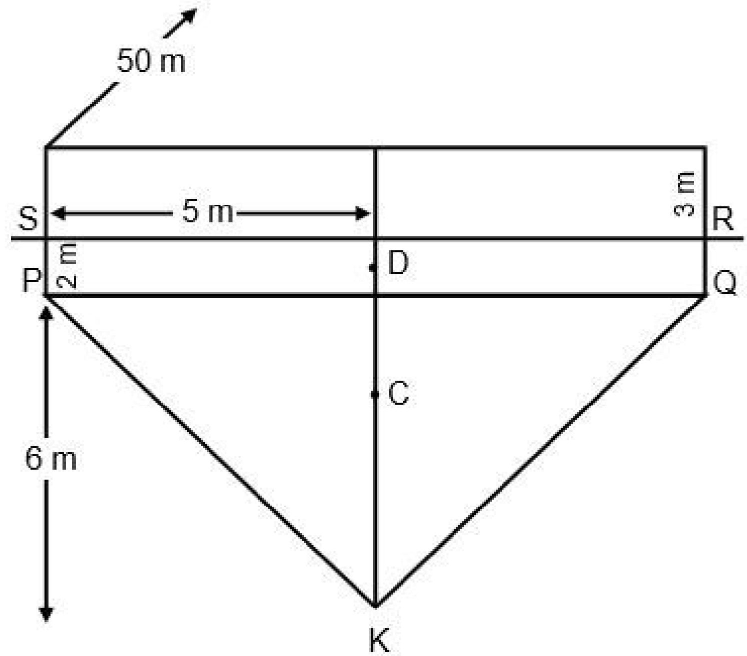


Let the half breadth of the water-plane = X metres. With reference to the figure above and considering similar triangles: X/5.6 = 5/7. X = 4.0 metres.

Breadth of the water-plane = 2 x 4 = 8 m
KB = draft x 2/3 = 5.6 x 2/3 = 3.733 m
BM = $B^2/6d$ = (8 x 8) / (6 x 5.6) = 1.905 m
KM = KB + BM .... = 5.638 m

Example 3

A vessel 50 m long has a uniform transverse cross-section throughout, consisting of a rectangle above a triangle. The rectangle is 10 m broad and 5 m high. The triangle is apex downwards, 10 m broad at the top and 6 m deep. Calculate the KM at 8 m draft.



To find the KB, take moments of area about K. (See accompanying figure).

KB = (Area PQK x KC) + (Area PQRS x KD) / Total area PKQRS

= (10 x 6 x 1/2) 4 + (10 x 2) 7 / (10 x 6 x 1/2) + (10 x 2) = 5.2 m

Volume of displacement = Area PKQRS x L = 50 x 50 = 2500 m^3.

Since water-plane is rectangular,

I *CL = $LB^3/12$ = 50 x $10^3/12$ = 4166.667 m^4

BM = I /V = 4166.667/2500 = 1.667 metres.

KM = KB + BM = 5.200 + 1.667 = 6.867 m.

Example 4

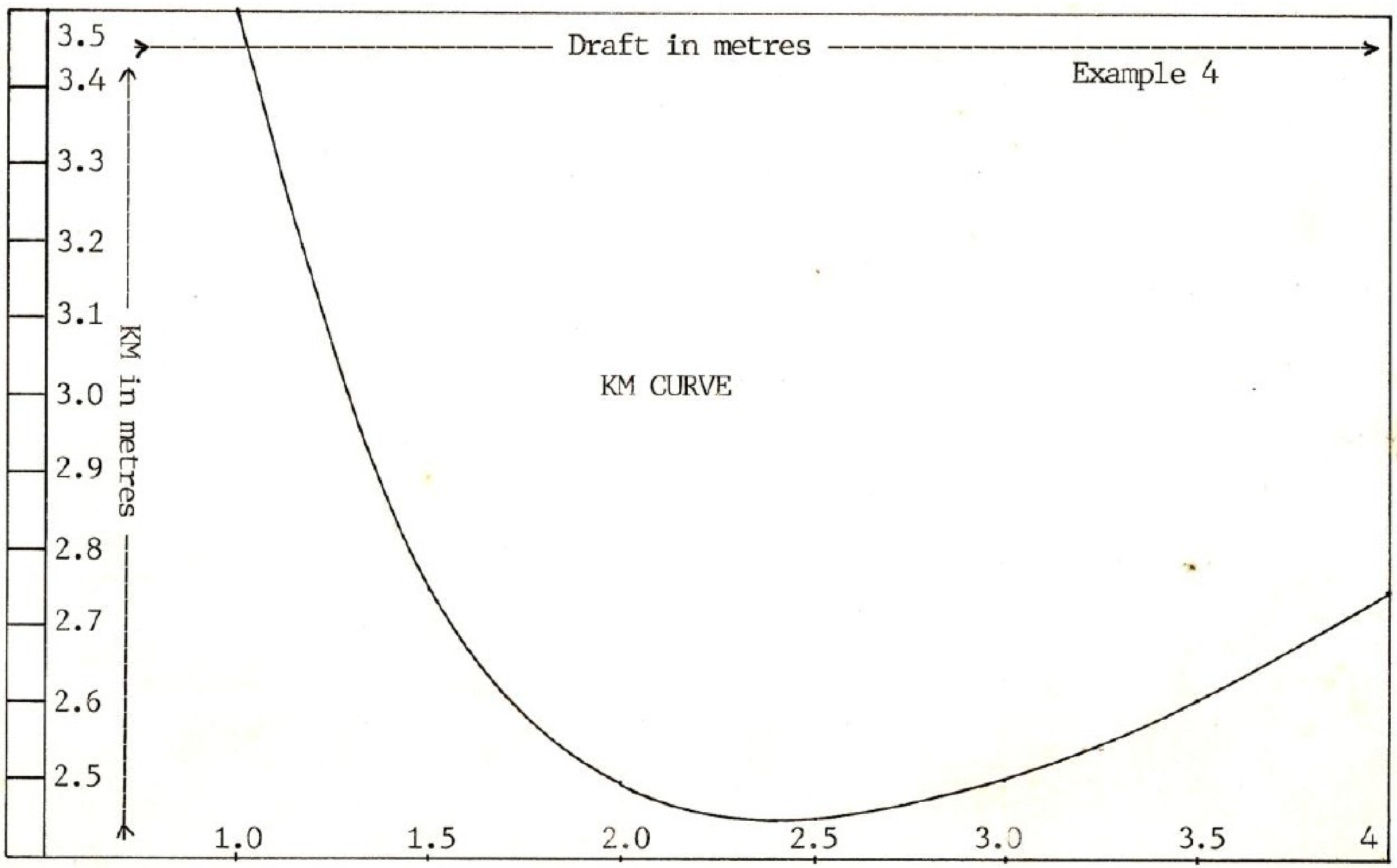
A box-shaped vessel is 32 m long and 6 m broad. Construct the KM curve between the drafts of 1 m & 4 m. From the curve, find the KM at 1.75 m draft.

KM = KB + BM = d/2 + $B^2/12d$ = d/2 + 3/d.

For the various drafts, KB and BM are calculated and tabulated as follows:

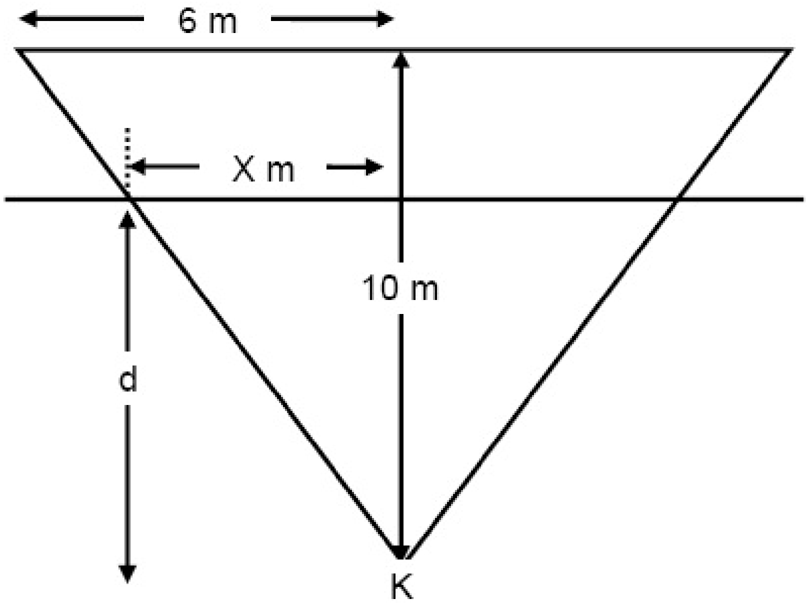
Draft	KB	+	BM	=	KM
1.0 m	0.5m		3.0 m		3.5 m
1.5	0.75		2.0		2.75
2.0	1.0		1.5		2.5
2.5	1.25		1.2		2.45
3.0	1.5		1.0		2.5

A graph should be drawn to scale, with draft on one axis & KM on the other, as shown here.
From the curve, KM at 1.75 draft = 2.6 m


Draft in metres
Example 4
KM in metres
KM CURVE
3.5
3.4
3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
1.0
1.5
2.0
2.5
3.0
3.5
4

Example 5

A triangular prism-shaped barge 60 m long is 12 m broad at the top and 10 m deep. Construct the KM curve up to 5 m draft & from it, find the KM at 4.6 m draft.

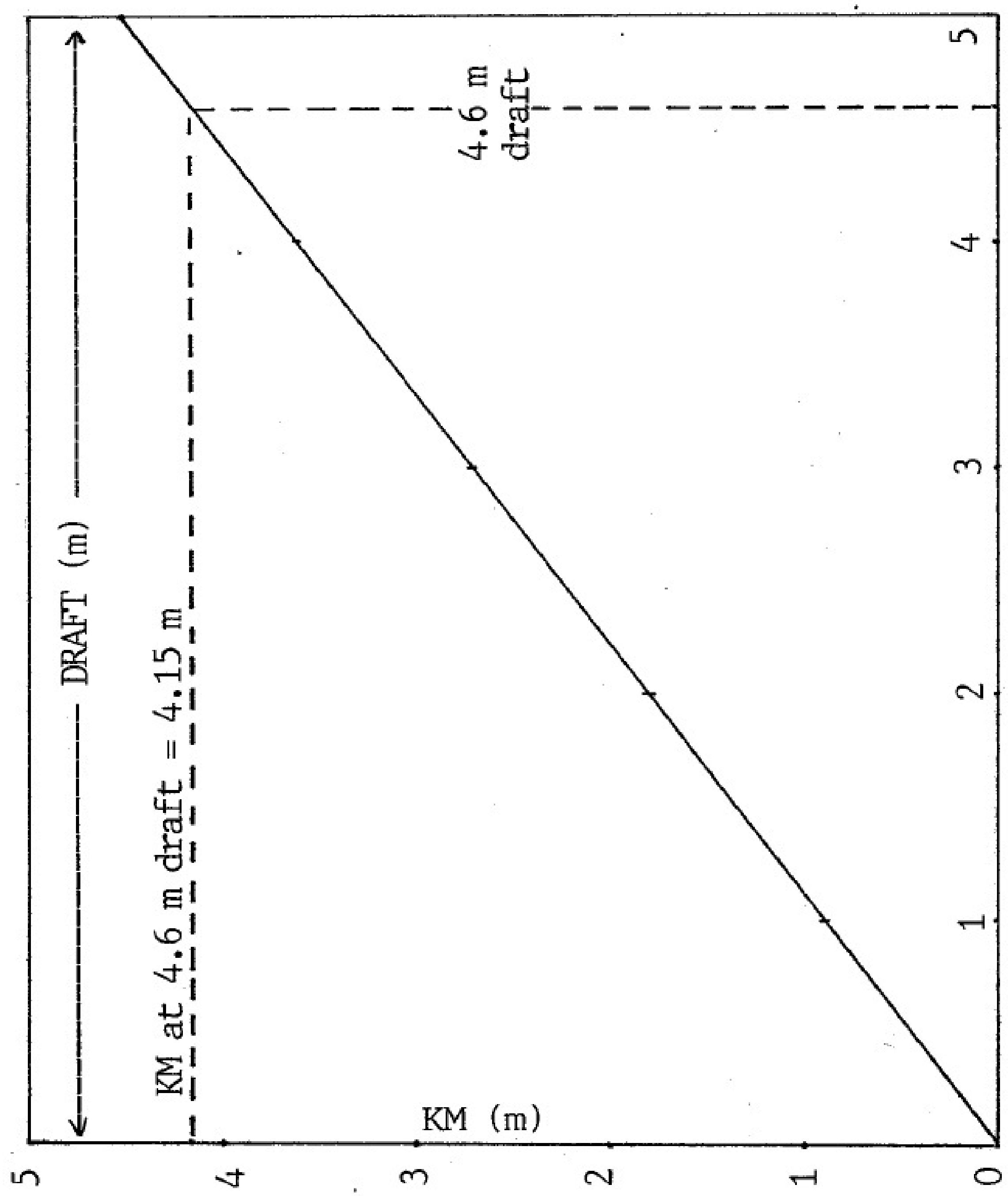


By the principle of similar triangles,

$x/d = 6/10$ so $x = 0.6d$ and $B = 1.2d$.

$KM = KB + BM = 2d/3 + (1.2d)^2/6d = 0.907d$

draft	KM m	draft	KM m	draft	KM m
1 m	0.907	2 m	1.814	3 m	2.721
4 m	3.628	5 m	4.535	6 m	5.442



Exercise 15
Calculation of BM & KM; KM Curves

1. A box-shaped barge is 40 x 25 x 10 m. Draft = 6 m. KG = 8 m. Calculate its KM & GM.

(Answer: 11.681 m: 3.681 m).

2. A box-shaped vessel 45 m x 8 m x 6 m, displaces 1476 t. Find the KM in SW.

(Answer: 3.333 m).

3. A box-shaped barge is 52 x 20 x 12 m. SW draft 7.922m. Find KM in RD 1.015.

(Answer: 8.167 m).

4. A box-shaped vessel 180 x 24 m floats at 8 m SW draft. Find KM in SW & FW.

(Answer: SW 10 m; FW 9.954 m).

5. Find the GM of a box-shaped vessel 120 m x 18 m when afloat at 10 m SW draft. KG is 6.9 m & FSM is 2000 tm.

(Answer: 0.71 m).

6. Calculate the list when 30 t of cargo is shifted 10 m to port on a box shaped vessel 100 x 16 m. SW draft 7 m; KG 5.5 m; FSM 4800 tm.

(Answer: 2.38° or 2° 23').

7. Draw the KM curve for a box-shaped vessel 90 x 12 m between 2m draft & 7 m. From the curve, find the minimum KM and the draft at which it occurs.

(Answer: 4.899 m at 5 m draft).

8. A barge is shaped like a triangular prism, 20 m broad at the top and 10 m deep. It is 45 m long and displaces 2952 t. Find the KM in SW.

(Answer: 10.666 m).

9. The underwater portion of a barge is in the shape of a prism, apex downwards, 14 m wide at the top, 8 m deep and 40 m long. Draw the KM curve up to 6 m draft and from the curve find the KM at (a) 2.5 m and (b) 4.75 m.

(Answer: (a) 2.95 m (b) 5.60 m).

10. A ship of W 10250 t, KB 5.6 m, KG 8.3 m floats in SW. If I*CL is 45000 m^4, & FSM is 2050 tm, find the GM fluid.

(Answer: 1.6 m).

11. A barge 45 m long has a uniform transverse cross-section throughout, consisting of a rectangle above a triangle. The rectangle is 8 m broad and 5 m high. The triangle is apex downwards, 8 m broad and 3 m deep. If W is 1620 t, find the KM when in FW.

(Answer: 4.852 m).

12. A barge 50 m long has a uniform transverse cross-section throughout, consisting of a rectangle above a semi-circle. The rectangle is 10 m broad & 4 m high. The semi-circle has a diameter of 10 m and its geometric centre is 3 m above the keel. Find the KM at 6 m draft . (Assume π= 22/7).

(Answer: 5.198 m).

13. Two barges, each 52 m long and 9 m broad at the waterline, float upright at 3 m even keel draft. KG = 3 m. One barge is rectangular while the other is a triangular prism floating apex downwards. Compare their GM.

(Answer: 0.75 m & 3.5 m).

14. Two box-shaped barges each 100 m long float at 4 m draft & have KG = 3.5 m. One barge is 10 m broad and the other is 12 m. Compare their initial GM.

(Answer: 0.583 & 1.5 m).

15. A homogenous log of square cross-section has RD = 0.72. Prove whether it can float with one side (of the square) parallel to the waterline.

(Answer: 35303.7 t; 58.55 tcm^{-1}).

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20. SIMPSON'S RULES

Simpson's Rules are very popular among mariners and naval architects because of their simplicity. They may be used to calculate the area, volume and geometric centre of the space enclosed by a straight line and a curve.

Calculation of areas

Equidistant points are chosen along the straight line, also called the axis, and the distance between them is called the common interval or 'h'. From each of these points, the perpendicular distance to the curve is measured off and called the ordinate or 'y'. Each ordinate is multiplied by a different number chosen from a series of numbers called Simpson's Multipliers and the product is obtained. The area contained between the axis, the curve and the end ordinates is calculated by the formula:

Area = Kh (sum of products)

where K is a constant.

There are three Simpson's Rules and for each, there are different multipliers. The value of the constant 'K' also is different for different rules. If y and h are in metres, the area obtained would be in square metres.

Simpson's First Rule

Area = (h/3) x (sum of products)

Here, K = 1/3 and Simpson's Multipliers are

1 4 1 if there are three ordinates,

1 4 2 4 1 if there are five ordinates,

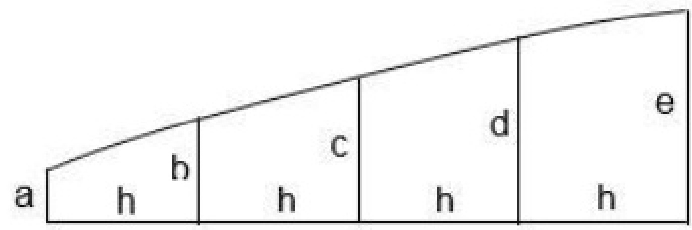
1 4 2 4 2 4 1 if the ordinates are seven

1 4 2 4 2 4 2 4 1 for nine ordinates,

1 4 2 4 ………………… 2 4 1 for any further odd number of ordinates.

This rule is usable wherever the number of ordinates chosen is an odd number and it gives accurate results if the curve is a parabola of the second order (i.e., where the equation of the curve is y = ax2 + bx + c, in which a, b and c are constants). This rule gives good results for ship-shapes and is hence used extensively by shipyards.

Illustration of this rule:



Ordinate (y)	Simpsons multiplier (SM)	Product for area
a	1	1a
b	4	4b
c	2	2c
d	4	4d
e	1	1e

Sum of products = 1a+4b+2c+4d+1e

Area = (h/3) x (1a + 4b + 2c + 4d + 1e)

Simpson's Second Rule

Area = (3h/8) x (sum of products)

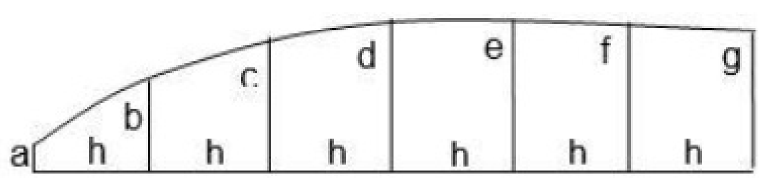
Here, K = 3/8 and Simpson's Multipliers are

1 3 3 1 if there are four ordinates,

1 3 3 2 3 3 1 …… for seven ordinates,

1 3 3 2 3 3 2 3 3 1..for ten ordinates, etc. This rule is usable wherever the number of ordinates chosen is 4, 7, 10, 13, 16, 19, 22, 25, etc. This rule gives accurate results if the curve is a parabola of the third order (i.e., where the equation of the curve is y = ax3 + bx2 + cx + d, where a, b, c and d are constants).

Illustration of the second rule:



Ordinate (y)	Simpsons multiplier (SM)	Product for area
a	1	1a
b	3	3b
c	3	3c
d	2	2d
e	3	3e
f	3	3f
g	1	1g

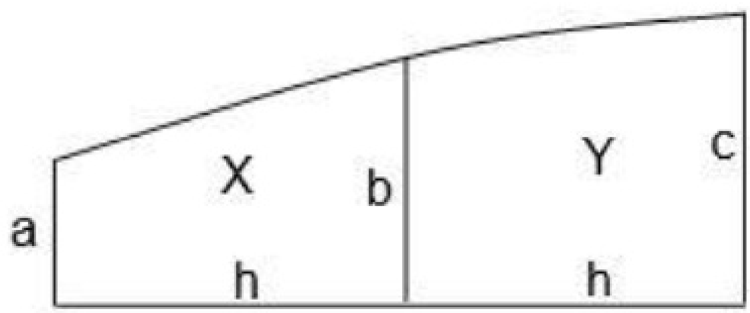
Sum of products = 1a+3b+3c+2d+3e+3f+1g

Area = (3h/8) (sum of products as above)

Simpson's Third Rule

This rule is also called the five-eight-minus-one rule. If three consecutive ordinates are known, the area between any two of them can be calculated by this rule. Here K = 1/12 and SM are 5, 8 and -1.

Illustration of the third rule:



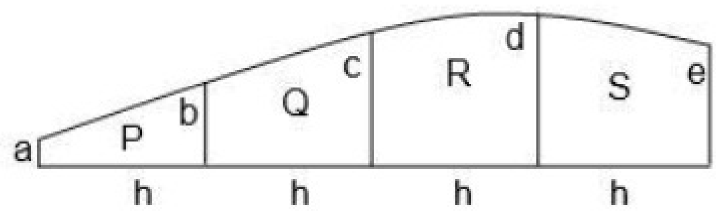
Area X = (h/12) (5a + 8b – c)

Area Y = (h/12) (5c + 8b – a)

The Trapezoidal Rule

If the value of the common interval 'h' is made very small, part of the curve between any two ordinates may be considered to be straight. The shape now gets divided into several trapezoids. Since the area of a trapezoid is the product of half the sum of the parallel sides and the perpendicular distance between them, the area of the given shape may be obtained by plane geometry without the application of Simpson's Rules.

Illustration of the trapezoidal rule.



Area P	=	h (a +b)/2	=	h (0.5a + 0.5b)
Area Q	=	h (b + c)/2	=	h (0.5b + 0.5c)
Area R	=	h (c + d)/2	=	h (0.5c + 0.5d)
Area S	=	h (d +e)/2	=	h (0.5d + 0.5e)

Total = h (0.5a + b + c + d + 0.5e)

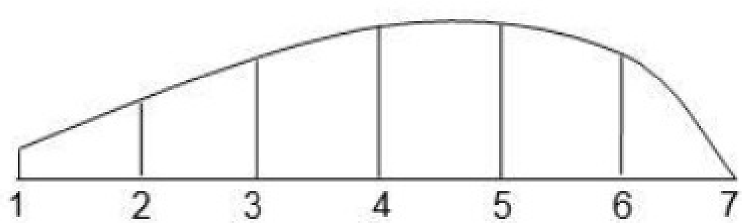
Area = h (sum of all intermediate ordinates and half sum of end ordinates)

To obtain accurate results by this rule, the value of 'h' would have to be very small. This means more physical work in measuring out so many ordinates. Simpson's Rules are widely used by shipyards, in preference to the trapezoidal rule, as good accuracy can be obtained by using fewer ordinates.

Example 1

A ship's water-plane is 120 m long. The half-breadths, measured at equal intervals from aft, are: 0.1 4.6 7.5 7.6 7.6 3.7 & 0 m.

Find the water-plane area.



Note 1: If half-breadths are put through Simpson's Rules, the area obtained would be half the water-plane area. Double this value would be the full area of the water-plane. If, instead, full breadths are used, the area obtained would directly be that of the full water-plane. In this question, half-breadths are given. Hence it would be simpler to use them as they are, the half-breadths then being called half-ordinates or semi-ordinates.

Note 2: Seven semi-ordinates means six equal intervals. So, h = 120/6 = 20 m.

y/2	(SM)	Product
0.1	1	00.1
4.6	4	18.4
7.5	2	15.0
7.6	4	30.4
7.6	2	15.2
3.7	4	14.8
0.0	1	00.0

Sum of products = 93.9

Half area = (h/3) (SOP as above)

Half area = (20/3) (93.9) = 626 m^2

Full area = 626 x 2 = 1252 m^2

Example 2

Example 1 had seven ordinates and could have been worked using Simpson's Second Rule as follows:

y/2	(SM)	Product
0.1	1	00.1
4.6	3	13.8
7.5	3	22.5
7.6	2	15.2
7.6	3	22.8
3.7	3	11.1
0.0	1	00.0

Sum of products = 85.5

Half area = (3h/8) (SOP as above)

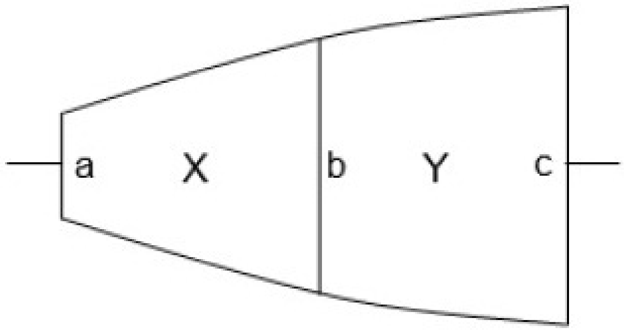
Half area = (20 x 3/8) (85.5) = 641.25 m^2

Full area = 641.25 x 2 = 1282.50 m^2

Note: Given the same particulars, the answers obtained by Simpson's First Rule and by Simpson's Second Rule are slightly different (less than 2.5% in this case). This is mentioned here to illustrate that the results obtained using Simpsons Rules are only very good approximations of the correct areas. The accuracy improves as the number of ordinates is increased i.e., the smaller the common interval, the greater the accuracy.

Example 3

The breadths of part of a ship's deck, at 5 m intervals are 13, 14 and 14.5 m. Find the area between the first two ordinates.



Area X = (h/12) (5a + 8b – c)

= (5/12) (65 + 112 – 14.5) = 67.708 m^2

Example 4

The half-breadths of a ship's waterplane 100 m long, at equal intervals from aft:

5.00   5.88   6.75   6.63   4.00   &   0.0 m.

Find the water-plane area and the TPC in SW.

Note 1: Since the given number of semi-ordinates is six, none of Simpsons Rules is directly applicable to all of them as a whole. Part of the area can be calculated using one rule and the other part by another rule. The sum of the two part areas would give the area of the semi-water-plane. Double this value would be the area of the whole water-plane. Here are some possibilities.

(a) Area between the first and the third semiordinate by the first rule and the remaining area by the second rule.

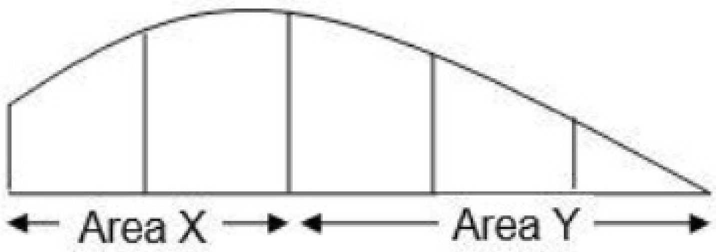
(b) Area between the first and the fourth semi-ordinate by the second rule & the remaining area by the first rule.

(c) Area between the first and the fifth semi-ordinate by the first rule and the remaining area by the third rule.

(d) Area between the first and the second semi-ordinate by the third rule & the remaining area by the first rule.

Note 2: The results obtained by different methods may differ slightly but would be within reasonable limits.

Note 3: The semi-ordinate which happens to be the boundary between the areas calculated separately is called the dividing semi-ordinate. It will be used twice - once in each calculation of part area. In this example, the third is the dividing semi-ordinate.



y/2	SM	Product	y/2	SM	Product
5.00	1	05.00	6.75	1	06.75
5.88	4	23.52	6.63	3	19.89
6.75	1	06.75	4.00	3	12.00
			0.00	1	00.00
SOP	=	35.27	SOP	=	38.64
Area X = (20/3) (35.27)			Area Y= (20) (3/8) (38.64)		
Area X = 235.133 m^2			Area Y = 289.800 m^2		

Semi-area = X + Y = 524.933 m^2.
Full area = 2 (524.933) = 1049.866 m^2.
TPC = 1.025A/100 = 1.025 (1049.866) / 100 = 10.761.

Exercise 16

Areas by Simpson's Rules

1. Find the area of a boat cover 10 m long if its breadth at equal intervals from forward are:
0, 2.25, 3, 2.25 & 0 m. (Answer: 20 m^2).

2. A small coaster's deck is 50 m long. Half-breadths at equal intervals from aft are 0.78, 2.89, 4.06, 2.34 & 0.31 metres. Calculate the deck area.
(Answer: 251.083 m^2).

3. Find the area of a collision bulkhead 12 m high. The half-breadths at equal intervals from top are:
7, 4.8, 2.95, 2, 1.65, 1.3 and 0 m.
(Answer: By Rule 1: 64.8 m^2; by Rule 2:64.65m^2).

4. Find the area of a transverse bulkhead 10 m high whose half-breadths, at equal vertical intervals, are: 10, 9.3, 8.3, 7.1, 5.7, and 3.8 m.
(Answer: By Rules 1 & 2: 149.75 m^2; by Rules 1 & 3: 149.701 m^2).

5. A ship's water-plane is 150 m long. Half-breadths at equal intervals from aft are: 2.97, 6.15, 7.84, 8.48, 8.06, 7.21, 5.72, 3.6 & 0 m. Find:

(a) The water-plane area. (Answer: 1849.625 m^2).

(b) The area coefficient. (Answer: 0.727).

(c) The TPC in salt water. (Answer: 8.959 tcm^{-1}).

6. Find the area of a tank top 21 m long, if equidistant breadths are: 19.2, 18.0, 17.1, 16.2, 14.4, 12.0, 9.3 & 6.0 m.

(Answer: By Rules 1 and 2: 299.438 m^2).

7. The half-breadths of a water-tight bulkhead, at 2 m intervals from the bottom, are:

1, 2.9, 4.2, 5.1 & 5.7 m.

Find (i) The area between the bottom two semi-ordinates (ii) the quantity of paint required to coat the entire bulkhead once, if the paint covers 10 square metres per litre.

(Answer: (i) 4 m^2 (ii) 6.28 litres).

8. A ship's water-plane is 90 m long. Half-breadths at equal intervals from forward are:

0.0, 2.5, 4.5, 6.5, 7.5, 8.5, 8.5, 8, 6 and 0 m.

Find (a) SW TPC (b) Area coefficient.

(Answer: (a) 10.839 tcm^{-1} (b) 0.691)

9. The breadths of a ship's water-plane 120 m long, at equal intervals from aft, are: 1.2, 9.6, 13.2, 15.0, 15.3, 15.6, 15.6, 14.7, 12.9, 9 & 0 m. Find:

(a) The water-plane area. (Answer: 1483.2 m^2).

(b) FWA if W = 6811 tonnes. (Answer: 11.2 cm).

10. Find the area of a ship's deck 99 m long whose half-breadths at equal intervals from forward are 0.45, 2.10, 3.75, 5.25, 6.45, 7.35, 7.80, 7.20, 5.85 and 3.00 metres respectively.

(Answer: 1053.113 m^2).

Calculation of volumes

If cross-sectional areas are put through Simpson's Rules, the volume of an enclosed space having curved boundaries can be calculated. These cross-sectional areas must be equally spaced (must have a common interval) and may be either transverse (like areas of imaginary water-tight bulkheads) or horizontal (like water-plane areas at equal intervals of draft).

The application of Simpson's Rules is the same for calculation of volumes as for calculation of areas. If semi-areas are put through the Rules, the result obtained would be the semi-volume.

Example 5

Find the volume of displacement of a barge 48 m long whose under water transverse cross-sectional areas are: 19.6, 25, 17.5, 13 and 0 m^2.

Area m^2	SM	Product
19.6	1	019.6
25.0	4	100.0
17.5	2	035.0
13.0	4	052.0
0.0	1	000.0
Sum of Products	=	206.6

Vol = (SOP) h/3 = (206.6) 12/3 = 826.4 m^3

Example 6

A ship's water-plane areas, at one metre intervals from keel upwards, are: 1730, 1925, 2030, 2100 & 2150 m^2. Find the W & the TPC in SW at 4 m draft.

Draft m	WP area m^2	SM	Product
4	2150	1	2150
3	2100	4	8400
2	2030	2	4060
1	1925	4	7700
0	1730	1	1730
Sum of Products		=	24040

Vol = (SOP) h/3 = (24040) 1/3 = 8013.333

W in SW = 8013.333 x 1.025 = 8213.7 tonnes.

TPC at 4 m draft = 1.025A / 100 = 1.025(2150) / 100 = 22.038.

Example 7

Given the following information, find the displacement at 6 m draft in SW:

Draft	6	5	4	3	2	1	0 m
TPC	61.5	61.7	61.8	61.8	61.7	57.4	51.3

Alternative 1

The given values of TPC can be converted into water-plane areas by the formula: TPC =1.025A/100. The water-plane areas, put through Simpson's Rules, would give the volume of displacement. This volume multiplied by 1.025 = SW displacement at 6 m draft.

Alternative 2

TPC = 1.025A/100 or A = (TPC) 100/1.025

Let X = 100/1.025 so A = TPC (X)

Draft m	WP area m^2	SM	Product
6	61.5X	1	61.5X
5	61.7X	4	246.8X
4	61.8X	2	123.6X
3	61.8X	4	247.2X
2	61.7X	2	123.4X
1	57.4X	4	229.6X
0	51.3X	1	51.3X
Sum of Products		=	1083.4X

Vol = (SOP) h/3 = 1083.4X/3 = 35232.52

W at 6 m = 35232.52 (1.025) = 36113.3 t.

Note: This problem may be solved using Simpson's Second Rule. W would then work out to 36157.5 t. (Difference < 0.15%).

Exercise 17

Volumes by Simpson's Rules

1. Given the following information, find the volume of displacement and the approximate mean TPC between the drafts of 8 m and 9 m:

Draft (metres)	7	8	9
WP area in m^2	2240	2295	2355

(Answer: 2324.583 m^3; 23.83 tcm^{-1}).

2. Find the volume of a lower hold 20 m long whose transverse cross-sectional areas at equal intervals from forward are 120, 116, 101 & 80 m^2.

(Answer: 2127.5 m^3).

3. Find the displacement at 5 m SW draft if the water-plane areas, in m^2, are:

Draft	6	5	4	3	2	1	0
Area	2550	2010	1920	1580	1300	920	780

(Answer: Rules 1 & 3: 7332.2 t; Rules 1 & 2:7317.6 t).

4. Find the quantity of coal (SF 4 m^3t^{-1}) that a coal bunker can hold if its cross-sectional areas, at 5 m intervals are: 9, 11.3, 12.6, 12.4 & 11.2 m^2.

(Answer: 58.4 t).

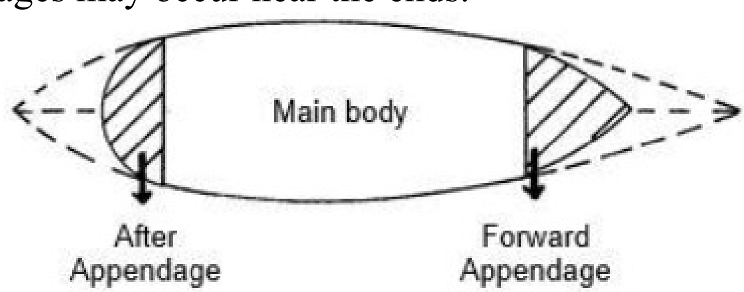
5. Find W & TPC at 6 m FW draft, if the water-plane areas, in m^2, are:

d	6	5	4	3	2	1	0 m
A	5855	5875	5893	5895	5900	5885	5850

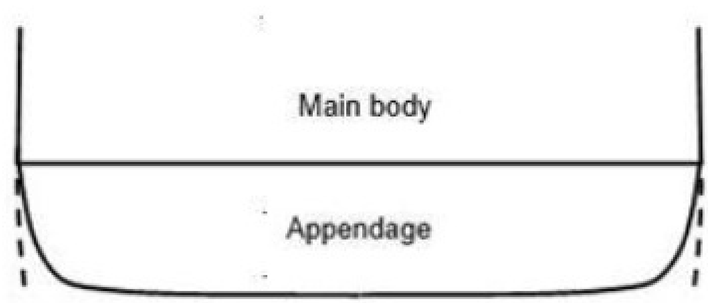
(Answer: 35303.7 t; 58.55 tcm^{-1}).

Appendages

Appendages are those parts of a curved boundary where the curvature changes considerably. In calculations of water-plane areas, appendages may occur near the ends.



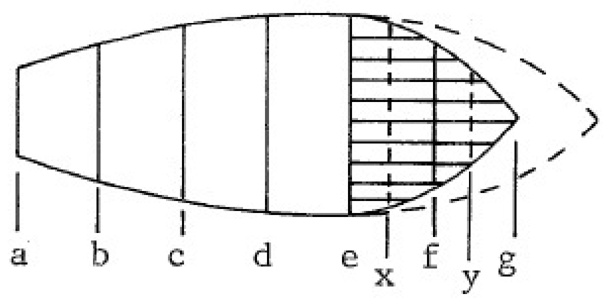
In calculations of underwater volumes, appendages occur in the region of the double bottom tanks as the curvature of the shell plating changes sharply at the bilges.



Areas/volumes of appendages are usually calculated separately and then added to the area/volume of the main body.

Intermediate ordinates

The greater the number of ordinates used, the greater the accuracy of the result obtained by Simpson's Rules. Where the change of curvature is not too severe, calculation of the area/volume of the appendage and of the main body can be done as a single calculation. First, the ordinates in the appendage are spaced at the same common interval as in the main body. Next, intermediate ordinates (also called half stations) are inserted in the appendage midway between the regular ordinates, as illustrated in the accompanying figure wherein 'a' to 'g' are regular ordinates while 'x' and 'y' are intermediate ordinates or half stations.



The calculation is then as follows:

Area of main body = (sum of products) h/3

= (1a + 4b + 2c + 4d + 1e) (h/3)

Appendage area = (sum of products) (h/2) /3

= (1e + 4x + 2f + 4y + 1g) (0.5h) /3

= (e/2 + 2x + 1f + 2y + g/2) (h/3)

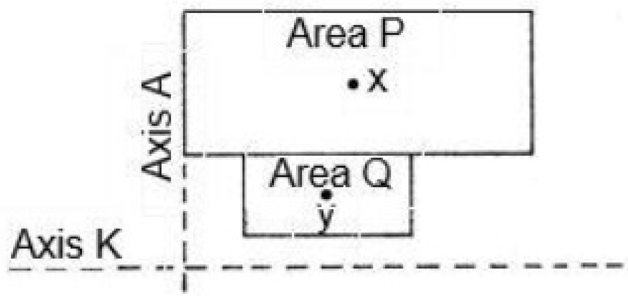
Total area = Main body + appendage

= [1a+4b+2c+4d+ (1.5e) +2x+1f+2y+g/2] (h/3)

Note: Simpson's Multipliers in the half station zone are halved except at the common ordinate for which the SM is 1.5. This holds good for half stations even where Simpson's Second Rule is used. If desired, the area/volume of the main body and of the appendage may be calculated separately and the results added together.

Geometric centres

The position of the geometric centre can be found by the principle of moments. A basic illustration is as follows:



In the foregoing figure, x is the geometric centre of area P and y, that of area Q. Ax and Ay are the perpendicular distances of the geometric centres from axis A. Kx and Ky are the perpendicular distances from the axis K. Required to find the position of z, the geometric centre of the whole figure (i.e., required to find Kz and Az).

Taking moments about axis K,

Area P (Kx) + area Q (Ky) = Area (P+Q) (Kz)

Kz, being the only unknown factor in the equation, can be obtained by calculation.

Taking moments about axis A,

Area P (Ax) + area Q (Ay) = Area (P+Q) (Az)

Az, being the only unknown factor in the equation, can be obtained by calculation.

Geometric centres by Simpson's Rules

Calculation of the position of the geometric centre of a space by Simpson's Rules also is based on the principle of moments. The geometric centre of a water-plane is the centre of flotation (COF) at that draft and AF is its distance from the after perpendicular of the ship. The geometric centre of the underwater volume of a ship is its centre of buoyancy (COB) whose position is indicated by KB and AB. The calculation of the position of the geometric centre, by Simpson's Rules, is illustrated by the worked examples that follow.

Example 8

A ship's water-plane is 120 m long. Half breadths,

at equal intervals from aft, are: 0.1, 4.6, 7.5, 7.6, 7.6, 3.7 & 0 m. Calculate the position of its COF.

Let A be the after end of the waterplane.

h = 120/6 = 20 metres.

y/2 (m)	SM	Product for semi-area	Lever abt A	Product for semi-moment
0.1	1	00.1	0h	00.0h
4.6	4	18.4	1h	18.4h
7.5	2	15.0	2h	30.0h
7.6	4	30.4	3h	91.2h
7.6	2	15.2	4h	60.8h
3.7	4	14.8	5h	74.0h
0.0	1	00.0	6h	00.0h
SOP	=	93.9	SOP =	274.4h

AF = 274.4h/93.9 = 58.445 metres.

Note 1: Lever about A is the distance of the semi-ordinate from the after end, in multiples of h. It may, if desired, be inserted directly in metres.

Note 2: Explanation of the final calculation of AF:

$$AF = \frac{\text{Mom about A}}{\text{Total area}} = \frac{\text{(SOP for mom about A) h/3}}{\text{(SOP for full area) h/3}}$$

$$= \frac{\text{(SOP for semi-moment)}}{\text{(SOP for semi – area)}} = \frac{274.4h}{93.9} = 58.445 \text{ m.}$$

Example 9

The transverse cross-sectional areas, of the underwater portion of a barge, at 12 m intervals from forward, are: 0, 13, 17.5, 25 and 19.6 m^2. The last ordinate is the after perpendicular of the barge. Calculate AB.

Area m^2	SM	Product for volume	Lever abt A	Product for moment
00.0	1	00.0	4h	00.0h
13.0	4	52.0	3h	156.0h
17.5	2	35.0	2h	70.0h
25.0	4	100.0	1h	100.0h
19.6	1	19.6	0h	00.0h
SOP	=	206.6	SOP =	326.0h

AB = 326.0h/206.6 = 18.935 metres.

Example 10

The water-plane areas of a ship are:-

Draft	5	4	3	2	1	m
Area	2150	2100	2030	1925	1730	m^2.

Between the keel and 1m draft, there is an appendage of 800 m^3 volume whose geometric centre is 0.7 m above the keel.

Find the displacement and the KB of the ship at 5 m draft in salt water.

d (m)	WP area	SM	Product for vol	Lever abt K	Product for mom about K
5	2150	1	2150	5h	10750h
4	2100	4	8400	4h	33600h
3	2030	2	4060	3h	12180h
2	1925	4	7700	2h	15400h
1	1730	1	1730	1h	1730h
	SOP	=	24040	SOP =	73660h

KB of main body = 73660h/24040 = 3.064 m

Vol of main body = (h/3) (SOP for volume) = 8013.333 m^3.

Taking moments about the keel,

[Main body] + [appendage] = [total volume]

8013.333 (3.064) + 800 (0.7) = (8813.333) KB

KB of ship = 2.849 metres.

W in SW = 8813.333 (1.025) = 9033.7 t.

Example 11

Half-breadths of a ship's water-plane from aft, at equal intervals, are: 5, 5.88, 6.75, 6.63, 4, 2.38 & 0 m. The common interval between the first five semi-ordinates is 20 m and between the last three is 10 m. The total length of the water-plane is 100 m. Find the area of the water-plane and the position of its CoF.

y/2 (m)	SM	Product for semi-area	Lever abt A	Product for semi-moment
5.00	1	05.00	0	00.00h
5.88	4	23.52	1h	23.52h
6.75	2	13.50	2h	27.00h
6.63	4	26.52	3h	79.56h
4.00	1.5	06.00	4h	24.00h
2.38	2	04.76	4.5h	21.42h
0.00	0.5	00.00	5h	00.00h
SOP	=	79.30	SOP =	175.50h

AF = 175.5h/79.3 = 44.262 metres.
Semi-area = (SOP) h/3 = 528.6667 m^2.
Full area = 2(528.6667) = 1057.333 m^2.

Example 12

The vertical ordinates of the after bulkhead of the port slop tank of a tanker, measured from the horizontal deckhead downwards, spaced at equal athwartship intervals of 1 m, are:

0, 3.25, 4.4, 5.15, 5.65, 5.9 and 6.0 m.

Find the distance of the geometric centre of the bulkhead from (a) the inner boundary and (b) the deckhead. (c) Find the thrust on this bulkhead when the tank is full of salt water.

Note 1: The distance of the GC from the inner boundary of the tank can be calculated by taking levers, in multiples of h or directly in metres, from the starboard side, as done in earlier examples.

Note 2: The distance of the GC of each ordinate y, from the deckhead, is y/2. This is the lever to be used to calculate the distance of the GC of the bulkhead from the deckhead.

Note 3: In the calculation below,

Column 1 x Column 2 = Column 3
Column 3 x Column 4 = Column 5
Column 3 x Column 6 = Column 7

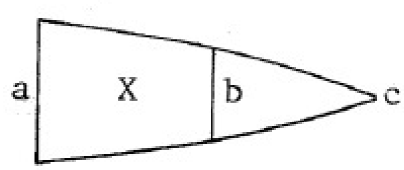
(1) Ord In (m)	(2) SM	(3) Product for area	(4) LEVER	(5) Product for mom about stbd side	(6) LEVER	(7) Product for mom about deck head
0.00	1	00.00	6h	00.00h	0.000	00.000
3.25	3	09.75	5h	48.75h	1.625	15.844
4.40	3	13.20	4h	52.80h	2.200	29.040
5.15	2	10.30	3h	30.90h	2.575	26.523
5.65	3	16.95	2h	33.90h	2.825	47.884
5.90	3	17.70	1h	17.70h	2.950	52.215
6.00	1	06.00	0h	00.00h	3.000	18.000
	SOP	73.90	SOP	184.05h	SOP	189.506

GC from stbd = 184.05h/73.9 = 2.491 m.
GC to deckhead = 189.506/73.9 = 2.564 m.
Area = (SOP) 3h/8 = 73.9 (3/8) = 27.713 m^2
Thrust = depth of GC x density x area
= 2.564 (1.025) 27.713 = 72.833 t.

Note 4: To save time and effort during calculation, column 6 may be taken as full 'y' and then the sum of products of column 7 may be divided by 2. If desired column 6 may be $y^2/2$ and put through SM to get column 7.

Example 13

The breadths of the forecastle of a barge, at 2 m intervals from aft, are: 3.31, 2 & 0 m. Calculate the area & the position of the geometric centre of the space between the first two ordinates.



Area X = (5a + 8b – c) h/12
= (16.55 + 16 – 0) 2/12 = 5.425 m^2
Moment of area X about ‘a’
= **(3a + 10b – c) (h^2/24)★**

= (9.93 + 20 – 0) 4/24 = 4.988 m^3.

GC of X from 'a' = 4.988/5.425 = 0.919 m

Note: The formula marked ★ is called the three-ten-minus-one rule for use in such cases.

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Exercise 18
Simpson's Rules

1. Calculate the area and the position of the CoF of a ship's water-plane whose half-breadths, at 10 m intervals from aft, are: 0, 6, 8, 8.5, 8.5, 7.5, 6.5, 4.5, 2.5 and 0 metres. (Answer: 1057.5 m^2; AF 40 m).

2. The breadths of a transverse water-tight bulkhead, at 2 m intervals from the bottom, are: 2, 5.8, 8.4, 10.2 & 11.4 m. Find (a) its area, (b) the distance of its geometric centre from the top and (c) the thrust when it is pressed up with SW to a head of 6 m above the top.

(Answer: (a) 62.8 m^2 (b) 3.227 m (c) 593.942 t).

3. The half-breadths of a transverse W/T bulkhead, at 2 m vertical intervals from the top, are:

10.6, 10, 9.3, 8.3, 7.1, 5.7 & 3.8 m.

Below the lowest semi-ordinate is a rectangular appendage 7.6 m broad and 1 m high. Find the total area of the bulkhead and the distance of its GC from the bottom of the appendage.

(Answer: By Rule 1: 198.533 m^2, 7.546 m; By Rule 2 198.550 m^2; 7.549 m).

4. Find KB and displacement at 4 m draft in SW, if the water-plane areas are:-

Draft m	5	4	3	2	1	0
Area m^2	2010	1920	1580	1300	920	780

(Answer: 2.322 m; 5227.5 t).

5. Find W and KB at 6 m SW draft:

Draft	6	5	4	3	2	1	0 m
TPC	22.6	22.2	21.6	20.9	19.7	17.8	14.6

(Answer: 12113.3 t; KB 3.173 m).

6. The half-breadths of a tank top, at 3 m intervals from forward, are:

3, 4.65, 6, 7.2, 8.1, 8.55, 9 & 9.6 m

Find the area and the distance of its geometric centre from forward.

(Suggestion: Use Rule 1 for the first five semi-ordinates & Rule 2 for the last four).

(Answer: 299.288 m^2; GC 12.028 m from forward).

7. The water-plane areas of a ship are:-

Draft	6	5	4	3	2	m
Area	2190	2150	2100	2040	1920	m^2

Below 2 m draft there is an appendage having a volume of 3200 m^3, whose GC is 1.2 m above the keel. Find the KB and W of the ship at 6 m draft in SW.

(Answer: 3.253 m; 11845.6 t).

8. Find the W and KB at 5 m draft in SW, given the water-plane areas as under:

d	5	4	3	2	1	0.5	0	m
A	6380	6320	6225	6090	5885	5740	5560	m^2

(Answer: 31282.1 t; 2.552 m).

9. The half-ordinates of a ship's water-plane, at equal intervals from forward, are:

0, 1.5, 2.78, 3.75, 4.2, 4.5, 4.2, 3.9, 3.3 & 2.25 m.

The common interval between the last four semi-ordinates is 3 m & between the others is 6 m. Find the distance of the GC from the ship's after end. (Suggestion: Use Simpson's Rule 2 with half-stations aft).

(Answer CoF 18.974 m from aft).

10. The half-breadths of a ship's water-plane 180 m long, at equal intervals from aft, are: 2.8, 4, 5.2, 6, 6.4, 6.8, 6.6, 6, 4.2 and 0 metres. Midway between the last two given figures, the half-breadth is 2.4 m. Find the area of the water-plane and the distance of the COF from the after end.

(Answer: 1886.667 m^2; AF 89.668 m).

11. The breadths of a ship's water-plane 144 m long, at equal intervals from forward, are: 0, 9, 12.9, 14.7, 15.6, 15.8, 15.8, 15.6, 15.3, 15, 13.2, 9.6 and 0 m. The intermediate ordinate between the first two is 6 m & between the last two, is 6.6 m. Find the area of the water-plane and the distance of the COF from amidships.

(Answer: 1866 m^2, HF 0.383 m aft).

12. The half-breadths of a ship's water-plane, at 12 m intervals from aft are 0.0, 3.3, 4.5, 4.8, 4.5, 3.6, 2.7 and 1.5 m. The half-breadth, midway between the first two from aft, is 2 m. At the forward end is an appendage by way of a bulbous bow 4.5 m long. Its area is 24 m^2 and its GC, 2 m from the forward extremity. Find the area of the water-plane and the position of the COF.

(Answer: 616.4 m^2; AF 43.091 m).

13. The transverse cross-sectional areas of a lower hold 21 m long, at equal intervals from forward, are 120, 116, 101 and 80 m^2. Find the volume of the hold and the distance of its GC from the after bulkhead.

(Answer: 2233.875 m^3; GC 11.179 m from A).

14. The transverse cross-sectional areas, of a ship's under-water portion 90 m long, are: 0.5, 22.9, 49, 73.5, 88.5, 83, 58.6, 31.8, 14.2, 8.1 and 4.5 m^2. The last given area is at the after perpendicular of the ship. The spacing between the last three sections is half the common interval between the rest. Find the AB & displacement in SW.

(Answer: 4363.9 t; AB 47.255 m).

15. The after bulkhead of the starboard slop tank of a tanker is 6 m high. It is bounded on the top by a horizontal deck, towards amidships by a vertical fore-and-aft bulkhead, and on the starboard side by the shell plating. The breadths of this bulkhead at equal vertical intervals are: 3, 3.15, 2.85, 2.1, 1.1 & 0 metres.Find the area of this bulkhead & the distances of its GC from the bottom and from the inner boundary.

(Answer: By Rules 1 and 2: 12.983 m^2; GC 3.751m from bottom & 1.308 m from port).

16. Three consecutive half-breadths of a bulkhead 6 m high, starting from the bottom, are: 5, 9 and 10 m. Find the area and position of the GC of the bottom three metres of this bulkhead.

(Answer: 43.5 m^2; GC 1.638 m from bottom).

17. The cross-sectional areas of a coal bunker, at 4 m intervals from forward are: 15, 42 and 45 m^2. Find the mass of coal (SF 4 m^3t^{-1}) that could be contained between the first two given cross-sectional areas & the distance of its GC from the after bulkhead. (Answer: 30.5 t; GC 5.705 m from aft).

18. Rework question 6 of this exercise, using Simpson's First Rule for the first seven ordinates and Simpson's Third Rule for the last three. (Compare the area and CoF obtained in both cases).

(Answer: Rules 1 & 3: 299.325 m^2; GC 12.028 m from fwd; Rules 1 & 2 as in Q 6: 299.288 m^2; 12.028 m from fwd).

19. The half-breadths of a ship's water-plane 150 m long, from forward in metres, are:

2.97, 6.15, 7.84, 8.48, 8.06, 7.21, 5.72, 3.60 & 0.

Find the area using the trapezoid rule. (Compare your answer with that of question 5 of exercise 16). (Answer: 1820.438 m^2; as per Q5/Ex 16: 1849.625 m^2).

20. The breadths of the deck of a ship, measured at 15 metre intervals from forward, are:

6.2, 13.8, 21.9, 26.4, 22.4, 14.7 and 7.4 metres.

Assuming that Simpson's First Rule is correct, find the % error that would be obtained by using: (a) The Trapezoidal rule & (b) Simpson's Second Rule. (Answer: (a) 1.181 % low (b) 0.435 % low).

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21. ANGLE OF LOLL – CALCULATION; REMEDIAL ACTION

Unstable equilibrium and angle loll were described earlier, in chapters 10 and 11 of this book. A vessel at the angle of loll is in an extremely precarious and dangerous situation - wrong action or no action on the part of the ship's staff may cause the ship to capsize. Even no action is dangerous because consumption of fuel and water from the double bottom tanks would cause increase of KG making the vessel more unstable, thereby increasing the angle of loll.

The angle of loll can be calculated by a simple formula derived from the wall-sided formula:

$$GZ = \sin\theta\,(GM + \tfrac{1}{2}\,BM\tan^2\theta)$$

At the angle of loll, GZ = zero. So

$$\sin\theta\,(GM + \tfrac{1}{2}\,BM\tan^2\theta) = 0$$

So, $\sin\theta = 0$ or $(GM + \tfrac{1}{2}\,BM\tan^2\theta) = 0$

At the angle of loll. $\theta \neq 0$ so $\sin\theta \neq 0$, hence

$GM + \tfrac{1}{2}\,BM\tan^2\theta = 0$, so $\tan^2\theta = -2GM/BM$

$$\tan\theta = \sqrt{\frac{-2GM}{BM}}$$

Where θ = Angle of loll
GM = The initial GM
BM = BM when upright

This formula is derived from the wall-sided formula. Wall-sided means that the ship's sides are straight and and parallel like the opposite walls of a room. The immersed wedge and the emerged wedge would be identical in shape until the deck edge immerses. Thereafter the immersed and emerged wedges would NOT be identical in shape and the wall-sided formula is no longer applicable.

Example

M.V. VIJAY is afloat at 6 m draft. Find the angle of loll if KG = 8.424 metres.

From appendix I of this book, at 6 m draft, KM = 8.234 m and KB = 3.205 m.

$$\begin{aligned} KM &= 8.234 \text{ m} \\ KB &= \underline{3.205} \text{ m} \\ BM &= 5.029 \text{ m} \end{aligned} \qquad \begin{aligned} KM &= 8.234 \text{ m} \\ KG &= \underline{8.434} \text{ m} \\ GM &= -0.200 \text{ m} \end{aligned}$$

$$\text{Tan } \theta = \sqrt{\frac{-2GM}{BM}} = \sqrt{\frac{-2\,(-0.2)}{5.029}} = 0.28203$$

Angle of loll = θ = 15.75° or 15° 45’

Remedial action

1) Press up all slack tanks.

2) Run up SW into the DB tank which has the smallest moment of inertia about its centre line. If this tank is not on the centre line of the ship, then on the lower side first, and after it is full, its counterpart on the higher side.

3) Repeat action 2 with another tank and so on until the ship becomes stable.

4) If discharging or jettisoning deck cargo, do so from the higher side first, then from the lower side. If using ship’s own gear, due allowance must be made for the shift of COG, of each sling of cargo, from the UD to the crane head during the operation.

Justification for such action

At the angle of loll, any existing free surface effect must be eliminated/minimised first. FW or HFO may require to be transferred internally such that the tanks finally remaining slack are those with the smallest moment of inertia about the tank’s centreline.

While running up ballast into a DB tank, FSE would be created. This must be kept to a minimum. The necessity to fill up the tank with the smallest ‘i’ about its centre line is, therefore, vital. So also, the necessity to fill up only one tank at a time.

If the tank being ballasted is not on the centre line of the ship, but on either side like No: 2 P and No: 2 S, then fill up the lower side tank first i.e., if the ship is lolled to starboard, then fill up No: 2 S first. After it is full, fill up No: 2 P. The reasons for this:

Let **‘A’** be the angle of loll to starboard at first.

‘p’ be the reduction in the angle of loll by completely filling up either No: 2 P or No: 2 S, by reduction of KG of the ship.

‘q’ be the list caused by filling up either No: 2 P or No: 2 S, being off the centreline of the ship.

‘**R**’ be the resultant inclination after completely filling up either No: 2 P or No: 2 S.

If No: 2 S is run up first, R = A – p + q

If No: 2 P is run up first, R= A – p – q

In both cases, final R is to starboard.

It appears that filling up the higher side tank would produce better results, but it is not so. The ship can loll to either side. If after the higher side tank is run up, wave action caused the ship to loll over to the other side (port side in this case), the ship would flop over to (A – p + q) to port and the momentum of flopping over will carry the inclination well beyond this. Since the GZ formed near the angle of loll is very small, the ship would heel over to port much more than (A – p + q) and take a very long time to return to this angle of inclination. If during this time (a) any openings went underwater &/or (b) a wave struck the ship adversely and/or (c) any cargo shifted, the ship may capsize.

By filling up the lower side tank first, the inclination would increase a bit to (A – p + q) at first, but this would be gradual and would last only until No: 2 P also is run up.

The same reasons apply when considering discharge or jettison of cargo from the upper deck.

If the ship is in calm waters, such as inside a dock, the possibility of flopping over to the angle of loll on the other side may not be there. In such a case, ballasting the higher side tank or discharging deck cargo from the lower side may prove more effective and immediate.

Exercise 19
Angle of loll

1. A vessel has an initial GM of -0.3 m & BM of 5 m. Find the angle of loll. (Answer: 19.11° or 19° 06’).
2. M.V. VIJAY is lying at the angle of loll of 16° to port, at 6.2 m hydrostatic draft. Find the initial GM. **Note**: From Appendix I, at 6.2 m draft, KM = 8.180 m and KB = 3.309 m. (Answer: -0.200 m).
3. M.V. VIJAY is unstable and lolling 12° to starboard at a hydrostatic draft of 6.8 m. Find the minimum quantity of cargo to shift by a shore crane, from the upper deck to the lower hold, through a

vertical distance of 10 m to make the ship stable.Note: From Appendix I, at 6.8 m draft, KM = 8.076 m and KB = 3.620 m. (Answer: 141 t).

4. A box-shaped vessel 100 x 12 x 8 m is lying at an angle of loll of 18°. If mean draft is 4 m, find its KG. (Answer: 5.158 m).

5. A homogenous wooden log of square cross-section has RD = 0.68. Would it float in FW with one face parallel to the water? If not, calculate the angle of inclination. (Answer: No! Angle of loll = 37° 48').

6. What should the RD of a homogenous log of square cross-section be for it to float in FW with one face parallel to the surface of water? (Answer: Less than 0.2113 or more than 0.7887).

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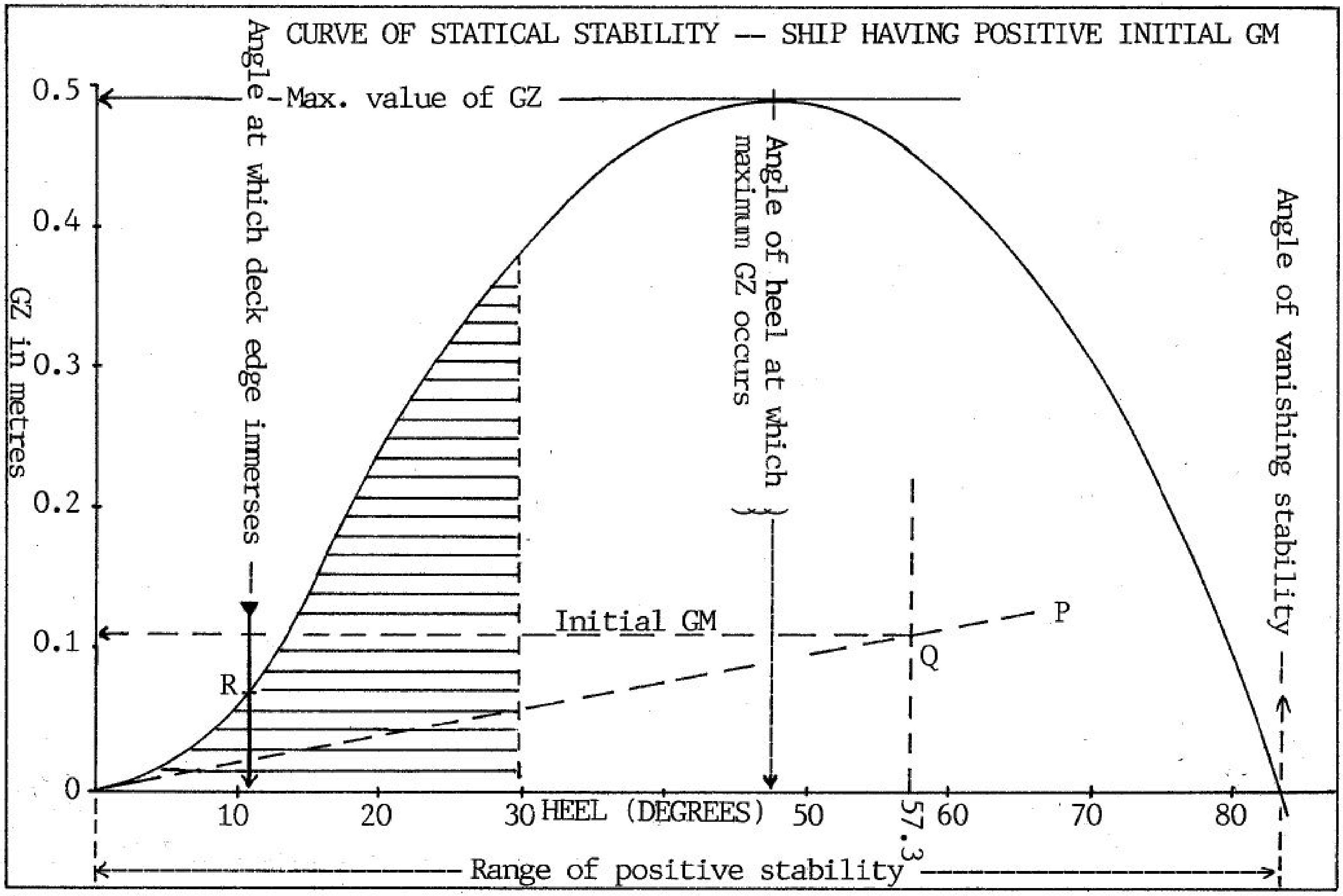
22. CURVE OF STATICAL STABILITY

A curve of statical stability is a graph wherein the righting lever (GZ) is plotted against the angle of heel. It is drawn, by the ship's Chief Officer, for the displacement and KG of that voyage.

Referring to the accompanying illustration, the information that may be obtained from a curve of statical stability is:

1. The maximum value of GZ.
2. The angle of heel at which maximum GZ occurs.
3. The angle of vanishing stability. This is the angle of heel at which GZ becomes zero again.
4. The range of positive stability. In normal cases, this would be from zero degrees to the angle of vanishing stability but in cases where the ship is initially unstable, it will not be from zero degrees onwards but from some other value as shown later in this chapter.
5. The initial GM. A tangent is drawn to the curve at the origin (OP in the figure).


CURVE OF STATICAL STABILITY — SHIP HAVING POSITIVE INITIAL GM
Max. value of GZ
Angle at which deck edge immerses
Angle of heel at which maximum GZ occurs
Angle of vanishing stability
Initial GM
R
Q
P
GZ in metres
0.5
0.4
0.3
0.2
0.1
0
10
20
30
HEEL (DEGREES)
50
57.3
60
70
80
Range of positive stability

A perpendicular is erected at 57.3° heel to meet the tangent (Q in the figure). The distance of the point of intersection from the base line, measured on the GZ scale, indicates the initial GM.

Note: In actual practice, the reverse happens. The initial fluid GM is cut off on the perpendicular at 57.3° to arrive at point Q in the figure. Q & O are joined by a straight line and while drawing the curve, it is ensured that the curve coincides with line OQ for the first few degrees.

6. The angle of heel at which the deck edge immerses. This is the angle of heel at which the point of contra-flexure of the curve occurs (point R in the figure)

7. The moment of statical stability at any given angle of heel. The GZ for the given angle of heel is obtained from the curve and multiplied by the displacement of the ship.

8. The dynamical stability of the ship at any given angle of heel. This is the work done in heeling the ship to the given angle. This is dealt with in more detail in 'Ship Stability at the Management Level'. Dynamical stability at θ° heel = W x A

Where

W: ship's displacement in tonnes.

A: area between the GZ curve and the base line, up to θ° heel, expressed in metre-radians.

Once the curve of statical stability has been drawn, the area under the curve up to any angle of heel can be calculated using Simpson's Rules. This area, multiplied by the displacement of the ship, would give the dynamical stability in tonne-metre-radians. In the preceding diagram, the area under the curve up to 30º has been shaded for illustration.

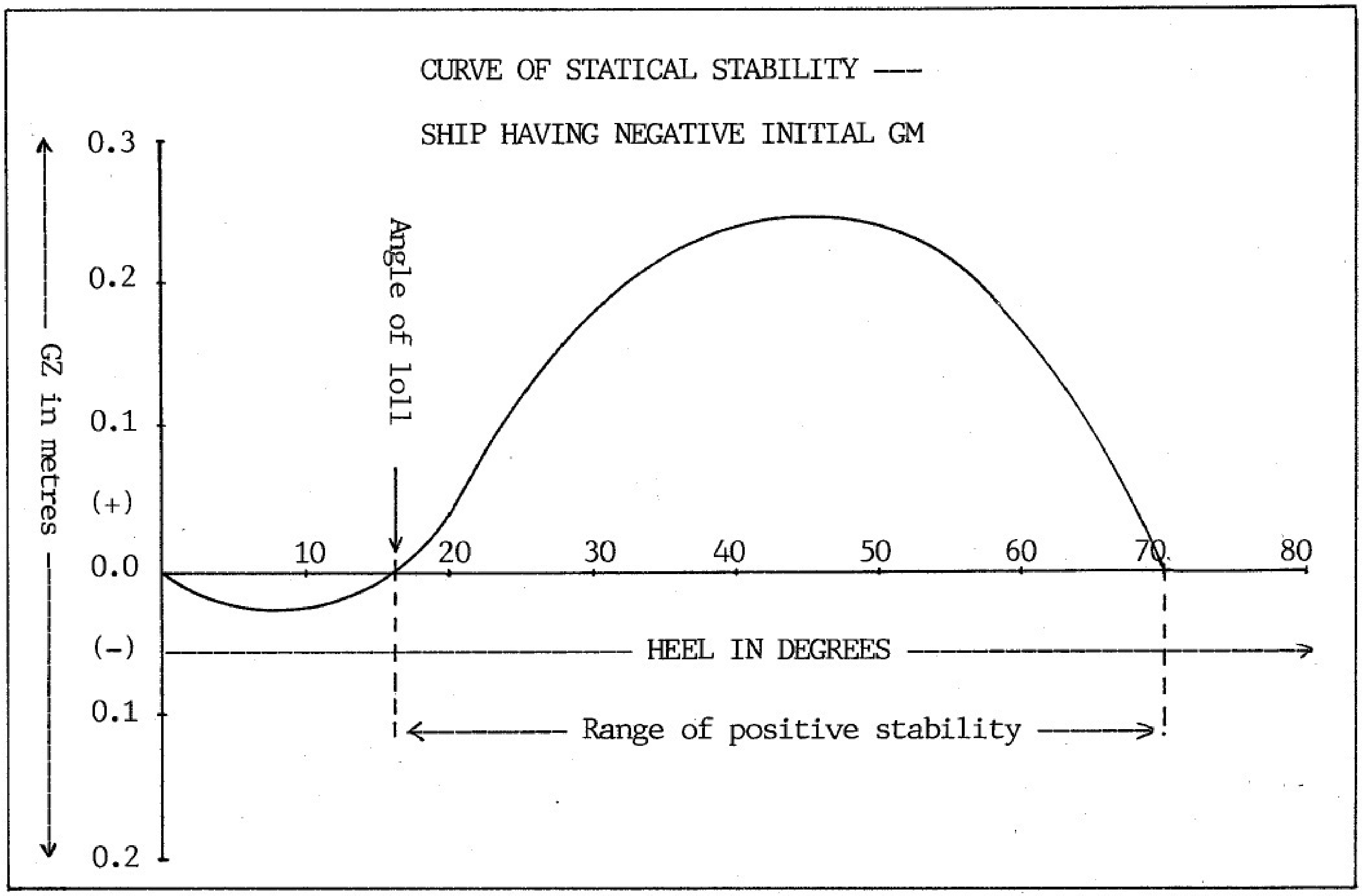
The curve would be the same whether the ship is heeled to starboard or to port. The only difference would be the direction of GZ: when heeled to port, GZ acts to starboard and when heeled to starboard, GZ acts to port.

The information required by the Chief Officer to construct a curve of statical stability, for the displacement and KG of the voyage, is supplied by the shipyard in the form of either Cross Curves or KN curves which are explained in the next two chapters.

Curve when initial GM is negative

An illustration of the GZ curves of a vessel, when it is initially unstable, follows. It will be seen therein that the range of positive stability is from the angle of loll onwards, not from zero.

Since the angle of loll could be to port or to starboard, the curve would be the same regardless of the direction of inclination of the ship. If the ship was lolled to port, GZ may be considered + when it resists further inclination to port and vice versa.

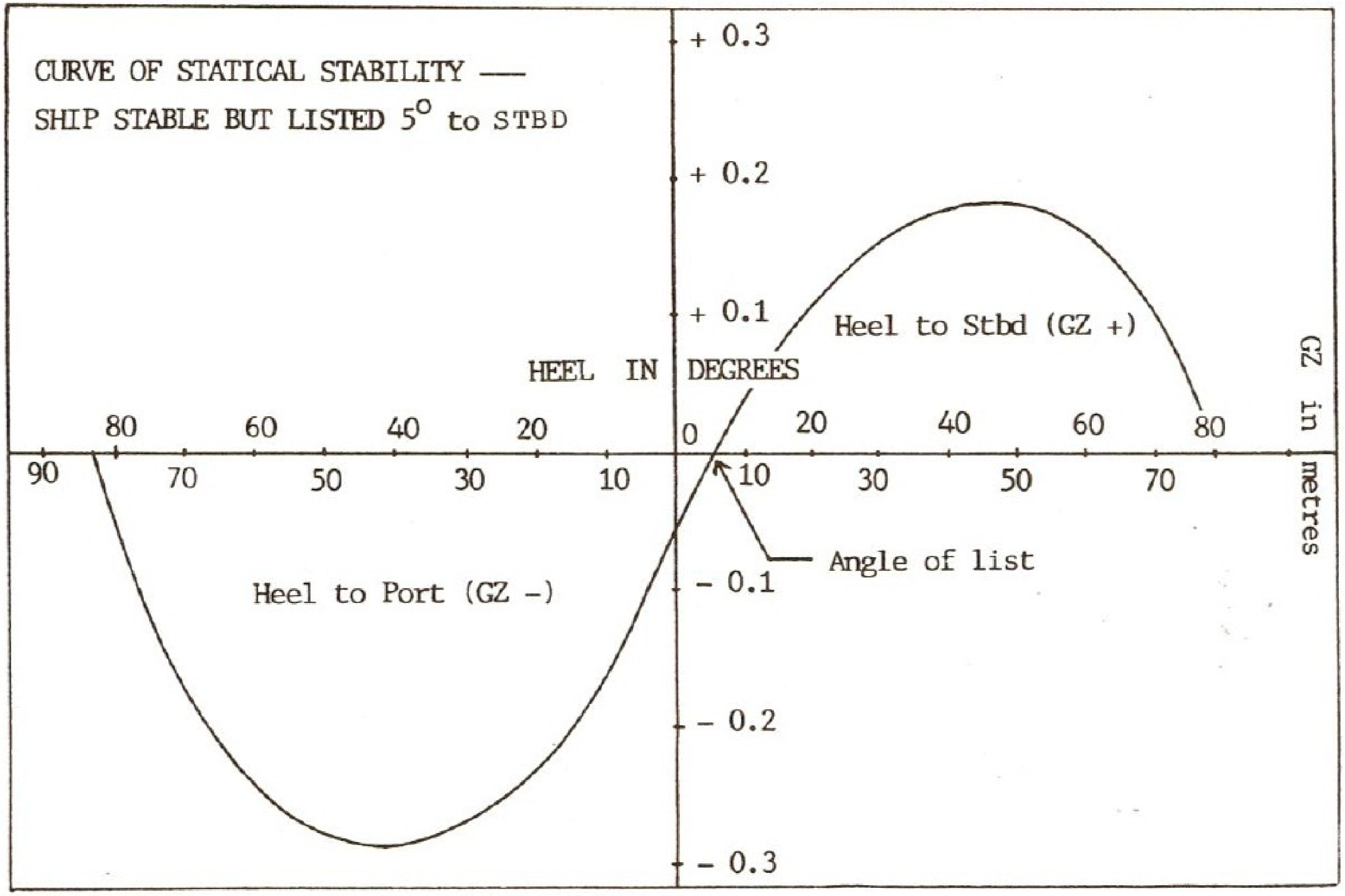

CURVE OF STATICAL STABILITY —
SHIP HAVING NEGATIVE INITIAL GM
Angle of loll
GZ in metres
0.3
0.2
0.1
(+)
0.0
(-)
0.1
0.2
10
20
30
40
50
60
70
80
HEEL IN DEGREES
Range of positive stability

Curve when ship is listed

When a ship with a positive initial GM has a list, it means that its CoG is off the centre line due to asymmetrical distribution of weights on board. The vessel is at rest the angle of list. The GZ curve will NOT, therefore, be the same for starboard and for port.

An illustration of the GZ curve for a ship with an initial list follows. As mentioned earlier in this chapter, the GZ of a ship in stable equilibrium acts towards port when heeled to starboard and vice versa. In this case, because the heel to port and to starboard is shown on the same graph, GZ is plotted as positive when acting in one direction, say towards port (ship heeled to starboard), and negative when acting towards starboard (ship heeled to port). It is emphasized here that, on either side of the angle of list, the GZ curve would NOT be symmetrical.

A curve of statical stability can be used to find the angle of list accurately, especially when the angle is large, and this is discussed in 'Ship Stability at the Management Level'.

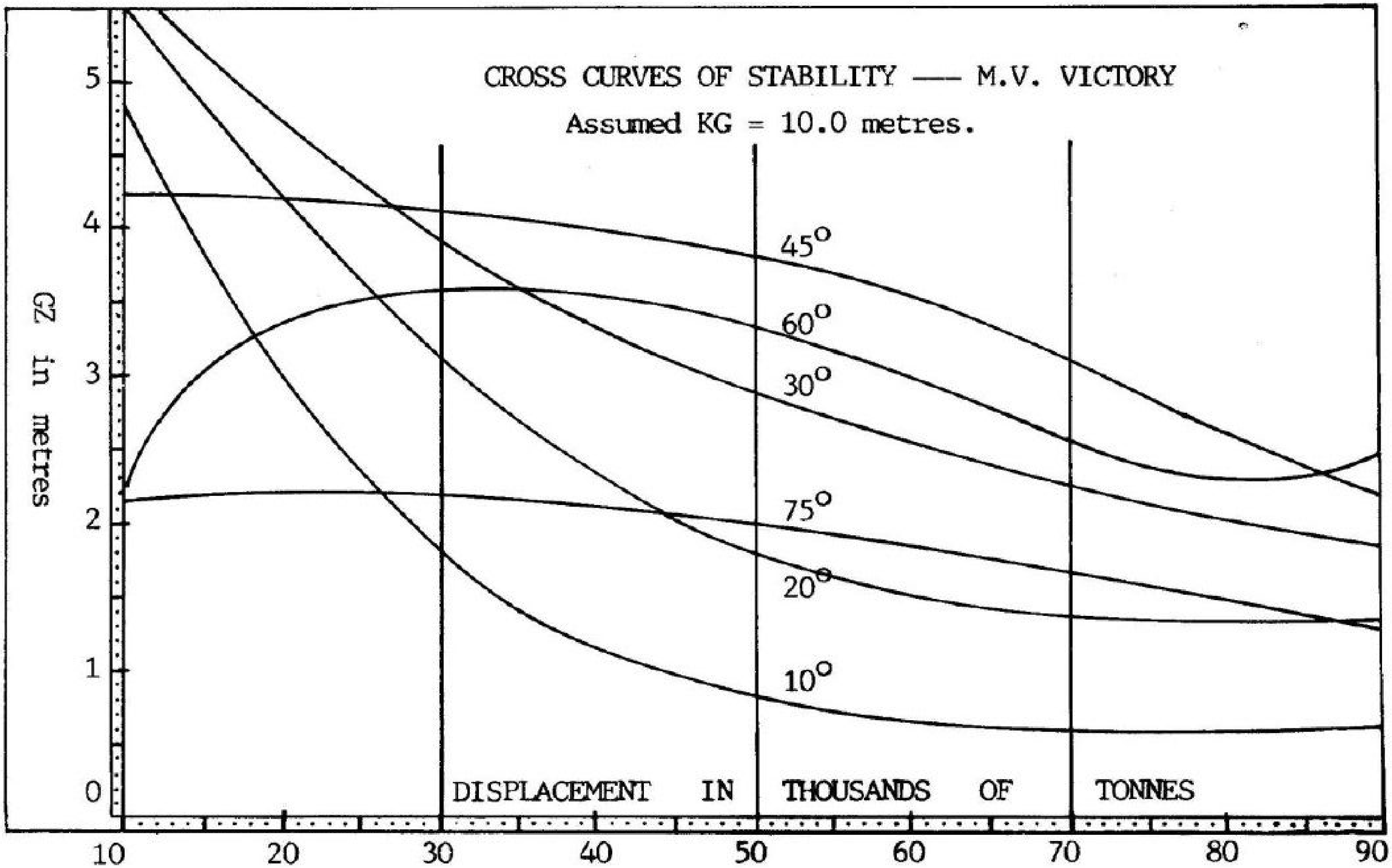

CURVE OF STATICAL STABILITY —
SHIP STABLE BUT LISTED 5° to STBD
+ 0.3
+ 0.2
+ 0.1
- 0.1
- 0.2
- 0.3
HEEL IN DEGREES
GZ in metres
Heel to Stbd (GZ +)
Heel to Port (GZ –)
Angle of list
90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80

23. CROSS CURVES OF STABILITY

As explained in the previous chapter, a curve of statical stability is a curve constructed, for the displacement and KG of each voyage, by the ship's Chief Officer. The information required to construct such a curve may be given by the shipyard in the form of 'Cross Curves' or in the form of 'KN Curves'. The former is explained here and the latter, in the next chapter.

GZ is a function of KG, KM and θ (the angle of heel). KM depends on draft. For the sake of convenience, the shipyard uses displacement in salt water, instead of draft. The variables, therefore, are GZ, θ, displacement in SW and KG.

Based on their calculations, the shipyard constructs a graph with GZ along y-axis and displacement along the x-axis. Separate curves are drawn for different values of θ – say 10°, 20°, 30°, 45°, 60° and 75°. These curves may cross one another, hence the name 'Cross Curves'. The graph is constructed for an assumed value of KG which is stated clearly therein. In this manner, all the variables affecting GZ are allowed for. The figure shows the cross curves for the bulk carrier M.V. VICTORY. Using the displacement for that voyage, the GZ for the various angles of heel can be obtained from the cross curves. However, these values of GZ would be correct only for the assumed value of KG.


CROSS CURVES OF STABILITY —— M.V. VICTORY
Assumed KG = 10.0 metres.
GZ in metres
0
1
2
3
4
5
45°
60°
30°
75°
20°
10°
DISPLACEMENT IN THOUSANDS OF TONNES
10
20
30
40
50
60
70
80
90

In the case of M.V. VICTORY, the assumed value of KG is stated to be 10 m. Corrections would have to be applied to obtain the correct values for the actual KG of that voyage.

Note: For this purpose, KG means fluid KG.

Fluid KG = Solid KG + FSC.

In the following two figures,

θ = angle of heel in degrees.

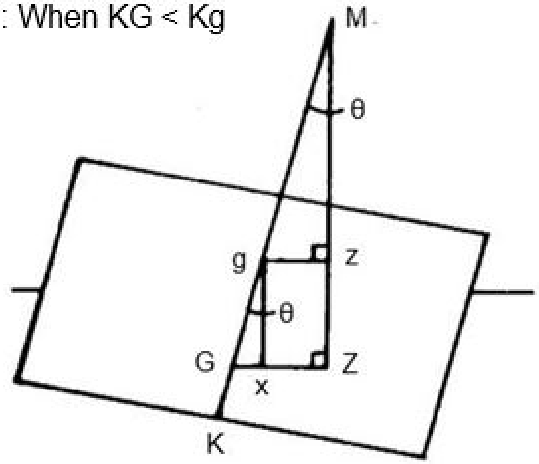
Kg = assumed height of COG for which the cross curves were constructed.

KG = Actual height of COG of that voyage inclusive of FSC.

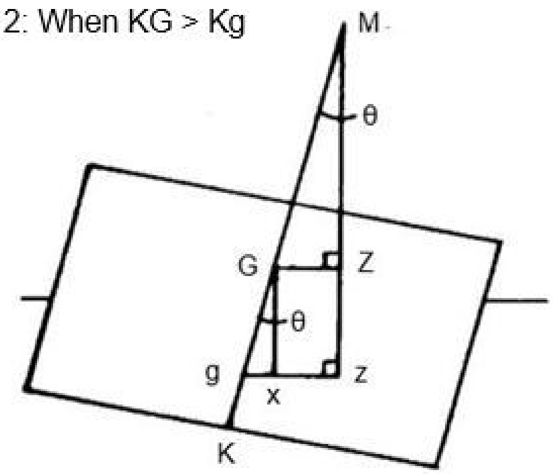
Gz = righting lever at θ° heel if height of COG is equal to Kg.

GZ = actual righting lever at θ° heel when the height of COG is KG.

Case 1: When KG < Kg



Case 2: When KG > Kg



Case 1			Case 2	
gx is parallel to zZ			Gx is parallel to Zz	
GZ	=	xZ + xG	GZ = xz	= gz - gx
	=	gz + xG		
	=	gz + gG (Sinθ)		= gz – gG (Sinθ)
Correction to apply to gz to obtain GZ is PLUS gG (Sin θ).			Correction to apply to gz to obtain GZ is MINUS gG (Sin θ).	

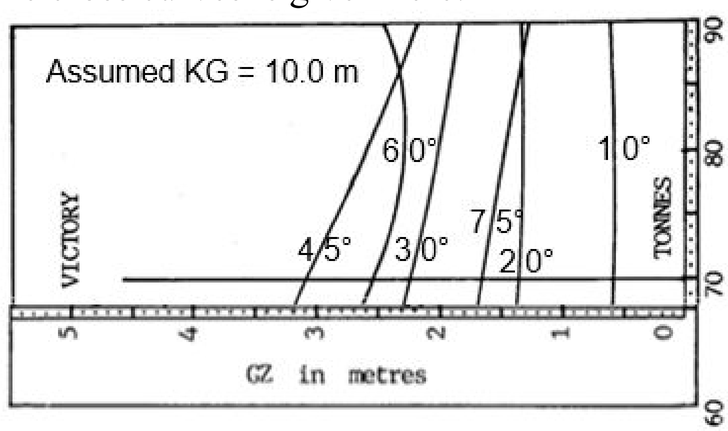
Example 1

Construct the curve of statical stability of m.v. VICTORY when W = 70,000 t, KG solid = 9.41 m, FSM = 6300 tm. From the curve, find the maximum GZ and the angle of heel at which it occurs. Also find the initial GM in that condition.

FSC = FSM/W = 6300/70,000 = 0.090 metre.

KG fluid = 9.410 + 0.090 = 9.500 metres.

A snip of the cross curves is given here:

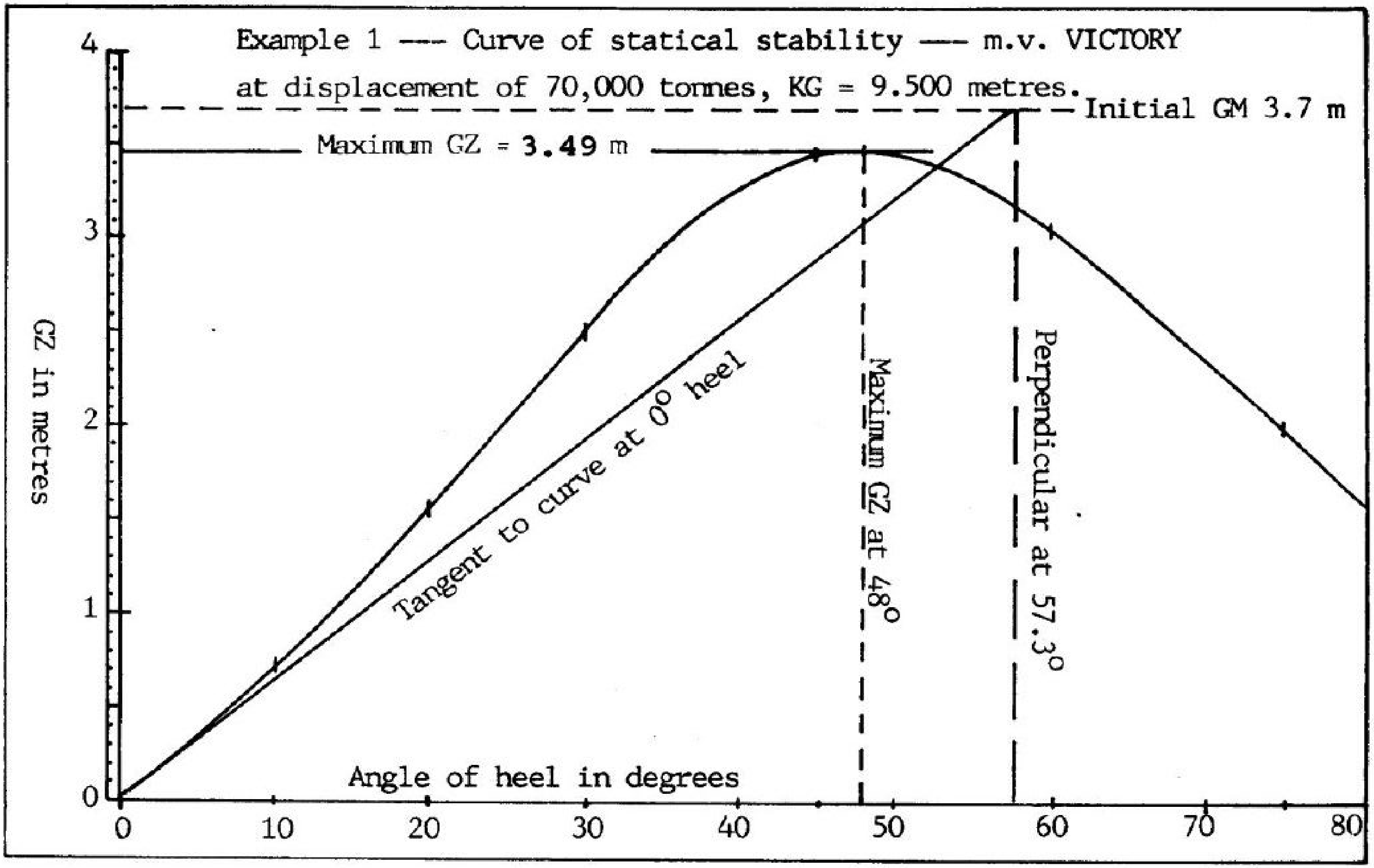


Extract the values of gz for the various angles of heel, for W of 70,000 t. Since KG fluid is 9.5 m and Kg is 10 m, apply the correction +gG (Sin θ) to gz & obtain GZ.

θ	gz	+	gG Sin θ		GZ
0°	0.00	+	0.5 Sin 0°	=	0.000 m
10°	0.60	+	0.5 Sin 10°	=	0.687
20°	1.38	+	0.5 Sin 20°	=	1.551
30°	2.25	+	0.5 Sin 30°	=	2.500
45°	3.13	+	0.5 Sin 45°	=	3.484
60°	2.58	+	0.5 Sin 60°	=	3.013
75°	1.68	+	0.5 Sin 75°	=	2.163

Now plot GZ against θ, using a suitable scale, as shown on the next page. Fair the curve as necessary to make it smooth and regular. Do NOT join the points by short straight lines. Read off the desired information from the curve.

Note: Since the fluid GM was required to be read off the curve, the calculated GM could not be used to construct the curve.


Example 1 --- Curve of statical stability --- m.v. VICTORY
at displacement of 70,000 tonnes, KG = 9.500 metres.
Initial GM 3.7 m
Maximum GZ = 3.49 m
Tangent to curve at 0° heel
Maximum GZ at 48°
Perpendicular at 57.3°
GZ in metres
Angle of heel in degrees
0
1
2
3
4
0
10
20
30
40
50
60
70
80

Example 2

Construct the GZ curve of m.v. VICTORY when W = 85000 t, KG solid 10.68 m, FSM 6761 tm. From the curve, find (a) Max GZ and the angle at which it occurs (b) the range of positive stability and (c) the angle of heel at which the deck edge would immerse.

KM from appendix II of this book = 13.181 m.

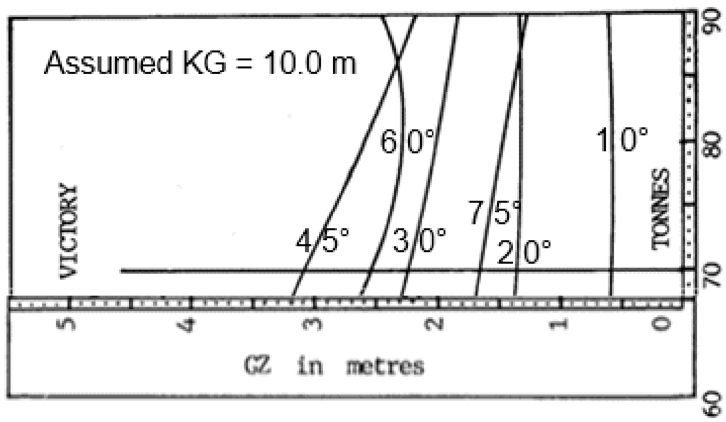
FSC = FSM/W = 6761/85000 = 0.080 metre.

KG_F = 10.68 + 0.08 = 10.760 metres.

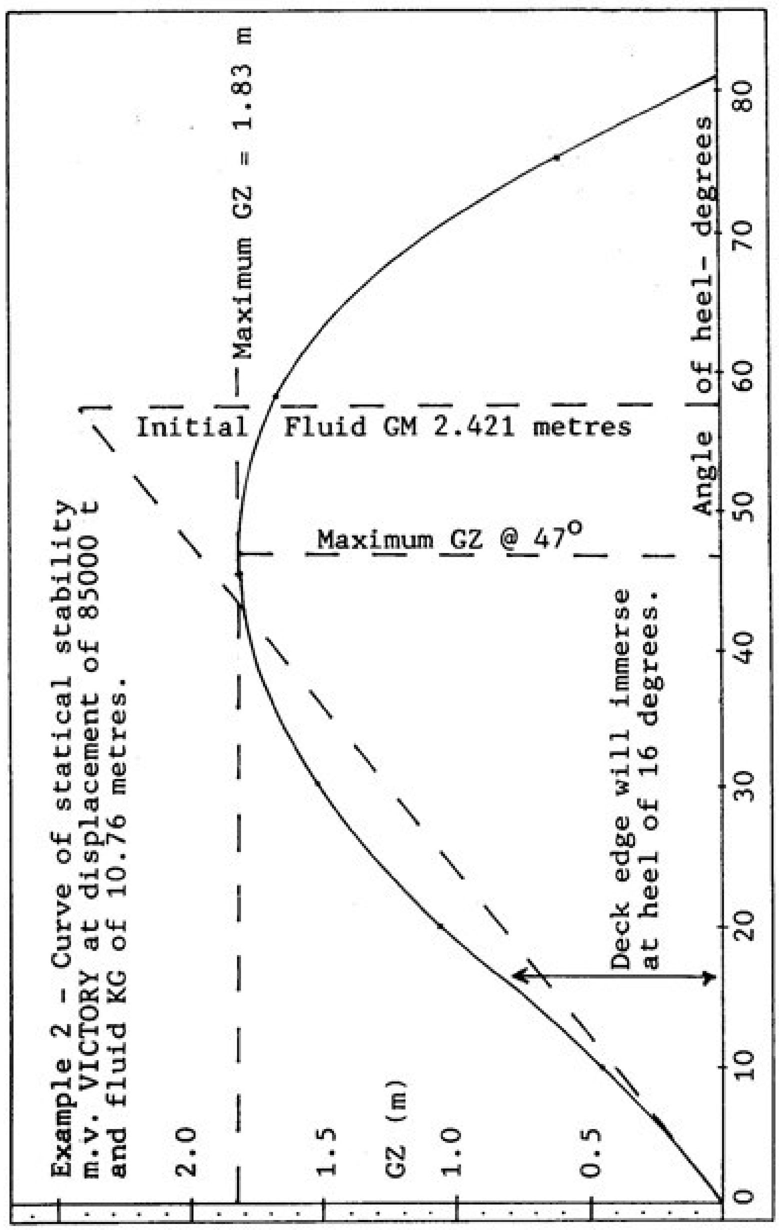
$GM_F = KM – KG_F$ =13.181 – 10.76 = 2.421 m

Since KG_F > Kg, gG (Sin θ) is MINUS

A snip of the cross curves is given here:



θ	gz	-	gG Sin θ	=	GZ
10º	0.58	-	0.76 Sin 10º	=	0.448
20º	1.30	-	0.76 Sin 20º	=	1.040
30º	1.90	-	0.76 Sin 30º	=	1.520
45º	2.35	-	0.76 Sin 45º	=	1.813
60º	2.28	-	0.76 Sin 60º	=	1.622
75º	1.35	-	0.76 Sin 75º	=	0.616



The curve is drawn, as shown in the accompanying diagram, ensuring that it coincides with the line OQ for the first few degrees.

From the curve of statical stability:

(a) Maximum GZ = 1.830 m at 47° heel.

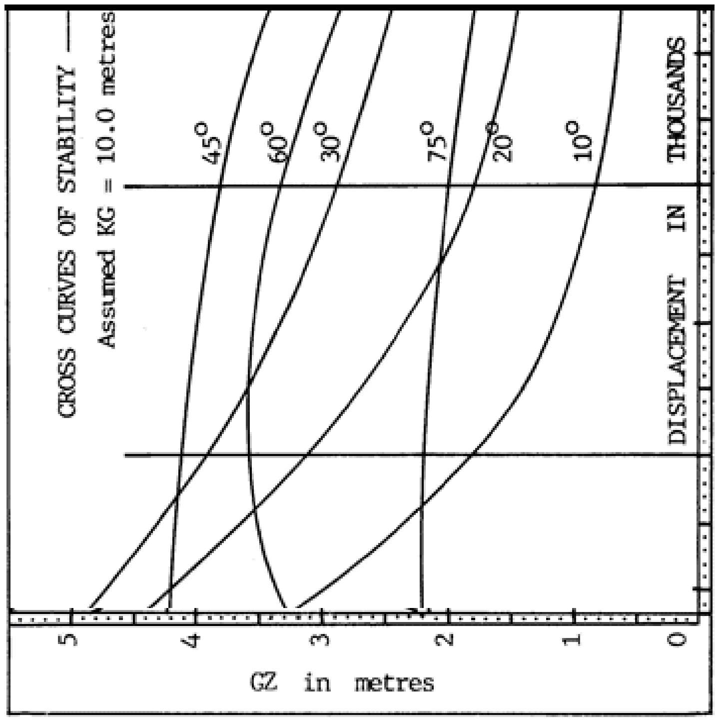
(b) Range of positive stability = 0° to 81°.

(c) Deck edge would immerse at 16° heel.

Exercise 20

Cross Curves of stability

Snip of the cross curves of m.v. Victory, for the displacements covered in this exercise, is give here:



1. Draw the curve of statical stability of M.V. Victory at W = 30,000 t, solid KG 10.983 m, FSM 9000 tm. From the curve, find the initial GM.

(Answer: 1.440 m).

2. Bulker M.V. Victory is at 40,500 t displacement, KM 16.124 m, KG solid 8.925 m, FSM 4738 tm. Draw the GZ curve and thence find the heel at which the deck edge would immerse.

(Answer: 20°).

3. Draw the curve of statical stability for the bulk carrier M.V. Victory when its W = 20,200 t, KM = 26.464 m, solid KG = 9.78 m and FSM = 4444 tm. From the curve, find the maximum GZ and the angle of heel at which it occurs.

(Answer: 4.7 m at 31°).

4. Find the range of positive stability of the ship Victory by constructing the curve of statical stability for W of 55,000 t (KM 14.03 m), KG solid of 10.691 m and FSM of 5129 tm.

(Answer: 0 to 86°).

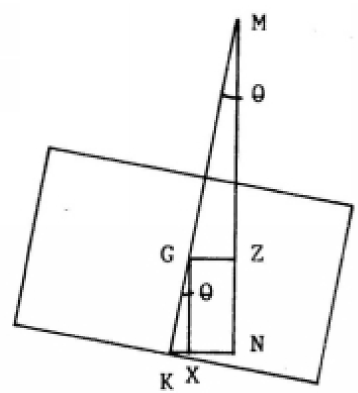
5. M.V. Victory has a displacement of 60,000 t (KM 13.663 m), KG solid of 9.243 m and FSM of 4200 tm. Draw the GZ curve and from it find the moment of statical stability at 35° heel.

(Answer: 190,800 tm at 35°).

24. KN CURVES

While using cross curves of stability, the correction gG(Sin θ) is sometimes positive and sometimes negative, depending on whether the actual fluid KG is less than or greater than the assumed Kg for which the curves were drawn. A bit of thought is necessary, each time, to decide on this and the chances of error are high – in his hurry, the Chief officer may add this correction instead of subtracting it, or vice versa. In order to eliminate this possibility of error, some shipyards draw the cross curves for an assumed value of zero Kg, and thence call the righting lever KN instead of gz. Since the fluid KG of the ship will always be positive, GZ < KN. Hence KGSin θ is always subtractive from KN to obtain GZ. The possibility of erroneous application of correction is thus eliminated.

$$GZ = XN = KN - KX = KN - KG (\sin\theta)$$



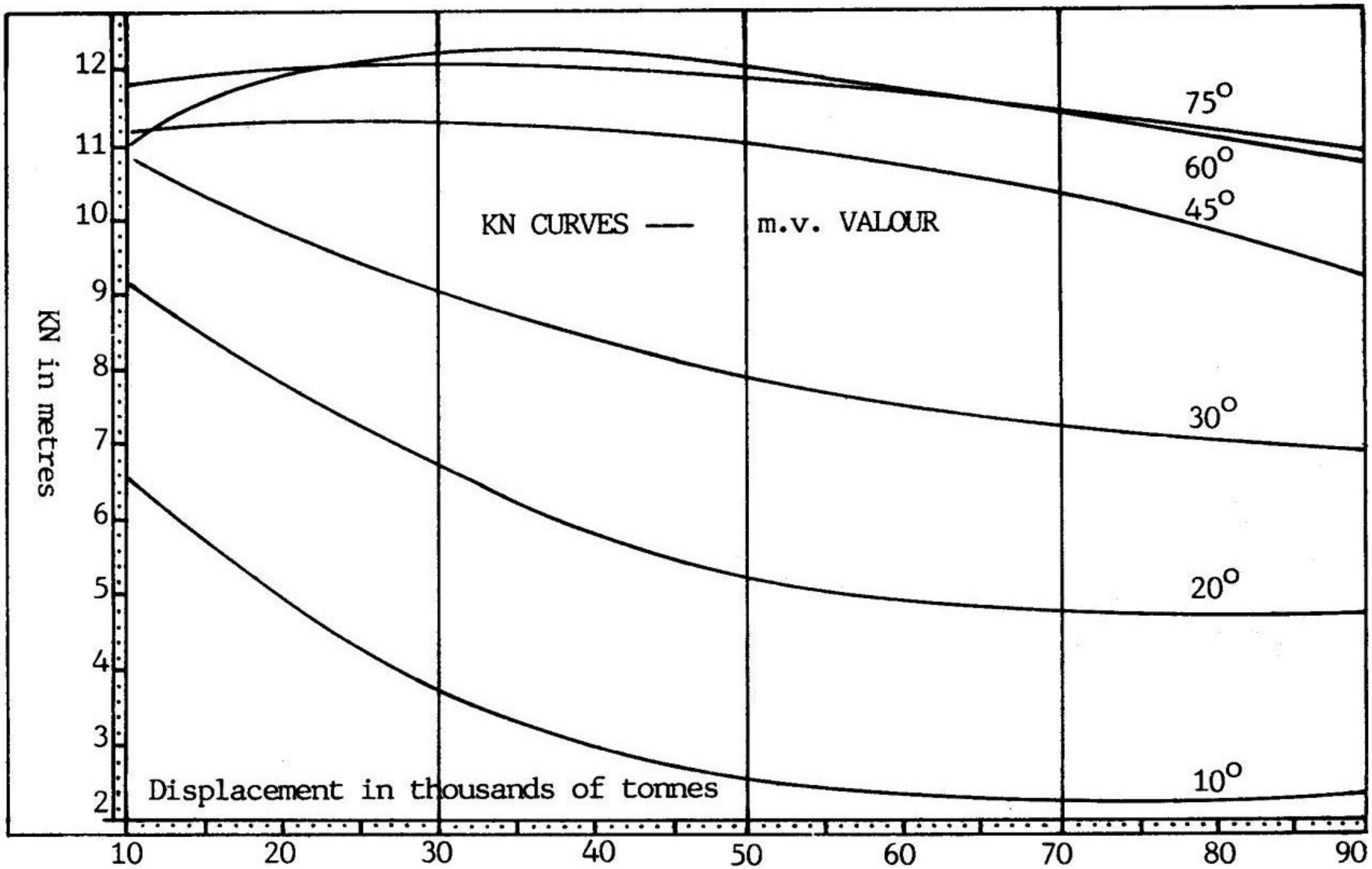
The information regarding GZ or KN may be given in tabular form. The KN table of M.V. Vijay is given below. The table is more convenient for use than the graph – high degree of accuracy can be obtained from a table contained in a small sheet of paper.

M.V. Vijay - KN Table

W	5°	10°	20°	30°	45°	60°	75°
6000	1.029	2.037	3.935	5.401	7.065	8.132	8.183
7000	0.953	1.890	3.717	5.247	7.041	8.185	8.322
8000	0.908	1.793	3.544	5.119	7.007	8.174	8.292
9000	0.875	1.724	3.415	5.012	6.962	8.106	8.254
10000	0.847	1.678	3.315	4.916	6.914	8.032	8.213
11000	0.827	1.642	3.241	4.843	6.863	7.957	8.166
12000	0.811	1.615	3.185	4.782	6.803	7.873	8.113
13000	0.798	1.595	3.153	4.733	6.741	7.788	8.057
14000	0.793	1.581	3.130	4.694	6.664	7.718	7.998
15000	0.794	1.575	3.110	4.657	6.580	7.645	7.941
16000	0.798	1.575	3.116	4.618	6.495	7.571	7.896
17000	0.793	1.577	3.127	4.580	6.408	7.495	7.854
18000	0.795	1.584	3.140	4.547	6.321	7.419	7.810
19000	0.802	1.601	3.134	4.510	6.237	7.341	7.766
20000	0.812	1.628	3.119	4.473	6.165	7.264	7.725

For the same accuracy, curves in graphical form would have to be very much bigger in size.

The following diagram shows the KN curves of M.V. Valour, a sister ship of M.V. Victory whose cross curves are given in the previous chapter. Having been built in different shipyards, one has cross curves, and the other, KN curves.


KN CURVES — m.v. VALOUR
KN in metres
Displacement in thousands of tonnes
75°
60°
45°
30°
20°
10°
12
11
10
9
8
7
6
5
4
3
2
10
20
30
40
50
60
70
80
90

Example 1

Using the KN curves on the previous page, construct the GZ curve of M.V. Valour when W = 65000 t, KM = 13.420 m, KG solid = 8.2 m & FSM = 6500 tm. From the curve find the GZ at 70º heel.

FSC = FSM/W = 6500/65000 = 0.100 metre.

KG fluid = 8.200 + 0.100 = 8.300 metres.

Initial GM fluid = 13.42 – 8.3 = 5.12 m.

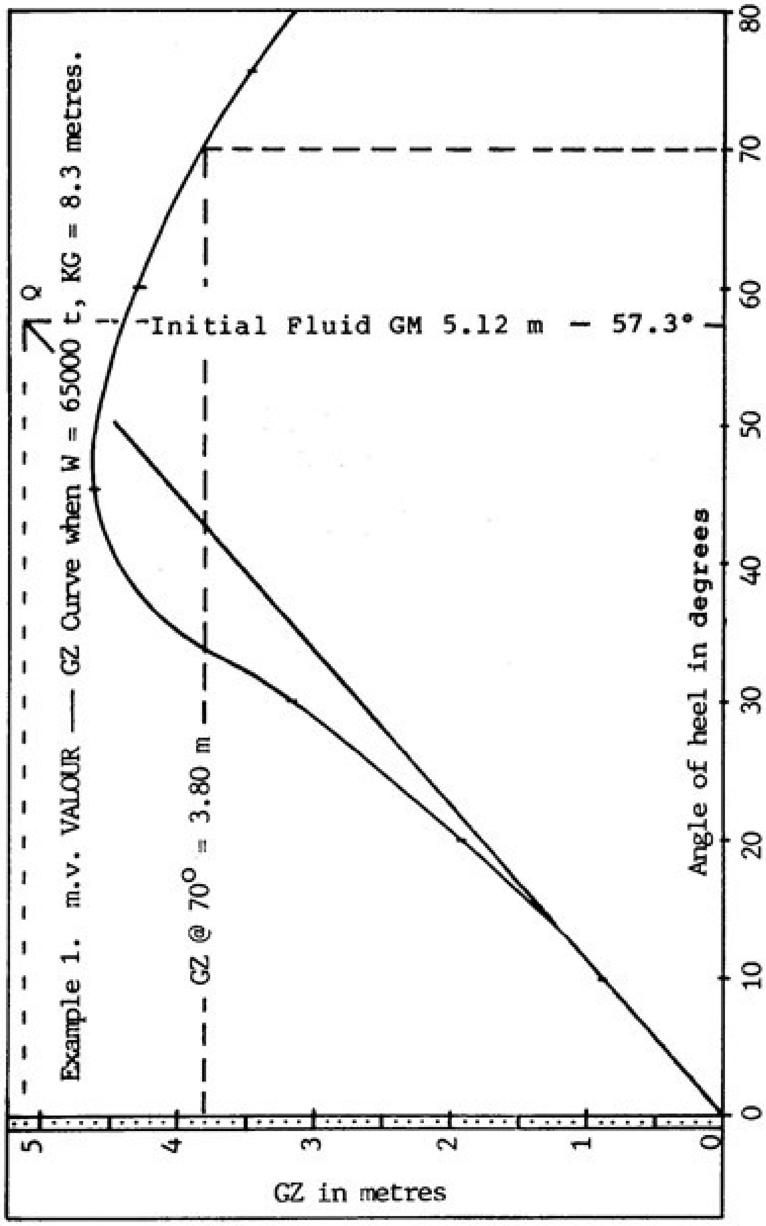
From KN curves of M.V. Valour (shown on the previous page), obtain the KN values for W = 65000 t. Tabulate the values, apply the correction 'minus KG Sin θ' & obtain the GZ as shown here:

θ	KN		KG Sin θ	=	GZ(m)
10°	2.3	-	8.3 Sin 10°	=	0.859
20°	4.8	-	8.3 Sin 20°	=	1.961
30°	7.3	-	8.3 Sin 30°	=	3.150
45°	10.5	-	8.3 Sin 45°	=	4.631
60°	11.5	-	8.3 Sin 60°	=	4.312
75°	11.5	-	8.3 Sin 75°	=	3.483

Note: Erect the initial fluid GM at 57.3° heel and draw line OQ. Construct curve, ensuring that it coincides with line OQ for the first two or three degrees.

Draw the GZ curve as shown herein and, from it, extract the GZ at 70°heel.

GZ at 70° heel = 3.800 metres.



Example 2

Construct the GZ curve for M.V. Vijay when KG (solid) = 6.1 m, FSM = 3050 tm, W = 15400 t, KM = 8.034 m. Find maximum value of GZ.
FSC = FSM/W = 3050/15400 = 0.198 metre.
Fluid KG = 6.100 + 0.198 = 6.298 metres.
GM fluid = 8.034 – 6.298 = 1.736 metres.
Extract from the KN Table of m.v. Vijay

W	5°	10°	20°	30°	45°	60°	75°
15000	0.794	1.575	3.110	4.657	6.580	7.645	7.941
16000	0.798	1.575	3.116	4.618	6.495	7.571	7.896

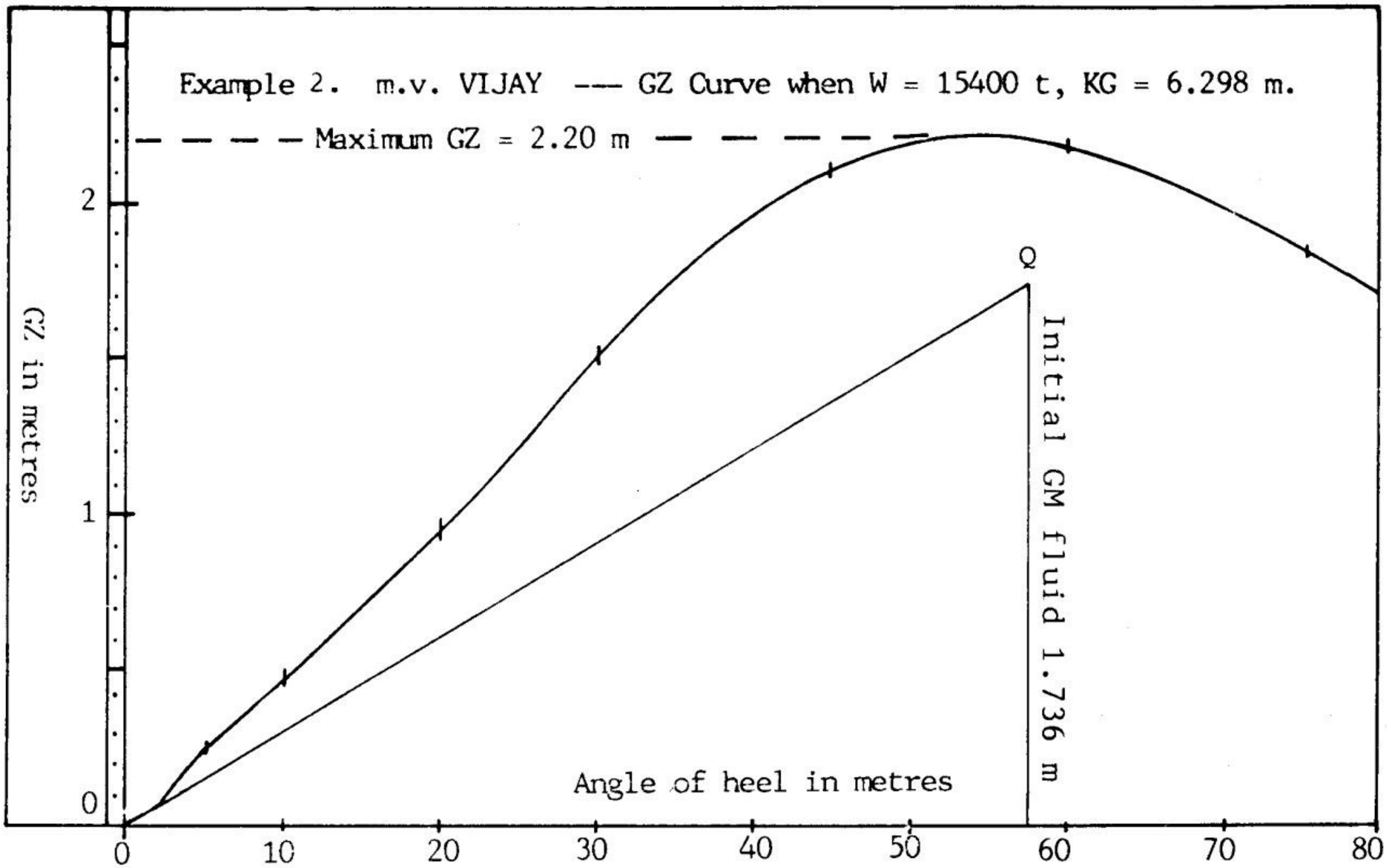
Interpolating for W of 15400 tonnes, tabulate the KN values & corrections as shown here:

θ	KN	-	KG Sin θ	=	GZ
5°	0.796	-	6.298 Sin 05°	=	0.247 m
10°	1.575	-	6.298 Sin 10°	=	0.481
20°	3.112	-	6.298 Sin 20°	=	0.958
30°	4.641	-	6.298 Sin 30°	=	1.492
45°	6.546	-	6.298 Sin 45°	=	2.093
60°	7.615	-	6.298 Sin 60°	=	2.161
75°	7.923	-	6.298 Sin 75°	=	1.840

Note: Erect the initial fluid GM at 57.3° heel and draw line OQ. Construct curve, ensuring that it coincides with line OQ for the first two or three degrees.

Plot the above values as a curve of statical stability (GZ curve), as shown herein.

From the curve, Maximum GZ = 2.200 m.


Example 2. m.v. VIJAY --- GZ Curve when W = 15400 t, KG = 6.298 m.
Maximum GZ = 2.20 m
Q
Initial GM fluid 1.736 m
Angle of heel in metres
GZ in metres
0
1
2
0
10
20
30
40
50
60
70
80

Exercise 21
KN Curves

1. Find the maximum GZ and the angle of heel at which it occurs for M.V. Vijay when W =19943 t, solid KG = 7.326 m, FSM = 1342 tm, KM = 8.461 m.

Extract from KN Tables of m.v. Vijay:

W	5°	10°	20°	30°	45°	60°	75°
19000	0.802	1.601	3.134	4.510	6.237	7.341	7.766
20000	0.812	1.628	3.119	4.473	6.165	7.264	7.725

(Answer: 0.95 m at 49°).

2. M.V. Vijay is displacing 13250 t with KG solid = 6.427 m, FSM = 1200 tm and KM 8.119 m. Construct the curve of statical stability and from it, find the angles of heel at which GZ = 1.6 m.

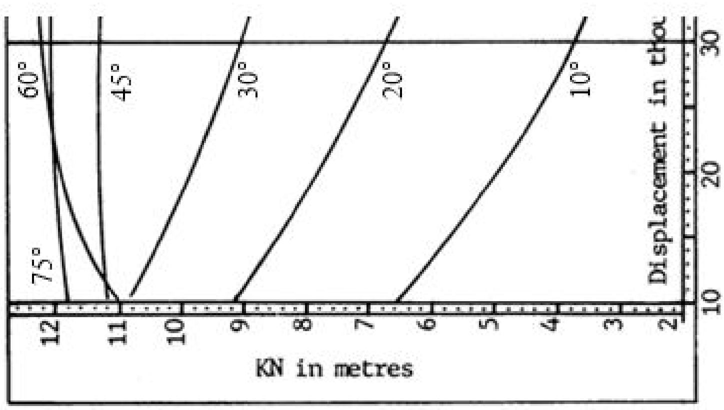
Extract from KN Tables of m.v. Vijay:

W	5°	10°	20°	30°	45°	60°	75°
13000	0.798	1.595	3.153	4.733	6.741	7.788	8.057
14000	0.793	1.581	3.130	4.694	6.664	7.718	7.998

(Answer: 33° and 80°).

3. Construct the curve of statical stability for M.V. Valour when displacement = 26000 t, KG solid = 7.014 m FSM = 7200 tm. KM is 21.592 m. Find the maximum GZ and the angle at which it occurs.

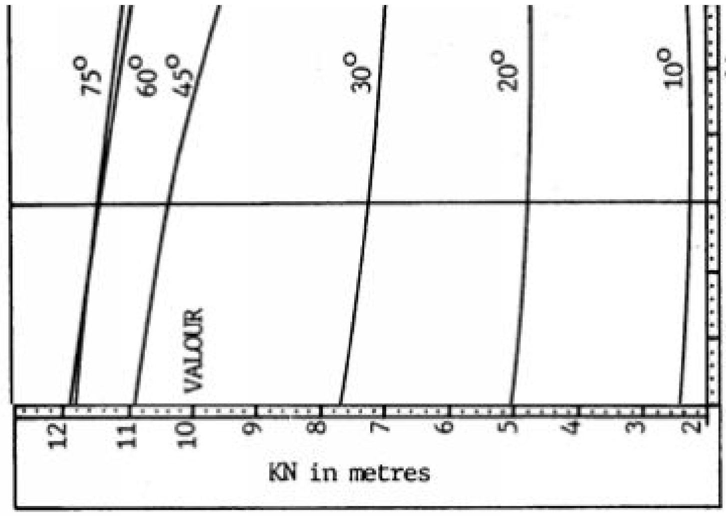
Snip from KN Curves of m.v. Valour:



(Answer: 6.17 m at 42.5°).

4. Construct the GZ curve of M.V. Valour when W = 81000 t, KG solid = 10.21 m, FSM = 6800 tm, KM 13.16 m. Find the GZ at 40º heel. (Answer 2.53 m).

Snip from KN Curves of m.v. Valour:



(Answer 2.53 m).

5. M.V. Valour is displacing 60000 t with solid KG = 8.661 m, FSM = 5020 tm and KM = 13.663 m. By constructing the curve of statical stability, find the angle of heel at which the deck edge would immerse. Use the snip from KN curves shown in question 4.

(Answer: 30°).

-o0o-

25. LONGITUDINAL STABILITY

When a ship is at rest in calm water, the COB and the COG will be in a vertical line as illustrated by following figure X.

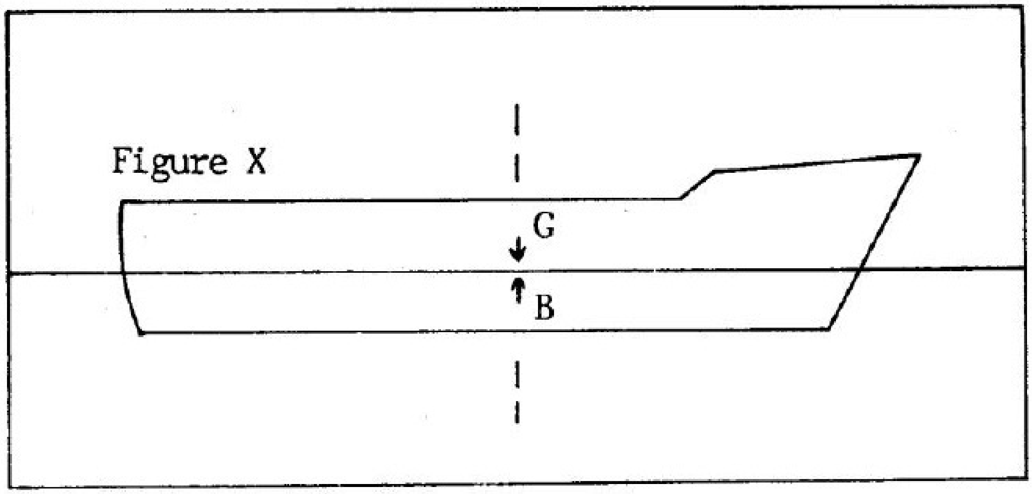
Pitch:

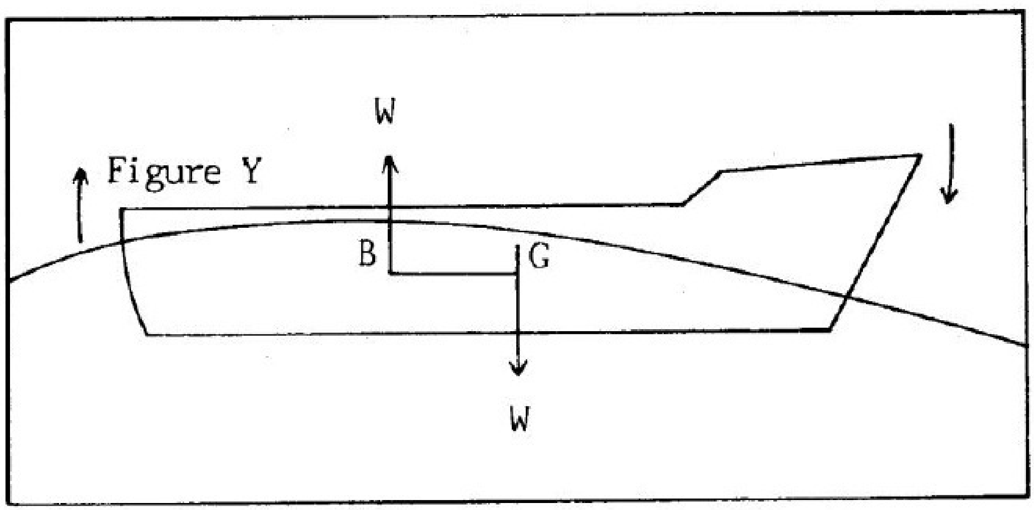
If waves cause an increase in the underwater volume aft, and a decrease fwd, the COB will shift aft. The forces of gravity and buoyancy now get separated by a fore and aft distance and form a couple which will cause the bow to dip downwards and the stern to lift upwards as shown in following figure Y.

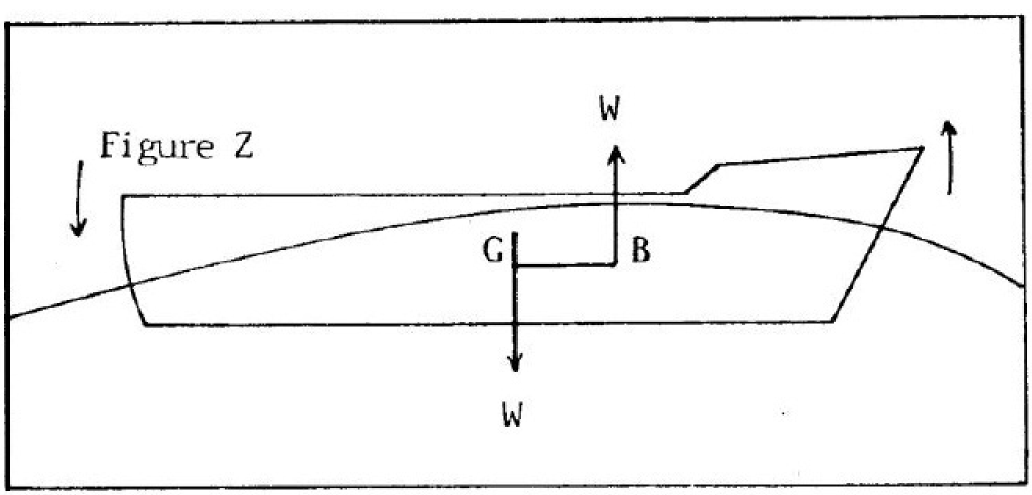
If waves cause an increase of underwater volume forward, and a decrease aft, COB will shift forward, and the forces of gravity and buoyancy will form a couple which will cause the bow to lift upwards and the stern to dip downwards as shown in following figure Z. This up and down movement of the ship's ends, due to longitudinal shift of COB resulting from wave action, is called pitch.

During pitch, the COG of the ship does not move because no weights are loaded, discharged or shifted. Pitching is the longitudinal equivalent of rolling.

PITCHING







Trim:

Trim is the difference between the drafts forward and aft, expressed in metres or in centimetres. If the draft aft is greater than the draft fwd, the ship is said to be trimmed by the stern. If the draft fwd is greater, the ship is said to be trimmed by the head. If the drafts fwd and aft are equal (if trim is zero), the ship is said to be on an even keel abbreviated to EK.

Trim is the longitudinal equivalent of list, but with three main differences:

1) List is measured in degrees. Trim is expressed in metres or centimetres only.

2) In the sailing condition, the ship is usually upright but rarely on an even keel. In other words, list is normally absent whereas trim is normally present.

3) If the ship is listed, it is not important whether it is to port or to stbd. Trim must be by the stern, never by the head. If trimmed by the head, the steering qualities and speed, especially the former, would be adversely affected.

Consider a ship at rest, on an even keel in calm water. The COB and the COG would be in a vertical line as shown in following figure 1. If a weight of ‘w’ tonnes is shifted aft by a distance ‘d’ metres, the COG of the ship would shift by GG_1 metres, as shown in following figure 2. The forces of gravity and buoyancy would form a couple and cause the stern to sink and the bow to rise. This would increase the underwater volume aft and decrease it forward – the COB will shift aft.

Figure 1

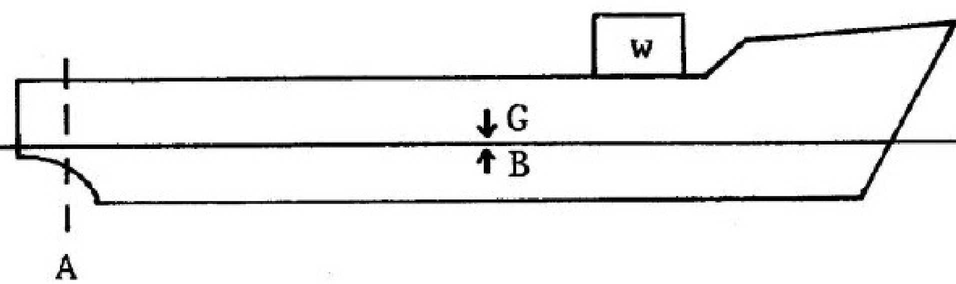


Figure 2

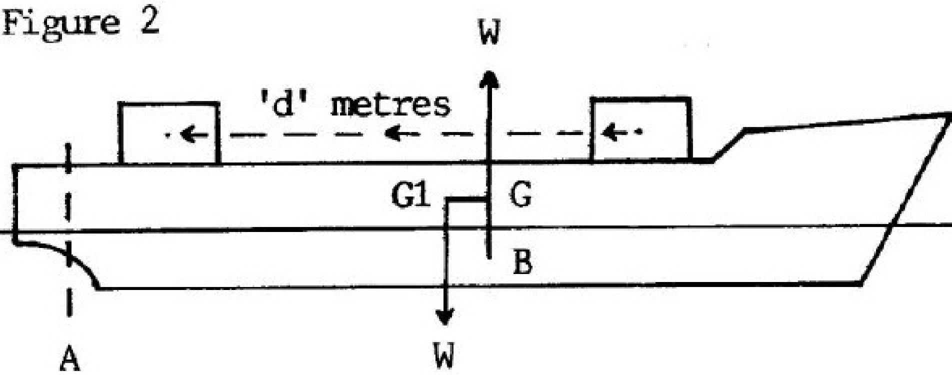
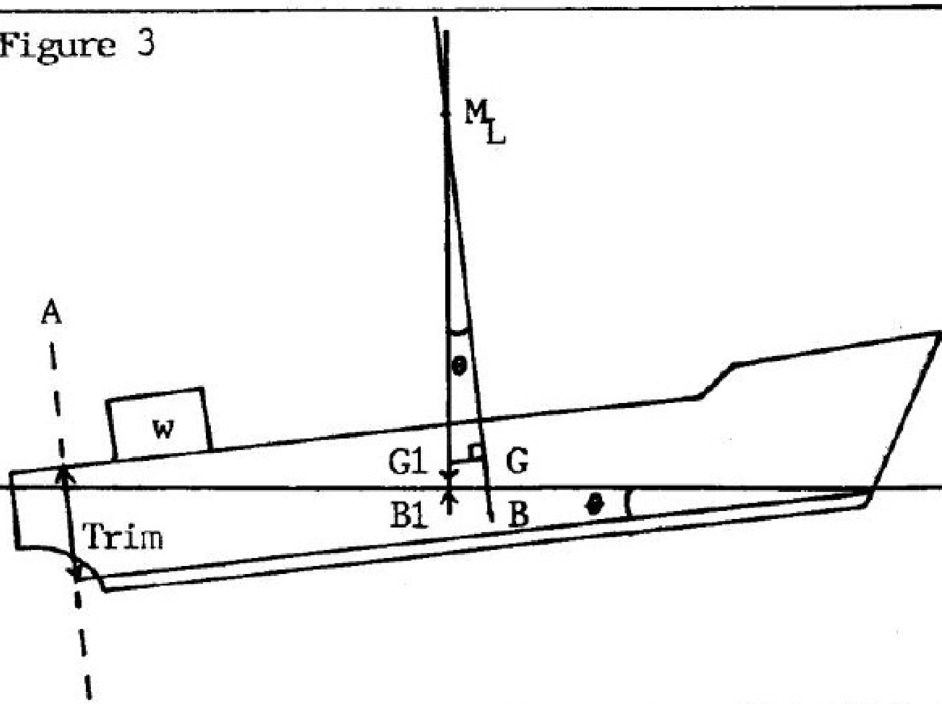


Figure 3



This would continue until the COB comes vertically under G1, as shown in foregoing figure 3.

In figure 3, M_L is the longitudinal metacentre – the point of intersection of the verticals through the COB when on an even keel and when trimmed. KM_L is the sum of KB and BM_L. KM_L is a function of draft and is given in the hydrostatic table/curves of the ship.

Referring to foregoing figure 3:

Trim / L = GG_1 / GM_L (since both = tan θ).

But GG_1 = wd / W

So, Trim / L = wd / (W x GM_L)

OR

trim = wd x L / (W x GM_L) metres

So, trim (in cm) = wd x [(100 x L) / (W x GM_L)]

= wd / [(W x GM_L) / 100 L]

Trim caused (in cm) = wd / MCTC = trimming moment / MCTC

MCTC is called the moment to change trim by 1 cm. Since GM_L is very large (more than the ship's length), use of BM_L instead of GM_L will not make any appreciable change in the value of MCTC.

$$MCTC = W.GM_L/100L \cong W.BM_L/100L$$

MCTC is calculated by using BM_L for the various salt water drafts and given in the ship's hydrostatic table/curves.

Centre of flotation (COF)

COF is that point about which the ship would pivot, when the trim is changed. COF is also called

the tipping centre. It is the geometric centre of the water-plane area of the ship at that draft. The position of COF is indicated by its distance from the after perpendicular of the ship (AF) or by its distance forward or abaft amidships (HF). AF or HF, as the case may be, depends on the hydrostatic draft of the ship. Hence the values of COF are indicated against draft in the hydrostatic tables /curves of the ship.

Change of draft fwd & aft

If COF is amidships, the change of draft fwd and the change of draft aft would be equal. So, if the trim caused (or Tc) is 80 cm by the stern, the stern would sink by 40 cm and the bow would rise by 40 cm. as shown in figure 1 on the following page.

If COF is not amidships, the change of draft at each end would be unequal:

Change of draft aft (or Ta) = (AF / LBP) x Tc.

Change of draft fwd (or Tf) = Tc – Ta.

For example, if the trim caused (Tc) is 80 cm by stern, AF = 52.5 m and LBP = 140 m:

Ta = (52.5 x 80) / 140 = 30.0 cm = 0.3 m.

Tf = Tc – Ta = 80 – 30 = 50.0 cm = 0.5 m.

Since Tc is by the stern, Ta will be (+) while Tf will be (-). In other words, the draft aft will increase by 0.3 m while the draft fwd will decrease by 0.5 m as shown in following figure 2.

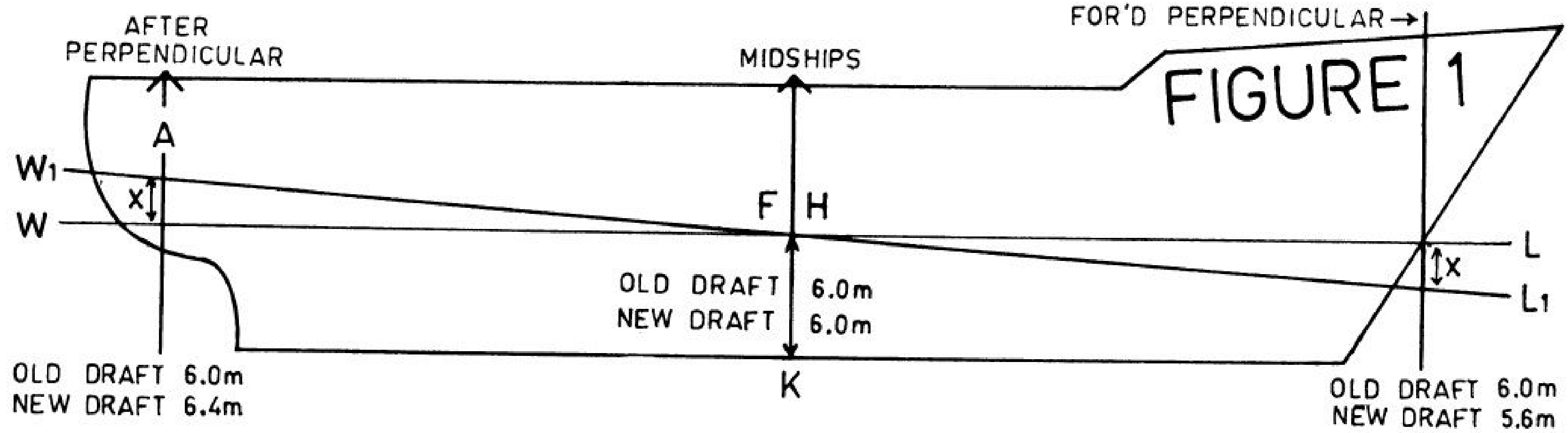


FIGURE 1

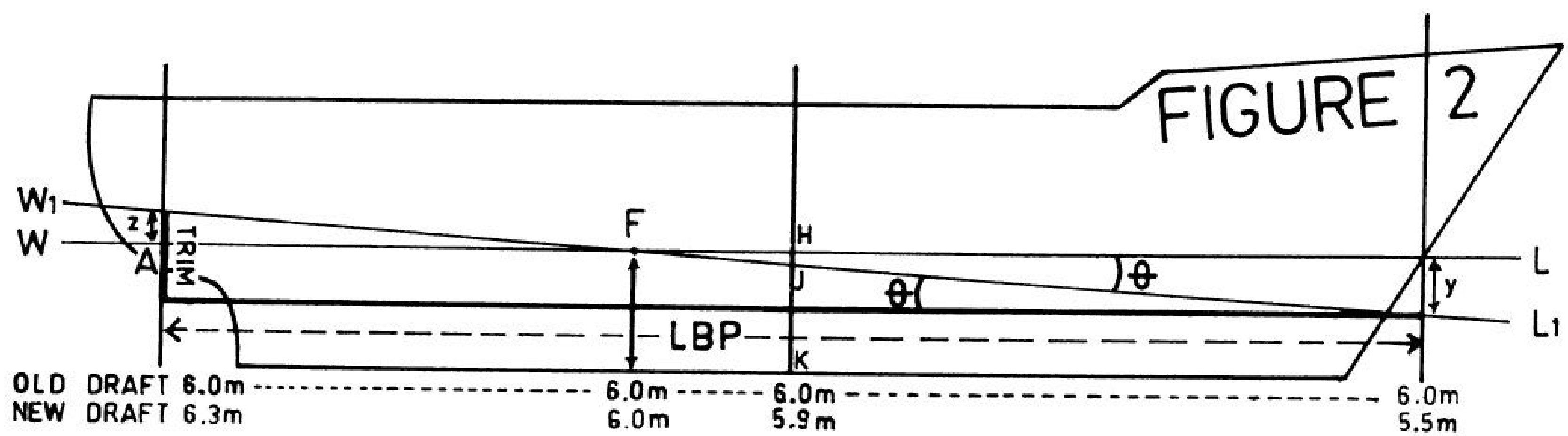


FIGURE 2

26. TRIM PROBLEMS TYPE A

In this book, trim problems have been divided into three groups, A, B & C. In problems of type A, limited information is given: TPC, MCTC and AF are considered constant. Trimming moments are taken about COF. Type A problems help in understanding the principles of trim and questions of this type do come in examinations for certificates of competency.

Type B problems on trim are those where hydrostatic particulars of a ship are given and where moments are taken about the ship's after perpendicular.

Type C problems are those where the hydrostatic particulars of a ship are given but where moments are taken about amidships.

Types B and C have a similar approach to the solution of trim problems. They are more practical, than type A, and are extensively used by shipyards. In types B and C, TPC, MCTC, AF, etc are not considered constants. These values are obtained against draft, when necessary, from the hydrostatic particulars of the ship. Worked examples have been given the suffix A, B or C, as appropriate, to help distinguish the types.

Note: Mean sinkage or rise (calculated by the formula w ÷ TPC), and trim caused or Tc (calculated by the formula trimming moment ÷ MCTC), would be in centimetres NOT in metres.

TYPE 'A' PROBLEMS

Example 1A – Shift of 'w' already aboard.

A ship 100 m long has COF 3 m abaft amidships and MCTC = 250 tm. Present drafts are 5.8 m fwd and 6.2 m aft. Find the new drafts fwd & aft if 200 t of FW is transferred from the fore peak to the after peak through 90 m.

Trimming moment (or TM) = wd = 200 x 90

= 18000 tm by the stern

Tc = TM / MCTC = 18000 / 250 = 72 cm by the stern

Ta = (AF / L) x Tc = (47 x 72) / 100 = 33.8 cm

Tf = Tc – Ta = 72 – 33.8 = 38.2 cm

	fwd	aft
Original drafts	5.800 m	6.200 m
Tf and Ta	- 0.382 m	+ 0.338 m
Final drafts	5.418 m	6.538 m

Note: Accuracy of calculation should be to three decimal places of a metre or one decimal of a centimetre.

Example 2A – Discharging a weight.

A ship 120 m long, COF 2.5 m abaft amidships (HF 2.5 m aft), MCTC 100 tm, TPC 25, floats at 7 m fwd and 10 m aft. Find the new drafts if 200 t is discharged from a position 50 m abaft amidships.

Mean rise = w /TPC = 200 / 25 = 8 cm.

Tc = wd / MCTC = (200 x 47.5) / 100 = 95 cm by head.

Note: d = distance from COF. Tc by head because cargo discharged was abaft COF.

Ta =(AF x Tc) / L= (57.5 x 95) / 120 = 45.5 cm.

Tf = Tc – Ta = 95 – 45.5 = 49.5 cm.

	Fwd	Aft
Original drafts	7.000 m	10.000 m
Mean rise	- 0.080 m	- 0.080 m
	6.920 m	9.920 m
Tf or Ta	+0.495 m	-0.455 m
Final drafts	7.415 m	9.465 m

Example 3A – Load/discharge several weights.

A ship is 150 m long. MCTC = 300 tm, TPC = 30, COF is 4 m abaft amidships (HF 4 m aft). Present drafts are 6.1 m fwd & 8.3 m aft. Find the final drafts if the following operations are carried out:

4000 t loaded 24 m abaft H (HG 24 m aft).
2000 t cargo loaded, HG 50 m fwd.
1000 t cargo discharged from HG 30 m fwd.
300 t SW run into AP tank, HG 70 m aft.

Weight		HF (m)	Trimming by head (tm)	Moment by stern (tm)
Loaded t	Disch t			
2000	-	54 fwd	108,000	-
-	1000	34 fwd	-	34,000
4000	-	20 aft	-	80,000
300	-	66 aft	-	19,800
6300	1000	Total	108,000	133,800
5300	-	Final	-	25,800

Mean sinkage = w / TPC = 5300 / 30= 176.7 cm.
Tc = TM / MCTC = 25800 / 300= 86 cm by the stern
Ta = (AF x Tc) / L = (71 x 86) / 150 = 40.7 cm.
Tf = Tc – Ta = 86 – 40.7 = 45.3 cm.

	Fwd	Aft
Original drafts	6.100 m	8.300 m
Mean sinkage	+1.767 m	+1.767 m
	7.867 m	10.067 m
Tf or Ta	- 0.453 m	+0.407 m
Final drafts	7.414 m	10.474 m

Example 4A – To finish at a desired trim.

A ship has to load 600 t of cargo. The drafts are 8.5 m fwd & 9.7 m aft. Space is available 60 m fwd & 40 m aft of COF, which is amidships. MCTC = 250 tm and TPC = 20. Find how to distribute this 600 t of cargo if the ship is to finish loading 0.5 m by the stern. State also the final drafts fwd and aft.

Present trim = 1.2 m by the stern
Desired trim = 0.5 m by the stern
Tc = 0.7 m by the head = 70 cm

Tc = TM / MCTC or TM = Tc x MCTC
Required TM = 70 x 250 = 17500 tm by head.
If cargo loaded fwd = X t, cargo aft = (600 – x) t
TM caused = 60X tm by head & 40 (600 – X) tm by stern. Required to cause 17500 by head

So 60X – 40 (600 – x) = 17500
X = 415 t and (600 – X) = 185 t

Cargo to be loaded in the forward space = 415 t and in the after space = 185 t.
Mean sinkage = w / TPC = 600 / 20= 30 cm = 0.3 m

	Fwd	Aft
Original drafts	8.500 m	9.700 m
Mean sinkage	+0.300 m	+0.300 m
	8.800 m	10.000 m
Tf or Ta = Tc/2	+0.350 m	-0.350 m
Final drafts	9.150 m	9.650 m

Example 5A – To find HF.

A ship is afloat at drafts of 6.6 m fwd & 7.4 m aft. 500 t of cargo is loaded 54 m fwd of H (amidships) & 800 t is loaded 52 m abaft H. If the final drafts are 6.85 and 8.51 m fwd & aft respectively, and MCTC = 200 tm, find HF (the distance of the COF from amidships).

Initial trim	=	0.800 m by the stern
Final trim	=	1.660 m by the stern
Trim caused	=	0.860 m by stern = 86 cm

Tc = TM / MCTC   or   TM = 86 x 200 = 17200 tm.

Let the COF be X metres abaft H. Then TM caused by head = 500 (54 + X) tm & by the stern = 800 (52 – X) tm. Since loading caused 17200 tm by the stern,

$$800\,(52 - X) - 500\,(54 + X) = 17200$$

$$X = -2 \text{ metres.}$$

Note: The minus sign indicates that the assumed direction of COF, from H, is wrong. In this case, COF was assumed to be abaft H.

Answer: COF is 2 m fwd of H (HF 2 m fwd)

Example 6A – Load keeping draft constant.

A ship 96 m long is floating at 5 m fwd and 6.4 m aft. MCTC = 180 tm, TPC = 16. COF is 2 m abaft H (HF 2 m aft). Find the location where a weight of 50 t should be placed to keep the aft draft constant.

Note: If the weight is loaded on the COF, the ship would sink bodily (parallel sinkage) by (w / TPC). The draft at both perpendiculars would increase by the same amount. If the weight is now shifted fwd by d metres, the draft aft would decrease by Ta and the draft fwd would increase by Tf. For the draft aft to return to its original value, mean sinkage must = Ta.

w / TPC = Ta = (AF / L) x Tc = (AF x wd) / (L x MCTC)

(46 x 50d) / (96 x 180) = 50 / 16 or   d = 23.5 m

50 t should be loaded 23.5 m fwd of COF.

Example 7A – Desired value of draft aft.

A ship 100 m long, MCTC 280 tm, TPC 25, HF 2 m fwd, is afloat at drafts of 6 m fwd and 8 m aft. Find how many tonnes of SW must be run into the fore peak tank (COG 48 m fwd of H) to bring the draft aft to 7.8 m.

Required reduction of draft aft = 0.2 metres

Ta – mean sinkage = 0.2 m = 20 cm.

(AF / L) x Tc – (w / TPC) = 20   or

(52 / 100) x (dw / MCTC) – (w /TPC) = 20

(52 / 100) x (46w / 280) – (w / 25)= 20

or w = 440.25 t.

Exercise 22

Trim problems – Type A

1. A ship 100 m long draws 4 m fwd and 5.2 m aft. HF 2 m abaft amidships, MCTC 160 tm & TPC 15. 100 t of cargo is shifted from No: 3 LH to No: 1 LH through a longitudinal distance of 32 m. Find the new drafts fwd and aft. (Answer: F 4.104 A 5.104 m).

2. A ship 150 m long has HF 3 m fwd, TPC 21 and MCTC 275 tm. Present drafts are 5.6 m fwd & 6.2 m aft. How much SW must be transferred to the fore peak from the after peak, through 130 m, to bring the ship on an even keel? (Answer: 126.9 t).

3. The present drafts of a ship 140 m long are 8.1 m fwd and 9.9 m aft. TPC 30, MCTC 250 tm, HF 3 m fwd. 300 t ballast was pumped out of No: 5 DBT COG 50 m abaft H. Find the new drafts fwd & aft. (Answer: F: 8.304 A: 9.468 m).

4. A ship is floating on an even keel draft of 10.2 m. TPC 30, MCTC 320 tm, HF 2.5 m aft. LBP 180 m. A 240 t heavy lift is loaded on deck, 40 m abaft COF. Find the new drafts fwd and aft. (Answer: F: 10.126 A: 10.426 m).

5. A ship of LBP 125 m, MCTC 318 tm, TPC 28, COF amidships (HF = 0 m), draws 7.9 m fwd and 10.4 m aft. Find the final drafts after the following operations have been carried out:

500 t loaded in No: 2 LH 40 m fwd of H
200 t loaded in No: 5 TD 50 m aft of H
100 t SW transferred 110 m from APT to FPT.

(Answer: **)** F: 8.480 A: 10.320 m).

6. The present drafts of a ship, whose LBP is 142 m, are 10.2 m & 11.6 m F & A. MCTC 170 tm. TPC 32. HF 3 m aft. Find the final drafts F & A after the following operations have been carried out:

(a) 1500 t cargo discharged from No: 2 LH, 43 m fwd of amidships (HG 43 m fwd)

(b) 2000 t cargo discharged from No: 4 LH,37 m aft of amidships (HG 37 m aft).

(c) 500 t FW received in No: 3 DB tank, 33 m fwd of amidships (HG 33 m fwd).

(Answer: F: 9.783 A: 10.183 m).

7. A ship left port drawing 8.2 m & 10 m F & A. LBP 160 m, TPC 32, MCTC 220 tm HF 2.4 m aft. Find the arrival drafts F & A if, en route, it consumed:

420 t HFO from No: 4 DBT (HG 35 m aft)

220 t HFO from No: 7 DBT (HG 60 m aft)

200 t FW from No: 1 DBT (HG 60 m fwd).

(Answer: **)** F: 8.262 A: 9.431 m).

8. A ship is 150 m long. MCTC = 200 tm, TPC = 25, HF = 2 m fwd. The present drafts are 8 m forward and 10 m aft. Calculate the initial hydrostatic draft. Space is available in No: 1 LH (HG 60 m fwd) & in No: 4 LH (HG 30 m aft). Find how much cargo to put in each of these spaces, if the ship is to finish loading at an even keel draft of 9.3 m. (Answer: 735.1 t in No: 1, 82.4 t in No: 4).

9. A ship of LBP 200 m, MCTC 300 tm, TPC 35, HF 5 m aft, is presently drawing 7 m fwd and 11 m aft. Calculate the present hydrostatic draft. Space is available for loading in No: 1 LH (HG 80 m fwd), and in No: 4 LH (HG 30 m aft). Calculate how much cargo to put in each of the two spaces in order to finish at a hydrostatic draft of 9.6 metres, trimmed 2 metres by the stern. State also, the final drafts forward and aft. (Answer: Initial hydrostatic draft 9.10 m; 943.2 t in No: 1, 806.8 t in No: 4 hold; F: 8.550 m A: 10.550 m).

10. A ship was trimmed 0.5 m by the head. After loading 500 t in No: 4 LH, HG 40 m aft, the trim was 0.5 m by the stern. If MCTC was 185 tm, find the HF. (Answer: HF 3 m aft**).**

11. A ship of LBP 130 m and MCTC 175 tm draws 7.2 m fwd and 7.8 m aft. 1600 t cargo was loaded in No: 2 LH, HG 30 m fwd, and 1400 t in No: 5 LH, HG 55 m aft. The drafts were then found to be 7.8 m fwd & 10.4 aft. Find HF. (Answer: HF 2 m fwd).

12. A ship drawing 7.6 m fwd & 8.4 m aft has LBP 140 m, HF 2.7 m aft, MCTC 170 tm, TPC 28. Find where 140 t may be placed if the after draft is to remain constant. State the draft forward after loading. (Answer: 12.630 m forward of CoF; F: 7.704 m A: 8.400 m).

13. A ship 160 m long has MCTC 200 tm, TPC 30, HF 3 m aft, draft fwd 6.8 m, aft 7.8 m. From where may ‘w’ tonnes be discharged such that the draft aft remains constant? (Answer: 13.85 m fwd of CoF).

14. A ship of LBP 120 m, MCTC 300 tm, TPC 25, HF 2 m fwd, floats at 9.6 m fwd & 10.8 m aft. 200 t of deck cargo is to be loaded.

Some shipside repairs are to be effected for which the fwd draft is to be maintained at 9.6 m. Find where this cargo may be loaded. State the final draft aft. (Answer: 24.82 m abaft CoF, F 9.600 A 10.965 m).

15. LBP 124 m, MCTC 180 tm, TPC 27, HF 2.5 m aft, draft fwd 5.8, aft 6.9 m. How many tonnes of SW must be run into the FP tank (HG 58 m fwd) in order to reduce the draft aft to 6.7 metres? State the final draft fwd. (Answer: 161 t; F: 6.141 A: 6.7 m).

16. A ship 160 m long has MCTC 200 tm, HF 2.8 m fwd, TPC 24. Present drafts are 7.4 m fwd & 8.8 m aft. 720 t cargo is to be loaded. Space is available in No: 2 LH (HG 45 m fwd) and in No: 4 LH (HG 35 m aft). Find how much to put in each if the draft aft is required to be 9 m on completion. What is the final draft fwd? (Answer: 388.5 t No: 2, 331.5 t No: 4; F: 7.793 A: 9.0 m).

17. A ship arrives port drawing 7 m fwd & 10 m aft. HF 0, MCTC 220 tm, TPC 25. The maximum permissible draft to cross a bar at the dock entrance is 9 m. Due to a damaged fore peak, the draft fwd is not to exceed 7 m. Find the minimum amount of cargo to discharge into barges from No: 2 TD (HG 30 m fwd) and from No: 4 TD (HG 50 m aft) so that both conditions are satisfied. (Answer: 506.3 t from No: 2, & 743.70 t from No: 4).

18. A ship arrives port drawing 8 m fwd & 10.5 m aft. LBP 166 m, HF 3 m aft, MCTC 175 tm, TPC 25. 250 t of dangerous deck cargo is to be discharged at anchorage from HG 73 m aft. How many tonnes of water must be transferred from the afterpeak tank to No: 1 DBT through 140 m, to make the final trim 1 m by the stern? State the final drafts fwd & aft. (Answer: 62.50 t; F: 8.677 A: 9.677 m).

19. A ship arrives port drawing 8 m fwd & 9 m aft. LBP 158 m, MCTC 190 tm, TPC 20 & HF 2 m aft. The maximum draft allowed to cross a bar is 8.6 m. There is no scope for transfer of any weights aboard. Hence it decided to off-load some cargo at

anchorage. Find the minimum quantity of cargo to off-load from No: 4 hold, HG 40 m aft. State the final draft fwd. (Answer: 271.2 t; F: 8.142 A: 8.600 m).

20. A ship leaves port drawing 9 m fwd and 9.8 m aft. LBP 170 m, MCTC 160 tm, TPC 24 & HF 1 m fwd. On passage it consumes the following:

520 t HFO from No: 2 DBT, HG 50 m fwd,

200 t HFO from No: 8 DBT, HG 60 m aft,

300 t FW from No: 3 DBT, HG 30 m fwd.

How much FW must be transferred between the peak tanks, 150 m apart, to bring the trim to 0.3 m by the stern? State the final drafts fwd and aft. (Answer 199.9 t AP to FP; F: 8.822 A: 9.122 m).

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27. TRIM PROBLEMS TYPE B

Consider a ship on an even keel as shown in following figure 1. COB and COG are in a vertical line. Due to shift of a weight aft, COB & COG get separated longitudinally as shown in following figure 2. The forces of buoyancy and gravity form a couple which trims the ship by the stern as shown in following figure 3. The moment of this couple = W.GG1 and is called the trimming moment or TM.

The word hydraft is the abbreviation used in this book to mean hydrostatic draft.

The trimming lever GG_1 may be substituted by AB~AG which is the longitudinal separation of COB & COG caused by shift of weight. AB~AG is hereinafter abbreviated to BG. The AB used here is the distance of the COB from the after perpendicular of the ship at that draft, when on even keel. BG is the longitudinal separation of COB (on even keel) and COG of ship, NOT the actual slant distance. The trimming moment, or TM, is thus equal to W.BG. TM, divided by MCTC, gives the trim. If COG lies abaft COB, trim will be by the stern and vice versa. For working trim problems of type B, the hydrostatic particulars of M.V. VIJAY are in Appendix I of this book from which extracts are included in this chapter for convenience.

Figure 1

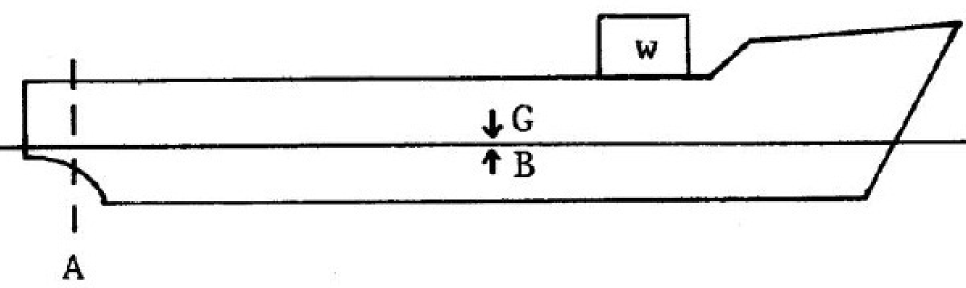


Figure 2

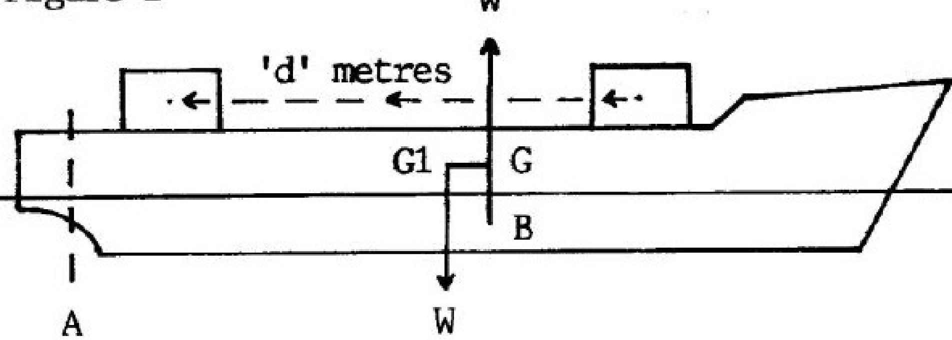
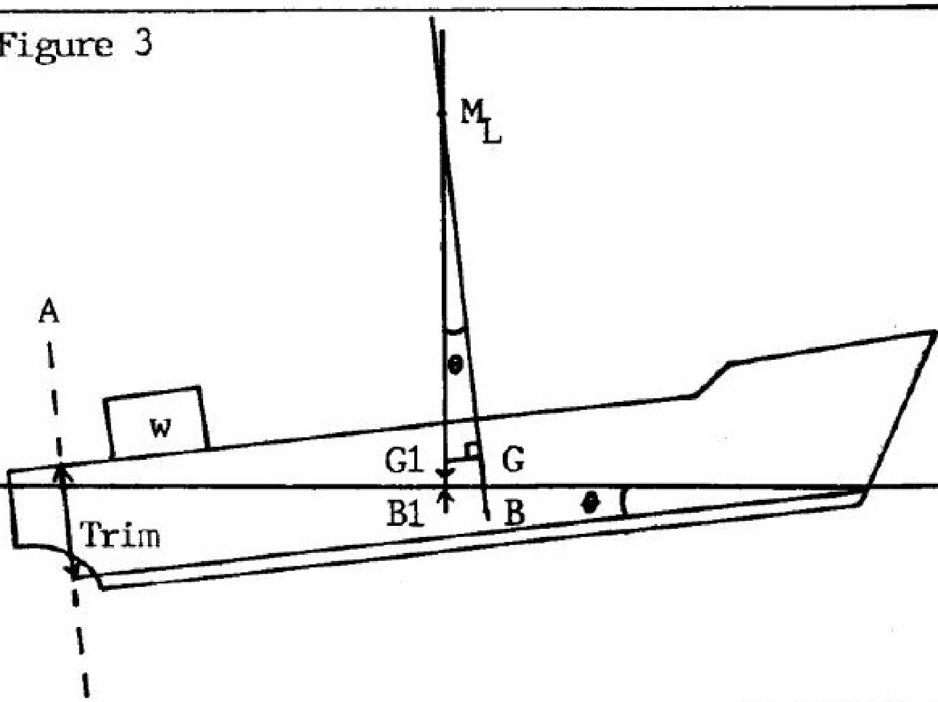


Figure 3



Procedure for most trim problems type B

1) Find the initial hydrostatic draft and thence the W, MCTC, AB & AF.

2) Find the initial AG, if not given.

3) Find the final W & AG by taking moments about A.

4) Find the final hydrostatic draft and thence the MCTC, AB & AF at that draft

5) Find the final BG and thence the final trim (Tc).

6) Split Tc (final trim) into Ta and Tf.

7) Apply Tf & Ta to the final hydrostatic draft & obtain final drafts fwd & aft.

Example 1B

M.V. VIJAY is floating in SW at an even keel draft of 5 m. Find the new drafts F & A if 200 t FW is transferred 30 m aft.

Note: This is similar to example 1A (previous chapter) except that MCTC and AF must be taken from the hydrostatic table of the ship.

From Appendix I, for SW draft 5 m:

MCTC = 165.7 tm and AF = 71.913 m.

Tc = TM / MCTC = (200 x 30) / 165.7 = 36.2 cm by stern.

Ta = (AF / L) x Tc = (71.913 / 140) x 0.362 = 0.186 m.

Tf = Tc – Ta = 0.362 – 0.186 = 0.176 m.

	fwd	aft
Final hydraft	5.000 m	5.000 m
Tf and Ta	-0.176 m	+0.186 m
Final drafts	4.824 m	5.186 m

Example 2B

M.V. VIJAY is floating in SW at drafts of 4.8 m fwd and 6.8 m aft. AG is 69.04 m. Find the drafts fwd and aft if 1000 t of cargo is loaded in No: 3 LH, AG 80 m.

Fwd 4.8 m, aft 6.8 m, trim 2 m by stern.

For mean draft 5.8 m, AF from Appendix 1 = 71.586m

Corrn = (AF / L) x trim = (71.586 / 140) x 2 = 1.023 m

Initial hydraft = 6.8 – 1.023 = 5.777 m

For 5.777 m hydraft, W from Appendix 1, = 11620.4 t.

Final W = 11620.4 + 1000 = 12620.4 t

From Appendix 1, particulars for final W are:

W (t)	Draft	MCTC	AB(m)	AF (m)
12620.4	6.220	174.78	71.937	71.313

Taking longitudinal moments about A,
11620.4 (69.04) + 1000 (80) = 12620.4 (AG)
Final AG = 69.908 m. Final AB = 71.937 m.
Final AB> final AG. Hence final trim is by the stern.
Trim = W.BG / MCTC = (12620.4 (2.029)) / 174.78 = 146.5 cm
Ta = (AF / L) x Tc = (71.313/140) (1.465)= 0.746 m
Tf = Tc – Ta = 1.465 – 0.746 = 0.719 m

	fwd	aft
Final hydraft	6.220 m	6.220 m
Tf and Ta	-0.719 m	+0.746 m
Final drafts	5.501 m	6.966 m

Example 3B

M. V. Vijay is floating in SW at drafts of 4 m fwd & 5.8 m aft. AG is 68.930 m. The following operations were carried out:

No: 2 LH (AG 102 m):	1800 t cargo loaded.
No: 4 LH (AG 58 m):	1600 t cargo loaded.
No: 1 DBT (AG 120 m):	160 t ballast out.
FP tank (AG 135 m):	100 t ballast out.

Find the final drafts fwd and aft.
Fwd 4 m, aft 5.8 m, trim 1.8 m by stern.
For mean draft 4.9 m, AF from Appendix 1 = 71.942m
Corr = (AF / L) x trim = 71.942(1.8) / 140 = 0.925 m
Initial hydraft = 5.8 – 0.925 = 4.875 m,
For which W = 9616 t, from Appendix I.

Remarks	Weight t		AG m	Moment abt A	
	Load	disc.		loaded	disch
Ship	9616	-	68.93	662831	-
Cargo	1800	-	102	183600	-
Cargo	1600	-	58	92800	-
Ballast	-	160	120	-	19200
Ballast	-	100	135	-	13500
Total	13016	260		939231	32700
Final	12756			906531	

Final AG = 906531/12756 = 71.067 m.
From Appendix I, for final W of 12756 t:

Draft	MCTC tm	AB (m)	AF (m)
6.280	175.316	71.929	71.267

Final AG = 71.067 m, final AB = 71.929 m

Final trim by stern; final BG = 0.862 m

Trim = W.BG / MCTC = (12756 x 0.862) / 175.316= 62.7 cm

Ta = (AF / L) x trim = (71.267 / 140) (0.627) = 0.319 m

Tf = Trim – Ta = 0.627 – 0.319 = 0.308 m

	fwd	aft
Final hydraft	6.280 m	6.280 m
Tf and Ta	- 0.308 m	+ 0.319 m
Final drafts	5.972 m	6.599 m

Example 4B

M.V. VIJAY is in SW drawing 6 m F & 7 m A. 1000 t cargo is loaded in No: 3 LH, AG 80 m. Find the final drafts F & A.

Note: AG of the ship is not given here but can be calculated using the given data and the hydrostatic table. This is the method normally used on board.

Fwd 6 m, aft 7 m, trim 1 m by the stern.

For mean draft 6.5 m, AF from Appendix 1 = 71.087m

Corr = (AF / L) x trim = (71.087 x 1)/140 = 0.508 m

Hydraft = 7 – 0.508 = 6.492 m. From Appendix 1:

Draft	W (t)	MCTC tm	AB(m)
6.492	13239.8	177.228	71.902

Trim in cm = W.BG / MCTC

or

BG =(trim x MCTC) / W

BG = (100 (177.228)) / 13239.8= 1.338 m

Since trim is by stern, AG < AB.

AG = AB – BG = 71.902 – 1.338 = 70.564 m

AG of ship in given condition = 70.564 m

Remarks	Weight	AG (m)	Moment
Ship	13239.8	70.564	934253
Loaded	1000	80	80000
Final	14239.8		1014253

Final AG = 1014253 / 14239.8 = 71.227 m

From Appendix I for final W = 14239.8 t:

Draft	MCTC tm	AB (m)	AF (m)
6.929	181.852	71.832	70.673

Since final AG < AB, final trim by stern

Final BG = 71.832 – 71.227 = 0.605 m

Final Tc = W.BG / MCTC = (14239.8 (0.605)) / 181.852 = 47.4 cm

Ta = (AF / L)x Tc = (70.673 /140) x 0.474 = 0.239 m

Tf = Tc –Ta = 0.474 – 0.239 = 0.235 m

	Fwd	Aft
Final hydraft	6.929 m	6.929 m
Tf and Ta	- 0.235 m	+ 0.239 m
Final drafts	6.694 m	7.168 m

Example 5B

M.V. VIJAY floats in SW, drawing 3.6 m & 6.4 m fwd and aft. 2000 t cargo is to be loaded. Space is available in No: 2, AG 102 m, and in No: 4, AG 58 m. Find how much cargo to put in each space in order to finish with a trim of 1 metre by the stern. State the final drafts fwd & aft.

Fwd 3.6 m aft 6.4 m, trim 2.8 m by stern

For mean draft 5.0 m, AF from Appendix 1 = 71.913m.

Corr = (AF / L) x trim = (71.913 (2.8)) / 140 = 1.438 m.

Initial hydraft = 6.4 – 1.438 = 4.962 m.

From Appendix 1:

Draft	W (t)	MCTC tm	AB(m)
4.962	9807.4	165.434	72.014

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

BG = (280 (165.434)) / 9807.4 = 4.273 m

Since trim is by stern, AG < AB.

AG = AB – BG = 72.014 – 4.273 = 67.291 m

AG of ship in given condition = 67.291 m

From Appendix I, for final W = 11807.4 t:

Draft	MCTC tm	AB (m)	AF (m)
5.860	171.781	71.972	71.552

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC)/ W

Final BG = (100 x 171.781) / 11807.4 = 1.455 m

Final Tc by stern so final AG < final AB

Final AG = 71.972 – 1.455 = 70.517 m

Let cargo loaded in No: 2 = X tonnes. So, cargo loaded in No: 4 = (2000 – X) tonnes

Remarks	Weight	AG (m)	Moment abt A	
Ship	9807.4	67.291	659950	
Cargo	X	102		102 X
Cargo	2000-X	58	116000	- 58X
Final	11807.4		775950	+ 44X

Final AG = (775950 + 44X) / 11807.4 = 70.517

X = 1288.0 t = quantity to load in No: 2

And (2000 – X) = 712 t to load in No: 4

Ta = (AF / L) x Tc = (71.552 / 140) x 1.000 = 0.511 m

Tf = Tc – Ta = 1.000 – 0.511 = 0.489 m

	Fwd	Aft
Final hydraft	5.860 m	5.860 m
Tf and Ta	- 0.489 m	+ 0.511 m
Final drafts	5.371 m	6.371 m

Example 6B

M.V. VIJAY is in a SW dock drawing 5.8 m fwd & 6.8 m aft. The maximum permissible draft at the exit lock is 6.7 m. Space is available in No: 1, AG 120 m, & in No: 4, AG 58 m. Find the maximum cargo that can be loaded & the distribution between the two holds.

Note: Max draft allowed = 6.7 m and max cargo is to be loaded. So, final drafts are to be 6.7 m fwd & aft.

Fwd 5.8 m aft 6.8 m, trim 1.0 m by stern

For mean draft 6.3 m, AF from Appendix 1 = 71.251m

Corr = (AF / L) x trim = (71.251/ 140) (1.0) = 0.509 m

Initial hydraft = 6.80 – 0.509 = 6.291 m

From Appendix 1:

Draft	W (t)	MCTC tm	AB(m)
6.291	12782.0	175.419	71.928

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

BG = (100 (175.419)) / 12782 = 1.372 m

Since trim is by stern, AG < AB.

AG = AB – BG = 71.928 – 1.372 = 70.556 m

AG of ship in given condition = 70.556 m

From Appendix I for final draft = 6.7 m:

W (t)	MCTC tm	AB (m)	AF (m)
13714.5	179.250	71.872	70.902

Cargo to load = 13714.5 – 12782 = 932.5t

Final Tc = 0 so final AG = AB = 71.872 m

Let cargo to load in No: 1 be X tonnes, so cargo to load in No: 4 = (932.5 – X).

Remarks	Weight	AG (m)	Moment abt A	
Ship	12782	70.556	901847	
Cargo	X	120.00		120X
Cargo	932.5 – X	58.00	54085	- 58X
Final	13714.5		955932	+ 62X

Final AG = (955932 + 62X) / 13714.5 = 71.872

X = 479.90 t = quantity to load in No: 1

and (932.5 – X) = 452.6 t to load in No: 4

Example 7B

M.V. VIJAY is in SW, drawing 6 m fwd and 6.8 m aft. From what location may 1200 t cargo be discharged if it is desired to keep the draft aft constant at 6.8 m? State the final draft fwd.

Fwd 6.0 m aft 6.8 m, trim 0.8 m by stern

For mean draft 6.4m, AF from Appendix 1 = 71.172 m

Corr = (AF / L) x trim = (71.172 / 140) (0.8) = 0.407 m

Initial hydraft = 6.80 – 0.407 = 6.393 m

From Appendix 1:

Draft	W (t)	MCTC tm	AB(m)
6.393	13014.1	176.337	71.915

Trim in cm = W.BG / MCTC
or
BG = (trim x MCTC) / W
BG = (80 (176.337)) / 13014.1= 1.084 m
Since trim is by stern, AG < AB.
AG = AB – BG = 71.915 – 1.084 = 70.831 m
AG of ship in given condition = 70.831 m
Final W = 13014.1 – 1200 = 11814.1 t
From Appendix 1:

W (t)	Draft	MCTC tm	AB (m)	AF (m)
11814.1	5.863	171.805	71.972	71.550

Final draft A = 6.8, hydraft = 5.863 m. So, trim by stern (final AG < final AB).

Ta = 6.8 – 5.863 = 0.937 m
Ta = (AF / L) x Tc or Tc = (L x Ta) / AF
Tc = (140 x 0.937) / 71.55 = 1.833 m.
Final draft fwd = 6.8 – 1.833 = 4.967 m.
Trim in cm = W.BG / MCTC
or
BG = (trim x MCTC) / W
Final BG = (183.3 (171.805)) / 11814.1 = 2.666 metres
Final AG = final AB – final BG
Final AG = 71.972 – 2.666 = 69.306 m.

Remarks	Weight	AG (m)	Moment abt A	
Ship	13014.1	70.831	921802	
Disch	1200	X		- 1200X
Final	11814.1		921802	- 1200X

Final AG = (921802 – 1200X) / 11814.1 = 69.306 m
X = 85.85 m = AG of weight to be discharged.
Rough check by method ‘A’ (chapter 26):
Ta = mean rise or
(AF / L) x (dw / MCTC) = w / TPC
(71.172 / 140) x (d / 176.4) = 1 / 22.64

or

d = 15.326 m

AG of cargo = d + AF = 87 m approx.

Example 8B

M.V. VIJAY is in SW drawing 3.8 m fwd and 4.2 m aft. 800 t of deck cargo is to be loaded. In order to keep a damaged part of the hull above water, it is decided that the sailing draft fwd should be 3.8 m. Find where this cargo may be loaded and state the final draft aft.

Fwd 3.8 m aft 4.2 m, trim 0.4 m by stern

For mean draft 4.0 m, AF from Appendix 1 = 72.127m

Corr = (AF / L) x trim = (72.127/140) (0.4) = 0.206 m

Initial hydraft = 4.20 – 0.206 = 3.994 m

From Appendix 1:

Draft	W (t)	MCTC tm	AB(m)
3.994	7695.1	157.746	72.008

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

BG = (40 (157.746)) / 7695.1 = 0.820 m

Since trim is by stern, AG < AB.

AG = AB – BG = 72.008 – 0.820 = 71.188 m

AG of ship in given condition = 71.188 m

Final W = 7695.1 + 800 = 8495.1 t

From Appendix 1:

W (t)	Draft	MCTC tm	AB (m)	AF (m)
8495.1	4.363	160.984	72.014	72.064

Final draft fwd = 3.8, hydraft = 4.363 m. So, trim by stern (final AG < final AB), and final

Tf = 4.363 – 3.800 =0.563 m.

Tf = (fwd length / L)x Tc

or

Tc = (L x Tf) / (140 - AF)

Tc = (140 x 0.563) / 67.936 = 1.160 m

Final draft aft = 3.8 + 1.160 = 4.960 m.

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

Final BG = (116.0 (160.984)) / 8495.1= 2.198 metres

Final AG = final AB – final BG

Final AG = 72.014 – 2.198 = 69.816 m

Remarks	Weight	AG (m)	Moment abt A	
Ship	7695.1	71.188	547799	
Disch	800	X		+800X
Final	8495.1		547799	+800X

Final AG = (547799 + 800X) / 8495.1 = 69.816

X = 56.618 m = AG of cargo to be loaded.

Rough check by method ‘A’ (chapter 26):

Tf = mean sinkage

or

((140 – AF) dw) / (L x MCTC) = w / TPC .

(67.873 / 140) x (d / 157.8) = 1 / 21.6

or

d = 14.402 m

AG of cargo = AF – d = 57.725 m approx.

Example 9B

M.V. VIJAY is in SW at 3.6 & 6.4 m F & A. Cargo is loaded in No: 2, AG 102 m, until the draft aft becomes 5.6 m. Find the amount loaded and the final draft fwd.

Note: This is a unique problem. Because w is not given, final W is not directly known. Final hydraft is not given. Hence the final hydrostatic particulars are not readily available. Using the initial hydrostatic particulars, the approximate value of w can be found by method ‘A’ (chapter 26). An accurate calculation is then made, assuming that the approximate calculated value of w is loaded. Then minor changes to the result can be made to bring the draft aft to exactly 5.6 m.

To find approx w: (as done in chapter 26)

Draft aft + sinkage – Ta = new draft aft

So, 6.4 + mean sinkage – Ta = 5.6

Since both sinkage & trim will be in cm,

640 + (w / TPC) – (AF / L) x (dw / MCTC) = 560

or

(AF / L) x (dw / MCTC) – (w / TPC) = 80

From Appendix 1:

Mean draft	MCTC tm	AF (m)	TPC
5.000 m	165.700	71.913	22.06

[(71.913 / 140) x w (102 – 71.913) / 165.7] – [(w / 22.06)] = 80

w = 1668.8 t approx.

Assuming that the cargo loaded is exactly 1668.8 t, to find the precise drafts fwd & aft:

Fwd 3.6 m aft 6.4 m, trim 2.8 m by stern

For mean draft 5.0 m, from Appendix 1 AF = 71.913m

Corr = (AF / L) x trim = (71.913 (2.8)) / 140 =1.438 m

Initial hydraft = 6.40 – 1.438 = 4.962 m

From Appendix 1:

Draft	W (t)	MCTC tm	AB(m)
4.962	9807.4	165.434	72.014

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

BG = (280 (165.434)) / 9807.4 = 4.273 m

Since trim is by stern, AG < AB.

AG = AB – BG = 72.014 – 4.723 = 67.291 m

AG of ship in given condition = 67.291 m

Remarks	Weight	AG (m)	Moment abt A
Ship	9807.4	67.291	659950
Loaded	1668.8	102	170218
Final	11476.2		830168

New AG = 830168 ÷ 11476.2 = 72.338 m

From Appendix 1, for W = 11476.2 t:

Draft	MCTC tm	AB (m)	AF (m)	TPC
5.713	170.689	71.983	71.623	22.339

New AG > new AB. So new Tc by the head.

New BG = 72.338 – 71.983 = 0.355 metres.

Tc = W.BG / MCTC = (11476.2 x 0.355) / 170.689 = 23.9 cm

Ta = (AF / L) x Tc = (71.623 / 140) x 0.239 = 0.122 m

Tf = Tc – Ta = 0.239 – 0.122 = 0.117 m

	Fwd	Aft
New hydraft	5.713 m	5.713 m
Tf and Ta	+ 0.117 m	- 0.122 m
New drafts	5.830 m	5.591 m

Note 1: It is found that after loading 1668.8 t at AG 102 m, the draft aft is 5.591 m instead of 5.6 m. In actual practice, this is acceptable to ship's officers because:

a) 9 mm would not be noticeable at the draft marks &

b) It is not feasible to load cargo at AG exactly 102 m.

Note 2: Calculation by method A is very quick & would suffice in actual practice

Example 10B

M.V. VIJAY is in FW drawing 3.2 m fwd and 5.8 m aft. 1350 t of cargo is loaded in No: 3 LH, AG 85 m. Find the final drafts fwd and aft in FW.

Fwd 3.2 m aft 5.8 m, trim 2.6 m by stern

For mean draft 4.5 m, AF from Appendix 1 = 72.035 m

Corr = (AF / L) x trim = (72.035/140) (2.6) = 1.338 m

Initial FW hydraft = 5.8 – 1.338 = 4.462

From Appendix 1:

Draft	W (t)	MCTC tm	AB(m)	AF (m)
SW 4.462	8711.5	161.734	72.016	72.043
FW 4.462	8499.0	157.789	72.016	72.043

Note: FW data is obtained by modifying the SW values as explained in chapters 17 and 18.

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

BG = (260 (157.789)) / 8499 = 4.827 m

Since trim is by stern, AG < AB.

AG = AB – BG = 72.016 – 4.827 = 67.189 m.

Remarks	Weight	AG (m)	Moment abt A
Ship	8499.0	67.189	571039
Loaded	1350.0	85	114750
Final	9849.0		685789

New AG = 685789 ÷ 9849 = 69.630 m.

Assuming same draft in SW & FW, for the sake of entering the hydrostatic table:

W in SW = W in FW (1.025) = 10095.2 t

From Appendix 1:

Draft	W (t)	MCTC tm	AB(m)	AF (m)
SW 5.092	10095.2	166.346	72.013	71.880
FW 5.092	9849	162.289	72.013	71.880

Note: FW data is obtained by modifying the SW values as explained in chapters 17 and 18.

Final AB = 72.013 m. Final AG = 69.630 m

AG < AB, so Tc is by stern, BG = 2.383 m

Tc = W.BG / MCTC = (9849 x 2.383) / 162.289 = 144.6 cm

Ta = (AF / L) x Tc = (71.880 /140) (1.446) = 0.742 m

Tf = Tc – Ta = 1.446 – 0.742 = 0.704 m

	Fwd	Aft
Final FW hydraft	5.092 m	5.092 m
Tf and Ta	- 0.704 m	+0.742 m
Final FW drafts	4.388 m	5.834 m

Example 11B

M.V. VIJAY is in DW of RD 1.013 at drafts of 4.2 m fwd & 3.6 m aft. Find the final drafts fwd & aft, in the same DW, after carrying out the following operations:

100 t pumped out of the FP tank, AG 135 m.

400 t HFO received in No: 4 DBT, AG 60 m.

500 t cargo loaded in No: 4 LH, AG 50 m.

Fwd 4.2 m aft 3.6 m, trim 0.6 m by head

Mean draft 3.9 m for which AF = 72.134 m

Corr = (AF / L) x trim = (72.134 / 140) (0.6) = 0.309 m

Initial DW hydraft = 3.6 + 0.309 = 3.909 m

From Appendix 1:

Draft	W (t)	MCTC tm	AB(m)	AF (m)
SW 3.909	7511.9	156.981	72.003	72.133
DW 3.909	7424.0	155.143	72.003	72.133

Note: DW data is obtained by modifying the SW values for the same draft.

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

BG = (60 (155.143)) / 7424 = 1.254 m

Since trim is by head, AG > AB.

AG = AB + BG = 72.003 + 1.254 = 73.257 m

Remarks	Weight	AG (m)	Moment
Ship	7424	73.257	543860
SW	- 100	135	- 13500
HFO	+ 400	60	+ 24000
Cargo	+ 500	50	+ 25000
Final	8224		579360

Final AG = 579360 ÷ 8224 = 70.447 m.

Assuming same draft in SW & DW, for the sake of entering the hydrostatic table:

W in SW = W in DW (1.025/1.013) = 8321.4 t

From Appendix 1:

Draft	W (t)	MCTC tm	AB(m)	AF (m)
SW 4.283	8321.4	160.305	72.013	72.081
DW 4.283	8224.0	158.428	72.013	72.081

Note: DW data is obtained by modifying the SW values for the same draft.

Final AG < final AB so final Tc by stern

Final BG = 72.013 – 70.447 = 1.566 m

Tc = W.BG / MCTC = (8224 x 1.566) / 158.428= 81.3 cm

Ta = (AF / L) x Tc = (72.081/ 140) x 0.813 = 0.419 m

Tf = Tc – Ta = 0.813 – 0.419 = 0.394 m

	Fwd	Aft
Final hydraft in DW	4.283	4.283
Tf or Ta	-0.394 m	+0.419 m
Final drafts in DW	3.889 m	4.702 m

Exercise 23

Trim problems – Type B

The hydrostatic table of m.v. Vijay, contained in Appendix 1 of this book, is reproduced here for quick reference while solving the problems in this exercise.

HYDROSTATIC TABLE OF M.V.'VIJAY

DRAFT	W t in SW	TPC $t\ cm^{-1}$	MCT Ctm cm^{-1}	AB m	AF m	KB m	KM_T m	KM_L m
3.0	5580	20.88	146.9	71.956	72.127	1.605	11.470	397.9
3.2	6000	21.07	149.6	71.968	72.141	1.710	11.030	375.8
3.4	6423	21.22	152.1	71.979	72.141	1.823	10.630	356.1
3.6	6849	21.36	154.1	71.990	72.141	1.931	10.274	339.1
3.8	7277	21.48	156.0	71.998	72.141	2.039	9.950	323.6
4.0	7708	21.60	157.8	72.008	72.127	2.147	9.660	309.9
4.2	8141	21.70	159.6	72.012	72.099	2.256	9.406	296.7
4.4	8576	21.80	161.3	72.015	72.056	2.367	9.182	285.0
4.6	9013	21.89	162.7	72.017	72.013	2.473	8.992	274.1
4.8	9451	21.97	164.3	72.016	71.970	2.576	8.828	263.9
5.0	9891	22.06	165.7	72.014	71.913	2.685	8.686	254.3
5.2	10333	22.14	167.1	72.011	71.842	2.789	8.566	245.4
5.4	10777	22.22	168.5	72.003	71.757	2.892	8.460	237.5
5.6	11223	22.30	169.9	71.990	71.671	2.998	8.374	229.9
5.8	11672	22.37	171.3	71.977	71.586	3.102	8.298	223.0
6.0	12122	22.45	172.9	71.960	71.472	3.205	8.234	217.2
6.2	12575	22.54	174.6	71.939	71.329	3.309	8.180	211.6
6.4	13030	22.64	176.4	71.914	71.172	3.413	8.136	206.6
6.6	13486	22.73	178.2	71.887	71.001	3.516	8.100	202.4
6.8	13943	22.83	180.3	71.856	70.802	3.620	8.076	198.4
7.0	14402	22.93	182.7	71.819	70.602	3.725	8.054	194.6

W displacement	Load W 19943 t	LOA 150.00m
A after perpendicular	Light W 6000 t	LBP 140.00 m
K keel	DWT 13943 t	GT 10,000 Tons
SW RD = 1.025		NT 5576 Tons

Exercise 23 – Trim problems Type B

1. M.V. VIJAY draws 4.5 m fwd & 6.5 m aft in SW. Find the new drafts if 100 t ballast is transferred from the AP tank, AG 3.5 m, to the FP tank, AG 136.5 m .

(Answer: F: 4.884 A: 6.097 m).

2. M.V. VIJAY is in DW Rd 1.015 drawing 6 m fwd & 5 m aft. Find the new drafts if 400 t cargo is shifted from No: 1 LH AG 120 m, to No: 3 LH AG 80 m.

(Answer: F: 5.534 A: 5.490 m).

3. M.V. VIJAY is in SW at drafts of 5.8 m fwd & 5 m aft. AG is 73.251 m. Find the new drafts if 600 t cargo is discharged from No: 1 TD, AG 124 m.

(Answer: F: 4.620 A: 5.688 m).

4. M.V. VIJAY is in SW, drawing 3.6 m fwd & 4.8 m aft. AG is 69.651 m. Find the new drafts fwd & aft if the following operations are carried out:

2000 t cargo loaded in No: 4, AG 60 m

1000 t discharged from No: 5, AG 20 m.

120 t SW run into AP tank, AG 3 m.

(Answer: F: 4.711 A: 4.678 m).

5. The drafts of M.V. VIJAY in SW are 4 m fwd & 3.6 m aft. AG is 72.854m. Find the final drafts if the following operations take place:

1400 t cargo loaded in No: 2, AG 98 m.

2100 t cargo loaded in No: 5. AG 22 m.

120 t FW transferred from APT AG 3m, to FPT AG 135 m.

(Answer: F: 4.059 A: 6.822 m).

6. M.V. VIJAY is drawing 5 m fwd & aft in SW. Find the new drafts if 1550 t of cargo is loaded in No: 4 LH, AG 50 m.

(Answer: F: 4.730 A: 6.710 m).

7. The drafts fwd & aft of M.V. VIJAY in SW are 5 m & 6.8 m. 1900 t cargo is loaded in No:3, AG 84 m. Find the new drafts fwd & aft.

(Answer: F: 6.532 A: 6.905 m).

8. M. V VIJAY arrives at a SW port drawing 4 m fwd & 5.9 m aft. Find the new drafts if 1600 t cargo is discharged from No:4, AG 60 m.

(Answer: F: 3.823 A: 4.583 m).

9. M. V VIJAY draws 3.3 m fwd & 6.3 m aft in a SW port. 2000 t of cargo is to be loaded. Space is available in No:2, AG 100 m, and in No:4, AG 60 m. Distribute this cargo in order to finish trimmed 1.5 m by the stern. State the final drafts fwd & aft.

(Answer: F: 4.929 A: 6.429 m 1183.4 t in # 2, 816.6 t in # 4).

10. M.V. VIJAY is in FM, drawing 4.8 m F & 4 m A. 1800 t cargo is yet to be loaded in No:2, AG 105 m, & in No:5, AG 20 m. Find how much to put in each hold to finish trimmed 1 m by the stern. State the final drafts F & A.

(Answer: 760.4 t in # 2, 1039.6 t in # 5; F: 4.764 A: 5.764 m).

11. The fwd & aft drafts of M.V. VIJAY in SW are 3.9 m & 4.9 m. Find how much cargo may go in No:1, AG 120 m, & in No:4, AG 55 m, to finish on an even keel draft of 5.8 m.

(Answer: 1060.2 t in No: 1, 2068.4 t in No: 4).

12. M.V. VIJAY floats in DW of RD 1.010 at 6.6 m F & A. Find how much cargo may be discharged from No:1, AG 118 m, and No:5, AG 16 m, to finish on an even keel draft of 6 m, in the same dock. (Answer: 727.80 t from No: 1, 616.20 t from No: 5)

13. M.V. VIJAY floats in SW, at drafts of 3.1 m fwd & 5.6 m aft. At what location must 500 t cargo be loaded if the after draft should remain at 5.6 m?

State also, the final draft fwd.

(Answer: AG of cargo 85.553 m; F: 3.543 A: 5.600 m).

14. M.V. VIJAY is in DW (RD 1.015) drawing 4.3 m fwd & 4 m aft. At what location should 800 t cargo be loaded if the final draft fwd is to be 4.3 m? State the final draft aft.

(Answer: AG of cargo 56.817 m; F: 4.300 A: 4.765 m)

15. M.V. VIJAY is in FW, at an even keel draft of 4.9 m. Find the location from which 1200 t of cargo may be discharged in order to finish at a draft of 4.9 m fwd. State, also, the final draft aft.

(Answer: AG of cargo 56.883 m; F: 4.900 A: 3.742 m).

16. M.V. VIJAY is in DW (RD 1.018) drawing 4.6 m fwd and 4 m aft. Find the location from which to discharge 1650 t cargo in order to finish with 4 m draft aft. State the final draft fwd.

(Answer: AG of cargo 86.211 m; F: 3.103 A: 4.000 m).

17. M.V. VIJAY is in SW, drawing 3.5 m fwd & 4.9 m aft. What quantity of cargo may be loaded in No:4 LH, AG 58 M, if the final draft aft is to be 6 m? State the final draft fwd.

(Answer: cargo 1245.80 t; F: 3.569 A: 6.000 m).

18. M.V. VIJAY is in DW (RD 1.013) drawing 5.2 m F and 6 m A. 800 t of cargo is to be discharged. What should be the AG of this cargo if the final draft F is to be 4.8 m? Also state the final draft A.

(Answer: Cargo AG 73.050m F: 4.800 A 5.675 m).

19. M.V. VIJAY arrives at a saltwater port drawing 3.7 m fwd & 4.5 m aft. 4000 t of cargo is to be loaded, of which:

1000 t must go into No:2, AG 100 m,

1000 t must go into No:4, AG 56 m,

1000 t must go into No:3, AG 80 m.

How much cargo must be put into No:1, AG 120 m, and into No:5, AG 18 m, to finish trimmed 1 m by the stern. State the final drafts fwd and aft.

(Answer: 284.5 t in No: 1 hold, 715.5 t in No: 5 hold; Final drafts F: 5.412 A: 6.412 m).

20. M.V. VIJAY arrives in DW (RD 1.016) at draft of 6.8 m fwd & 7.0 m aft. Part of her bulk cargo is to be discharged as follows:

500 tonnes from No:1, AG 122 m,
500 tonnes from No:5, AG 18 m,
500 tonnes from No:3, AG 80 m,

A further amount of 1500 t is to be discharged, part from No:2, AG 100 m, & part from No:4, AG 56 m. Calculate the quantity to discharge from Nos:2 and 4, if the final trim is to be 0.8 metre by the stern. State the final drafts F & A.

(Answer: 674.3 t from No: 2, 825.7 t from No: 4; Final drafts F: 5.174 m A: 5.974 m).

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28. TRIM PROBLEMS TYPE C

These problems are very similar to those of type B, except that all distances are expressed from amidships (H) instead of from the after perpendicular (A). These have the disadvantage that, each time, distances and moments have to be identified as forward of, or abaft, amidships. However, problems of type C have the advantage that the values used are much smaller than in problems of type B where the after perpendicular is used for reference.

Problems of type C are included here because the hydrostatic tables issued by some shipyards give distances from amidships only. The basic theory, and order of work, is very similar to that of type B. For working problems of type C, the hydrostatic table of M.V. VICTORY, given in Appendix II at the end of this book, may be used. However, extracts are given, where necessary, for convenience.

Example 1C

M.V. VICTORY is afloat in SW at an even keel draft of 13 m. 300 t is shifted aft by 80 m. Find the new drafts fwd & aft.

From hydrostatic table, in Appendix II, for 13 m draft, MCTC = 1159.1 tm and HF = 0.27 m aft.

Tc = TM /MCTC =(300 x 80) / 1159.1= 20.7 cm by stern.

Ta = (AF / L) (Tc) = ((L/2 – 0.27) / 236) 0.207 = 0.103 m

Tf = Tc – Ta = 0.207 – 0.103 = 0.104 m

	Fwd	Aft
Final hydraft	13.000 m	13.000 m
Tf or Ta	- 0.104 m	+ 0.103 m
Final drafts	12.896 m	13.103 m

Example 2C

M.V. VICTORY is afloat in SW at drafts of 12.8 m fwd and 14.8 m aft. HG is 1.669 m fwd. Find the new drafts fwd and aft if 3000 t of cargo is loaded in No: 3 LH, HG 52 m fwd.

Fwd 12.8 m aft 14.8 m, trim 2 m by stern

For mean draft 13.8 m, HF (Appendix II) = 0.98 m aft.

To obtain initial hydraft (explained in chapter 18):

corrn = (HF / L) x trim = (0.98 (2)) / 236 = 0.008 m

Note: Trim is by stern and HF is aft. So, correction to mean draft is positive.

Initial hydraft = 13.8 + 0.008 = 13.808 m.

For 13.808 m hydraft, W from Appendix II = 90541.8 t

Final W = 90541.8 + 3000 = 93541.8 t

From Appendix II, particulars for final W are:

W (t)	draft	MCTC tm	HB fwd	HF aft
93541.8	14.231	1198.303	4.116	1.313

Remarks	Weight	HG (m)	moment abt H
Ship	90541.8	1.669 fwd	151114 fwd
Cargo	+3000	52 fwd	156000 fwd
Final	93541.8		307114 fwd

Final HG = 307114/93541.8 = 3.283 m fwd.

Final HG 3.283 fwd, final HB 4.116 fwd.

COG is abaft COB so final trim by stern.

Final BG = 4.116 – 3.283 = 0.833 metres.

Tc = W.BG / MCTC = (93541.8 x 0.83) / 1198.303 = 65 cm

AF = (L/2) – HF = 118 – 1.313 = 116.687 m.

Ta = (AF x Tc) / L = (116.687 x 0.65) / 236 = 0.321 m.

Tf = Tc - Ta = 0.650 – 0.321 = 0.329 m.

	Fwd	Aft
Final hydraft	14.231 m	14.231 m
Tf or Ta	- 0.329 m	+ 0.321 m
Final drafts	13.902 m	14.552 m

Example 3C

M.V. VICTORY is afloat in SW at drafts of 10 m fwd & 13.8 m aft. HG is 0.46 m aft. Find the new drafts fwd & aft after the following operations:

10,000 t of cargo loaded at HG 72 m fwd

6,000 t of cargo loaded at HG 52 m aft

1,500 t SW pumped out from HG 110 m fwd

Fwd 10 m aft 13.8 m, trim 3.8 m by stern

For mean draft 11.9m, HF (from Appendix II) = 0.86 m fwd

Corrn = (HF / L) (trim) = (0.86 (3.8)) / 236 = 0.014 m

Trim by stern & HF fwd so correction (-)

Initial hydraft = 11.9 – 0.014 = 11.886 m by which the initial W, from Appendix II, = 77054.4 tonnes.

Remarks	Weight	HG (m)	moment abt H
Ship	77054.4	0.46 aft	35,445 aft
Cargo	+10000	72 fwd	720,000 fwd
Cargo	+ 6000	52 aft	312,000 aft
SW	- 1500	110 fwd	165,000 aft
Final	91554.4		207,555 fwd

Final HG = 207555 / 91554.4 = 2.267 m fwd
From Appendix II, particulars for final W are:
Final HG 2.267 fwd, final HB 4.230 fwd.
COG is abaft COB so final trim by stern.
Final BG = 4.230 – 2.267 = 1.963 metres.
Tc = W.BG / MCTC = (91554.4 x 1.963) / 1189.773 = 151.1 cm.
AF = (L/2) – HF = 118 – 1.101 = 116.899 m.
Ta = (AF (Tc)) / L = (116.899 x 1.511) / 236 = 0.748 m.
Tf = Tc – Ta = 1.511 – 0.748 = 0.763 m.

	Fwd	Aft
Final hydraft	13.951 m	13.951 m
Tf or Ta	- 0.763 m	+ 0.748 m
Final drafts	13.188 m	14.699 m

Example 4C

M.V. VICTORY is in SW drawing 12.2 m fwd and 16.2 m aft. 5000 t cargo is loaded into No: 4 LH, HG 31 m fwd. Find the new drafts fwd and aft.

Fwd 12.2 m aft 16.2 m, trim 4 m by stern
For mean draft 14.2 m, HF(Appendix II) = 1.29 m aft.
Corrn = (HF / L) x trim = (1.29 x 4) / 236 = 0.022 m
Trim by stern & HF aft so correction (+)
Initial hydraft = 14.2 + 0.022 = 14.222 m.
From Appendix II:

Draft	W (t)	MCTC	HB fwd
14.222	93480.5	1198.049	4.120

Trim in cm = W.BG / MCTC
or
BG = (trim x MCTC) / W
BG = (400 (1198.049)) / 93480.5 = 5.126 m
Since trim is by stern, COG is abaft COB

Initial HG = 5.126 – 4.120 = 1.006 m aft

Remarks	Weight	HG (m)	Moment abt H
Ship	93480.5	1.006 aft	94041 aft
Cargo	+ 5000	31.00 fwd	155000 fwd
Final	98480.5		60959 fwd

Final HG = 60959 ÷ 98480.5 = 0.619 m fwd
From Appendix II, for final W 98480.5 t:

Draft	MCTC tm	HB fwd	HF aft
14.923	1218.510	3.825	1.794

Finally, HG = 0.619 fwd & HB = 3.825 fwd.
COG abaft COB, so final trim is by stern
Final BG = 3.825 – 0.619 = 3.206 metres.
Final Tc = W.BG / MCTC = (98480.5 (3.206)) / 1218.51 = 259.1 (cm)
AF = (L/2) – HF = 118 – 1.794 = 116.206 m.
Ta = (AF / L) x Tc = (116.206 x 2.591) / 236 = 1.276 m
Tf = Tc – Ta = 2.591 – 1.276 = 1.315 m

	Fwd	Aft
Final hydraft	14.923 m	14.923 m
Tf or Ta	- 1.315 m	+1.276 m
Final drafts	13.608 m	16.199 m

Example 5C
M.V. VICTORY is afloat in SW drawing 11 m fwd & 14.4 m aft. 8000 t of cargo is yet to be loaded. Space is available in No:2 HG 72 m fwd, and in No:7, HG 31 m aft. Find how much to put in each space to finish loading 1.5 m by the stern. State the final drafts fwd and aft.
Fwd 11 m aft 14.4 m, trim 3.4 m by stern
For mean draft 12.7 m, HF (Appendix II) = 0.02 m fwd

Note: An extract of the hydrostatic table is given here. In this case, as HF for 12.6 m draft is fwd whereas for 12.8 m, it is aft.

d	Wsw	TPC	MCTC	HB	HF
12.60	82032	69.88	1145.5	4.79F	0.12F
12.80	83434	70.03	1152.4	4.71F	0.08A

Corrn = (HF / L) x trim =(0.02 (3.4)) /236 = < 0.001 m
Initial hydraft = mean draft = 12.700 m.
Extract from Appendix II:

Draft	W (t)	MCTC	HB fwd
12.700	82733	1148.950	4.750

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

BG = (340 (1148.950)) / 8733 = 4.722 m

Since trim is by stern, COG is abaft COB

Initial HG = 4.750 – 4.722 = 0.028 m fwd

Final W = 82733 + 8000 = 90733 tonnes, for which the particulars, from Appendix II, are:

Draft	MCTC tm	HB fwd	HF aft
13.835	1186.184	4.276	1.008

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

BG = (150 (1186.184)) / 90733 = 1.961 m

Final trim by stern, so COG is abaft COB

Final HG = 4.726 – 1.961 = 2.315 m fwd.

Let cargo to load in No: 2 = X tonnes.

So, cargo to load in No: 7 = 8000 – X tonnes.

Remarks	Weight	HG (m)	Moment abt H
Ship	82733	0.028 fwd	2317 fwd
No: 2	X	72 fwd	72 X fwd
No: 7	8000 – X	31 aft	24800 – 31X aft

Final moment = (2317 + 72 X) – (24800 – 31 X)

(Since final HG is fwd final mom is fwd)

Final HG = final moment/final W = 2.315 metres.

[(2317 + 72 X) – (24800 – 31 X)]/90733 = 2.315

X = 4424.5 t = cargo to load in No:2 LH

& (8000 – X) = 3575.5 t cargo in No:7 LH

AF = (L/2) – HF = 118 – 1.008 = 116.992 m.

Ta = (AF / L) x Tc = (116.992 x 1.500) / 236 = 0.744 m

Tf = Tc – Ta = 1.500 – 0.744 = 0.756 m

Final hydraft	13.835 m	13.835 m
Tf or Ta	- 0.756 m	+ 0.744 m
Final drafts	13.079 m	14.579 m

Example 6C

M.V. VICTORY is afloat in SW drawing 11 m fwd & 13 m aft. She is to sail on an even keel draft of 13.6 m. Find how much cargo to put in No: 3, HG 52 m fwd, and in No: 7, HG 32 m aft.

Fwd 11 m aft 13 m, trim 2 m by the stern

For mean draft 12.0 m, HF (from Appendix II) = 0.74 m fwd

Corrn = (HF / L) x trim = (0.74 x 2) / 236 = 0.006 m

Trim by stern & HF fwd so correction (-)

Initial hydraft = 12.0 – 0.006 = 11.994 m.

From Appendix II:

Draft	W (t)	MCTC	HB fwd	HF fwd
11.994	77803.4	1123.757	5.022	0.747

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

BG = (200 (1123.757)) / 77803.4 = 2.889 m

Initial trim by stern means COG is abaft COB

Initial HG = 5.022 – 2.889 = 2.133 m fwd

From Appendix II:

Draft	W (t)	MCTC tm	HB fwd	HF aft
13.60	89070	1178.800	4.380	0.810

Can load = 89070.0 – 77803.4 = 11266.6 t

Even keel means final HG = HB = 4.380 m fwd.

Let cargo to load in No: 3 = X tonnes. So, cargo to load in No: 7 = (11266.6 – X) t.

Remarks	Weight	HG (m)	Moment	abt H
Ship	77803.4	2.133 fwd	165955	fwd
No: 2	X	52 fwd	52 X	fwd
No: 7	11266.6 - X	32 aft	360531-32X	aft

Final moment = (165955+52x) - (360531-32x)

(Since final HG is fwd final moment is fwd)

Final HG = final moment/final W = 4.380

[165955+52X – (360531-32X)]/89070 = 4.38

X = 6960.7 t = cargo to load in No: 3 LH

11266.6 – X = 4305.9 t cargo in No: 7 LH

Example 7C

M.V. VICTORY is in SW drawing 14 m fwd & 14.8 m aft. From what location must 2500 tonnes cargo be discharged if the draft aft is to remain constant? State the final drafts fwd & aft.

Fwd 14 m aft 14.8 m, trim 0.8 m by stern

From hydrostatic table, for mean draft 14.4 m, HF = 1.44 m aft.

Corrn = (HF / L) (trim) = (1.44 (0.8)) / 236 = 0.005 m

Trim by stern & HF aft so correction (+)

Initial hydraft = 14.4 + 0.005 = 14.405 m

From Appendix II:

Draft	W (t)	MCTC	HB fwd
14.405	94782.7	1203.448	4.038

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

BG = (80 (1203.448)) / 94782.7 = 1.106 m

Initial trim by stern, hence COG is abaft COB

Initial HG = 4.038 – 1.106 = 3.022 m fwd

Final W = 94782.7 – 2500 = 92282.7 t

From Appendix II:

W(t)	Draft	MCTC	HB fwd	HF aft
92282.7	14.053	1192.927	4.189	1.180

Ta = final draft aft – final hydraft

Ta = 14.800 – 14.053 = 0.747 metre

Ta = (AF / L) (Tc) or

Tc = (236 (0.747)) / (118 -1.18) = 1.509 m

Final draft fwd = 14.8 – 1.509 = 13.291 m

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

BG = (150.9 (1192.927)) / 92282.7 = 1.951 m

Final trim by stern, so COG is abaft COB

Final HG = 4.189 – 1.951 = 2.238 m fwd.

Let HG of cargo to discharge = X m fwd.

Remarks	Weight	HG (m)	Moment abt H
Ship	94782.7	3.022 fwd	286433 fwd
Cargo	-2500	X fwd	2500X aft
Final	92282.7		286433-2500X fwd

(Since final HG is fwd final moment is fwd)
Final HG = final moment/final W = 2.238
(286433 – 2500X) / 92282.7 = 2.238
or X = 31.962 m fwd
HG of cargo to discharge = 31.962 m fwd.
Note: If the value of X was found to be negative, the assumed direction of COG, from H, would have to be changed. The value obtained would still hold good.
Rough check by method A
Mean rise = Ta
or w / TPC = (AF (dw)) / (L (MCTC))
Using initial hydrostatic particulars:
d = (L (MCTC)) / (AF (TPC)) = (236 x 1203.448) / (118-1.44)71.193 = 34.226 m
HG of cargo = 34.226 – 1.440 = 32.786 m.
Example 8C
M.V. VICTORY is in SW drawing 11.8 m fwd and 12.2 m aft. 3000 t cargo is to be loaded. To effect some shipside repairs, the fwd draft has to be maintained at 11.8 m. Find where this cargo should be loaded and state the final draft aft.
Fwd 11.8 aft 12.2 m, trim 0.4 m by stern
For mean draft 12.0 m, HF (from Appendix II) = 0.74 m fwd.
Corrn = (HF / L) (trim) = (0.74 (0.4)) / 236 = 0.001 m
Trim by stern & HF fwd so correction (-)
Initial hydraft = 12 – 0.001 = 11.999 m.
From Appendix II:

Draft	W(t)	MCTC tm	HB fwd	HF fwd
11.999	77838.1	1123.960	5.020	0.741

Trim in cm = W.BG / MCTC
or
BG = (trim x MCTC) / W
BG = (40 (1123.96)) / 77838.1 = 0.578 m
Initial trim by stern:- COG is abaft COB

Initial HG = 5.020 – 0.578 = 4.442 m fwd
Final W = 77838.1 + 3000 = 80838.1 t
From Appendix II:

W (t)	Draft	MCTC	HB fwd	HF fwd
80838.1	12.429	1139.441	4.858	0.291

Since final trim is by the stern,
Tf = final hydraft – final draft forward = 12.429 – 11.800 = 0.629 m.
(Fwd length (Tc)) / L = Tf or
Tc = (236 (0.629)) / (118 – 0.291)
Tc = Final trim = 1.261 m by the stern
Final draft aft = 11.8 + 1.261 = 13.061 m
Trim in cm = W.BG / MCTC
or
BG = (trim x MCTC) / W
BG = (126.1 (1139.441)) / 80838.1 = 1.777 m
Final trim by stern, so COG is abaft COB
Final HG = 4.858 – 1.777 = 3.081 m fwd.
Let HG of cargo to be loaded be X m fwd.

Remarks	Weight	HG (m)	Moment abt H
Ship	77838.1	4.442 fwd	345757 fwd
Cargo	+3000	X fwd	3000X fwd
Final	80838.1		345757+3000X fwd

Final HG = final moment/final W = 3.081 m
(345757+3000X) / 80838.1 = 3.081, X = -32.232 m fwd
HG of cargo to be loaded = 32.232 m aft.
Note: HG of the cargo was intentionally assumed to be X m fwd, just to illustrate the meaning of the negative sign obtained at the end of the calculation.
Rough check by method A
Mean sinkage = Ta or
w / TPC = (fwd length (dw)) / (L x MCTC)
3000 / 69.4 = ((118 – 0.74) 3000d) / (236 x 1123.296)
or
d = 32.595 aft
HG of cargo = 32.595 – 0.74 = 31.855 aft
Example 9C

M.V. VICTORY is alongside a loading berth with a conveyor chute loading into No: 2 LH, HG 72 m fwd. The present drafts are 10 m fwd & 13 m aft. Find how much cargo to put in No: 2 in order to bring the aft draft to 12 m. State the final draft fwd.

Note: Because w is not given, the final W is not directly known and neither is the final hydraft given. Hence the final hydrostatic particulars are not readily available. Using the initial hydrostatic data, an approximate value of w is obtained by method A. This value is assumed to be loaded and the precise results calculated. Then minor changes are effected, as necessary, to obtain the precise quantity to load.

Fwd 10 m aft 13 m, trim 3 m by the stern

For mean draft 11.5m, HF (from Appendix II) = 1.345m fwd

Corrn = (HF / L) (trim) = (1.345 (3)) / 236 = 0.017 m

Trim by stern & HF fwd so correction (-)

Initial hydraft = 11.5 – 0.017 = 11.483 m

From Appendix II:

Draft	W (t)	MCTC	HB fwd	HF fwd
11.483	74266.1	1102.945	5.201	1.366

Trim in cm = W.BG / MCTC

or

BG = (trim x MCTC) / W

BG = (300 (1102.945)) / 74266.1 = 4.455 m

Initial trim by stern as COG is abaft COB

Initial HG = 5.201 – 4.455 = 0.746 m fwd

To find approximate w by method A:

Old draft + sinkage – Ta = new draft aft

1300 + (w / TPC) – (AF (dw)) / (L(MCTC)) = 1200

[(w / 69) – ((118 + 1.366) (72-1.366)) / (236 x 1102.945) w] = -100

w = 5587 tonnes (approximately).

Assuming that exactly 5587 t is loaded:-

Remarks	Weight	HG (m)	Moment abt H
Ship	74266.1	0.746 fwd	55403 fwd
Cargo	+5587.0	72 fwd	402264 fwd
Final	79853.1		457667 fwd

Final HG = 457667 ÷ 79853.1 = 5.731 fwd.

W (t)	Draft	MCTC	HB fwd	HF fwd
79853.1	12.288	1134.433	4.909	0.437

Since COG is fwd of COB, trim is by head
and final BG = 5.731 – 4.909 = 0.822 m.
Tc = W.BG / MCTC = (79853.1 x 0.822) / 1134.433 = 57.9 cm.
Ta = (AF / L) (Tc) = ((118 + 0.437) 0.579) / 236 = 0.291
Tf = Tc –Ta = 0.579 – 0.291 = 0.288 m

	Fwd	Aft
New hydraft	12.288 m	12.288 m
Tf or Ta	+ 0.288 m	- 0.291 m
New drafts	12.576 m	11.997 m

Note: After loading 5587 t in No: 2, the draft aft is found to be 11.997 m instead of 12.000 m. This is acceptable in practice because:
(a) 0.003 m (i.e., 3 mm) difference is not notice
able at the draft marks and
(b) The HG of cargo loaded cannot be exactly 72 m.

Example 10C

M.V. VICTORY - FW drafts F 11.4 m & A 11 m. Find the final FW drafts if 8000 t cargo is loaded in No: 7 LH, HG 32 m aft.
Fwd 11.4 m aft 11 m, trim 0.4 m by head.
For mean draft 11.2 m, HF (from Appendix II) = 1.172 m fwd
Corrn. = (HF / L) (trim) = (1.172 (0.4)) / 236 = 0.003 m
Trim by head & HF fwd so correction (+)
Initial hydraft = 11.2 + 0.003 = 11.203 m
From Appendix II:

Draft	W (t)	MCTC	HB fwd	HF fwd
SW 11.203	72335.7	1091.423	5.299	1.716
FW 11.203	70571.4	1064.803	5.299	1.716

Trim in cm = W.BG / MCTC
or
BG = (trim x MCTC) / W
BG = [40 x 1064.803] ÷ 70571.4 = 0.604 m
Initial trim by head means COG is fwd of COB
Initial HG = 5.299 + 0.604 = 5.903 m fwd

Remarks	Weight	HG (m)	Moment abt H
Ship	70571.4	5.903 fwd	416583 fwd
Cargo	+8000	32 aft	256000 aft
Final	78571.4		160583 fwd

Final HG = 160583 ÷ 78571.4 = 2.044 m fwd
From Appendix II:

W (t)	draft	MCTC	HB fwd	HF fwd
SW 80535.7	12.386	1137.905	4.875	0.335
FW 78571.4	12.386	1110.151	4.875	0.335

Final COG is abaft COB so Tc is by stern and final BG = 4.875 – 2.044 = 2.831 m.
Tc = W.BG / MCTC = (78571.4 x 2.831) / 1110.151 = 200.4 cm.
Ta = (AF / L) (Tc) = ((118 + 0.335) 2.004) / 236 = 1.005 m
Tf = Tc – Ta = 2.004 – 1.005 = 0.999 m

Final hydraft	12.386 m	12.386 m
Tf or Ta	-0.999 m	+1.005 m
Final drafts	11.387 m	13.391 m

Example 11C
M.V. VICTORY is in DW of RD 1.012 drawing 13 m fwd & 13.6 m aft. Find the final drafts fwd & aft in the same dock if the following operations are carried out:
5000 t cargo loaded in No: 4, HG 30 m fwd
1000 t HFO received in No: 5, HG 60 m aft
500 t SW transferred from the FP tank HG 110 m fwd, to the AP tank, HG 114 m aft.
Fwd 13 m aft 13.6 m, trim 0.6 m by stern
For mean draft 13.3 m, HF (Appendix II) = 0.55 m aft.
Corrn = (HF / L) (trim) = (0.55 (0.6)) / 236 = 0.001 m
Trim by stern & HF aft so correction (+)
Initial hydraft = 13.3 + 0.001 = 13.301 m
From Appendix II:

W (t)	draft	MCTC	HB fwd
SW 13.301	86958.6	1169.083	4.500
DW 13.301	85855.7	1154.255	4.500

Trim in cm = W. BG / MCTC
or

BG = (trim x MCTC) / W
BG = [60 x 1154.255] ÷ 85855.7 = 0.807 m
Initial trim by stern means COG is abaft COB
Initial HG = 4.500 – 0.807 = 3.693 m fwd

Remarks	Weight	HG (m)	Moment abt H
Ship	85855.7	3.693 fwd	317065 fwd
Cargo	+5000	30 fwd	15000 fwd
HFO	+1000	60 m aft	60000 aft
SW transferred 500 x 224 aft			112000 aft
Final	91855.7		160065 fwd

Final HG = 160065 ÷ 91855.7 = 1.743 fwd
From Appendix II:

W (t)	draft	MCTC	HB fwd	HF aft
SW 93035.7	14.159	1196.162	4.146	1.260
DW 91855.7	14.159	1180.991	4.146	1.260

Final COG is abaft COB so Tc is by stern and final BG = 4.146 – 1.743 = 2.403 m.
Tc = W.BG / MCTC = (91855.7 x 2.403) / 1180.991 = 186.9 cm.
Ta = (AF / L) (Tc) = ((118 -1.260) 1.869) / 236= 0.925 m
Tf = Tc – Ta = 1.869 – 0.925 = 0.944 m.

	Fwd	Aft
Final hydraft	14.159 m	14.159 m
Tf or Ta	-0.944 m	+0.925 m
Final drafts	13.215 m	15.084 m

Exercise 24
Trim problems - Type C

The hydrostatic table of m.v. Victory, contained in Appendix II of this book, is reproduced here for quick reference while solving the problems in this exercise.

Hydrostatic particulars of M.V. VICTORY

d	W_{sw}	TPC	MCTC	HB	HF	KB	KM_T	KM_L
11.00	70941	68.58	1083.0	5.37F	1.96F	5.64	13.24	366
11.20	72315	68.74	1091.3	5.30F	1.72F	5.75	13.22	362
11.40	73693	68.91	1099.5	5.23F	1.47F	5.85	13.20	358
11.60	75074	69.07	1107.8	5.16F	1.22F	5.95	13.18	354
11.80	76458	69.24	1115.9	5.09F	0.98F	6.06	13.17	351
12.00	77845	69.40	1124.0	5.02F	0.74F	6.16	13.16	347
12.20	79237	69.56	1131.3	4.94F	0.53F	6.26	13.16	343
12.40	80633	69.72	1138.4	4.87F	0.32F	6.37	13.16	340
12.60	82032	69.88	1145.5	4.79F	0.12F	6.47	13.16	336
12.80	83434	70.03	1152.4	4.71F	0.08A	6.58	13.17	333
13.00	84839	70.19	1159.1	4.62F	0.27A	6.68	13.18	329
13.20	86246	70.34	1165.8	4.54F	0.46A	6.79	13.19	326
13.40	87657	70.49	1172.3	4.46F	0.64A	6.89	13.21	323
13.60	89070	70.63	1178.8	4.38F	0.81A	7.00	13.22	320
13.80	90485	70.78	1185.1	4.29F	0.98A	7.10	13.25	316
14.00	91904	70.92	1191.3	4.21F	1.14A	7.21	13.27	313
14.20	93324	71.06	1197.4	4.13F	1.29A	7.31	13.30	310
14.40	94747	71.19	1203.3	4.04F	1.44A	7.42	13.33	308
14.60	96173	71.32	1209.2	3.96F	1.58A	7.52	13.36	305
14.80	97600	71.45	1215.0	3.88F	1.72A	7.63	13.39	302
15.00	99030	71.57	1220.7	3.79F	1.84A	7.73	13.43	299

d = draft in metres	K = keel	Light W 14000 t
LOA 245 m	H = amidships	Load W 98000 t
LBP 236 m		DWT 84000 t
SW RD = 1.025	GT 42000 Tons	NT 28000 Tons

Exercise 24 Trim problems - Type C

1. M.V. VICTORY is in SW at 12.5 m F & 14.5 m A. Find the new drafts if 500 t of SW goes from the AP (HG 114 m A) to the FP (HG 110 m F).

(Answer: F: 12.979 A: 14.026 m).

2. M.V. VICTORY draws 13.8 m fwd and 16 m aft in DW of RD 1.010. Find the new drafts if 1500 t HFO is shifted from No: 5 hopper tank, HG 58 m aft, to the fwd deep tank, HG 104 m fwd.

(Answer: F: 14.827 A: 15.003 m).

3. M.V. VICTORY draws 12.2 m F & 14.6 m A in SW. HG is 1.248 m fwd. Find the drafts F & A if 4820 t cargo is loaded in No: 3, HG 52 m fwd.

(Answer: F: 13.977 A: 14.196 m).

4. M.V. VICTORY draws 13.7 m F and 13 m A in SW. HG is 5.42 m fwd. Find the drafts if:
8000 t is disch from No: 3 LH HG 52 m fwd
5000 t is disch from No: 5 LH HG 10 m fwd
2000 t is disch from No: 9 LH HG 72 m aft
1000 t SW taken into FPT HG 110 m fwd.

(Answer: F: 10.784 A: 11.912 m).

5. The drafts of M. V. VICTORY in SW are 11 m F & 11.5 m A. HG is 4.531 m fwd. Find the new drafts F & A after loading the following:
6000 t in No: 2 hold, HG 72 m fwd
5000 t in No: 4 hold, HG 30 m fwd
5000 t in No: 6 hold, HG 10 m aft
10000 t in No: 8 hold, HG 52 m aft.

(Answer: F: 14.797 A: 15.086 m).

6. M.V. VICTORY is in SW drawing 11.45 m fwd & aft. Find the drafts if 11000 t cargo is loaded in No: 6, HG 10 m aft.

(Answer: **)** F: 10.949 A: 11.949 m).

7. The drafts of M.V. VICTORY are 13 m & 14.8 m fwd and aft in SW. Find the new drafts if 9500 t cargo is discharged from No: 7 LH, HG 32m aft.

(Answer: F: 12.930 A: 12.189 m).

8. M.V. VICTORY arrives port drawing 12 m fwd & 12.4 m aft in SW. Find the new drafts if 4200 t cargo is discharged from No: 3 hold, HG 52 m fwd.

(Answer: F: 10.436 A: 12.779 m)

9. M. V. VICTORY draws 13 m F & 14 m A in SW. 7000 t is yet to be loaded. Conveyors are ready to load in No: 3, HG 52 m F, & in No: 7, HG 32 m A. Find how much ore to load in each of these two holds to finish with a trim of 0.40 m by the stern. State the final drafts F & A.
(Answer: F: 14.286 A: 14.686 m No: 3 3388.5 t, No: 7 3611.5 t).

10. M.V. VICTORY is in FW, drawing 14.8 m fwd & 14 m aft. 6000 t of cargo is to be discharged, part from No: 3 HG 52 m fwd and part from No: 8 HG 52 m aft. Calculate the quantities to discharge & the final FW drafts if the trim on completion is to be 1 m by the stern.
(Answer: 4934.3 t from No: 3, 1065.7 t from No: 8; F: 13.025 A: 14.025 m).

11. M. V. VICTORY draws 12 m F & 13.2 m A in SW. How much cargo may be put in No: 1 #, HG 92 m fwd, & in No: 9 #, HG 72 m aft, to complete loading on an EK draft of 14.8 m?

(Answer: 7589.4 t in No: 1, 7985.6 t in No: 9).

12. M.V. VICTORY is in DW RD 1.012 at an even keel draft of 14.6 m. How much cargo may be discharged from No: 3 LH, HG 52 m fwd, & from No: 7 HG 31 m aft, in order to finish at 13.6 m draft, even keel, in the same dock?

(Answer: 2508.9 t from No: 3, 4504t from No: 7)

13. M.V. VICTORY is in SW at 11.1 m F & 13.6 m A. Where may 1000 t be loaded if the draft A is to remain at 13.6 m? State the final draft F.

(Answer: HG 31.333 m fwd, F: 11.382 m).

14. M.V. VICTORY is in DW RD 1.018 drawing 12.5 m fwd and 11.9 m aft. Where may 4000 t cargo be loaded if the draft fwd is to remain at 12.5 m? State the final draft aft.

(Answer: Cargo HG 32.329 m aft; A: 13.054m).

15. M.V. VICTORY is in FW at 12.9 m draft, even keel. Find the location from which 3000 t cargo may be discharged in order to finish with 12.9 m draft aft. State the final draft fwd.

(Answer: Cargo HG 32.424 m fwd, F: 12.024).

16. M.V. VICTORY is in DW RD 1.010 drawing 12.4 m fwd and 12.6 m aft. Find where 2800 t may be loaded if the ship is to sail with 12.4 m draft fwd. State the final draft aft.

(Answer: Cargo HG 33.071 m aft, A: 13.408 m).

17. M.V. VICTORY is in SW with drafts of 11.8 m fwd & 12 m aft. How much cargo may be loaded into No: 7, HG 32 m aft, in order to finish at 13 m draft aft? State the final draft fwd.

(Answer: 3482 t; Final drafts F: 11.801).

18. M.V. VICTORY is afloat in DW RD 1.017 at drafts of 13.7 m fwd and 14 m aft. How much ore is to be discharged from No: 2, HG 72 m fwd, if the final draft fwd is to be 12 m? What would be the final draft aft?

(Answer: 3706 t; Final drafts A: 14.632 m).

19. M.V. VICTORY arrives at a SW port at 14.6 m even keel. Cargo is to be discharged in stream to lighten the ship sufficiently to enter the docks at an even keel draft of 11.6 m. The master decides to discharge

4500 t of cargo from each of hold Nos: 3 (HG 52 m fwd) 5 (HG 10 m fwd) and 7 (HG 31 m aft). Find the quantities to discharge from Nos : 1 (HG 92 m fwd) & 9 (HG 72 m aft).
(Answer: 2445.7 t from No: 1, 5153.30 t from No: 9).

20. M.V. VICTORY arrives in DW of RD 1.009 drawing 14.6 m fwd & 14.8 m aft. Ore is to be discharged as follows: 6000 t from No: 4, HG 30 m fwd, 8000 t from No: 6, HG 10 m aft. A further 6000 t is to be discharged, part from No: 2 (HG 72 m fwd) and part from No: 8 (HG 52 m aft). Find how much to discharge from each of these two spaces if the final trim is to be one metre by the stern. State the final DW drafts fwd and aft.
(Answer: 2328.40 t from No: 2, 3671.6 t from No: 8; Final drafts F: 11.321 m A: 12.321 m).

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Appendix I

HYDROSTATIC TABLE OF M.V.'VIJAY'

DRAT	W t in SW	TPC t cm^{-1}	MCTCt m cm^{-1}	AB m	AF m	KB m	KM_T m	KM_L m
3.0	5580	20.88	146.9	71.956	72.127	1.605	11.470	397.9
3.2	6000	21.07	149.6	71.968	72.141	1.710	11.030	375.8
3.4	6423	21.22	152.1	71.979	72.141	1.823	10.630	356.1
3.6	6849	21.36	154.1	71.990	72.141	1.931	10.274	339.1
3.8	7277	21.48	156.0	71.998	72.141	2.039	9.950	323.6
4.0	7708	21.60	157.8	72.008	72.127	2.147	9.660	309.9
4.2	8141	21.70	159.6	72.012	72.099	2.256	9.406	296.7
4.4	8576	21.80	161.3	72.015	72.056	2.367	9.182	285.0
4.6	9013	21.89	162.7	72.017	72.013	2.473	8.992	274.1
4.8	9451	21.97	164.3	72.016	71.970	2.576	8.828	263.9
5.0	9891	22.06	165.7	72.014	71.913	2.685	8.686	254.3
5.2	10333	22.14	167.1	72.011	71.842	2.789	8.566	245.4
5.4	10777	22.22	168.5	72.003	71.757	2.892	8.460	237.5
5.6	11223	22.30	169.9	71.990	71.671	2.998	8.374	229.9
5.8	11672	22.37	171.3	71.977	71.586	3.102	8.298	223.0
6.0	12122	22.45	172.9	71.960	71.472	3.205	8.234	217.2
6.2	12575	22.54	174.6	71.939	71.329	3.309	8.180	211.6
6.4	13030	22.64	176.4	71.914	71.172	3.413	8.136	206.6
6.6	13486	22.73	178.2	71.887	71.001	3.516	8.100	202.4
6.8	13943	22.83	180.3	71.856	70.802	3.620	8.076	198.4
7.0	14402	22.93	182.7	71.819	70.602	3.725	8.054	194.6

W displacement	Load W 19943 t	LOA 150.00 m
A after perpendicular	Light W 6000 t	LBP 140.00 m
K keel	DWT 13943 t	GT 10,000 Tons
SW RD = 1.025		NT 5576 Tons

Appendix II

Hydrostatic particulars of M.V. VICTORY

d	W_{sw}	TPC	MCTC	HB	HF	KB	KM_T	KM_L
11.00	70941	68.58	1083.0	5.37F	1.96F	5.64	13.24	366
11.20	72315	68.74	1091.3	5.30F	1.72F	5.75	13.22	362
11.40	73693	68.91	1099.5	5.23F	1.47F	5.85	13.20	358
11.60	75074	69.07	1107.8	5.16F	1.22F	5.95	13.18	354
11.80	76458	69.24	1115.9	5.09F	0.98F	6.06	13.17	351
12.00	77845	69.40	1124.0	5.02F	0.74F	6.16	13.16	347
12.20	79237	69.56	1131.3	4.94F	0.53F	6.26	13.16	343
12.40	80633	69.72	1138.4	4.87F	0.32F	6.37	13.16	340
12.60	82032	69.88	1145.5	4.79F	0.12F	6.47	13.16	336
12.80	83434	70.03	1152.4	4.71F	0.08A	6.58	13.17	333
13.00	84839	70.19	1159.1	4.62F	0.27A	6.68	13.18	329
13.20	86246	70.34	1165.8	4.54F	0.46A	6.79	13.19	326
13.40	87657	70.49	1172.3	4.46F	0.64A	6.89	13.21	323
13.60	89070	70.63	1178.8	4.38F	0.81A	7.00	13.22	320
13.80	90485	70.78	1185.1	4.29F	0.98A	7.10	13.25	316
14.00	91904	70.92	1191.3	4.21F	1.14A	7.21	13.27	313
14.20	93324	71.06	1197.4	4.13F	1.29A	7.31	13.30	310
14.40	94747	71.19	1203.3	4.04F	1.44A	7.42	13.33	308
14.60	96173	71.32	1209.2	3.96F	1.58A	7.52	13.36	305
14.80	97600	71.45	1215.0	3.88F	1.72A	7.63	13.39	302
15.00	99030	71.57	1220.7	3.79F	1.84A	7.73	13.43	299

d = draft in metres	K = keel	Light W 14000 t
LOA 245 m	H = amidships	Load W 98000 t
LBP 236 m		DWT 84000 t
SW RD = 1.025	GT 42000 Tons	NT 28000 Tons