Tujuan Tatap Muka Matakuliah Rancang Bangun Kapal Perikanan

1. Mahasiswa Memahami Beberapa Definisi Dasar Geometry Perkapalan Dalam Rancang Bangun Kapal Perikanan.
2. Mahasiswa Memahami Beberapa Definisi Dasar Hydrostatic Curve dan Bonjean Curve
3. Mahasiswa Memahami Teori Stabilitas Kapal Perikanan
4. Mahasiswa Memahami tentang Sheel Expantion.

What is your mind about this movie1, movie2, movie3 and movie4

Basic Ship Theory

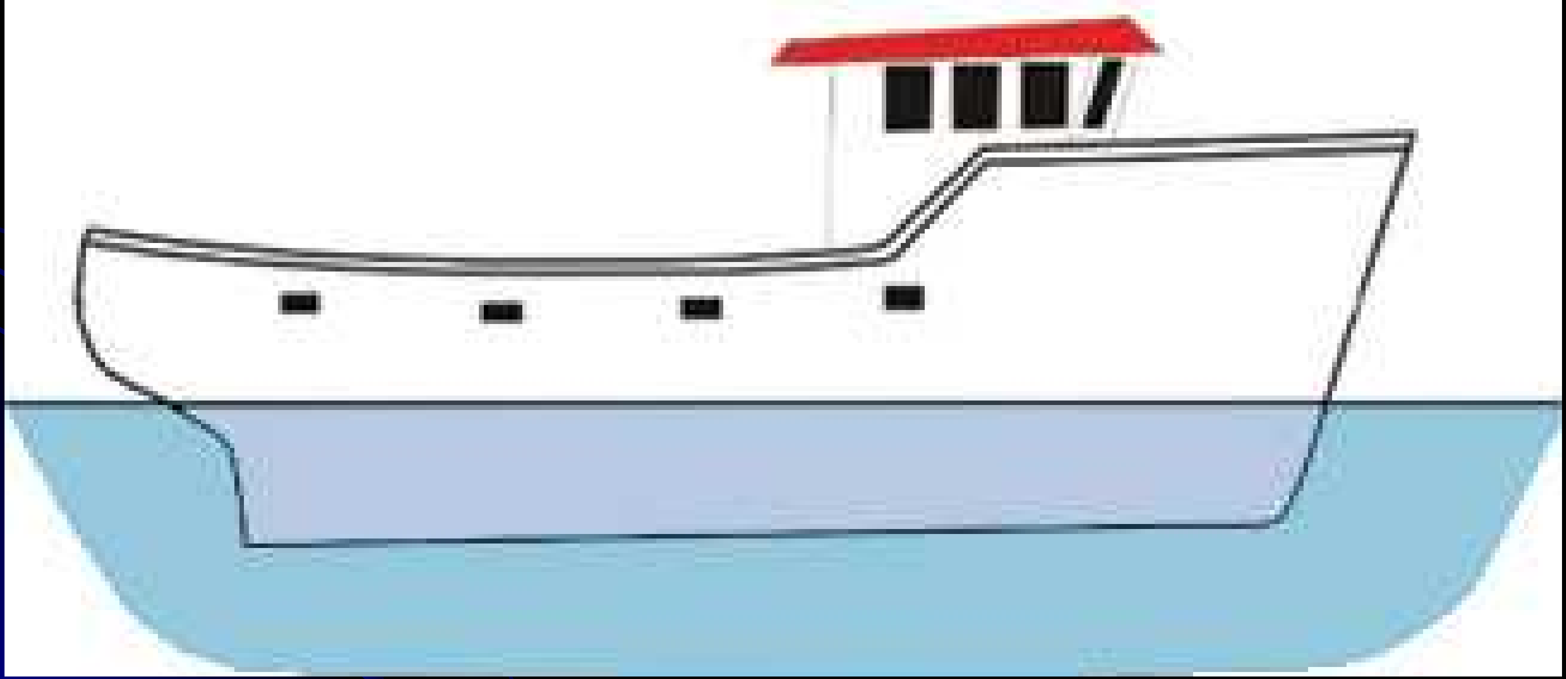
Definitions

DISPLACEMENT

Archimedes principle: Every floating body displaces its own weight of the liquid in which it floats

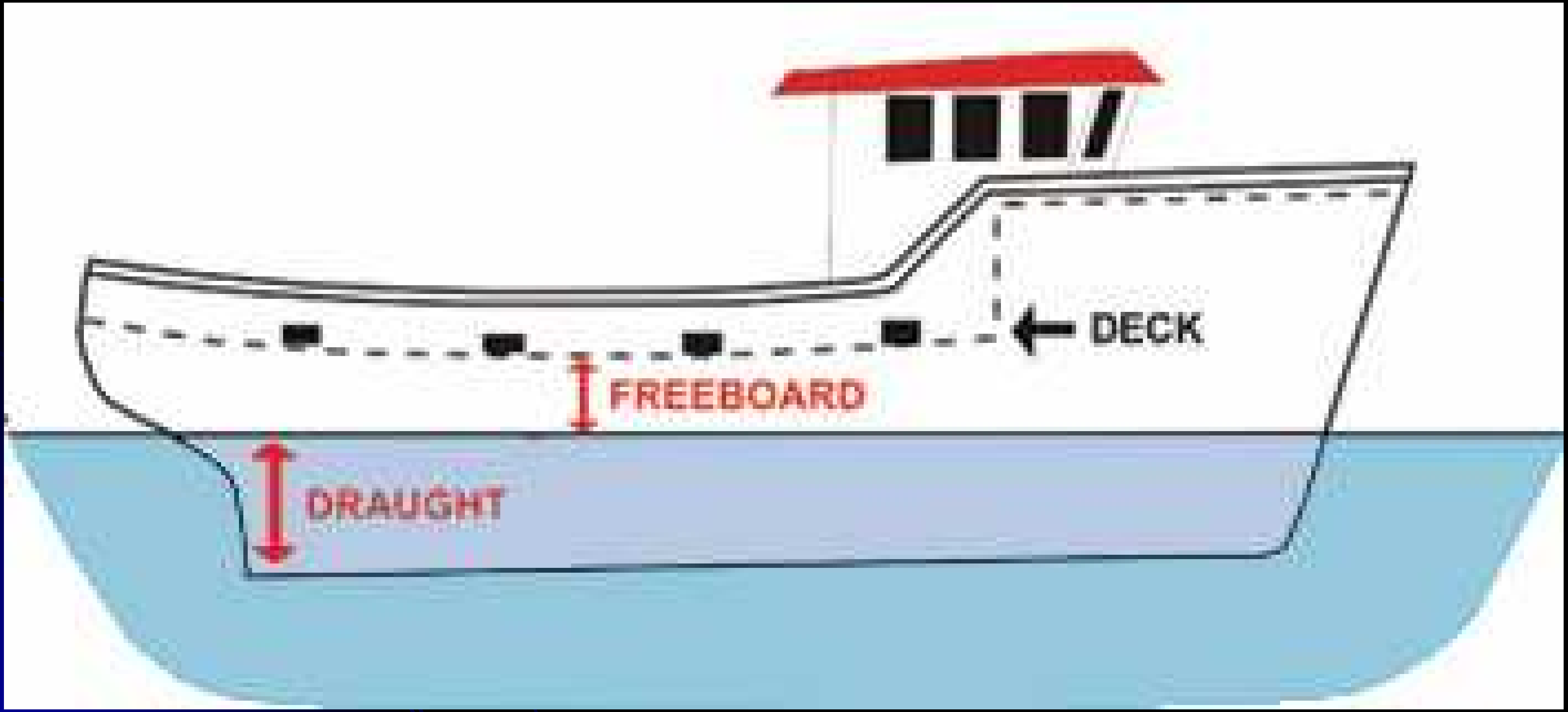
For a vessel to float freely in water, the weight of the vessel must be equal to the weight of the volume of water it displaces

Displacement is the volume of water the vessel displaces



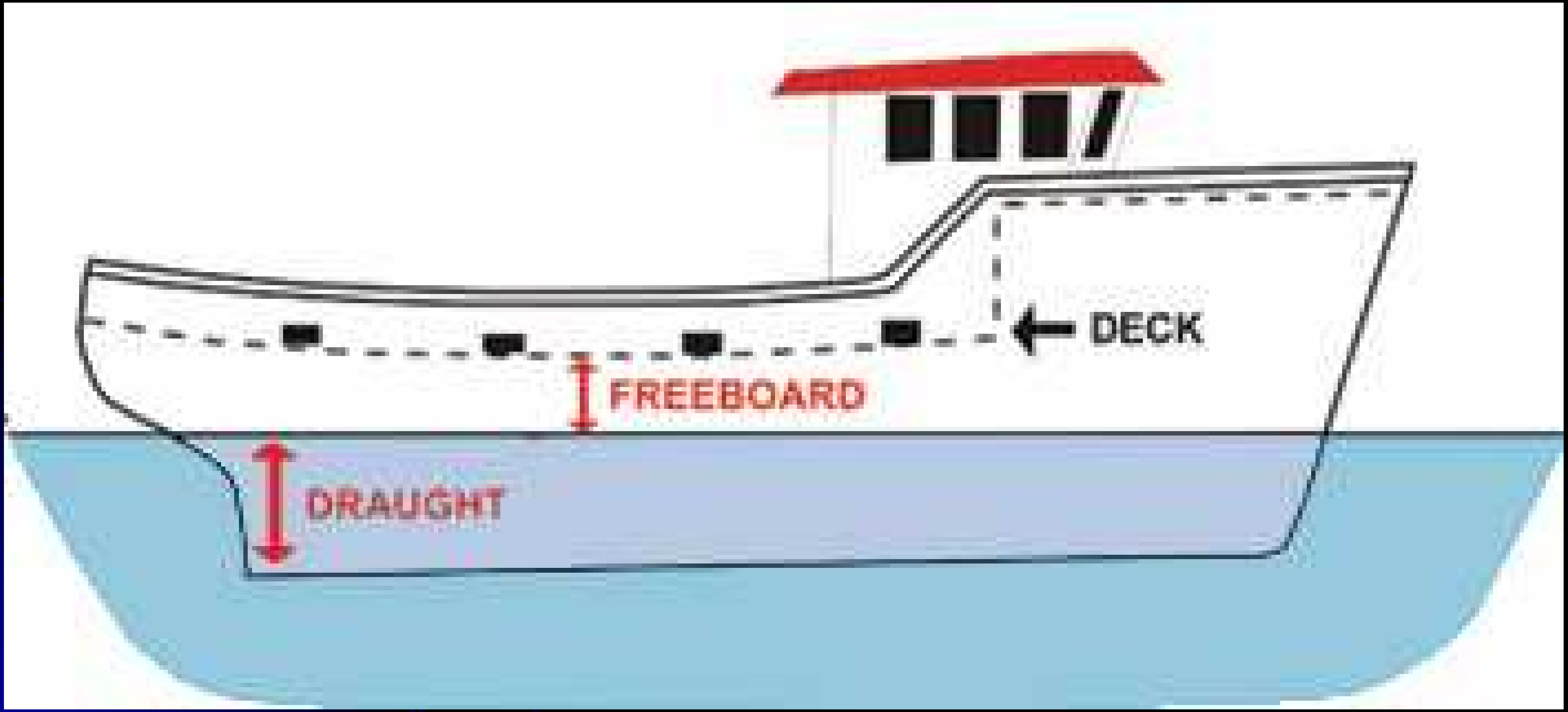
DRAUGHT

Draught relates to the depth of water required for a vessel to float freely and is measured vertically from the underneath side of the keel to the waterline



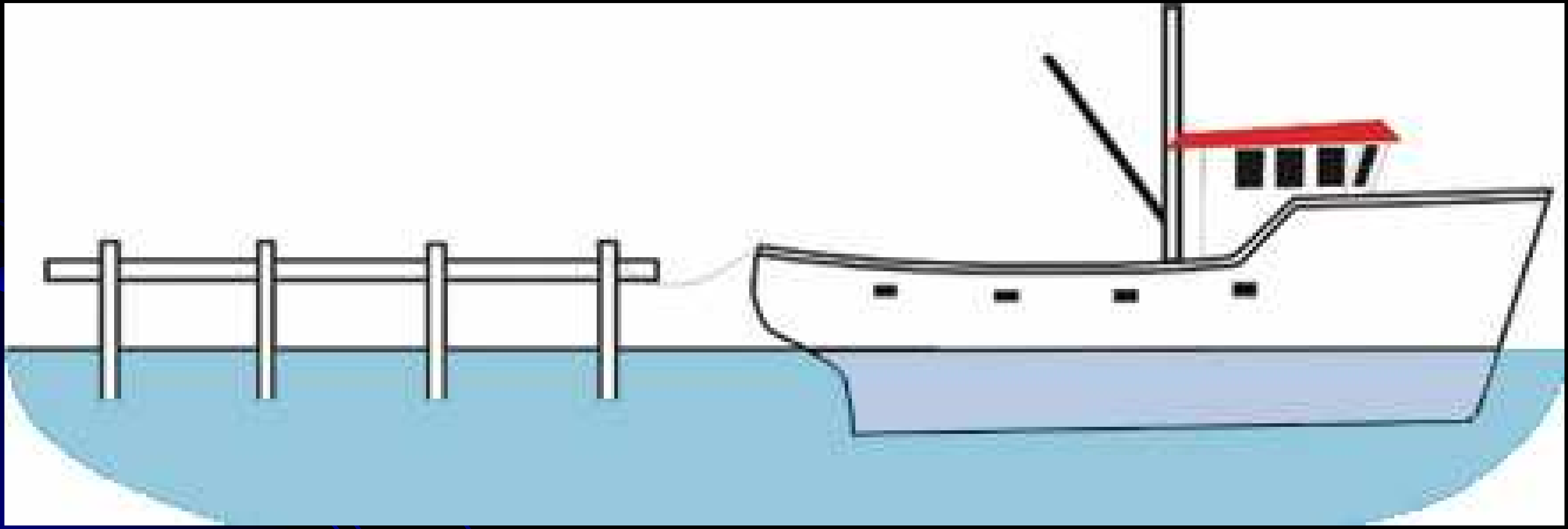
FREEBOARD

Freeboard is the vertical distance from the top of the lowest point of the working deck at the side of the vessel to the waterline



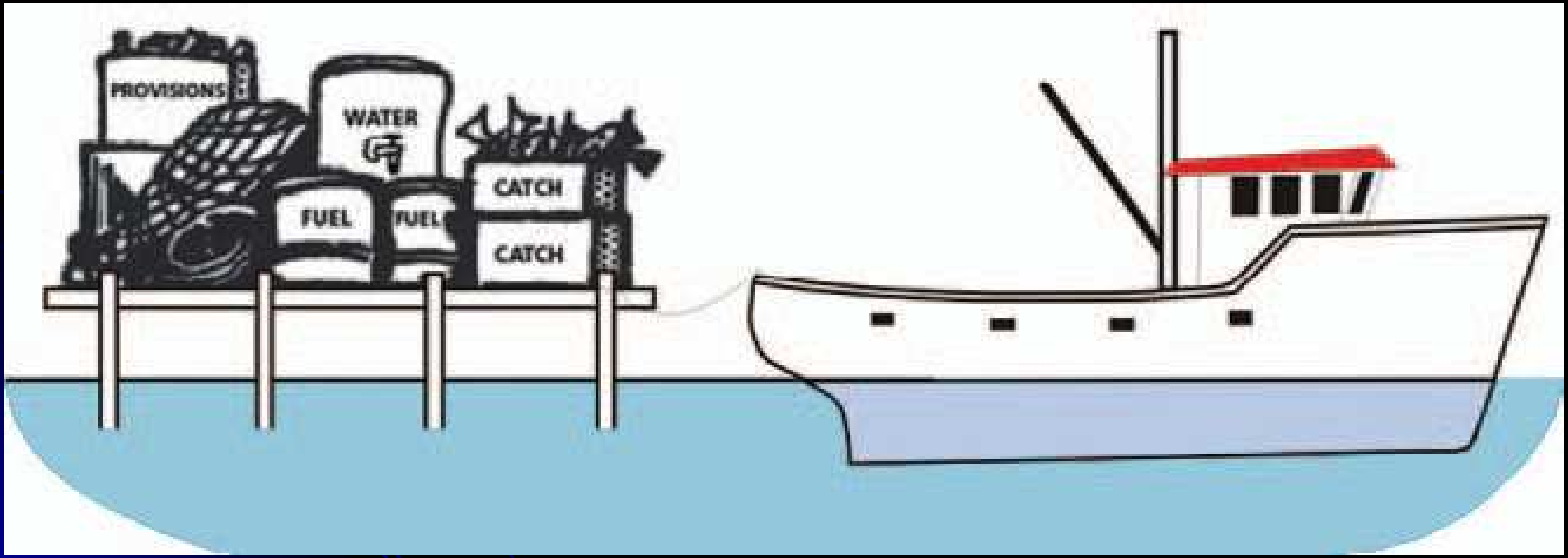
LIGHT SHIP WEIGHT

The light ship weight is the actual weight of a vessel when complete and ready for service but empty



DEADWEIGHT

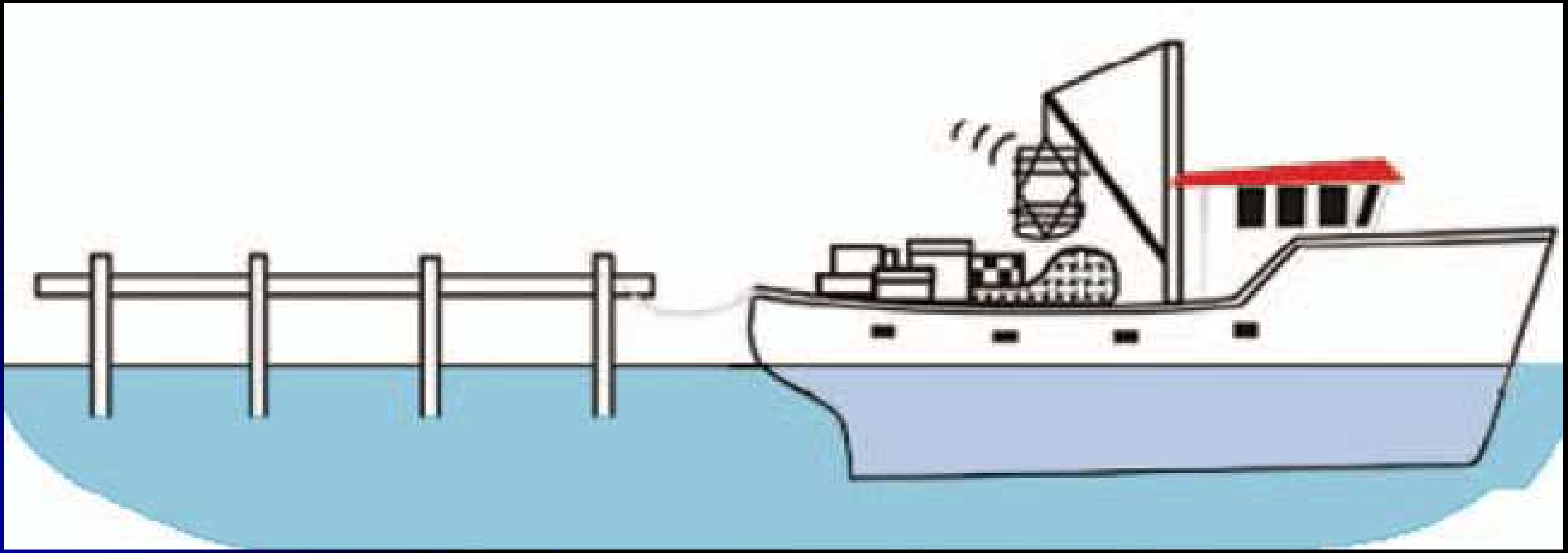
Deadweight is the actual amount of weight in tonnes that a vessel can carry when loaded to the maximum permissible draught (includes fuel, fresh water, gear supplies, catch and crew)



DISPLACEMENT MASS

Displacement mass is the total weight of the vessel, i.e.:

Lightship weight + deadweight = displacement mass

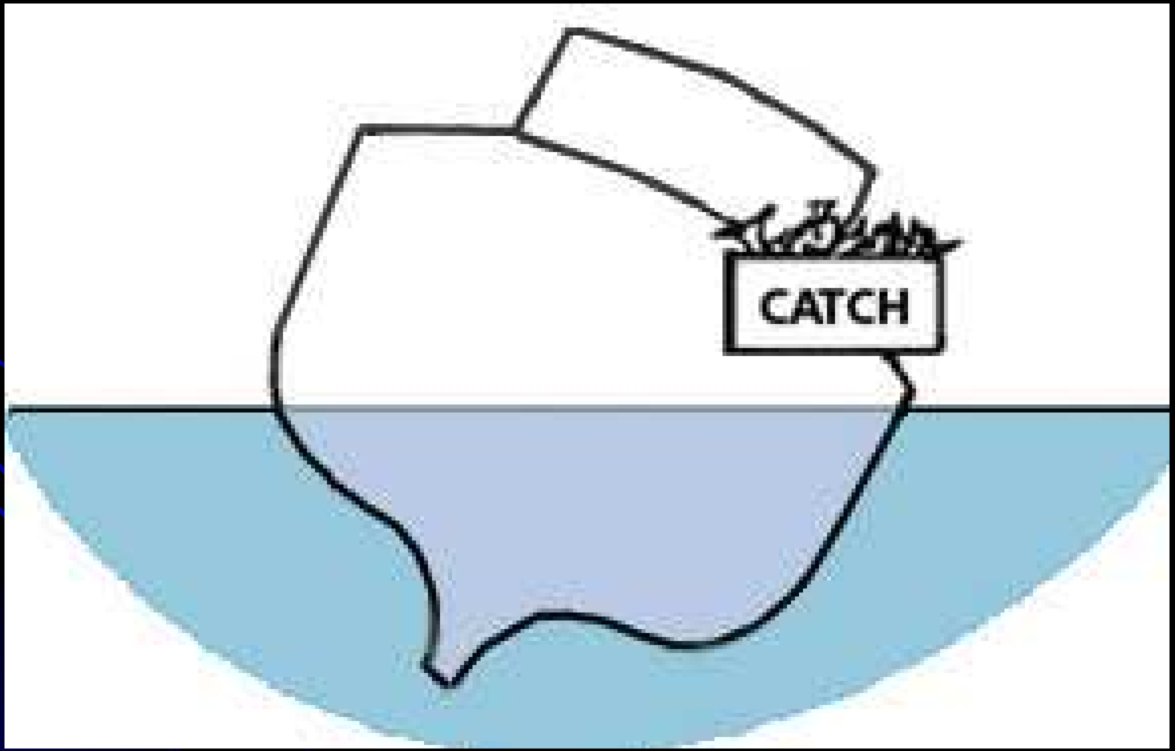


LIST

A vessel is said to be listed when it is inclined by forces within the vessel, e.g. movement of weight within the vessel

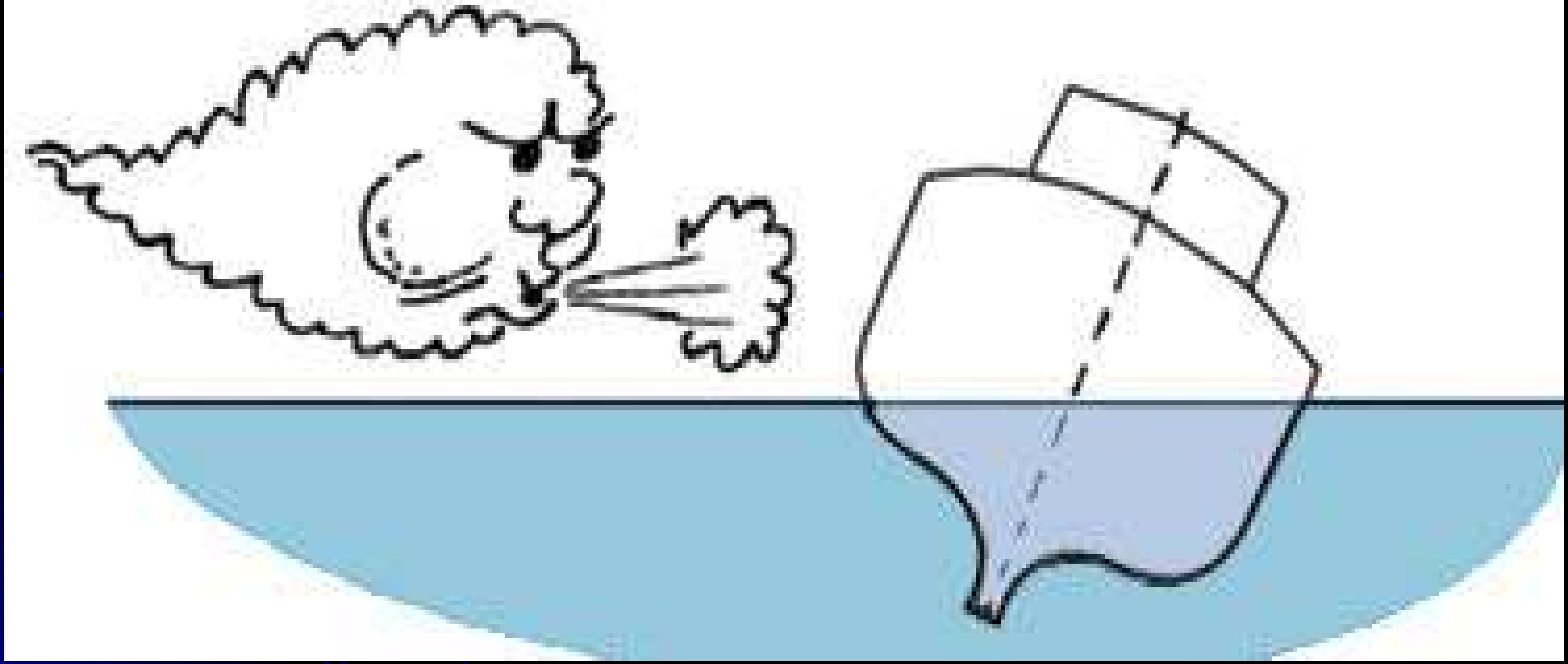
A list reduces the stability of the vessel

When a list is corrected by increasing the displacement mass,
the additional weight should be placed as low as possible in the vessel



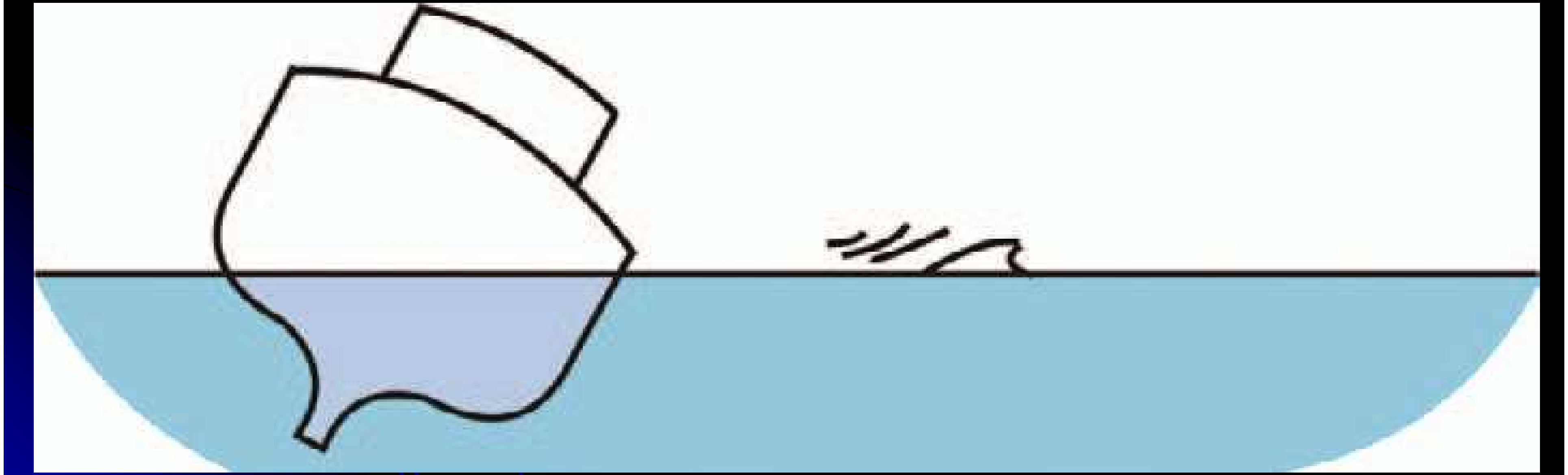
HEEL

A vessel is said to be heeled when it is inclined by an external force, e.g. from waves or the wind



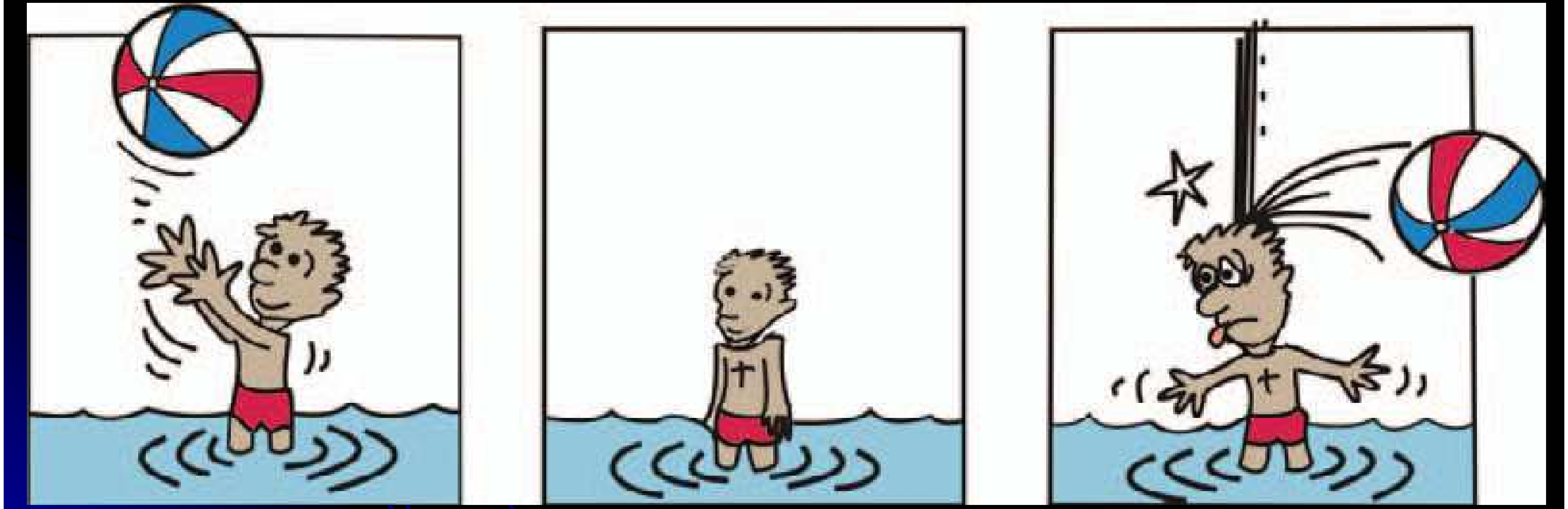
LOLL

The term “loll” describes the state of a vessel which is unstable when upright and which floats at an angle from the upright to one side or the other. If an external force, e.g. a wave or wind, changes this state, the vessel will float at the same angle to the other side. Loll is quite different from list or heel as it is caused by different circumstances and requires different counter-measures to correct. It is, therefore, most important that fishermen are able to distinguish between these terms



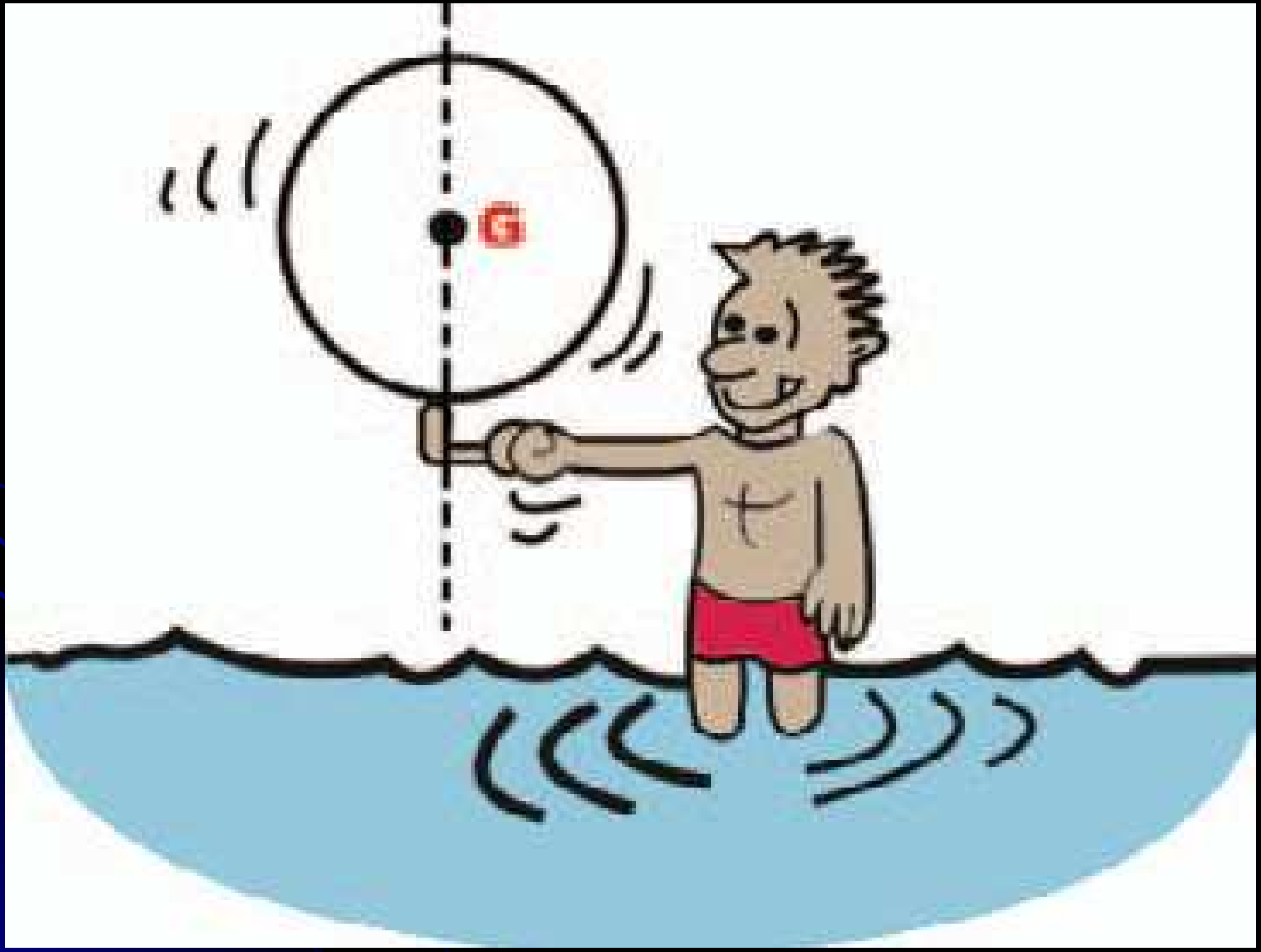
GRAVITY

“What goes up must come down”.
Throw a ball in the air. It soon comes back down in response to the earth’s gravitational pull



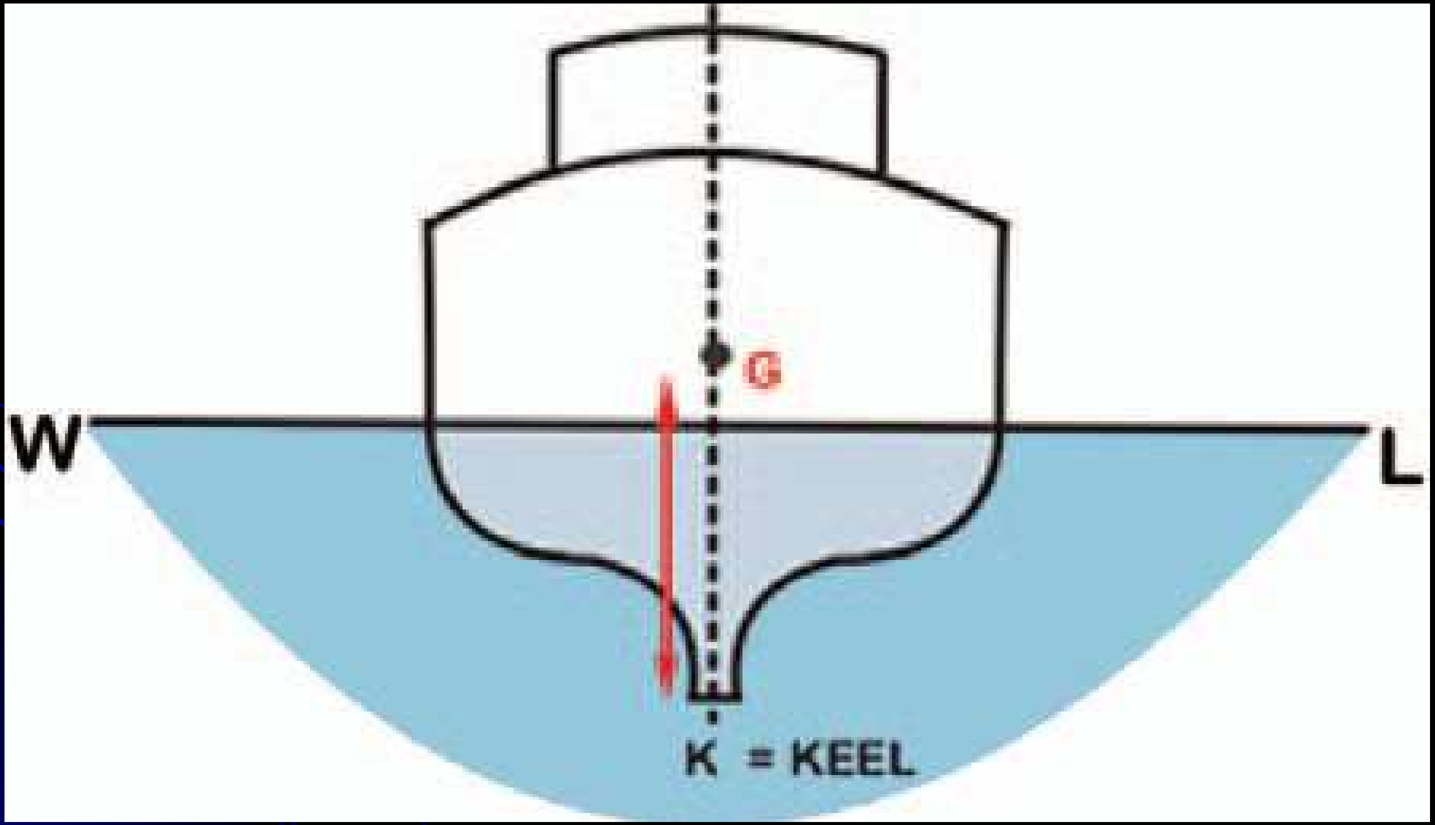
CENTRE OF GRAVITY

Centre of gravity is the point (**G**) at which the whole weight of a body can be said to act vertically downwards



CENTRE OF GRAVITY

The centre of gravity depends upon weight distribution within the vessel and its position may be found by carrying out an inclining test or by calculation. The position of the centre of gravity (**G**) is measured vertically from a reference point, usually the keel of the vessel (**K**). This distance is called **KG**



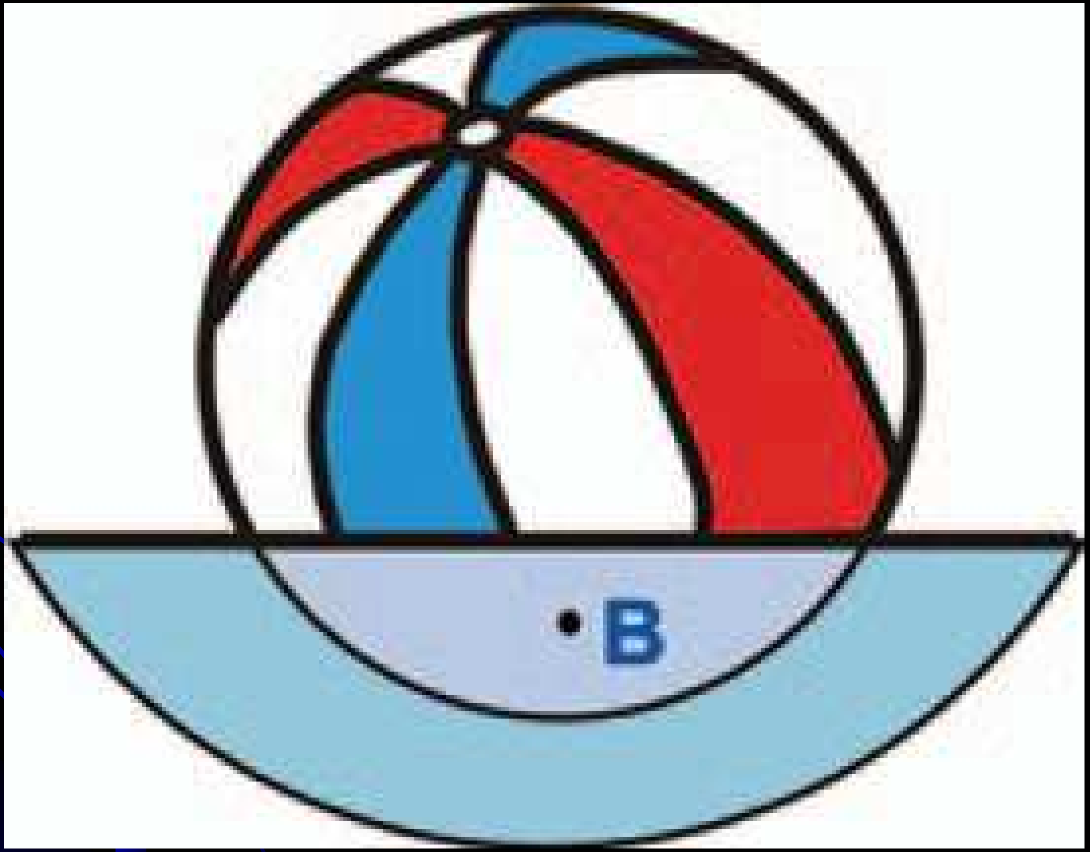
BUOYANCY

If a ball is pushed underwater it will soon bob up again. This force is called buoyancy.

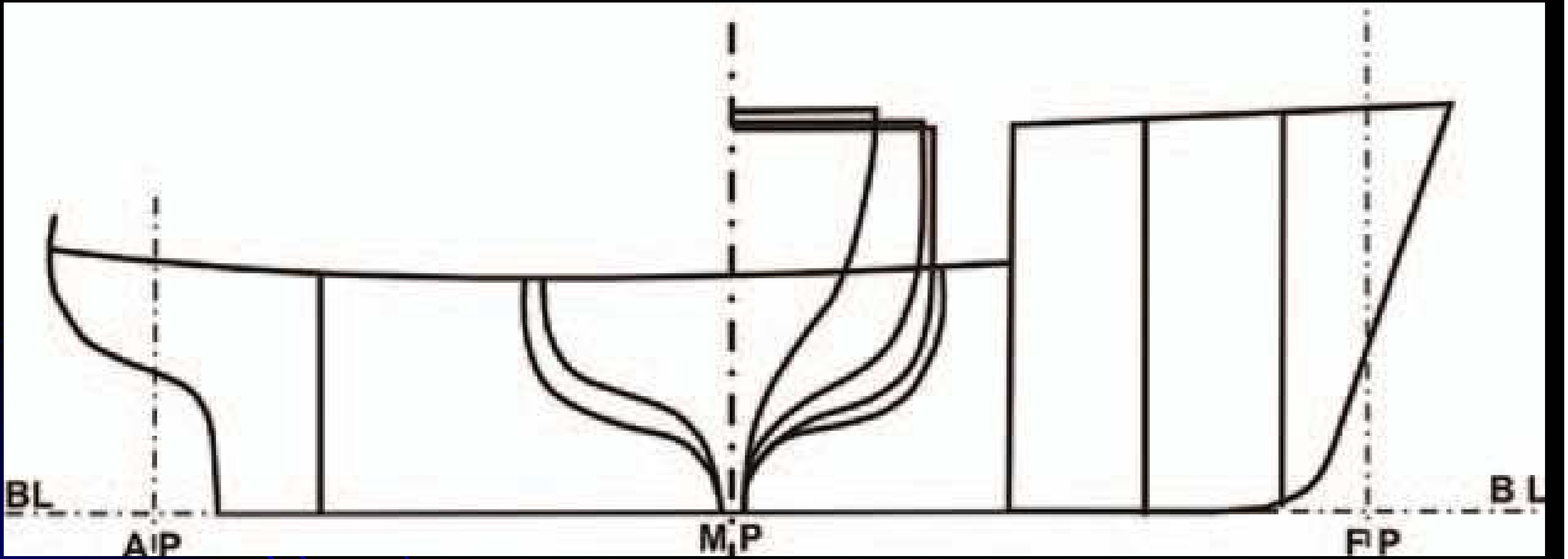
When a vessel floats freely, its buoyancy is equal to its displacement mass

CENTRE OF BUOYANCY

The centre of buoyancy (**B**) is the point through which the force of buoyancy is considered to act vertically upwards. It is located at the geometric centre of the underwater section of the vessel

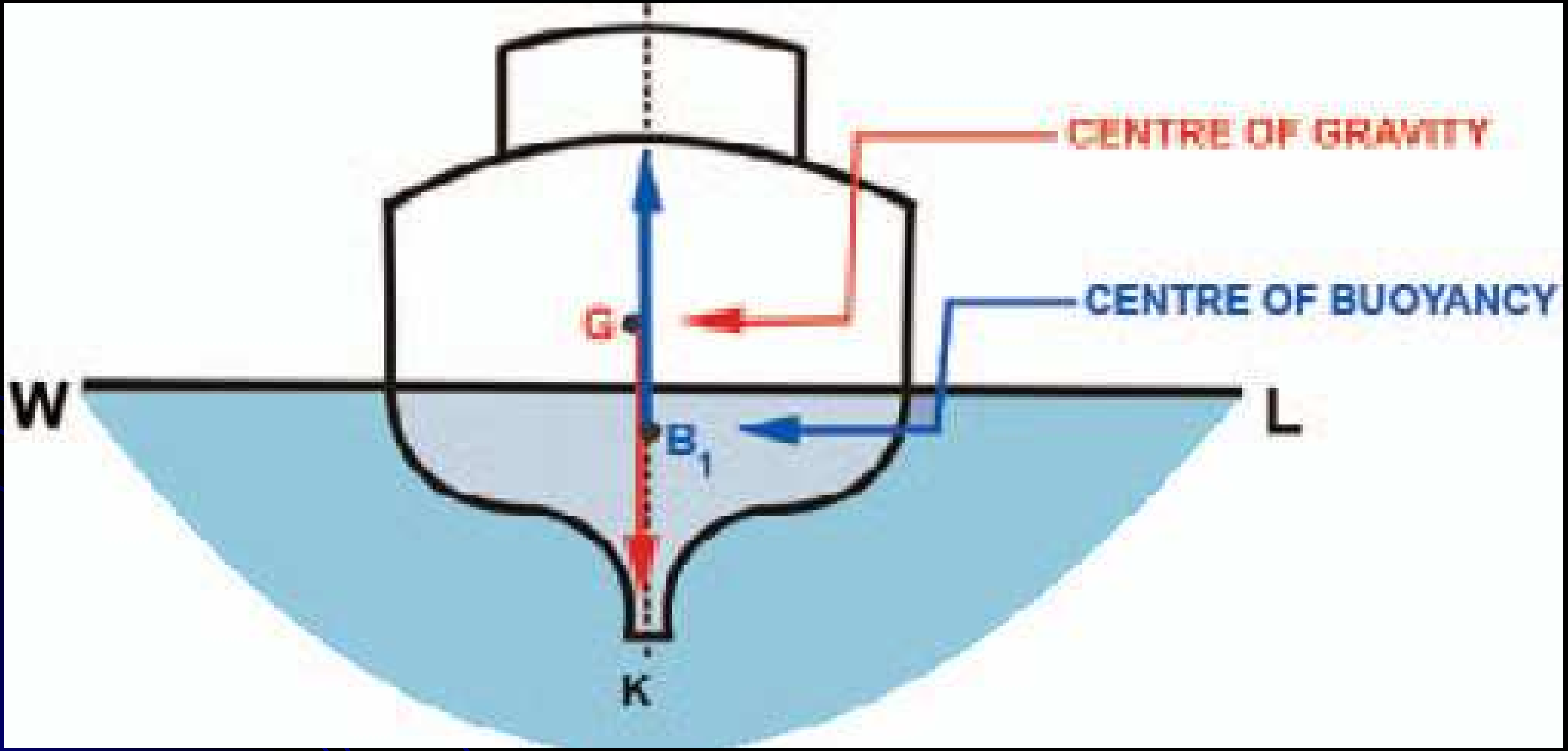


When the shape of the hull of a vessel is known, the designer, often a naval architect, can calculate the centre of buoyancy (**B**) for the various combinations of displacement, trim and heel



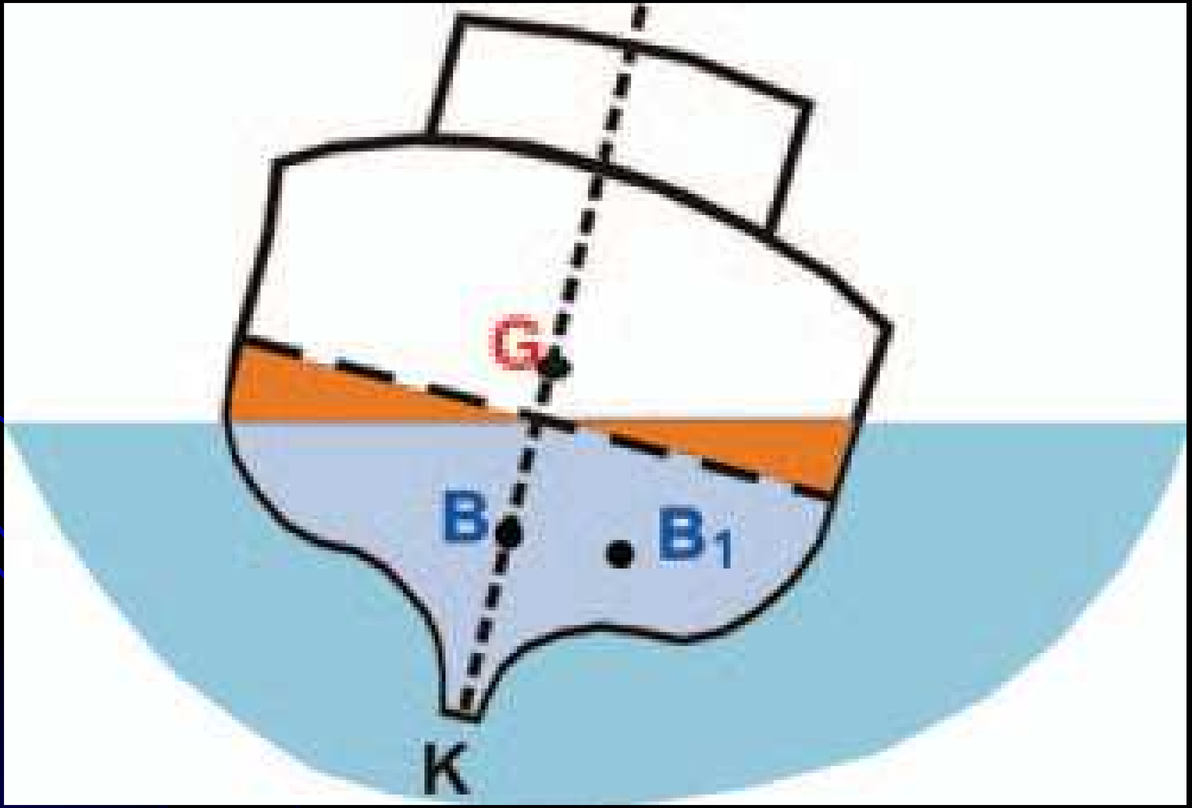
TRANSVERSE STABILITY

When a vessel is floating upright (at equilibrium) in still water, the centre of buoyancy (upthrust) and the centre of gravity (downthrust) will be on the same line, vertically above the keel (**K**)



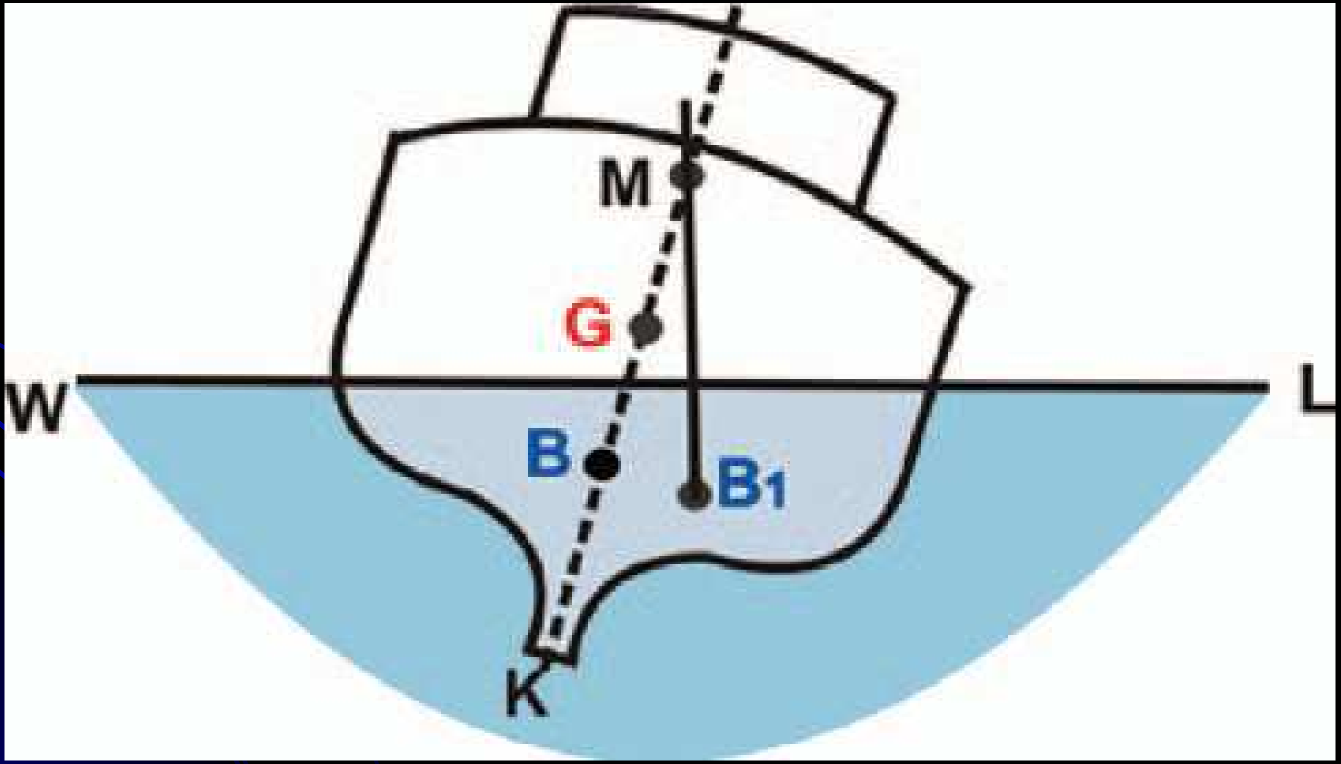
TRANSVERSE STABILITY

If the vessel is inclined by an external force (i.e. without moving internal weight) a wedge of buoyancy is brought out of the water on one side and a similar wedge of buoyancy is immersed on the other side. The centre of buoyancy being the centre of the underwater section of the vessel has now moved from point **B** to **B1**

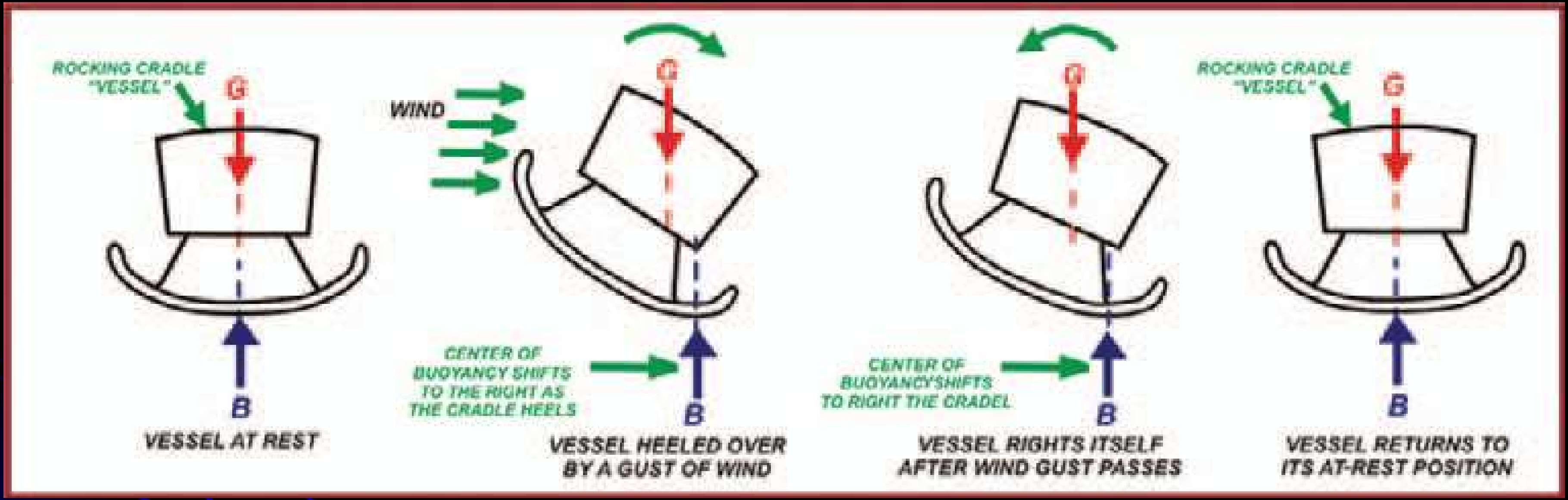


METACENTRE

Vertical lines drawn from the centre of buoyancy at consecutive small angles of heel will intersect at a point called the metacentre (**M**). The metacentre can be considered as being similar to a pivot point when a vessel is inclined at small angles of heel. The height of the metacentre is measured from the reference point (**K**) and is, therefore, called **KM**

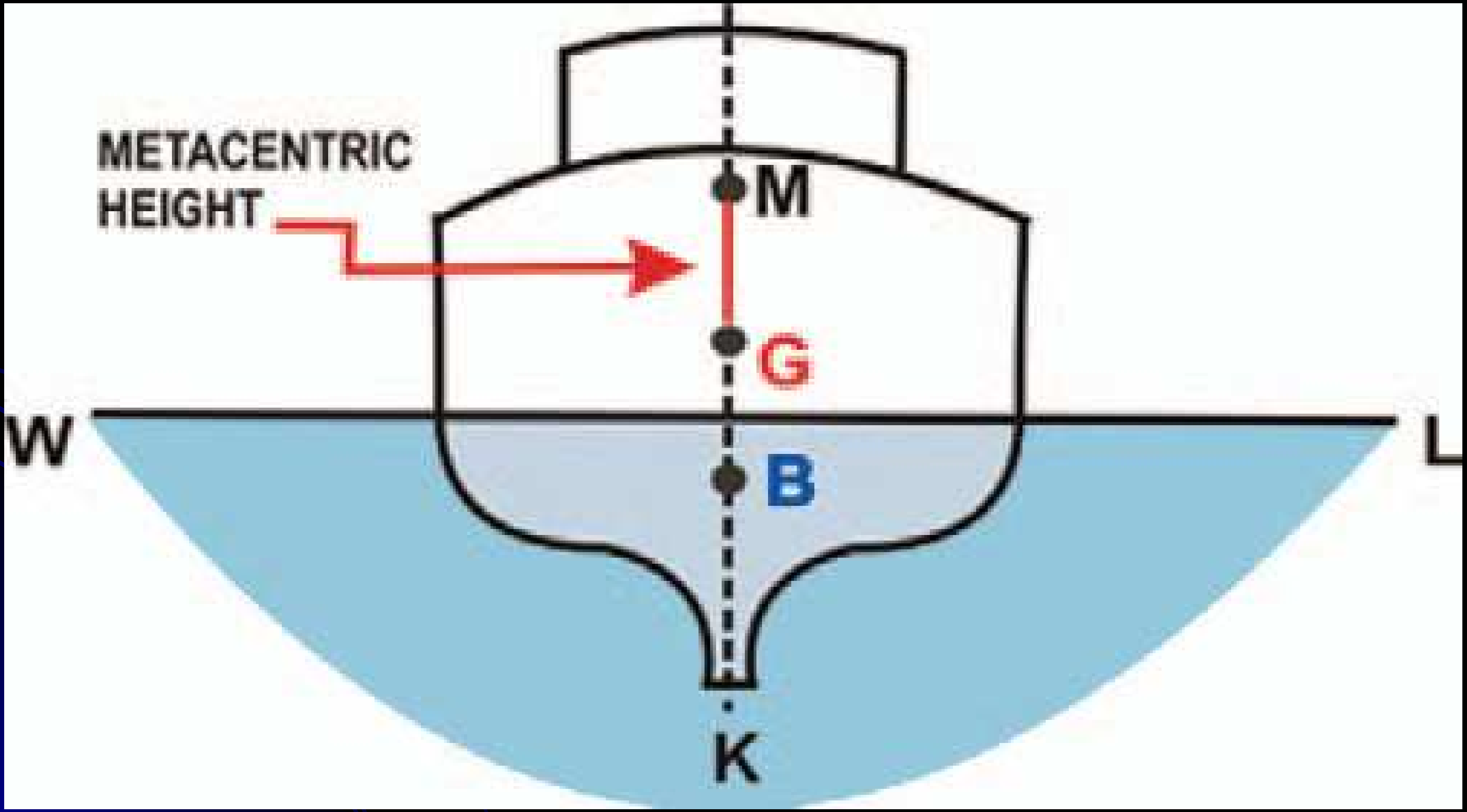


WHY A FISHING VESSEL REMAINS UPRIGHT



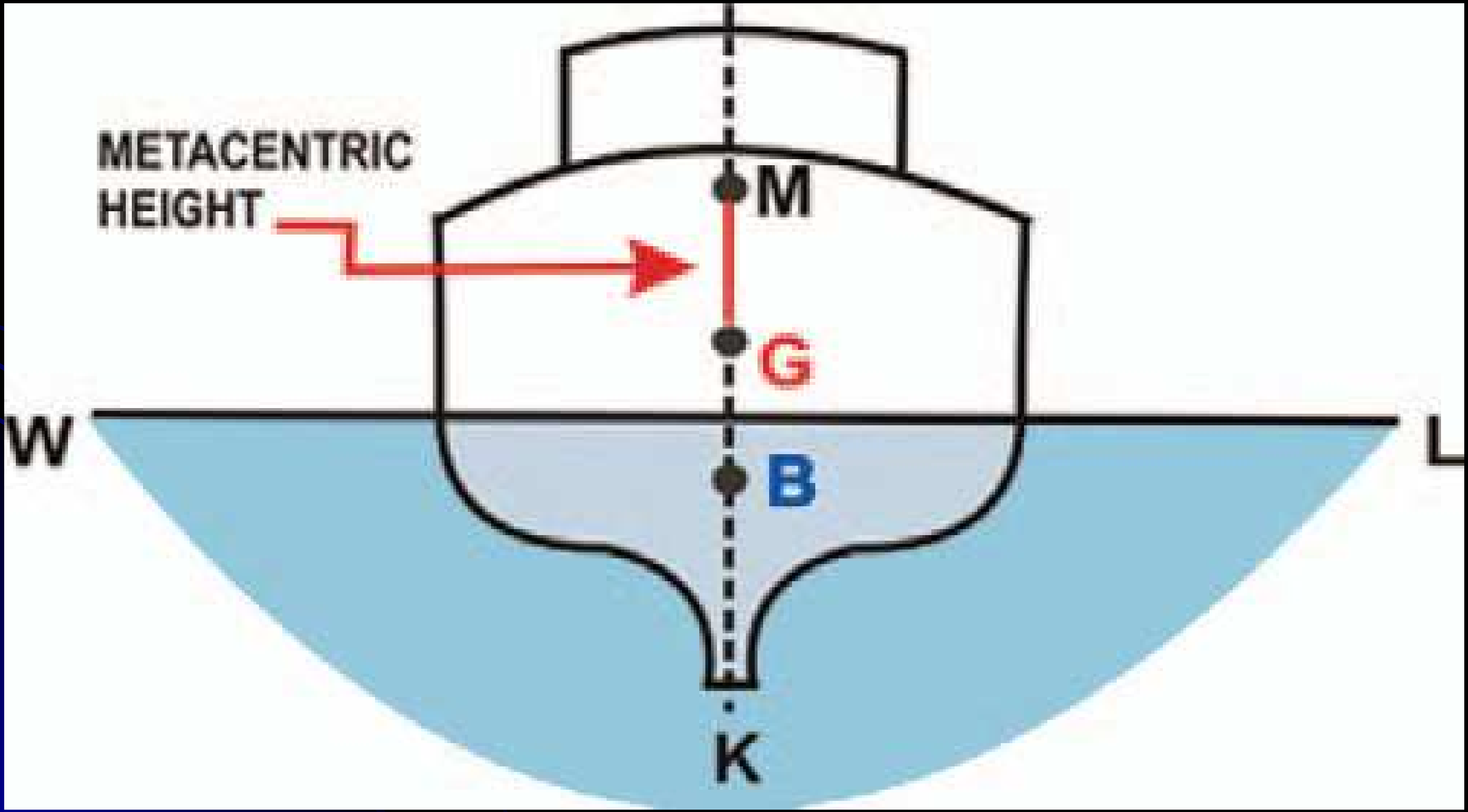
EQUILIBRIUM

A vessel is said to be in stable equilibrium if, when inclined, it tends to return to the upright. For this to occur the centre of gravity (**G**) must be below the metacentre (**M**)



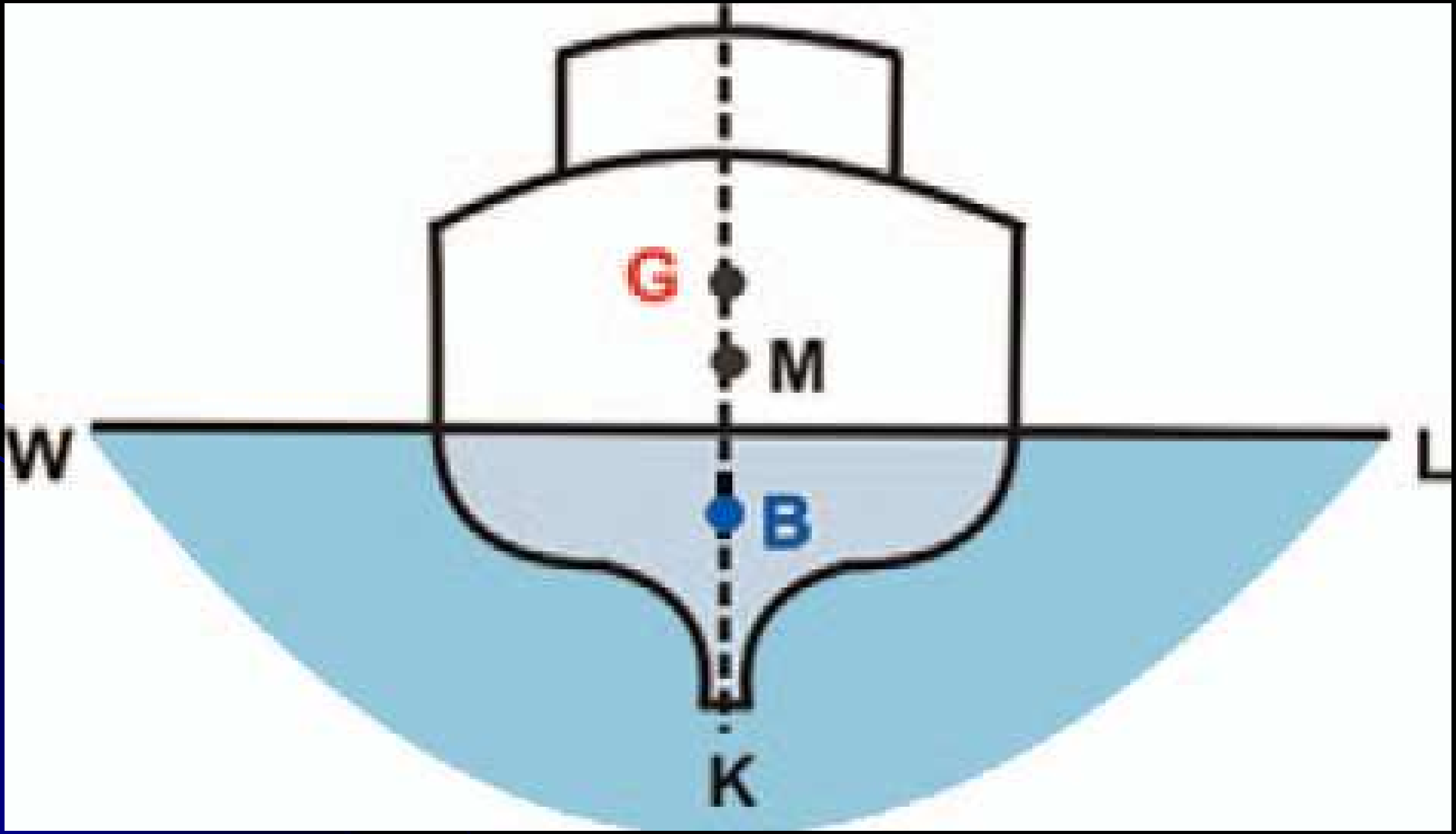
METACENTRIC HEIGHT

The distance between **G** and **M** is known as the metacentric height (**GM**). A stable vessel when upright is said to have a positive metacentric height (**GM**), i.e. when the metacentre (**M**) is found to be above the centre of gravity (**G**). This is usually referred to as having a positive **GM** or a positive initial stability



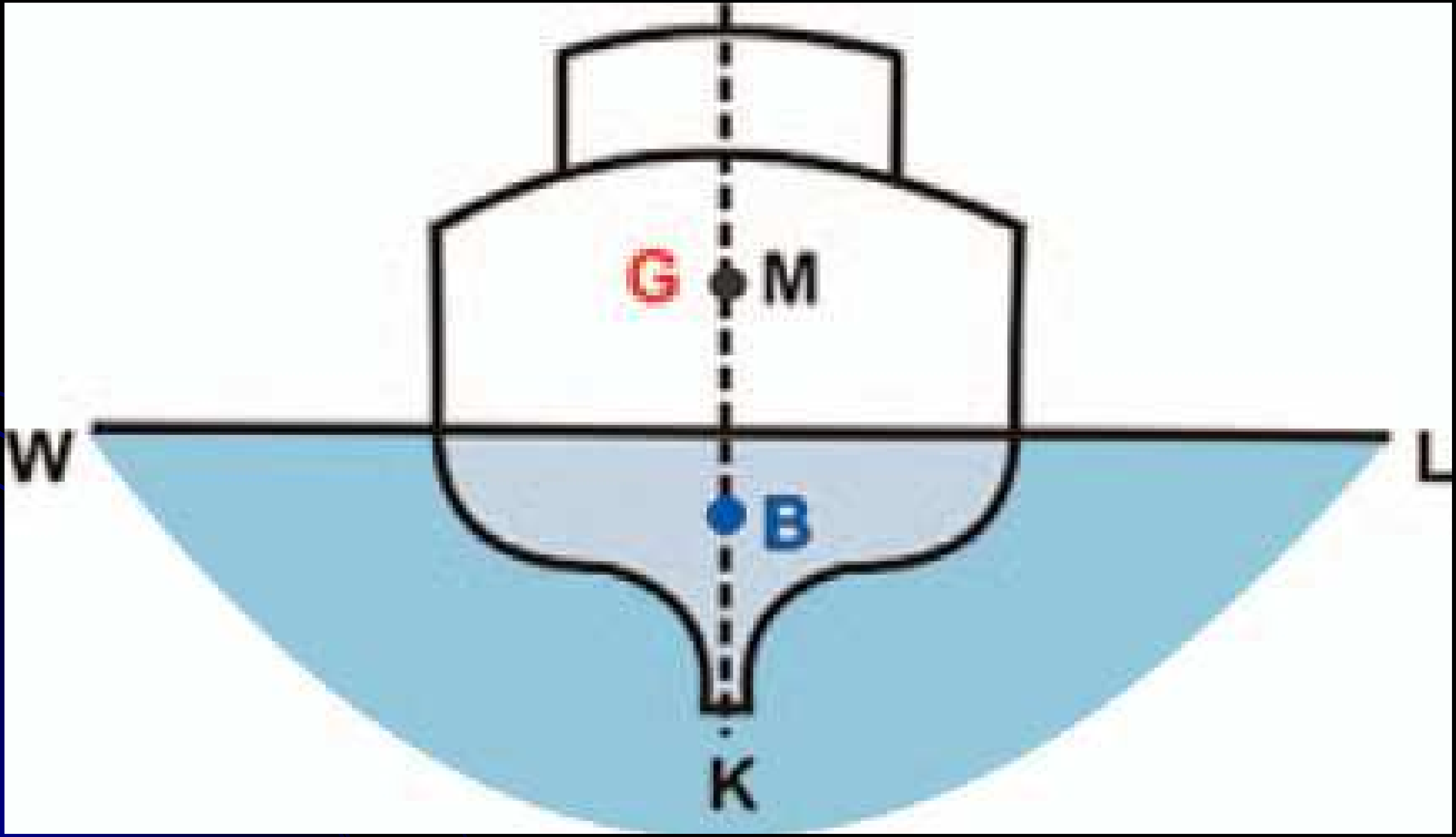
UNSTABLE EQUILIBRIUM

If the centre of gravity (**G**) of a vessel is above the metacentre (**M**) the vessel is said to have a negative **GM** or a negative initial stability. A vessel in this state has a loll, i.e. it floats at an angle from the upright to one side or the other and there is a danger that it may capsize



NEUTRAL EQUILIBRIUM

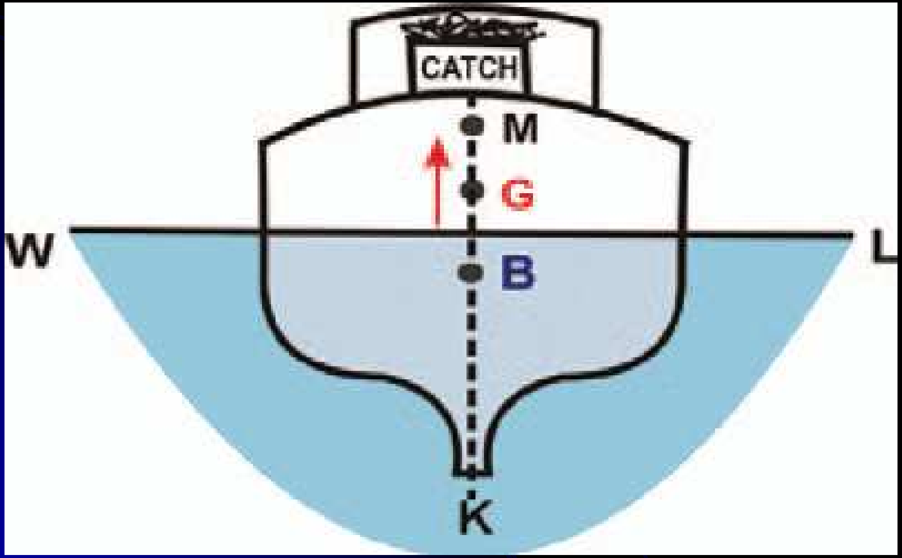
When the position of a vessel’s centre of gravity (**G**) and the metacentre (**M**) coincide the vessel is said to be in neutral equilibrium (**Zero GM**) and if inclined to a small angle of heel it will tend to remain at that angle

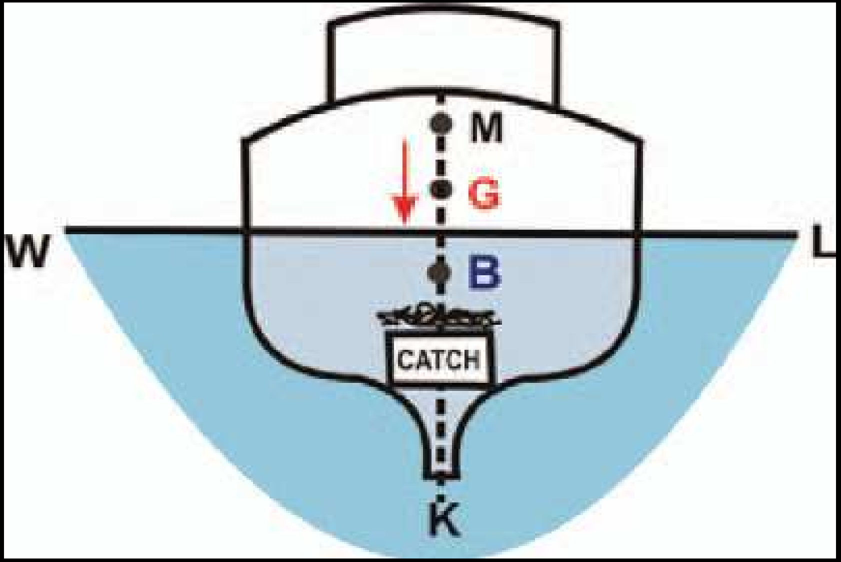


STIFF AND TENDER VESSELS

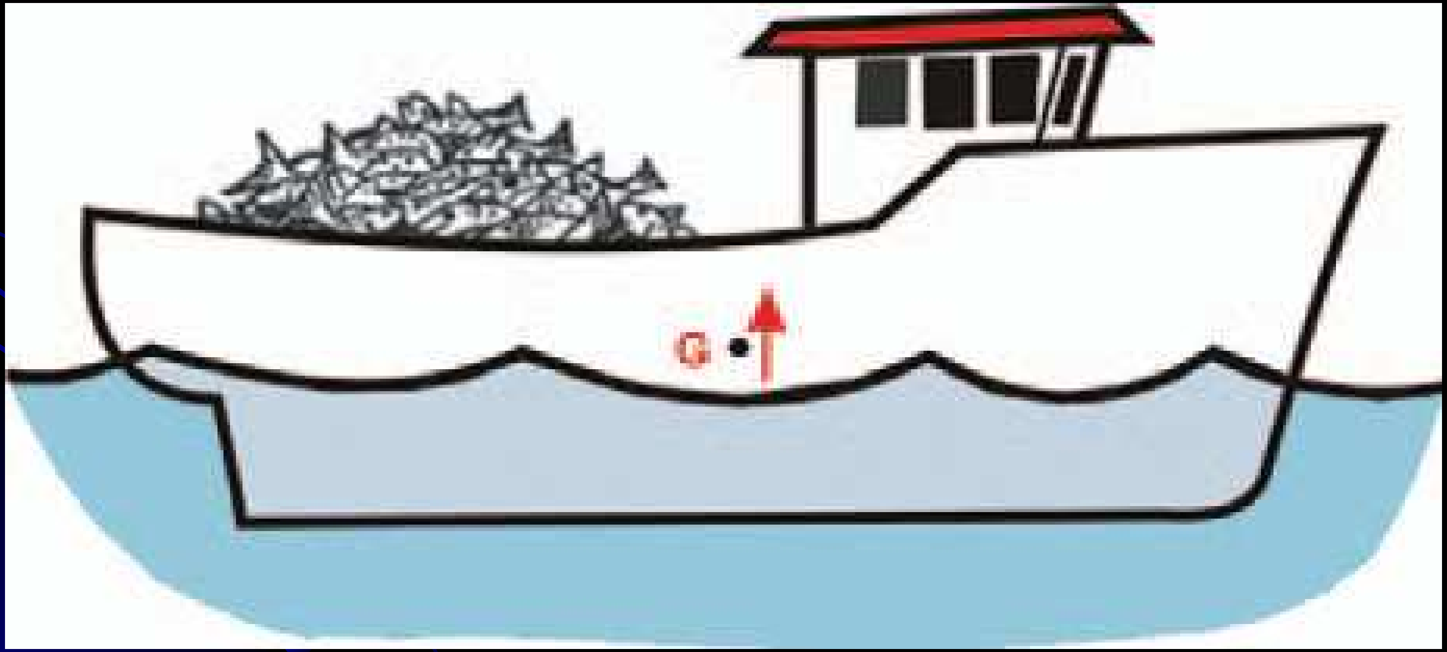
When weight is added to a vessel, the centre of gravity (**G**) of the vessel always moves in the direction of the added weight. Weight added at deck level results in the vessel’s centre of gravity (**G**) rising, causing a decrease in the vessel’s metacentric height (**GM**) and thereby its stability. A vessel with little or no metacentric height is said to be **tender**

Weight added low down in the vessel lowers the vessel’s centre of gravity (**G**) and consequently causes an increase in the vessel’s metacentric height (**GM**). A vessel with a large metacentric height is said to be a **stiff** vessel





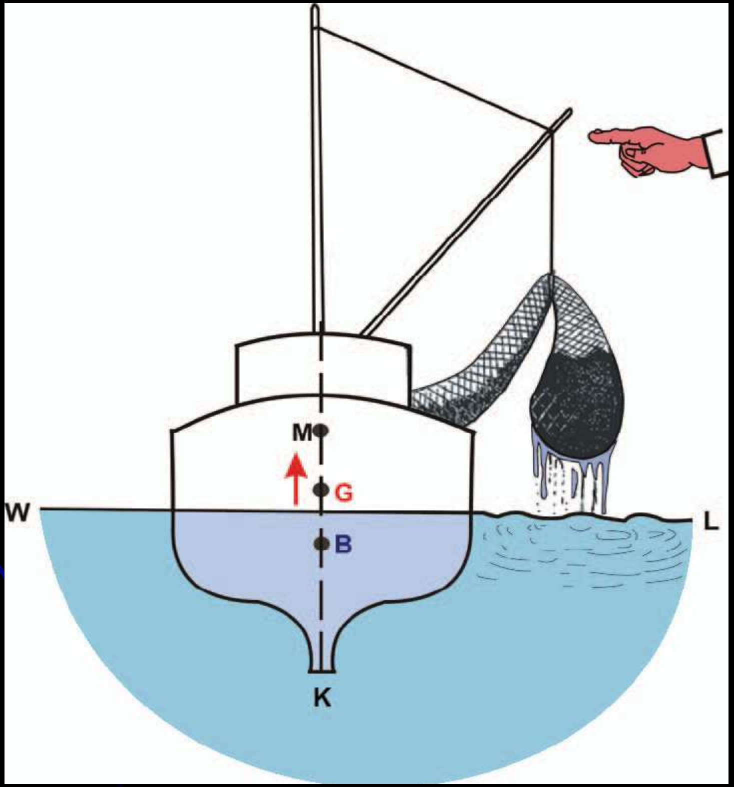
Heavy weights should always be positioned as low as possible and catch should generally not be carried on deck as the vessel's centre of gravity (**G**) will rise and the metacentric height (**GM**) will decrease which will increase the likelihood of a capsize of the vessel. A stiff vessel tends to be comparatively difficult to heel and will roll from side to side very quickly and perhaps violently. A tender vessel will be much easier to incline and will not tend to return quickly to the upright. The time period taken to roll from side to side will be comparatively long. This condition is not desirable and can be corrected by lowering the vessel's centre of gravity (**G**)



SUSPENDED WEIGHT

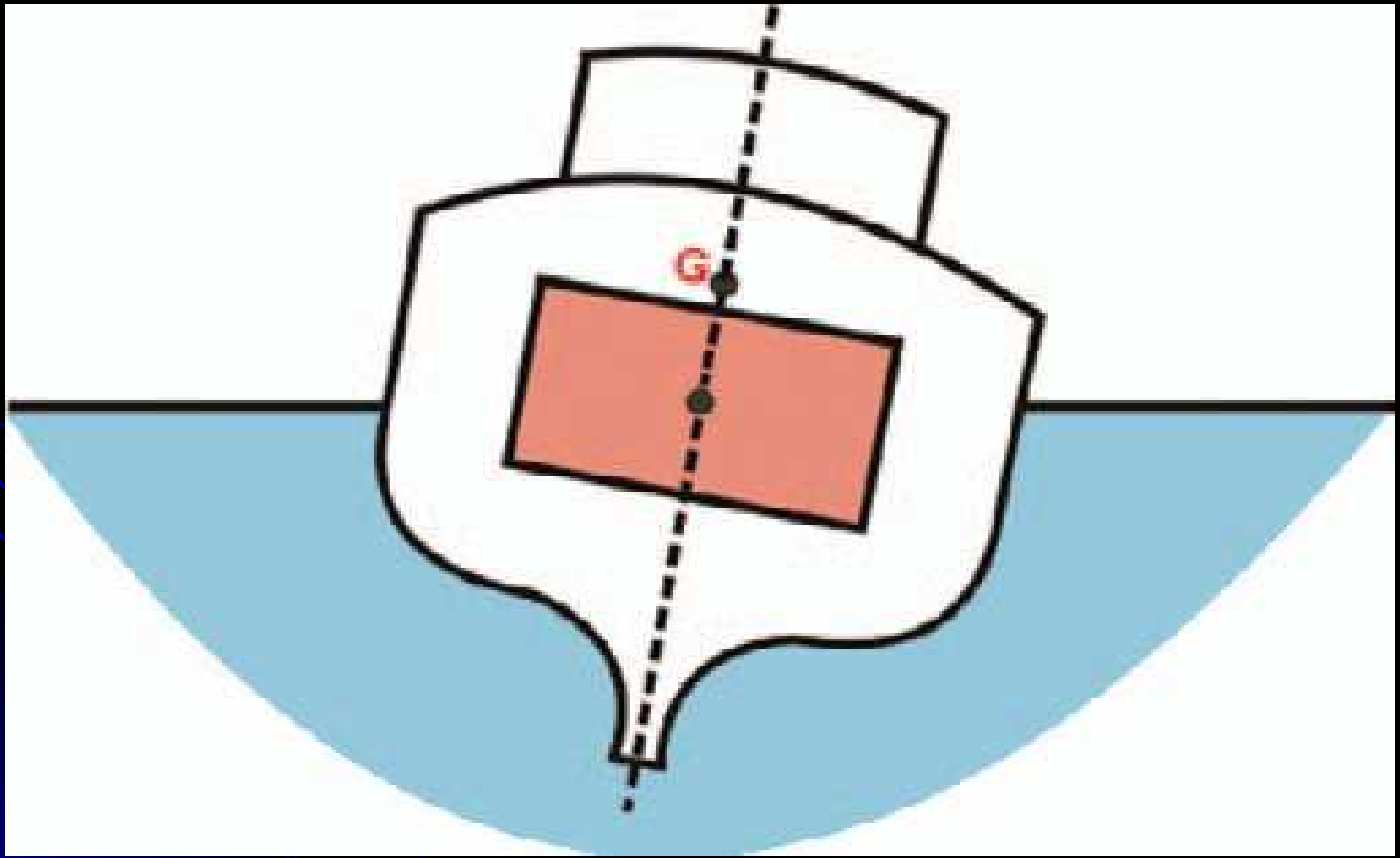
The centre of gravity of a suspended weight can be considered to be acting at the point of suspension. Therefore, a net lifted clear of the water has the same effect on the vessel’s centre of gravity **(G)** as if the net were actually at the head of the boom

If not at the centreline, this weight will also exert a heeling force upon the vessel and may, under unfavourable circumstances, capsize the vessel

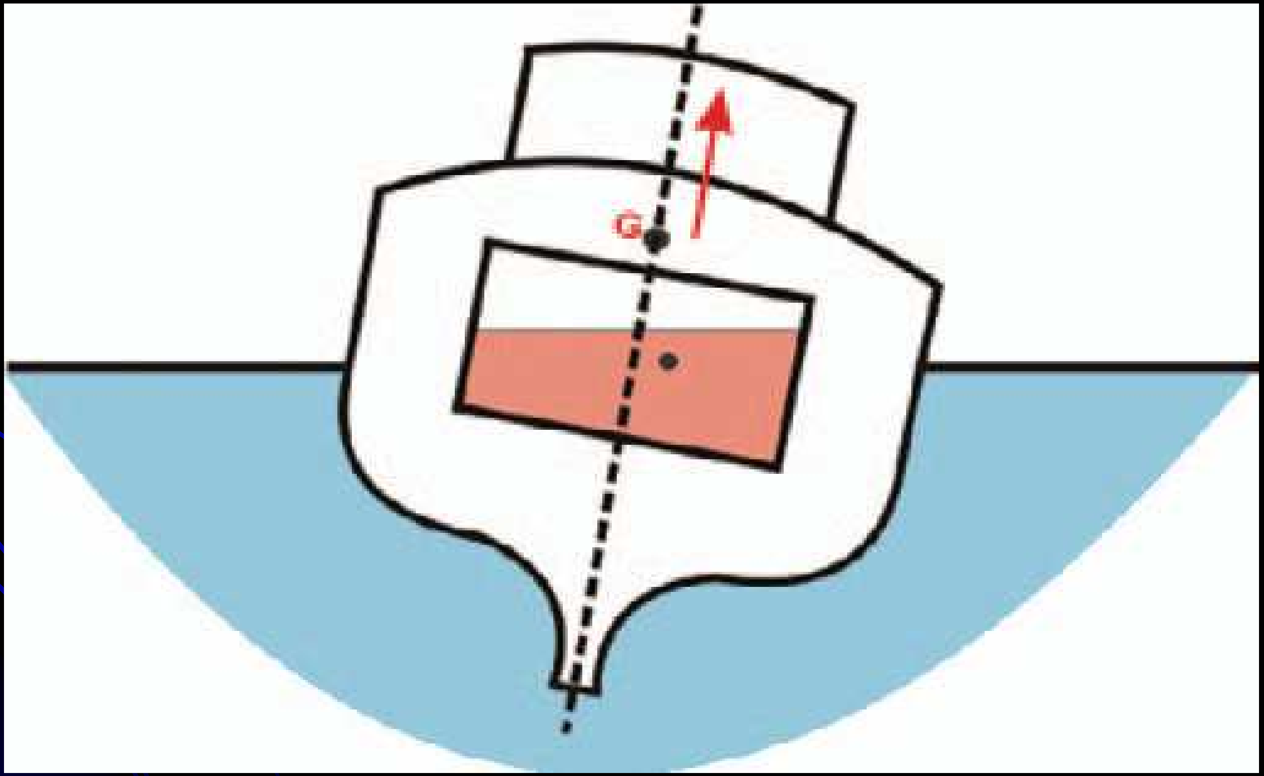


FREE SURFACE EFFECT

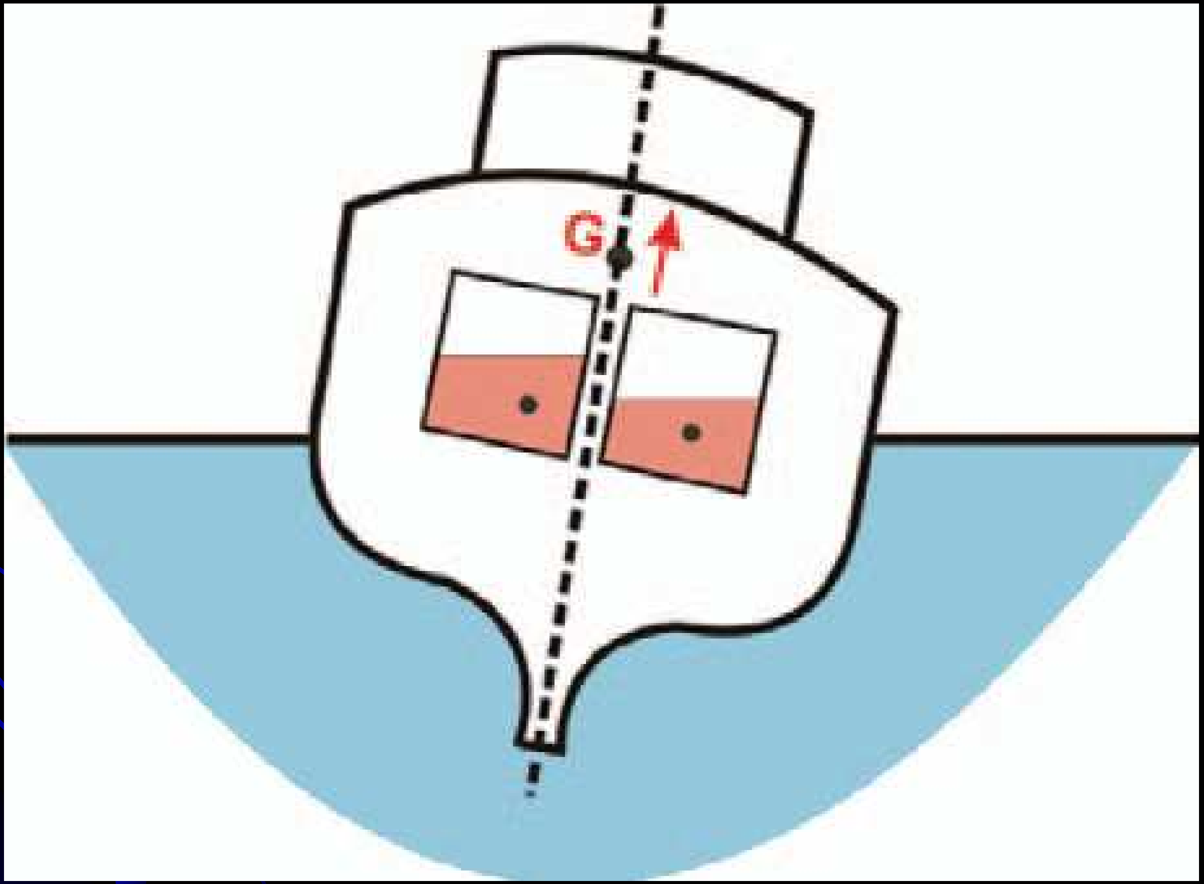
When a vessel with a full tank is heeled, the liquid within the tank acts like a solid mass. Its centre of gravity, being the centre of its volume, remains constant and therefore does not cause any change in the vessel's centre of gravity (**G**) or its metacentric height (**GM**) as the vessel is heeled



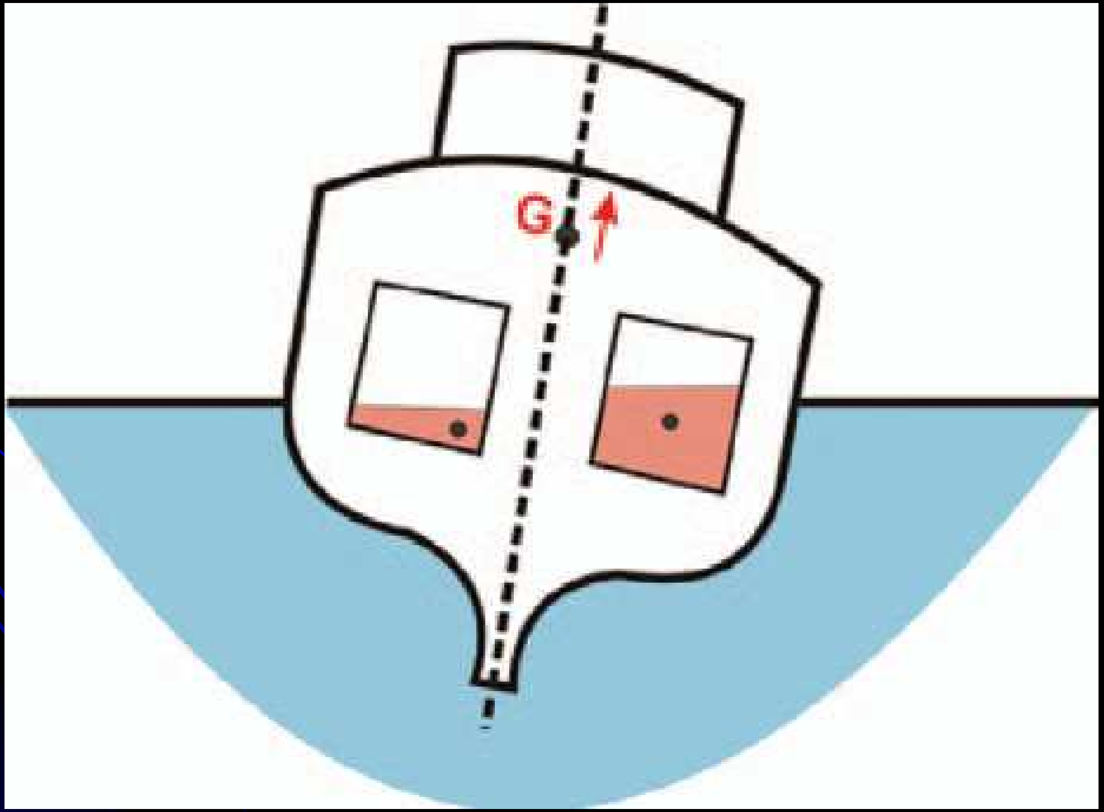
When a vessel with a partially-filled tank is heeled, the liquid will seek to remain parallel with the waterline. The centre of gravity of the liquid, being the centre of its volume, will move with the liquid and can have a considerable effect upon the vessel’s stability. This effect is similar to that caused by adding weight on deck, i.e. rise of the vessel’s centre of gravity (**G**) which causes a decrease in the vessel’s metacentric height (**GM**) and thereby its stability



Partially-filled tanks have the greatest adverse effect upon a heeled vessel’s metacentric height (**GM**). The division of the tank into two equal parts by the use of a watertight bulkhead will reduce the adverse effect on the vessel’s metacentric height (**GM**) by up to 75 percent of that of an undivided tank

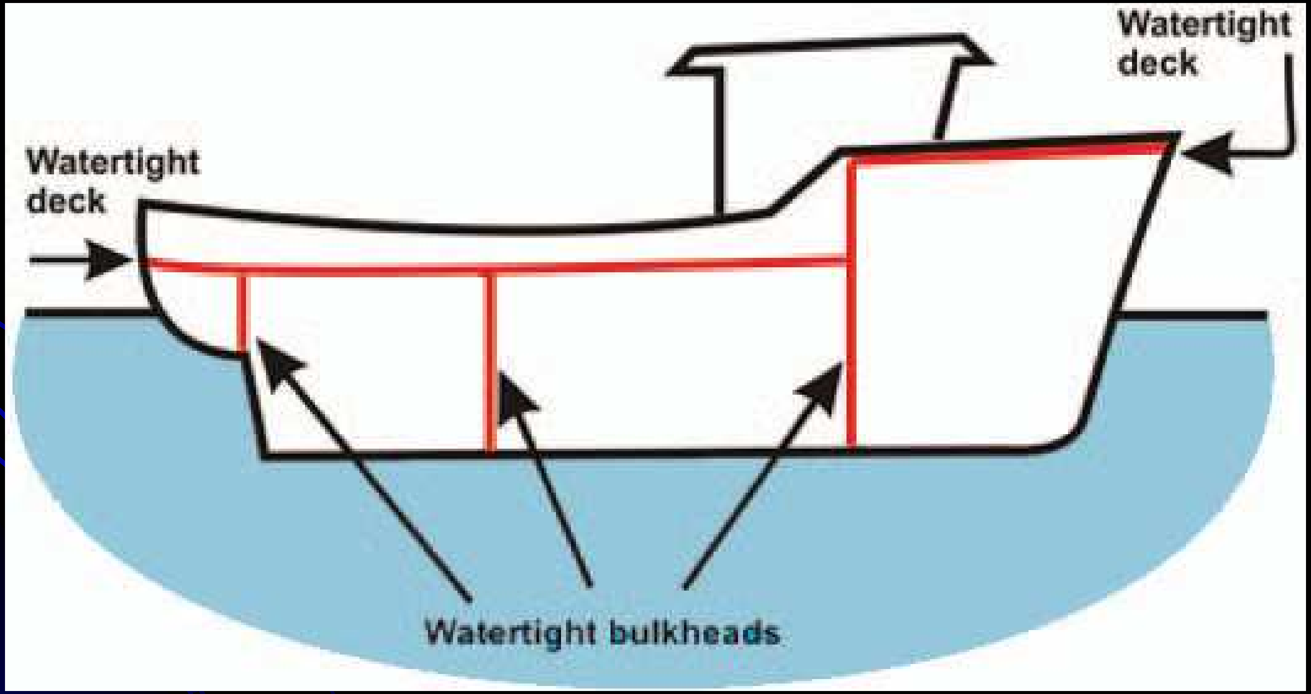


- Care should be taken when endeavouring to correct a list by filling tanks. Having two partially-filled tanks will create additional free surface effect. If there is a possibility that the vessel's list is caused by loll, it is recommended that the tank on the low side be filled before commencing to fill the tank on the high side
- Free surface effects are not only caused by partially-filled tanks. They can, for example, also be caused by accumulated water on deck. To enable the water to run off quickly, a vessel should have adequate freeing ports. Poundboards should be arranged so that water can flow easily to the freeing ports which should always be clear

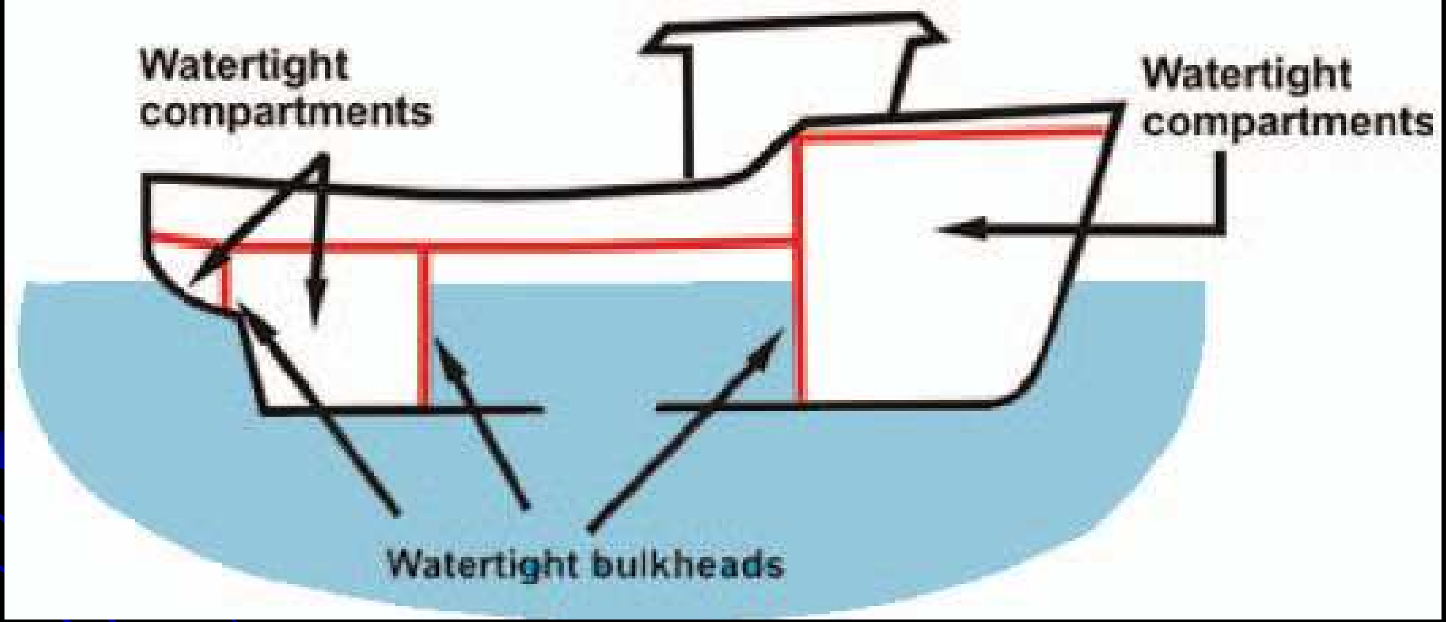


WATERTIGHT AND WEATHERTIGHT INTEGRITY

The vessel’s hull must be tight to prevent water from entering the vessel. Closing devices to openings, through which water can enter the hull and deckhouses, should be kept closed in adverse weather. This applies to doors, hatches and other deck openings, ventilators, air pipes, sounding devices, sidescuttles and windows and inlets and discharges. Any such device should be maintained in good and efficient condition



Vessels are often subdivided into compartments by bulkheads in order to minimize the effects of water flowing from one part of the vessel to another

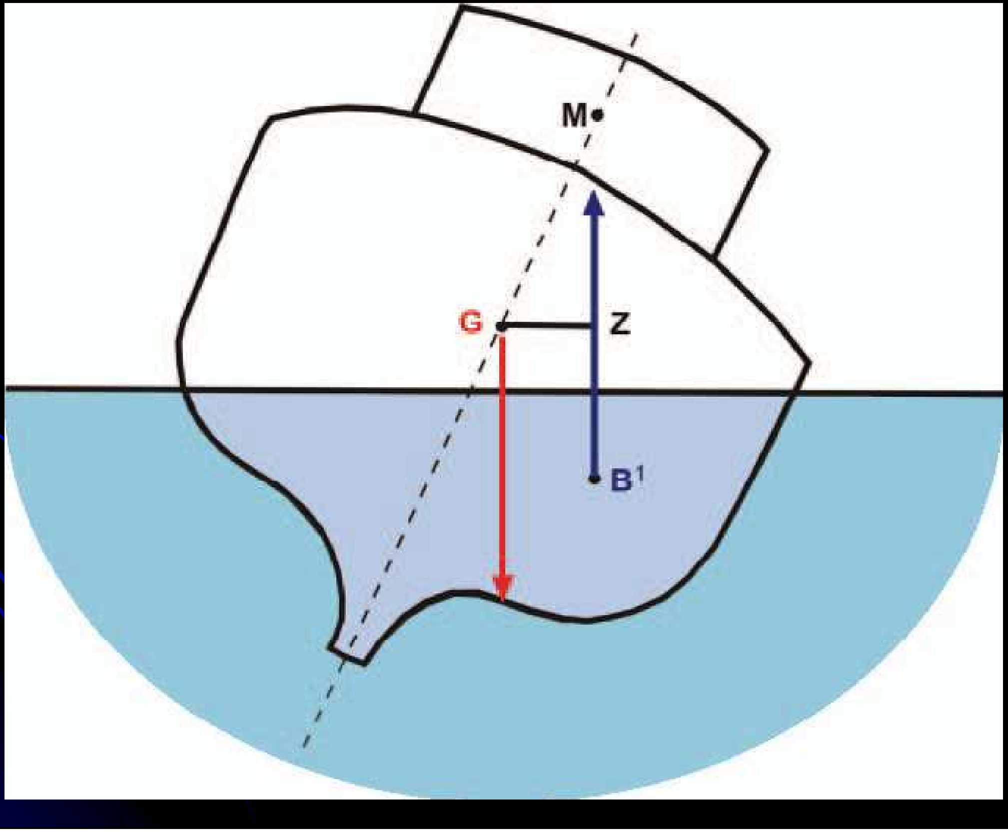


“Watertight” means that a structure is designed and constructed to withstand a static head of water without leakage. Water (or any other liquid) is not able to pass through the structure into or out of any of the watertight compartments, i.e. prevention from the passage of water in any direction. The vessel’s hull, working deck (weather deck) and bulkheads between compartments must be watertight. Watertight bulkheads must be watertight up to the working deck. Any openings on such bulkheads must be equipped with watertight closing devices. “Weathertight” means that in any sea condition water will not penetrate into the vessel, i.e. prevention from the passage of water in one direction only. Hatches, sidescuttles and windows must be equipped with weathertight closing devices. The same applies for doors and other openings on enclosed superstructures

RIGHTING LEVER

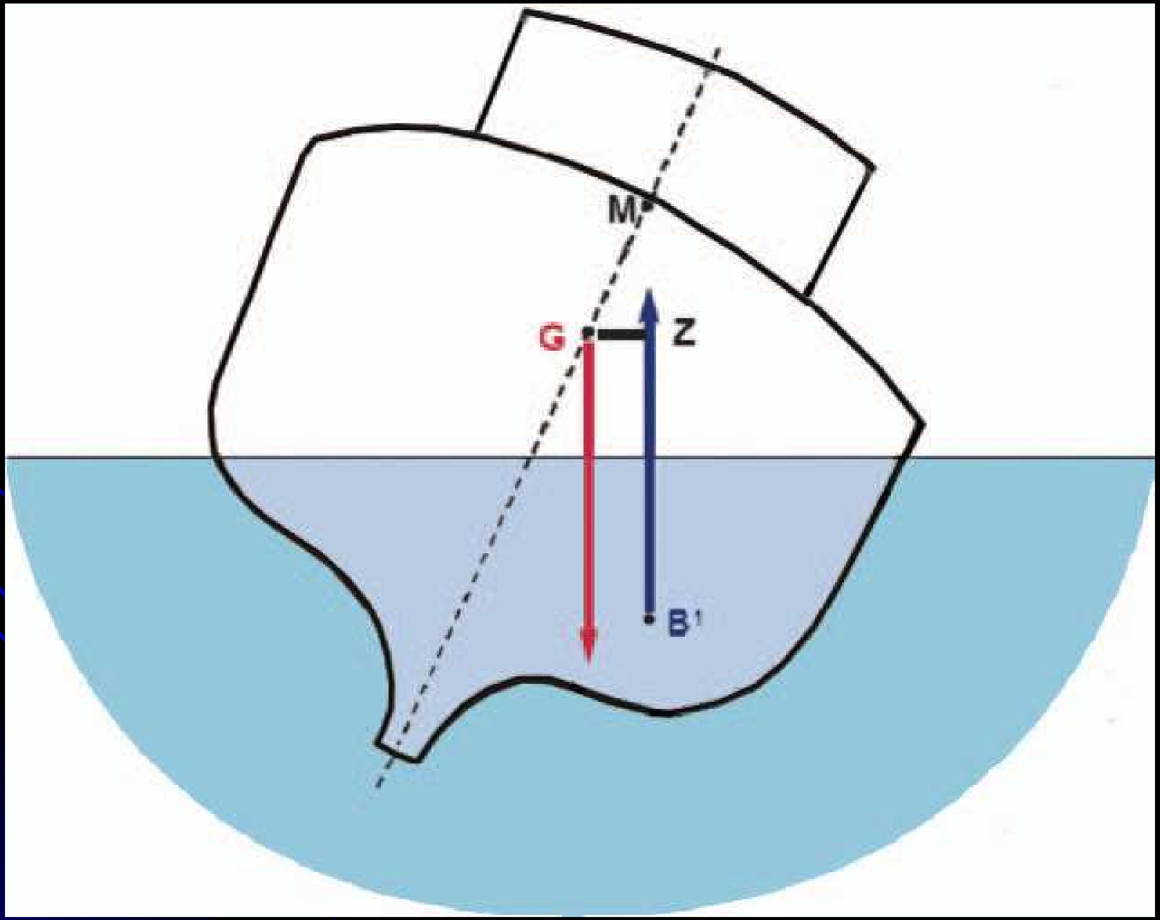
When heeled by an external force, the vessel’s centre of gravity (G), which is unaffected by the heel and the weight (of the vessel), is considered to act vertically downward through G. The centre of buoyancy (B) (being the geometric centre of the underwater section) has moved to a new position B1 and the force of buoyancy (equal to the weight of water being displaced) is considered to act vertically up through the new centre of buoyancy B1. The horizontal distance from the centre of gravity (G) to the vertical line from B1 is called the righting lever. This distance can be measured and is usually referred to as GZ.

Therefore, the force involved in returning the vessel to the upright position is the weight of the vessel acting down through the centre of gravity (G) multiplied by the righting lever (GZ). This is referred to as the moment of statical stability



The vessel’s centre of gravity (G) has a distinct effect on the righting lever (GZ) and consequently the ability of a vessel to return to the upright position. The lower the centre of gravity (G), the bigger is the righting lever (GZ)

Should the vessel’s centre of gravity (G) be near the metacentre (M) the vessel will have only a small metacentric height (GM) and the righting lever (GZ) will also be a small value. Therefore, the moment of statical stability to return the vessel to the upright position will be considerably less than that of the previous
illustration



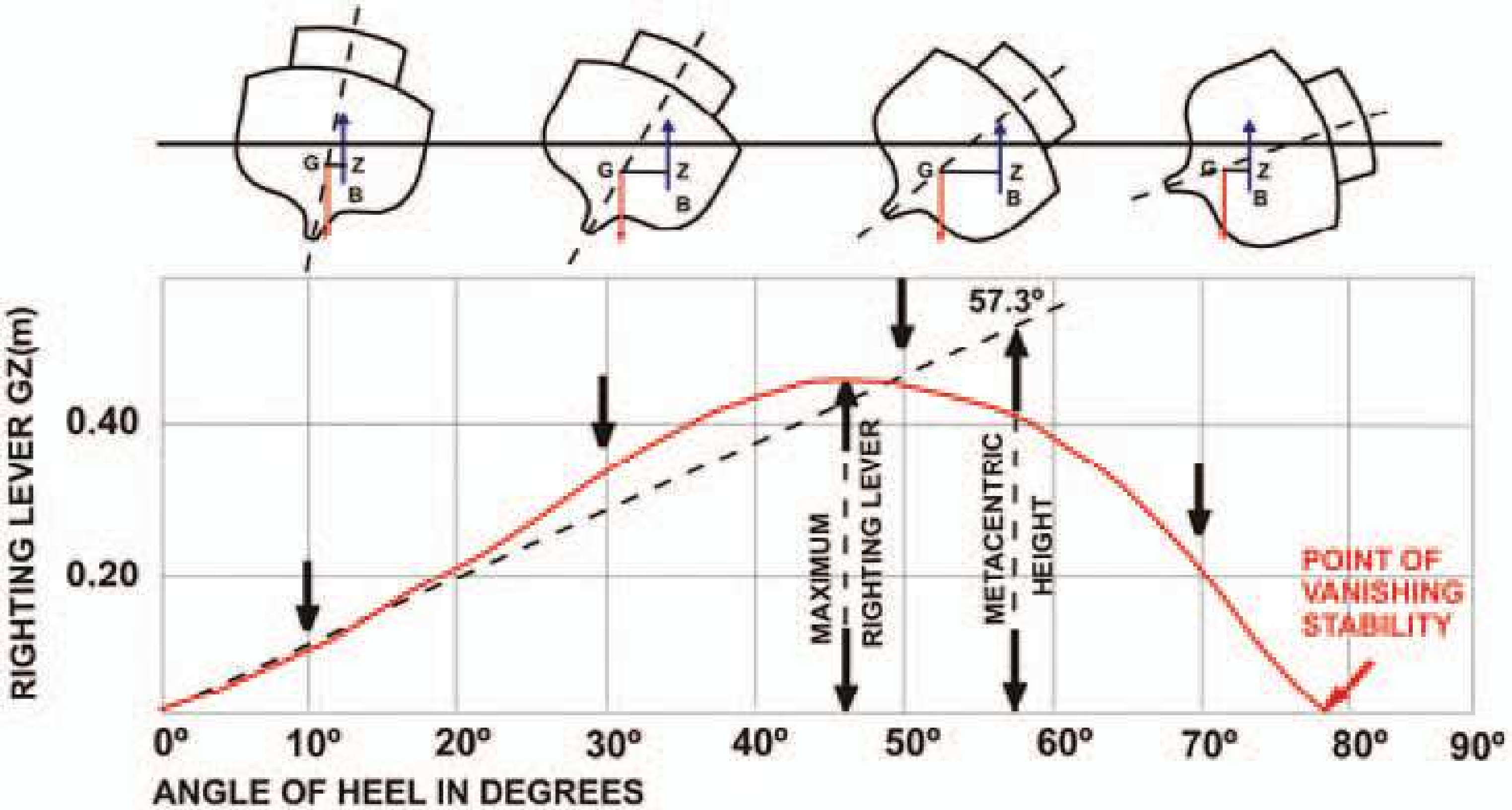
STABILITY CURVES (GZ CURVES)

Stability curves (**GZ** curves) are used to show graphically the stability levers (**GZ**) exerted by a vessel to return itself to a position of equilibrium from the various conditions of heel. The curves have several general characteristics and the following factors should be observed:

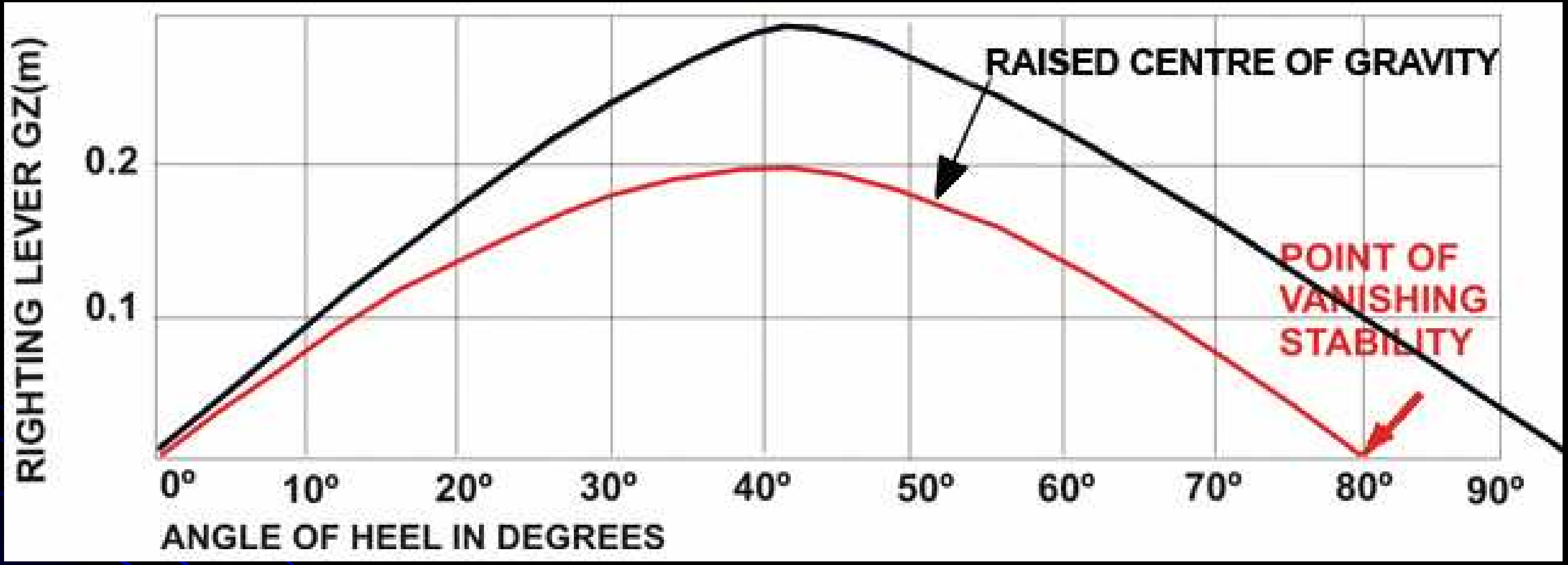
(a) the metacentric height (**GM**);

(b) the maximum value of the righting lever (**GZ**); and

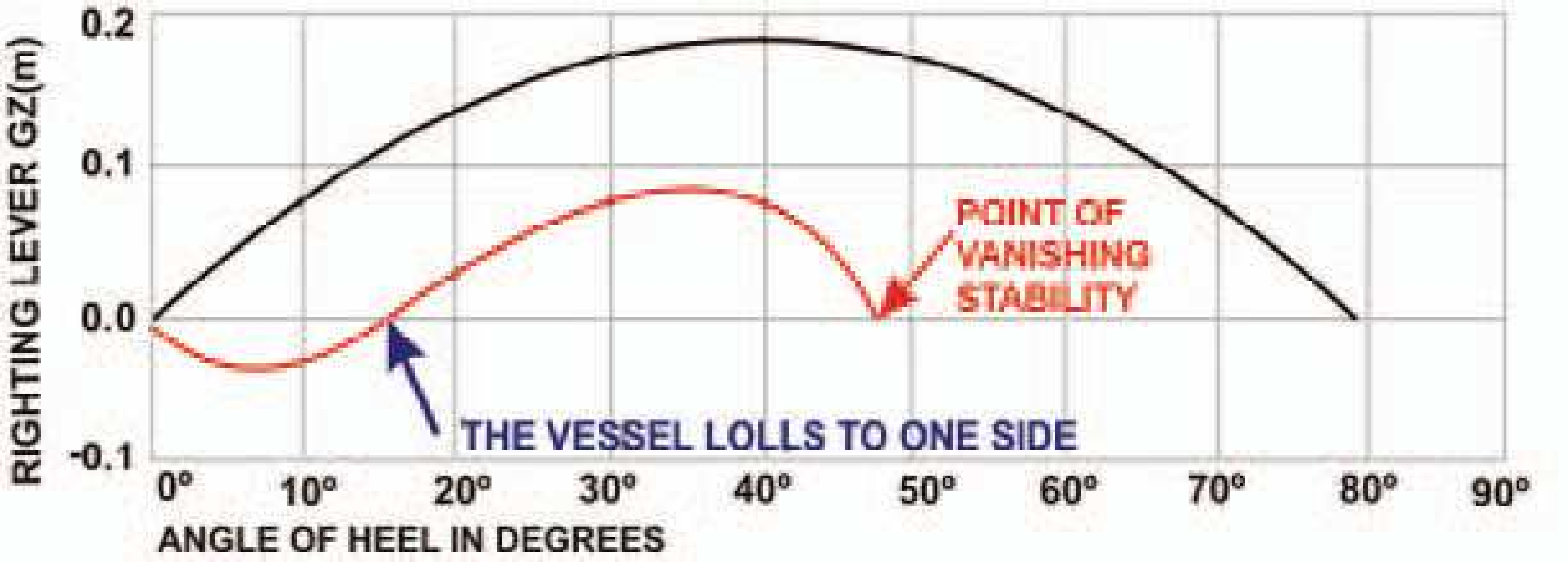
(c) the point of vanishing stability



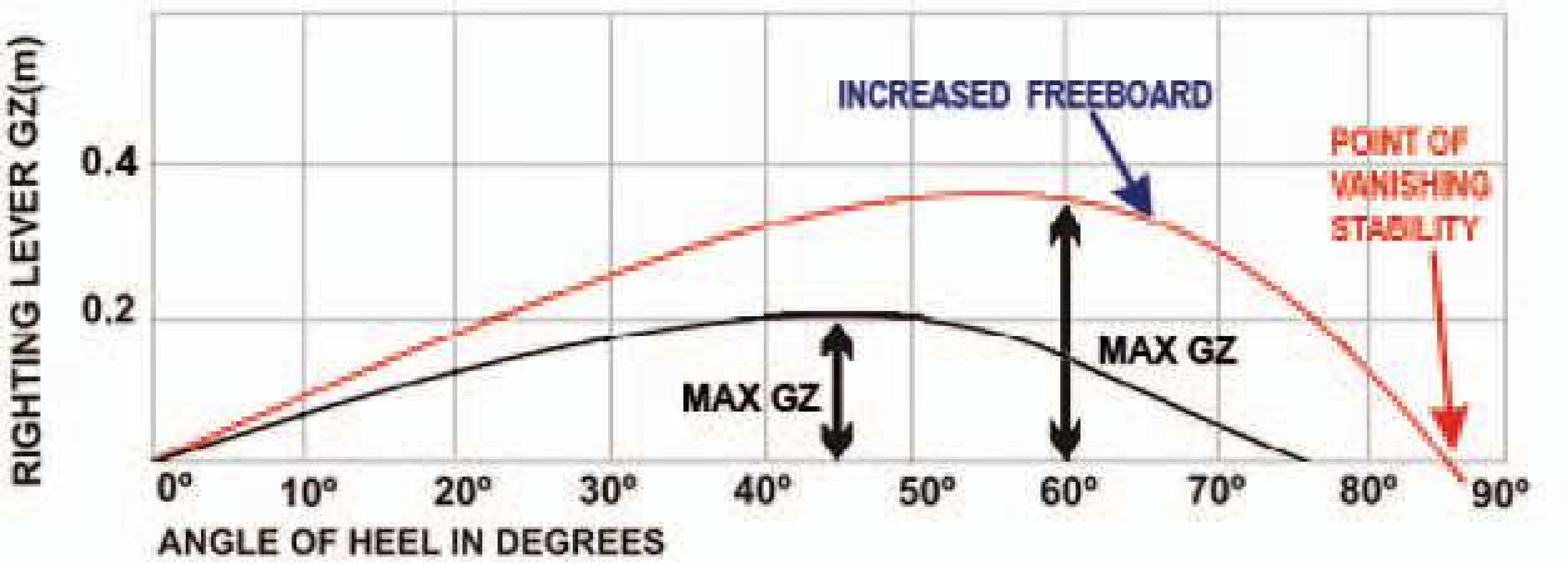
The shape of the righting lever curves is dependent on the form of the vessel's hull and its loading. The shape of the curve at small angles of heel generally follows the slope of the line plotted to the initial metacentric height (GM). In this regard, the freeboard and the ratio between the vessel's breadth and depth are also very important



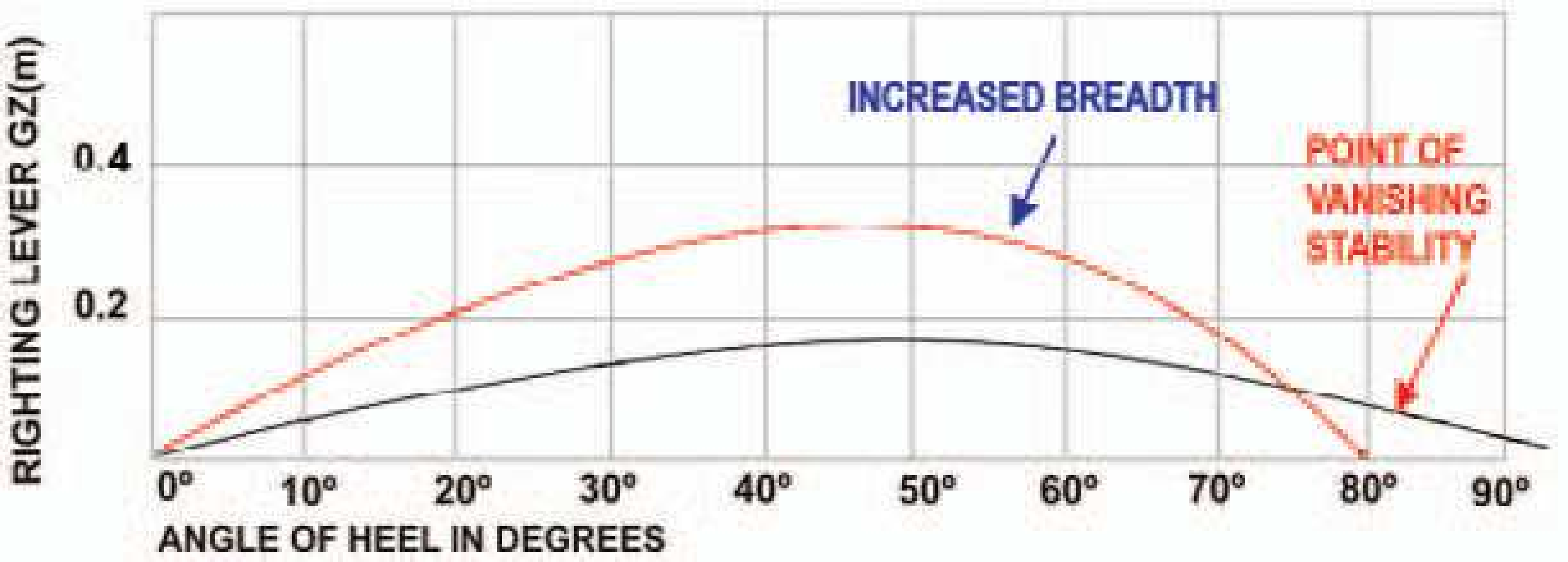
Raising the vessel's centre of gravity (**G**) causes a decrease in the metacentric height (**GM**) and thereby smaller values of the righting levers (**GZ**)



If the vessel’s centre of gravity (**G**) is above the metacentre (**M**), the vessel is in an unstable equilibrium. The vessel has a negative **GM** and is not able to float upright. Either the vessel will capsize of or float at an angle from the upright to one side



- By loading less the vessel will have more freeboard and the values of the righting lever (**GZ**) will, in general, be higher. The point of vanishing stability will also be higher, i.e. the vessel’s ability to return to upright after having been heeled to large angles of heel is better



- The hull form of a vessel is an important factor in determining the characteristics of its stability. Increased breadth (beam) will result in higher values for metacentric heights (**GM**) and righting levers (**GZ**). However, the point of vanishing stability will be less, i.e. the vessel will capsize at a **smaller** angle of heel

DYNAMIC STABILITY

This is the stability characteristic of the vessel when moving (particularly rolling) and is the energy necessary to incline a vessel to a certain angle of heel and thereby counteract the **moment of statical stability**.

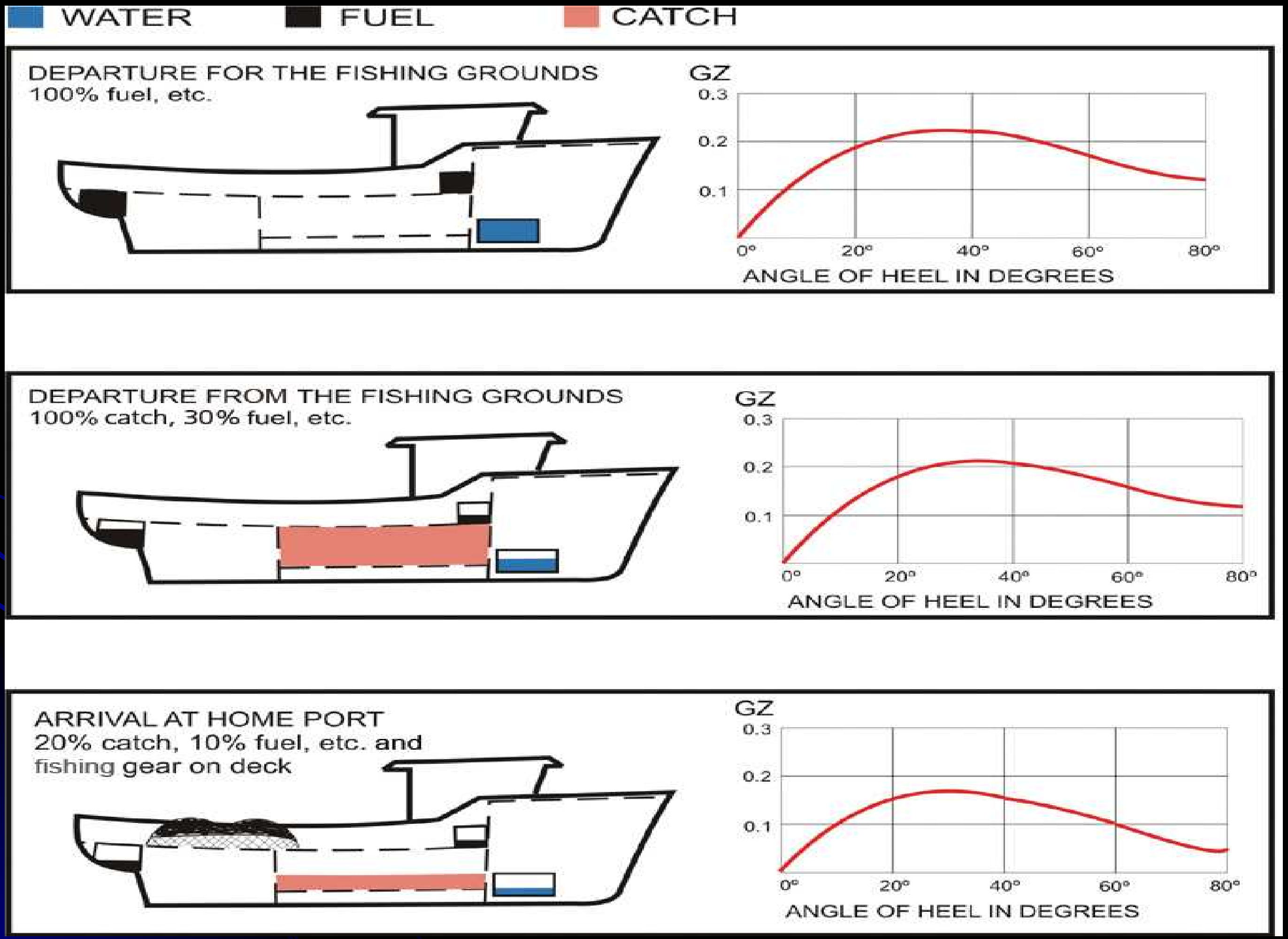
The dynamic stability may be determined by measuring the area under the righting lever curve (**GZ** curve) up to a certain angle of heel. The larger the area, the better is the dynamic stability.

Waves are the most common external force that causes a vessel to heel. Steep waves with short wavelengths, particularly breaking waves, are the most dangerous to small vessels.

The relationship between a vessel’s dynamic stability and wave energy is complex and is, for example, dependent on the speed and course of the vessel in relation to the speed and direction of the wave. However, in general, the smaller the vessels, the smaller the waves they are able to cope with

CHANGES IN THE STABILITY CURVE DURING A VOYAGE

A fishing vessel’s stability constantly changes during its voyage, depending on how the vessel is loaded and operated



Basic Ship Theory

Basic Ship Geometric Concepts

vocabulary Ship

The technical vocabulary of people with long maritime tradition has peculiarities of origins and usage. As a first important example in English let us consider the word **ship;** it is of Germanic origin. Indeed, to this day the equivalent Danish word is **skib**, the Dutch, **schep**, the German, **Schiff** (pronounce **'shif'**), the Norwegian **skip** (pronounce **'ship'**), and the Swedish, **skepp**. For mariners and Naval Architects a ship has a soul; when speaking about a ship they use the pronoun**'she'**.

The main parts of a typical Ship

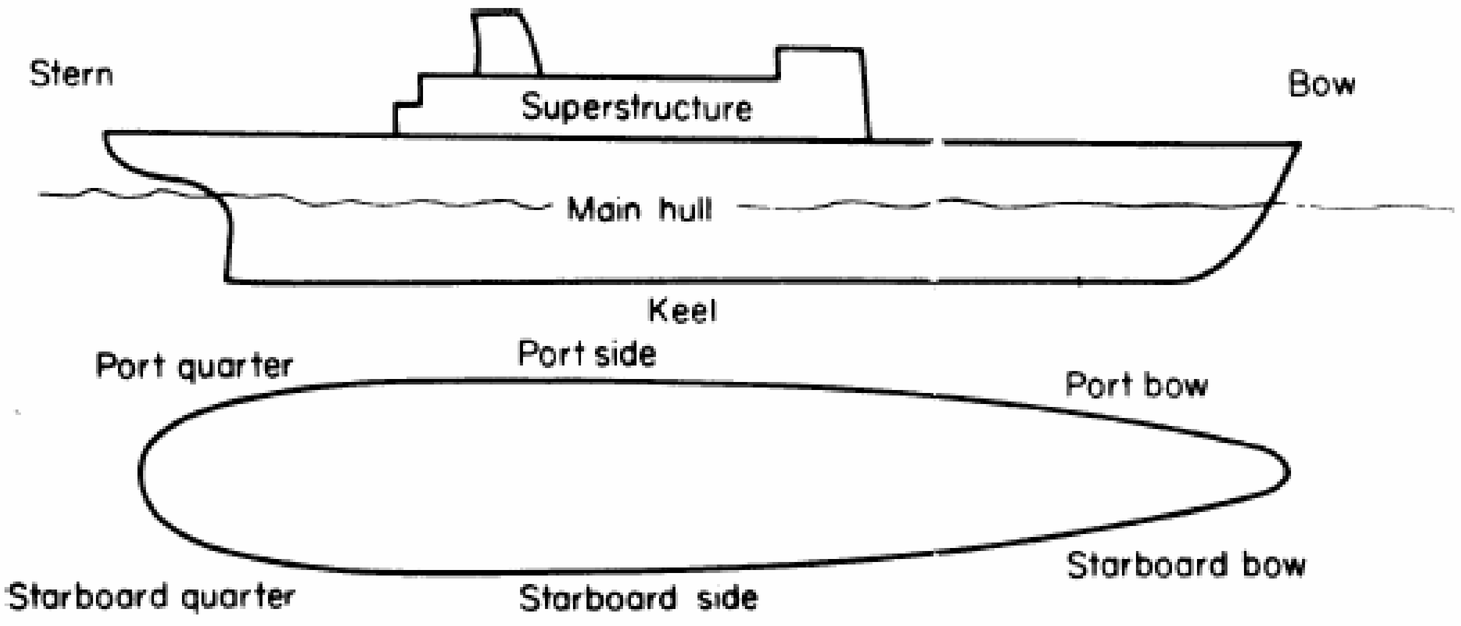
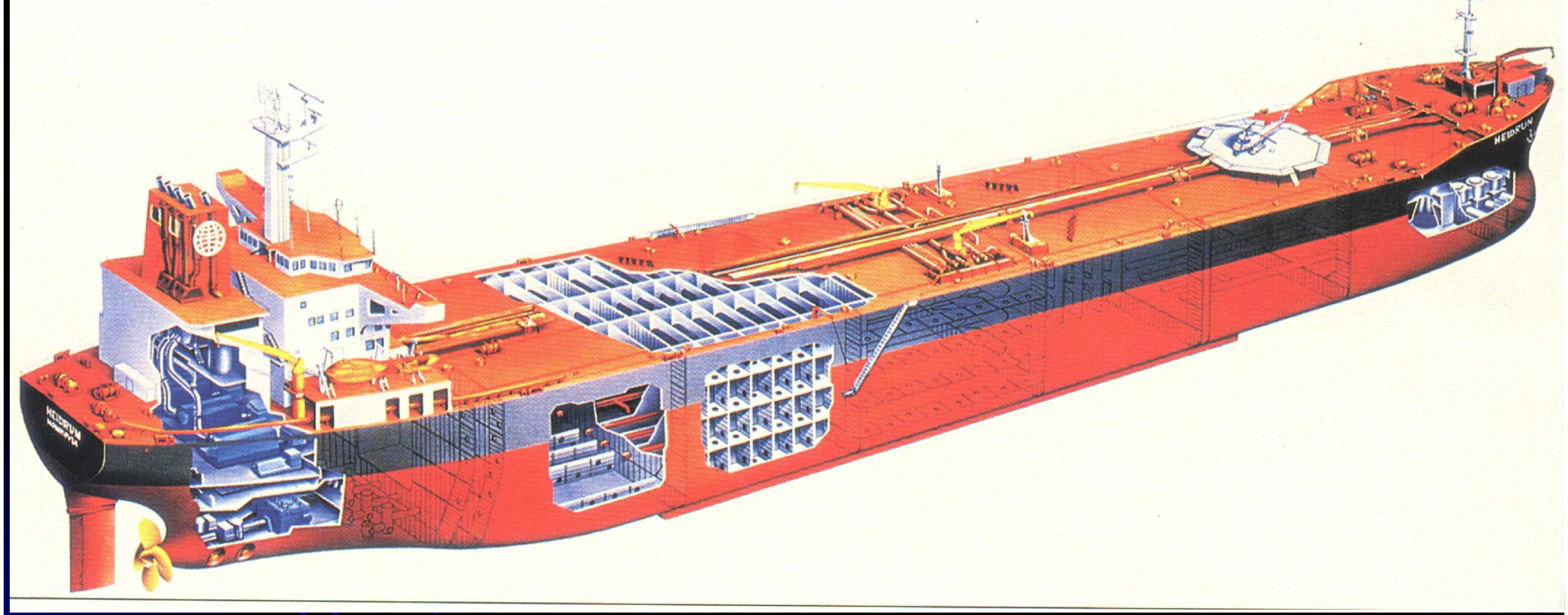


Fig. 2.1

An Example



The principal dimensions of a ship

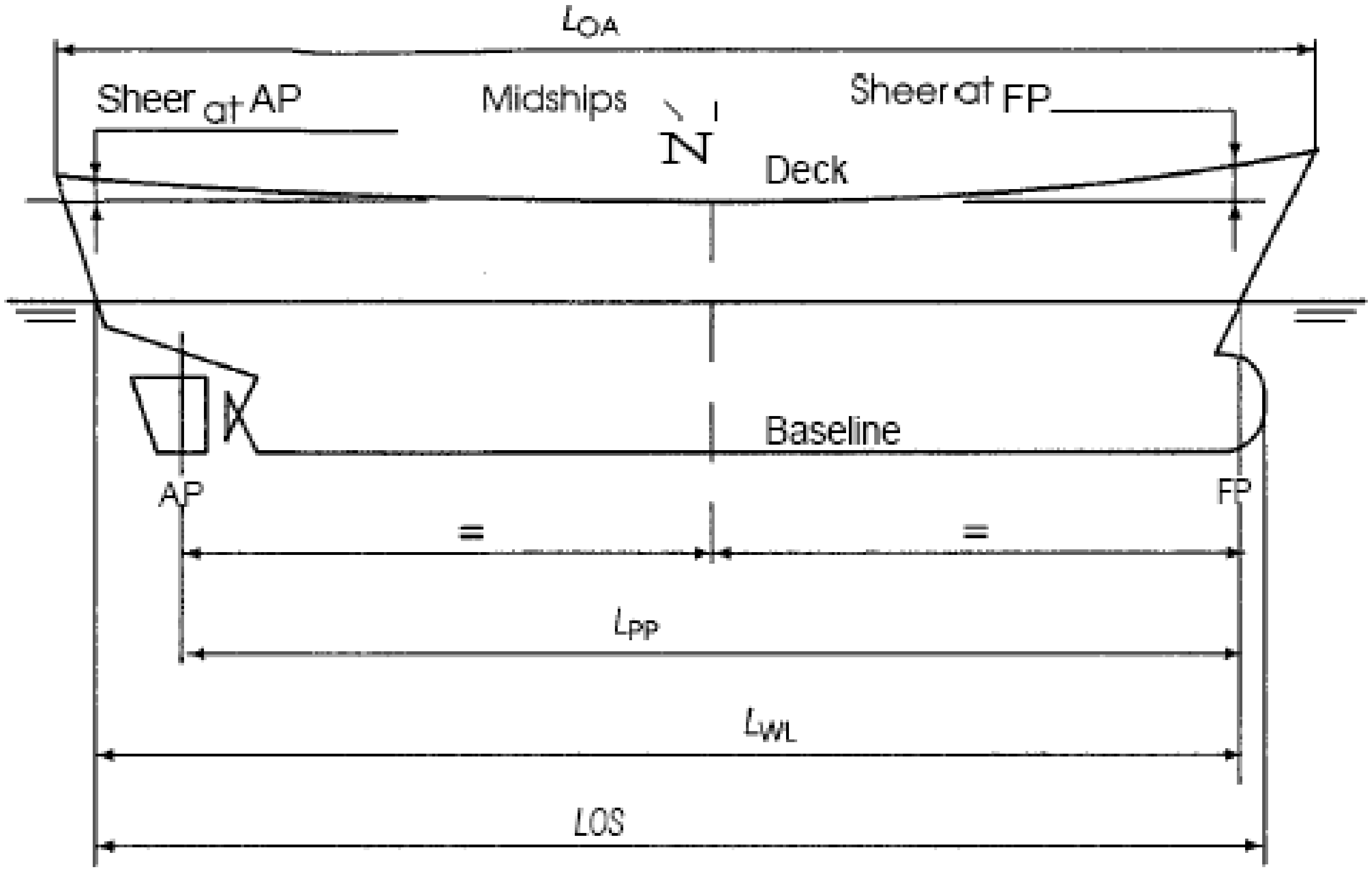


Figure 1.1 Length dimensions

The principal dimensions of a ship

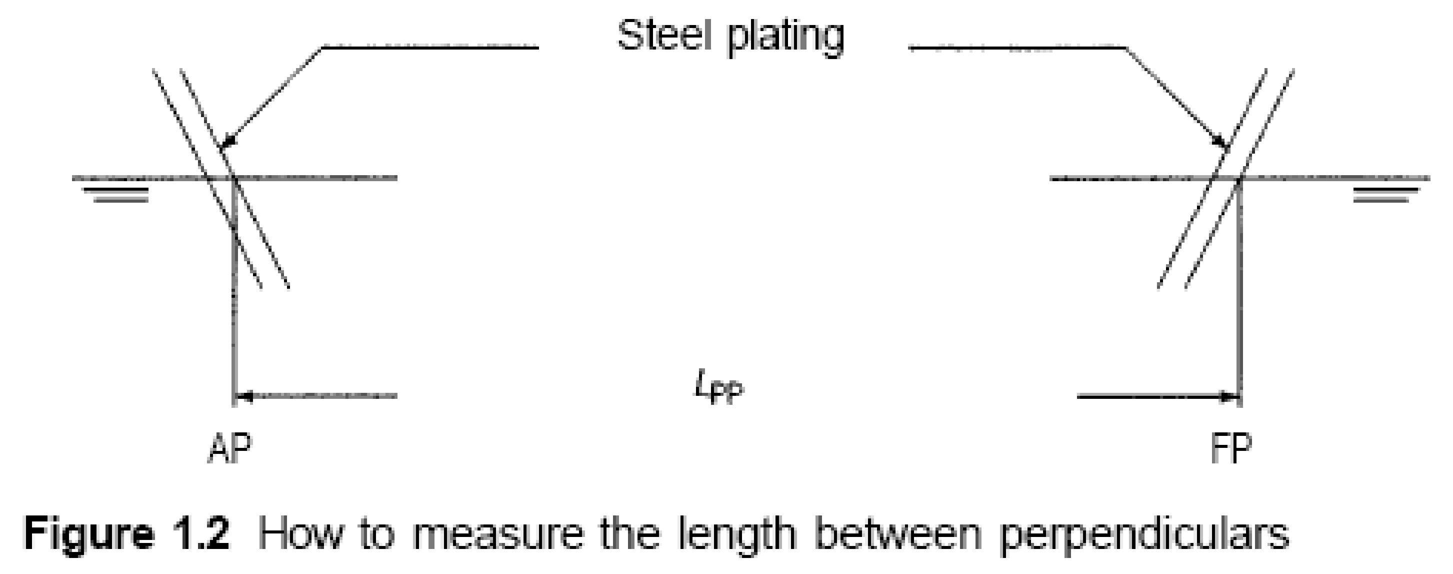


Figure 1.2 How to measure the length between perpendiculars

The principal dimensions of a ship

The baseline, shortly **BL**, is a line lying in the longitudinal plane of symmetry and parallel to the designed summer load waterline

The after perpendicular, or **aft perpendicular**, noted **AP**, is a line drawn perpendicularly to the load line through the after side of the rudder post or through the axis of the rudder stock.

The forward perpendicular, **FP**, is drawn perpendicularly to the load line through the intersection of the fore side of the stem with the load waterline.

The principal dimensions of a ship

The distance between the after and the forward perpendicular, measured parallel to the load line, is called **length between perpendiculars** and its notation is **Lpp**. An older notation was **LBP**

We call **length overall**, **LOA** the length between the ship extremities.

- The **length overall submerged**, **LOS** is the maximum length of the submerged hull measured parallel to the designed load line.

We call station a point on the baseline, and the transverse section of the hull surface passing through that point and The station placed at half Lpp is called **midships**.

The principal dimensions of a ship

The moulded depth, **D**, is the height above baseline of the intersection of the underside of the deck plate with the ship side

The moulded draught, **T**, is the vertical distance between the top of the keel to the designed summer load line, usually measured in the midships plane

The distance between the intersection of this auxiliary line with the aft perpendicular and the load line is called **aft draught** and is noted with **TA**

The principal dimensions of a ship

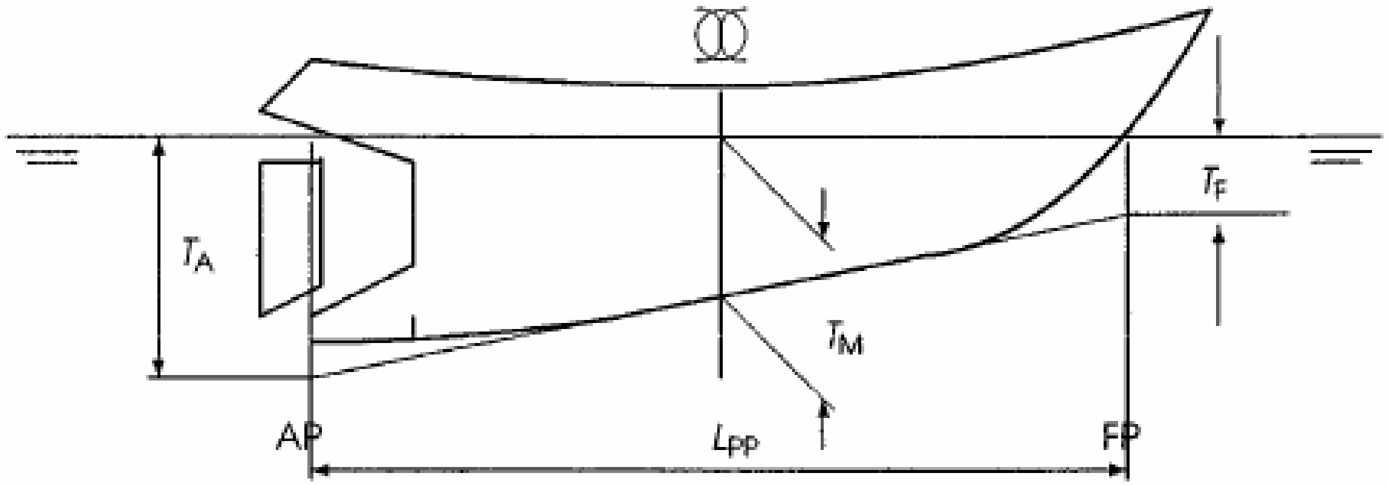


Figure 1.3 The case of a keel not parallel to the load line

The principal dimensions of a ship

The distance between the load line and the intersection of the auxiliary line with the forward perpendicular is called **forward draught** and is noted with **Tp**.

Then, the draught measured in the midship section is known as **midships draught** and its symbol is **TM**

The difference between depth and draft is called **freeboard**

The principal dimensions of a ship

The **moulded volume of displacement** is the volume enclosed between the submerged, moulded hull and the horizontal water plane defined by a given draught. This volume is noted by **V**

European literature as nabla the Latin 'carina

Spanish it is called 'carena

Figure 1.5 (a) Midships symbol in English literature, (b) Midships symbol in German literature

The principal dimensions of a ship

The vertical distance between the lowest and the highest points of the deck, in a given transverse section, is called **camber**

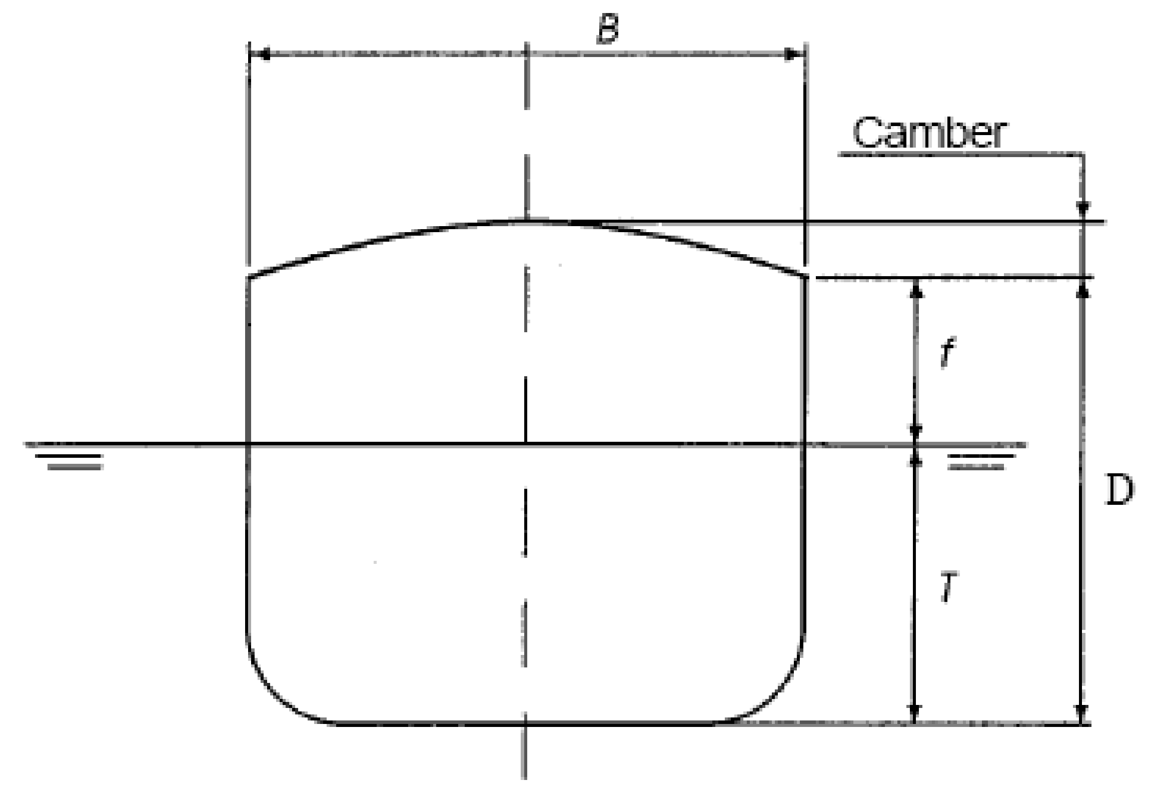


Figure 1.4 Breadth, depth, draught and camber

The definition of the hull surface

Coordinate systems

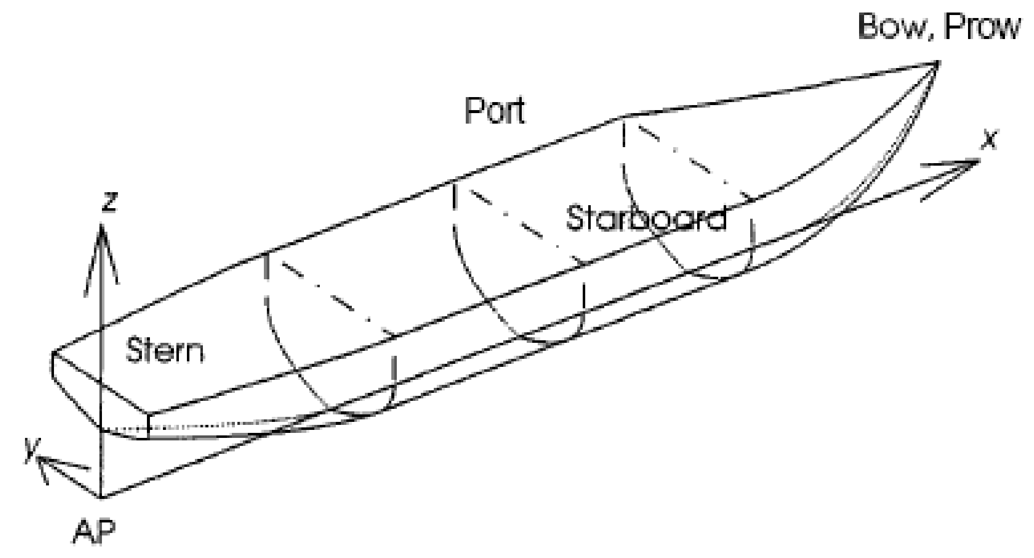
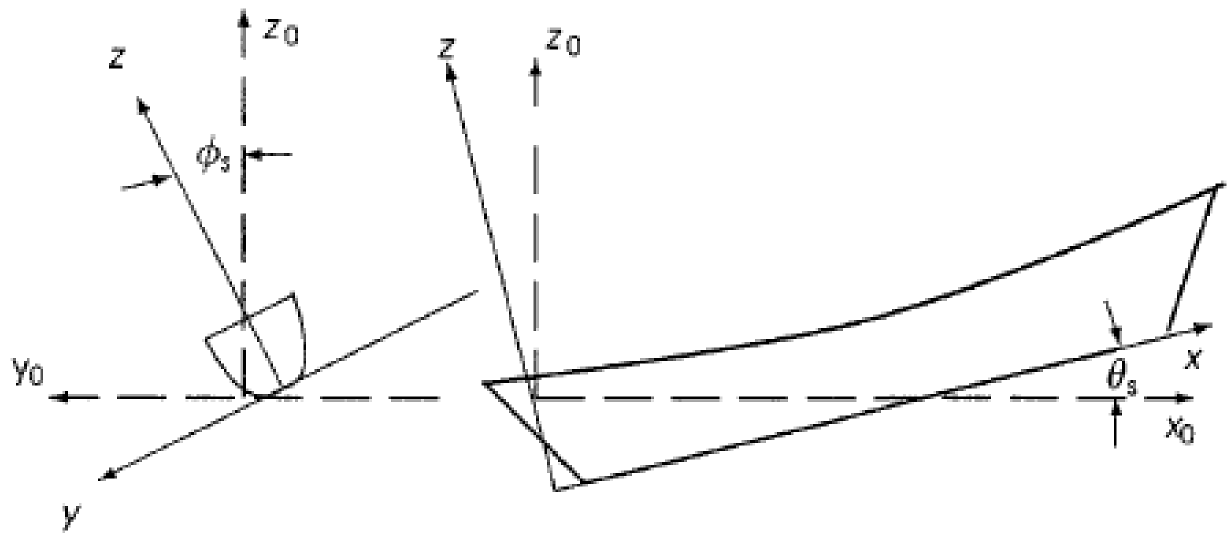


Figure 1.6 System of coordinates recommended by DIN 81209-1

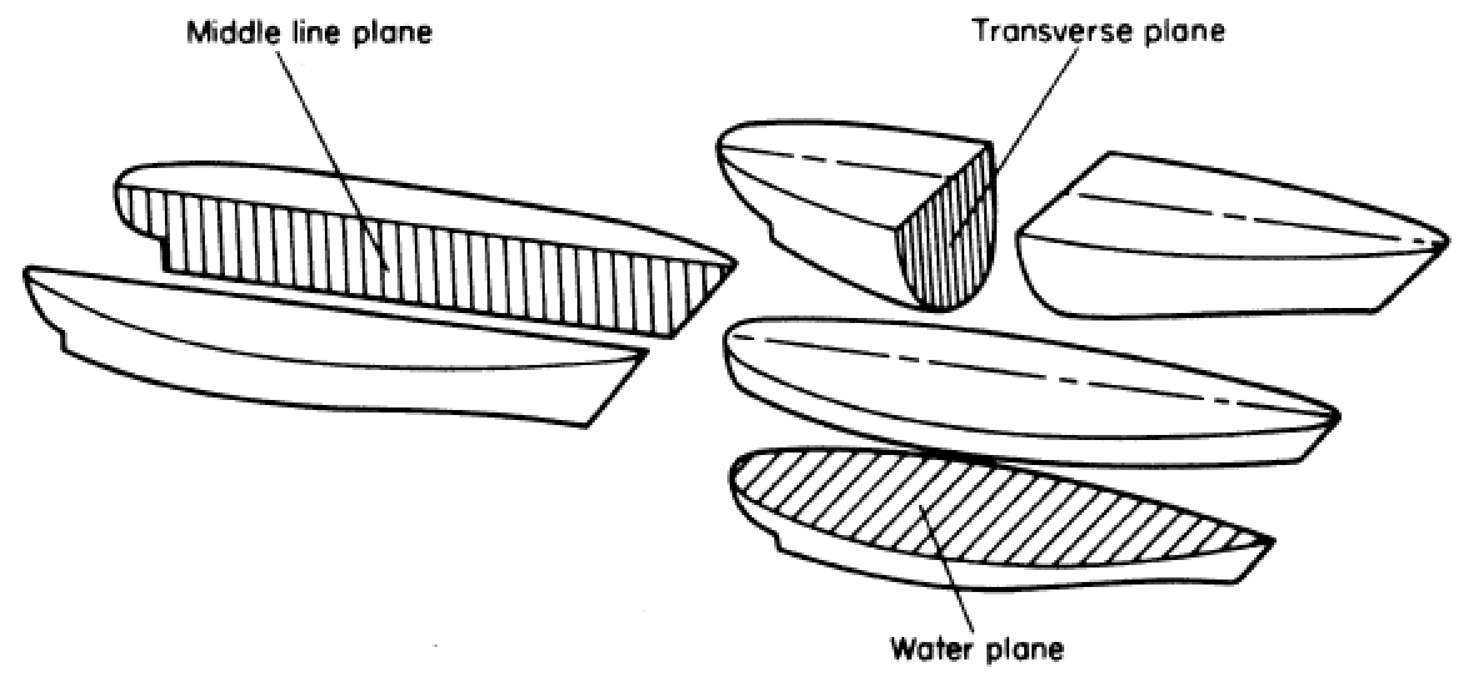
The definition of the hull surface



(a) heel (b) trim

Figure 1.7 Heel and trim

Orthogonal Planes of ship



The definition of the hull surface

Graphic description

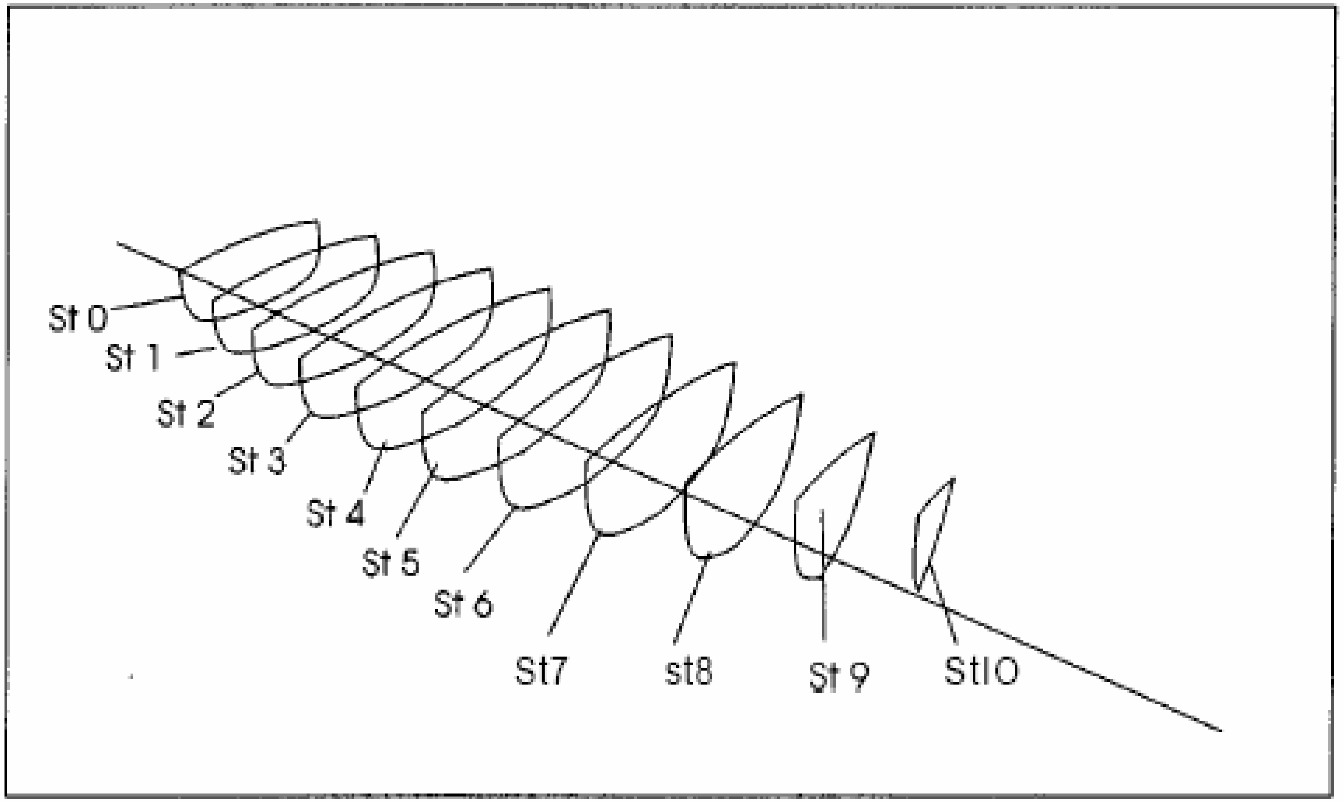


Figure 1.8 Stations

The definition of the hull surface

Graphic description

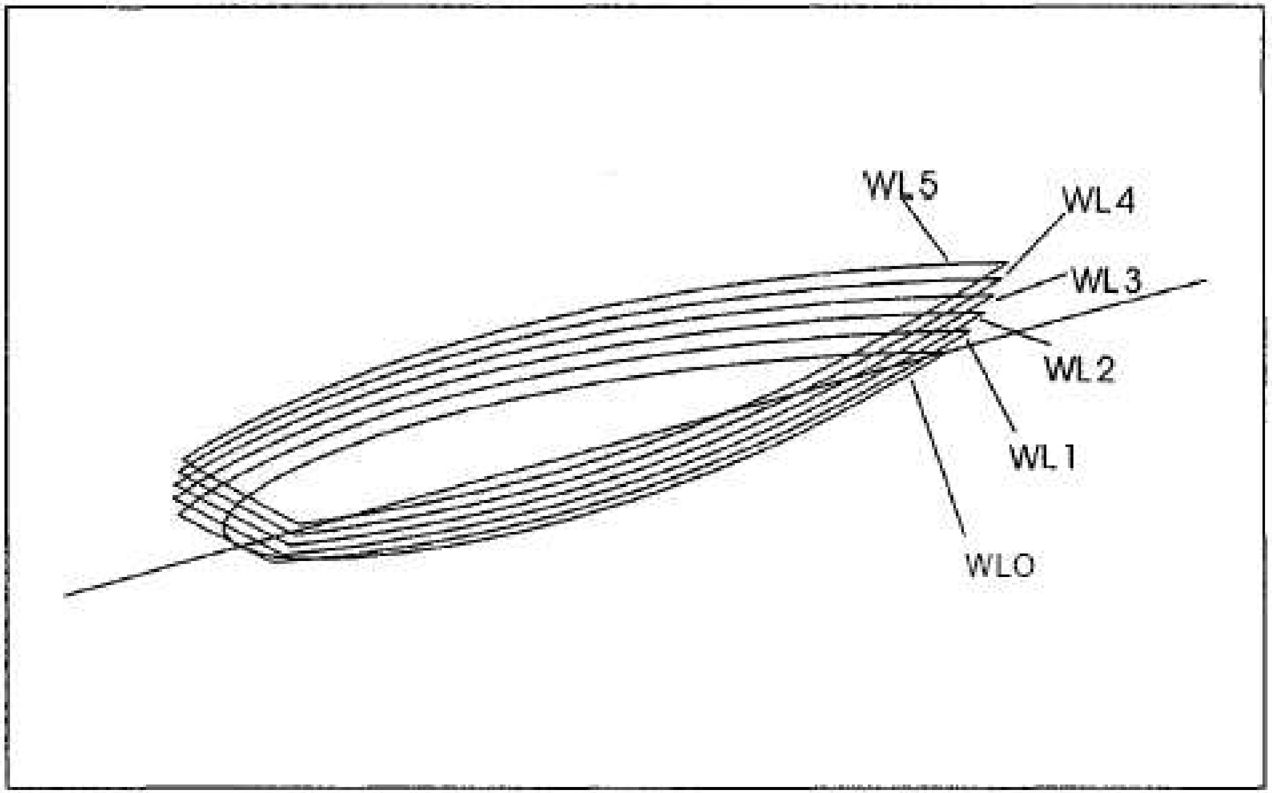


Figure 1.9 Waterlines

The definition of the hull surface

Graphic description

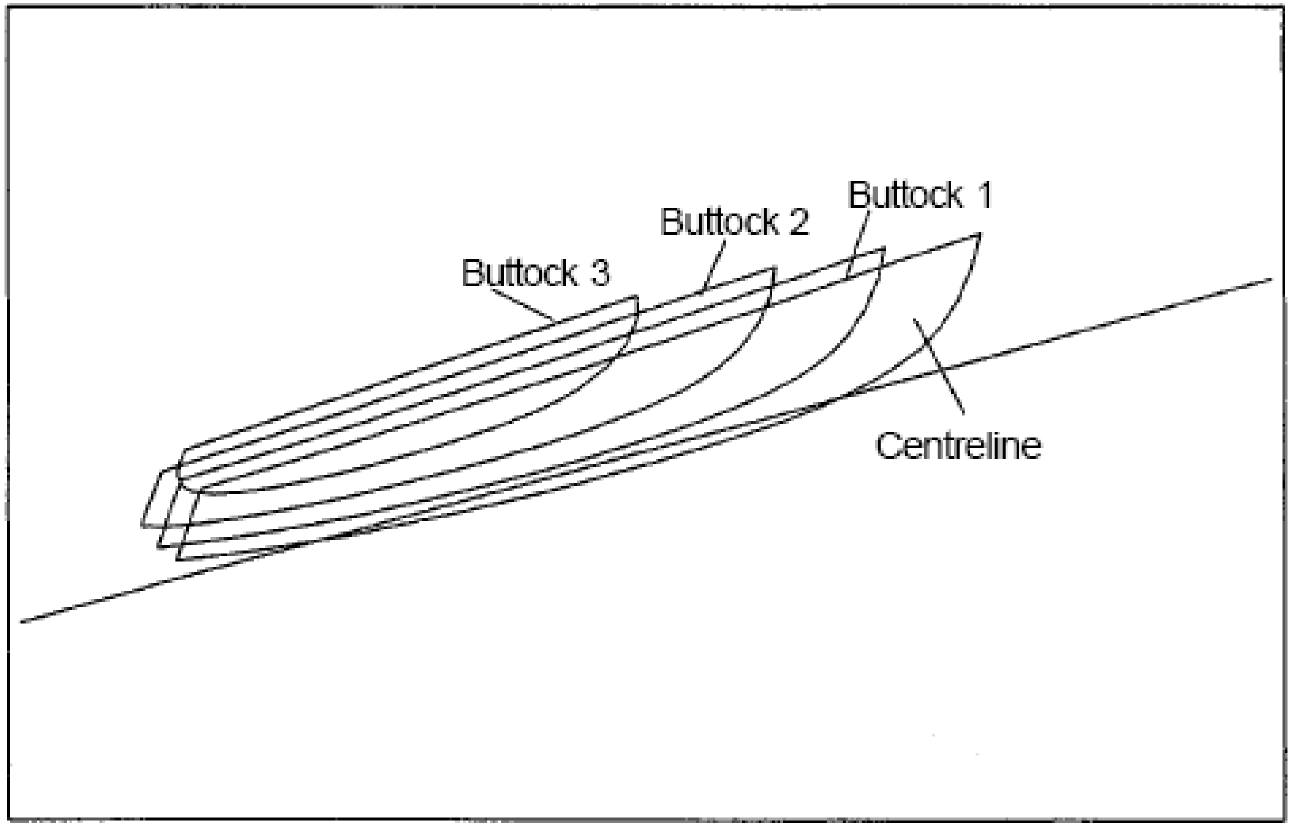


Figure 1.10 Buttocks

The definition of the hull surface

Graphic description

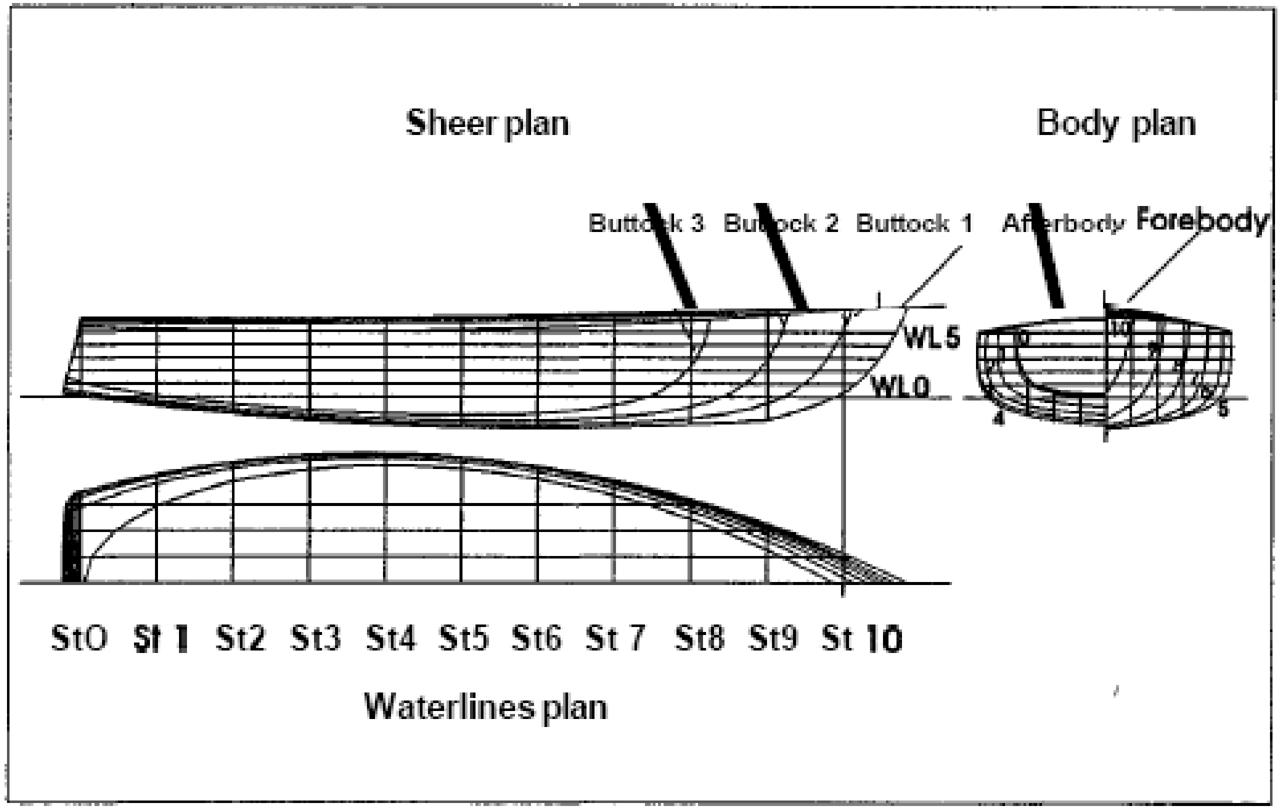


Figure 1.11 The lines drawing

The definition of the hull surface

Table of offsets

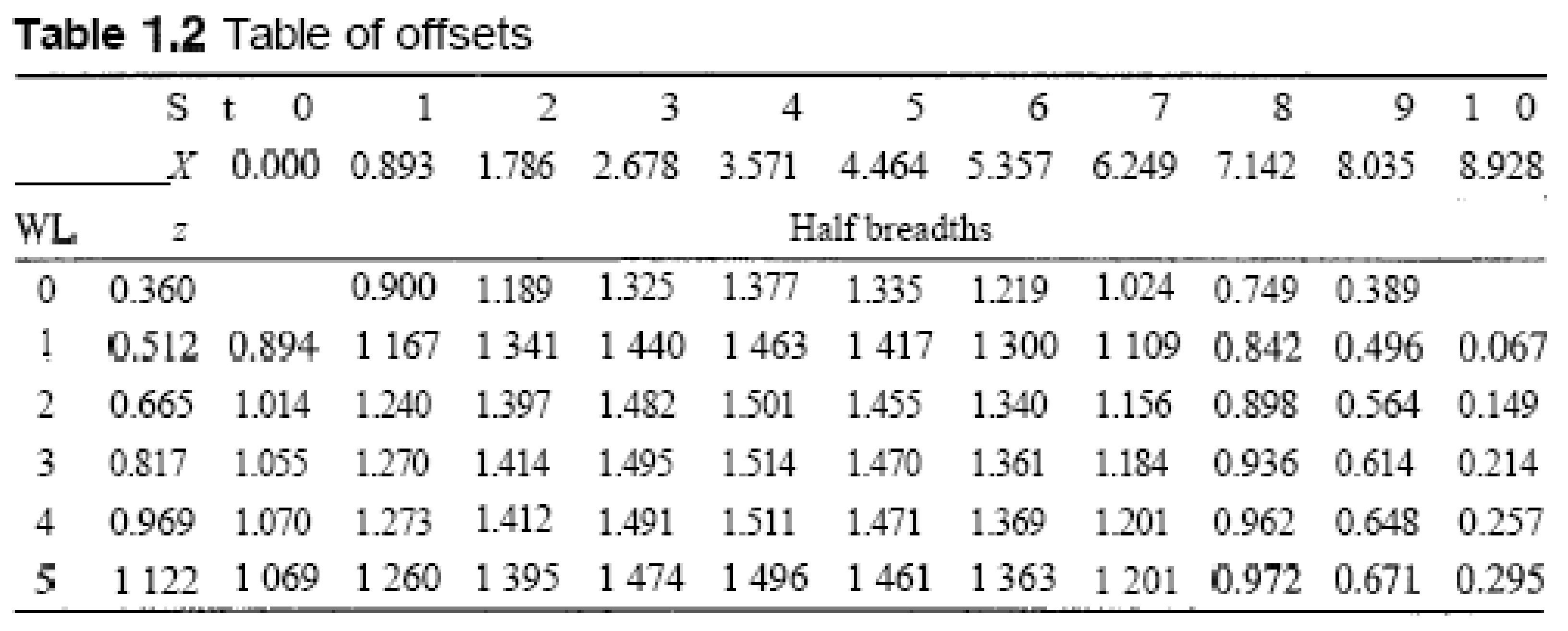


Table 1.2 Table of offsets

	St	0	1	2	3	4	5	6	7	8	9	10
	X	0.000	0.893	1.786	2.678	3.571	4.464	5.357	6.249	7.142	8.035	8.928
WL	*z*						Half breadths					
0	0.360		0.900	1.189	1.325	1.377	1.335	1.219	1.024	0.749	0.389	
1	0.512	0.894	1 167	1 341	1 440	1 463	1 417	1 300	1 109	0.842	0.496	0.067
2	0.665	1.014	1.240	1.397	1.482	1.501	1.455	1.340	1.156	0.898	0.564	0.149
3	0.817	1.055	1.270	1.414	1.495	1.514	1.470	1.361	1.184	0.936	0.614	0.214
4	0.969	1.070	1.273	1.412	1.491	1.511	1.471	1.369	1.201	0.962	0.648	0.257
5	1 122	1 069	1 260	1 395	1 474	1 496	1 461	1 363	1 201	0.972	0.671	0.295

Coefficients of form

The block coefficient is the ratio of the moulded displacement volume, V, to the volume of the parallelepiped (rectangular block) with the dimensions L, B and T

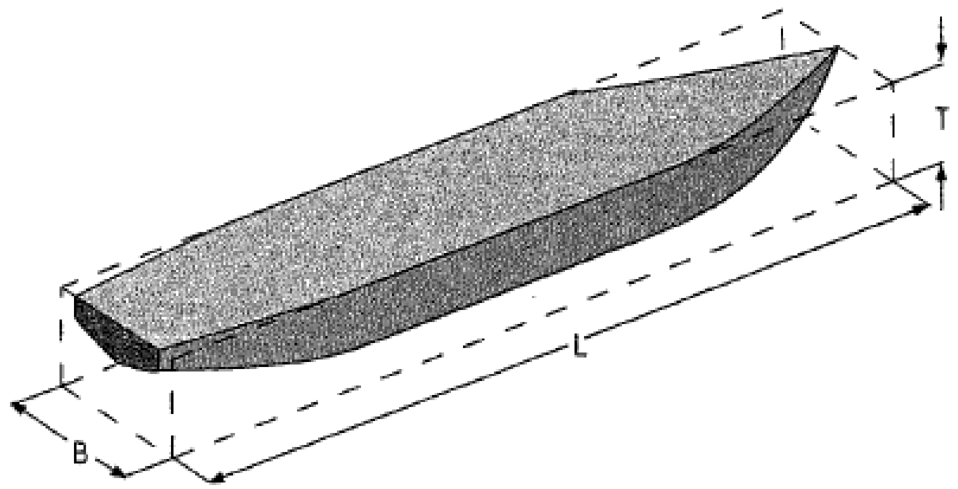


Figure 1.14 The definition of the block coefficient, C_B

$$C_B = \frac{\nabla}{LBT}$$

Coefficients of form

The midship coefficient, **CM**, is defined as the ratio of the midship-section area, AM, to the product of the breadth and the draught, BT,

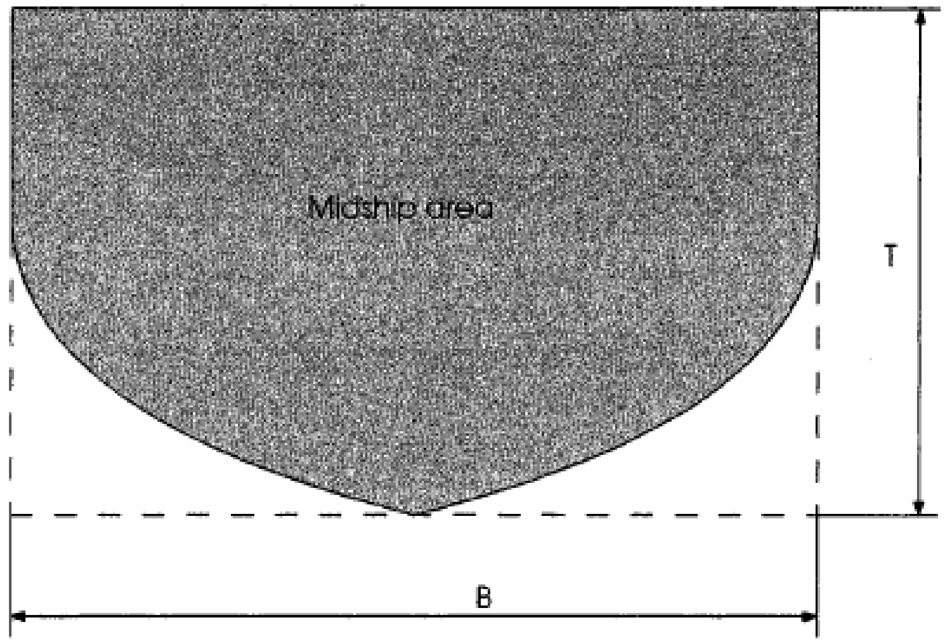


Figure 1.15 The definition of the midship-section coefficient, C_M

$$C_M = \frac{A_M}{BT}$$

Coefficients of form

The **prismatic coefficient**, Cp, is the ratio of the moulded displacement volume, V, to the product of the midship-section area, AU, and the length, L

Cp is an indicator of how much of a cylinder
with constant section AM and length L is filled by the submerged hull

$$C_P = \frac{V}{A_M L} = \frac{C_B LBT}{C_M BTL} = \frac{C_B}{C_M}$$

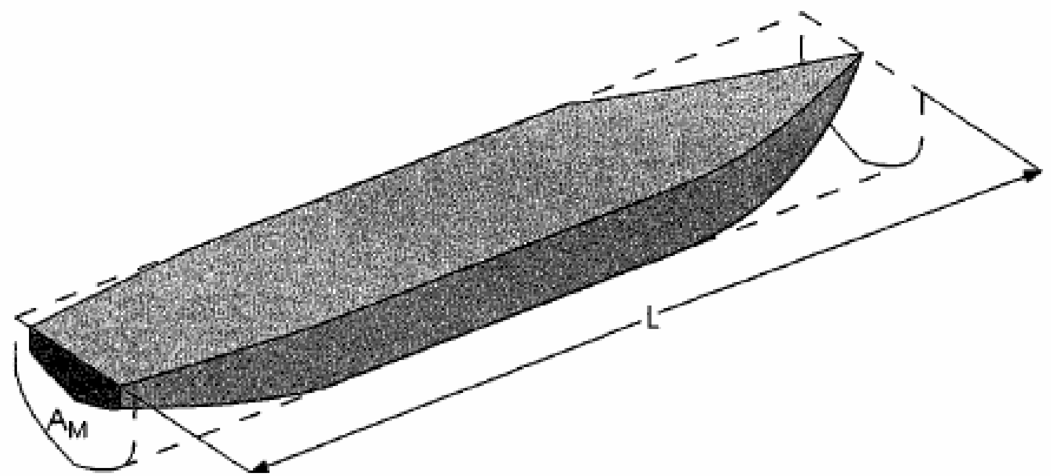


Figure 1.16 The definition of the prismatic coefficient, Cp

Coefficients of form

we define the waterplane-area coefficient by

$$C_{WL} = \frac{A_W}{LB}$$

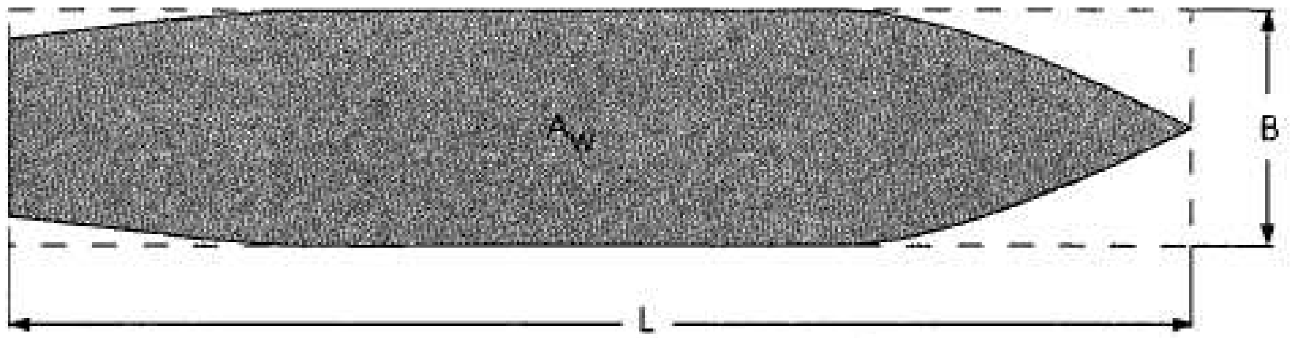


Figure 1.17 The definition of the waterplane coefficient, C_{WL}

Coefficients of form

The vertical prismatic coefficient is calculated as

$$\mathrm{CVP} = \frac{V}{A_W T}$$

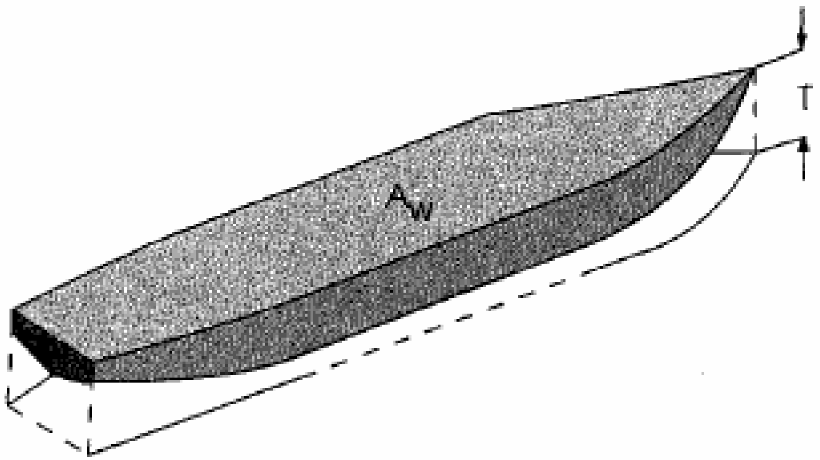


Figure 1.18 The definition of the vertical prismatic coefficient, CVP

Coefficients of form

The length coefficient of Froude, or length-displacement ratio is

$$\textcircled{M} = \frac{L}{\nabla^{1/3}}$$

Hydrostatic curves

We call these properties hydrostatic data and show how to plot them,
as functions of draught, in curves that allow further calculations

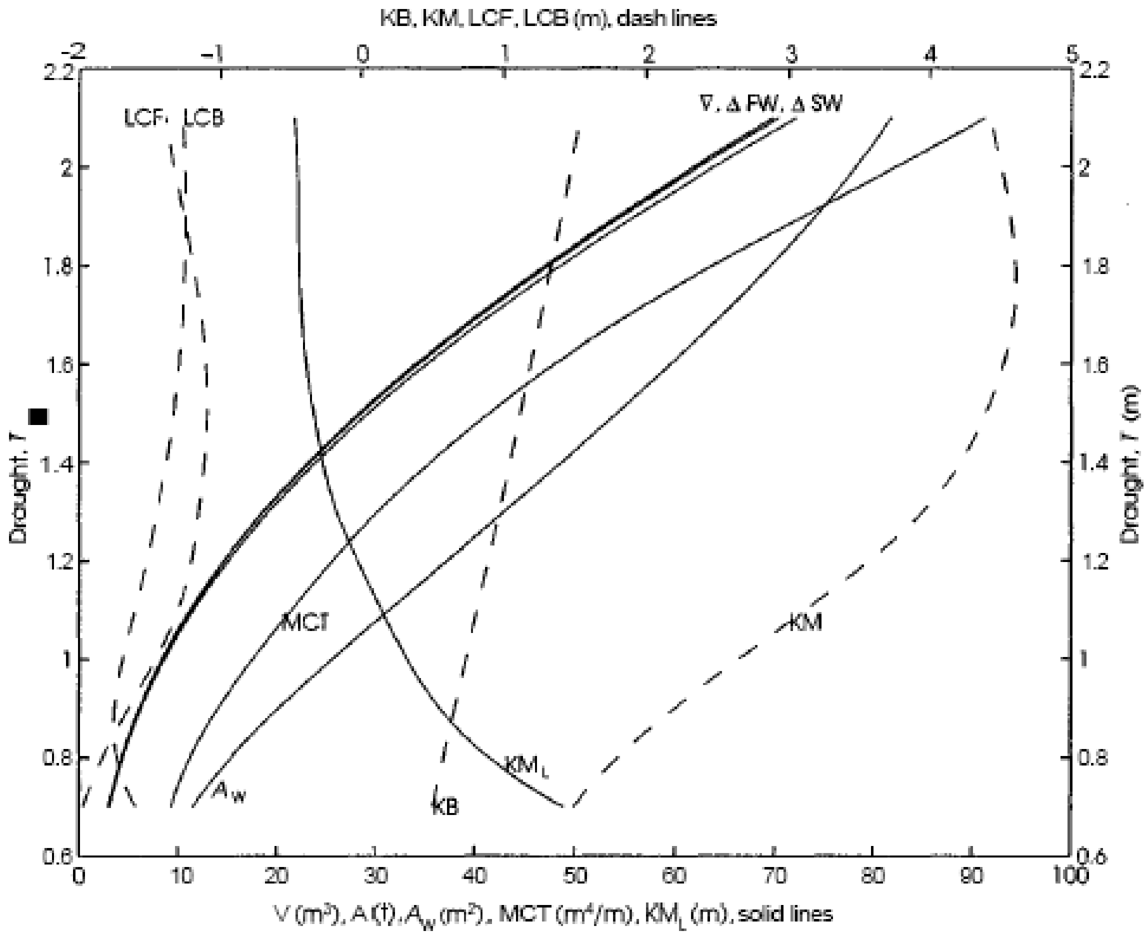


Figure 4.2 Hydrostatic curves of Ship *Lido 9*

Hydrostatic curves

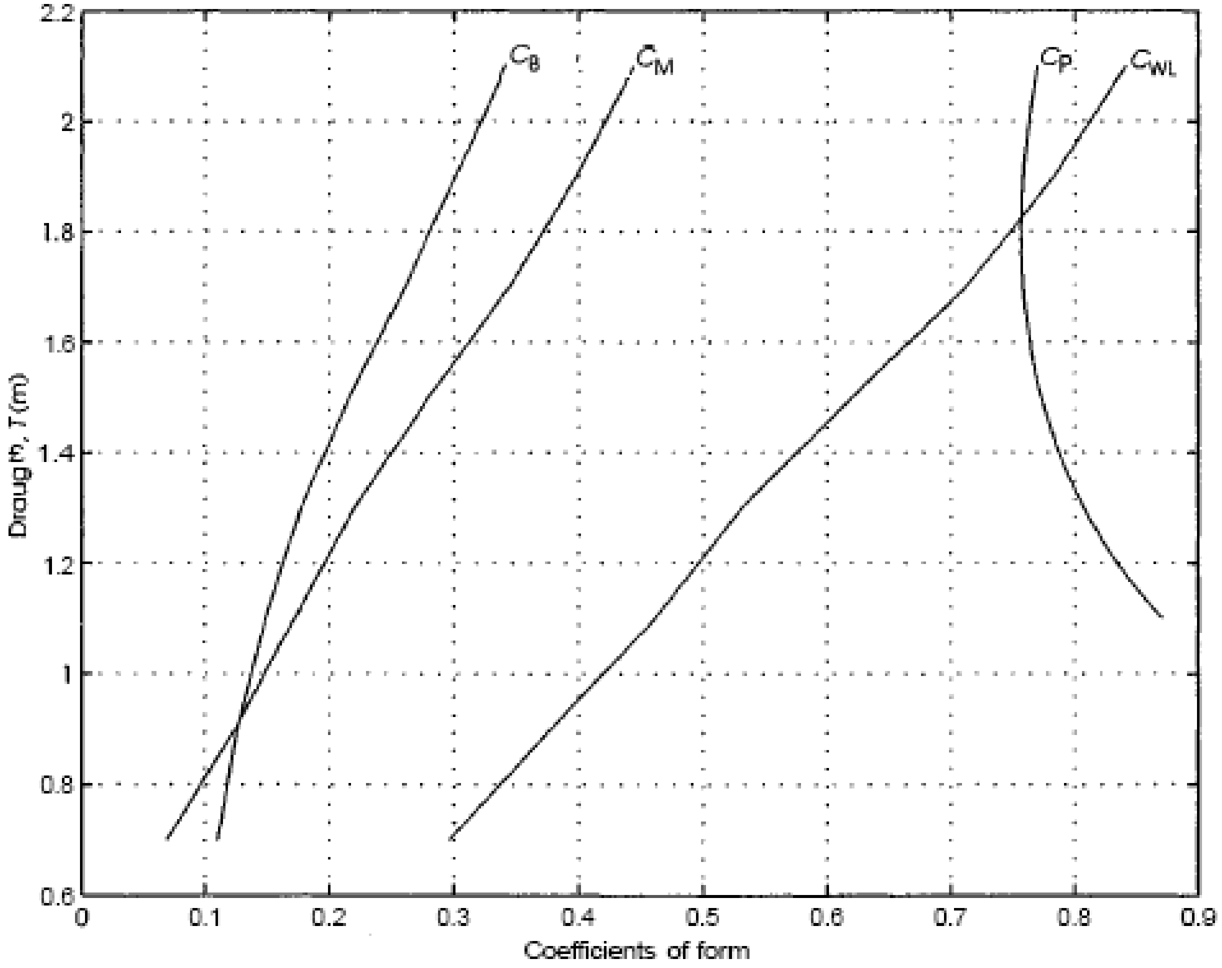


Figure 4.3 Coefficients of form of Ship *Lido 9*

Hydrostatic curves

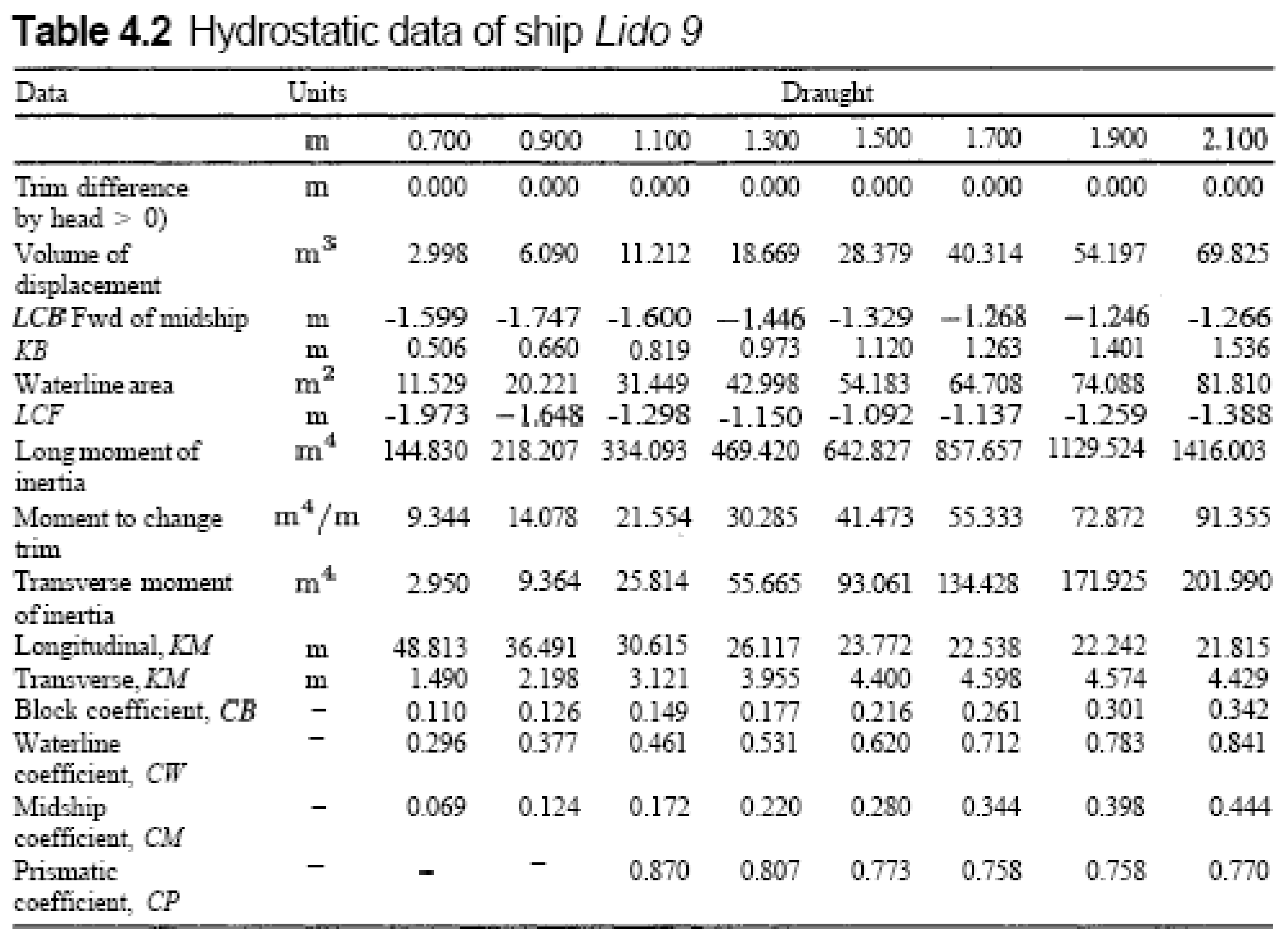


Table 4.2 Hydrostatic data of ship *Lido 9*

Data	Units	Draught							
	m	0.700	0.900	1.100	1.300	1.500	1.700	1.900	2.100
Trim difference by head > 0)	m	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Volume of displacement	m^3	2.998	6.090	11.212	18.669	28.379	40.314	54.197	69.825
LCB Fwd of midship	m	-1.599	-1.747	-1.600	−1.446	-1.329	−1.268	−1.246	-1.266
KB	m	0.506	0.660	0.819	0.973	1.120	1.263	1.401	1.536
Waterline area	m^2	11.529	20.221	31.449	42.998	54.183	64.708	74.088	81.810
LCF	m	-1.973	−1.648	-1.298	-1.150	-1.092	-1.137	-1.259	-1.388
Long moment of inertia	m^4	144.830	218.207	334.093	469.420	642.827	857.657	1129.524	1416.003
Moment to change trim	m^4/m	9.344	14.078	21.554	30.285	41.473	55.333	72.872	91.355
Transverse moment of inertia	m^4	2.950	9.364	25.814	55.665	93.061	134.428	171.925	201.990
Longitudinal, *KM*	m	48.813	36.491	30.615	26.117	23.772	22.538	22.242	21.815
Transverse, *KM*	m	1.490	2.198	3.121	3.955	4.400	4.598	4.574	4.429
Block coefficient, *CB*	–	0.110	0.126	0.149	0.177	0.216	0.261	0.301	0.342
Waterline coefficient, *CW*	–	0.296	0.377	0.461	0.531	0.620	0.712	0.783	0.841
Midship coefficient, *CM*	–	0.069	0.124	0.172	0.220	0.280	0.344	0.398	0.444
Prismatic coefficient, *CP*	–	–	–	0.870	0.807	0.773	0.758	0.758	0.770

Bonjean curves

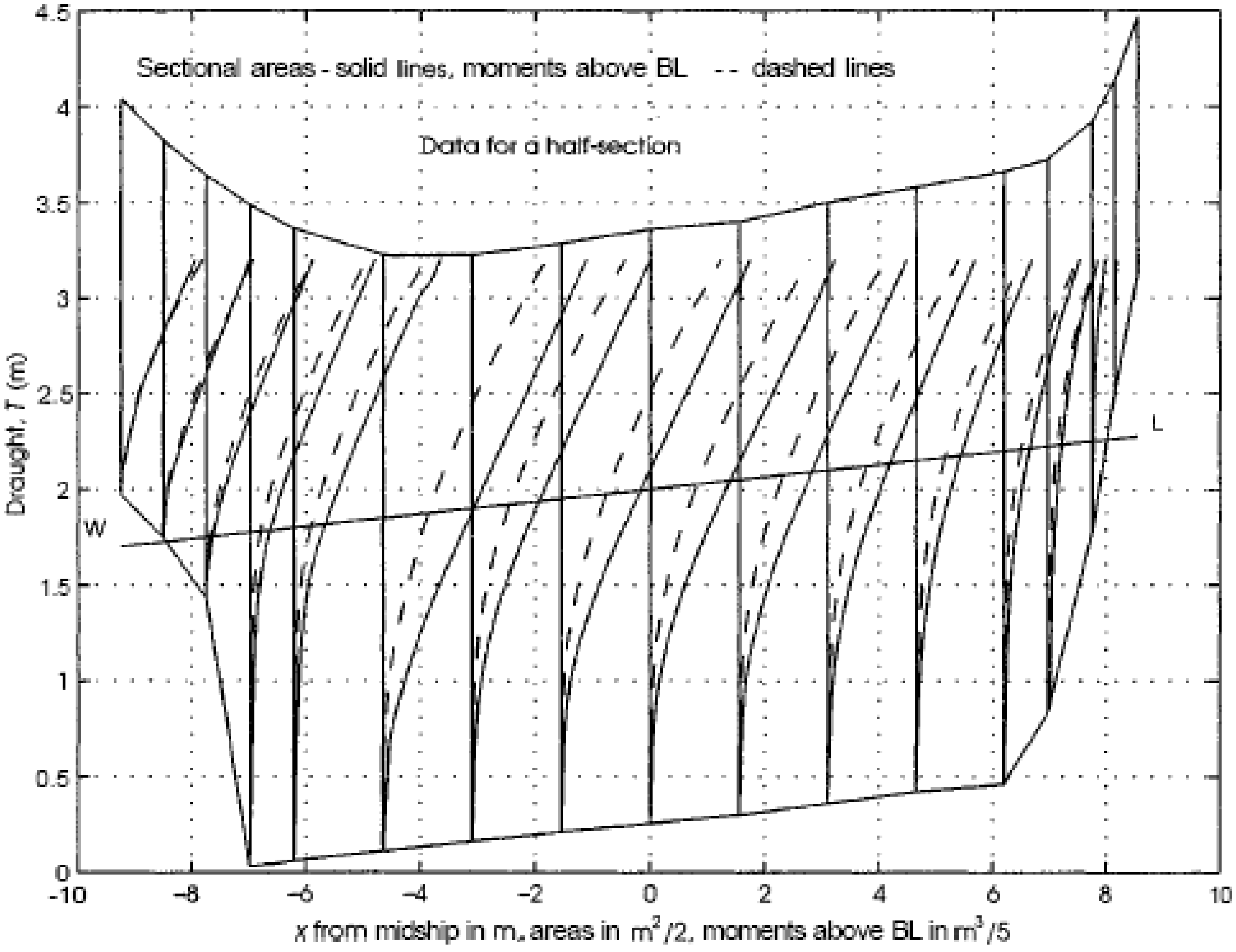


Figure 4.5 Bonjean curves of Ship *Lido 9*

Example 1

Coefficients of a fishing vessel
In INSEAN (1962) we find the test data of a fishing-vessel hull called C.484 and whose principal characteristics are: (Assumption Lwl = Lpp)

Lwl	14.251 m
B	4.52 m
TM	1.908m
V	58.536m3
Am	6.855 rn2
Aw	47.595m2

Find Cb, Cwl, Cm
Cp and check Cp

$$Cb = \frac{V}{LPP*B*TM} = \frac{58.536}{14.251 \times 4.52 \times 1.908} = 0.476$$

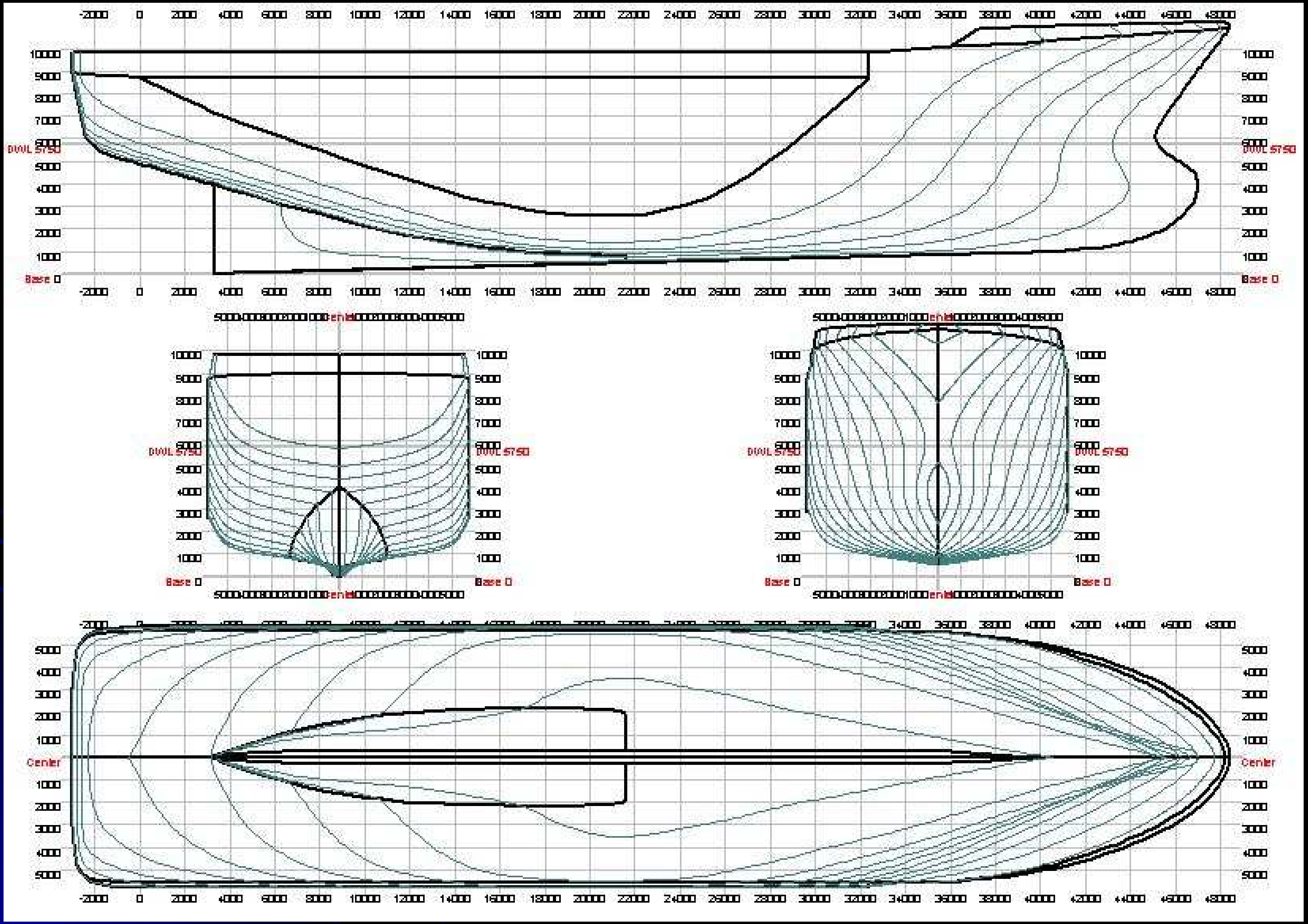
$$Cwl = \frac{Aw}{Lwl * B} = \frac{47.595}{14.251 \times 4.52} = 0.739$$

$$Cm = \frac{Am}{B * TM} = \frac{6.855}{4.52 \times 1.908} = 0.795$$

$$Cp = \frac{V}{Lwl * B} = \frac{58.536}{6.855 \times 14.251} = 0.599$$

$$Cp = \frac{Cb}{Cm} = \frac{0.476}{0.795} = 0.599$$

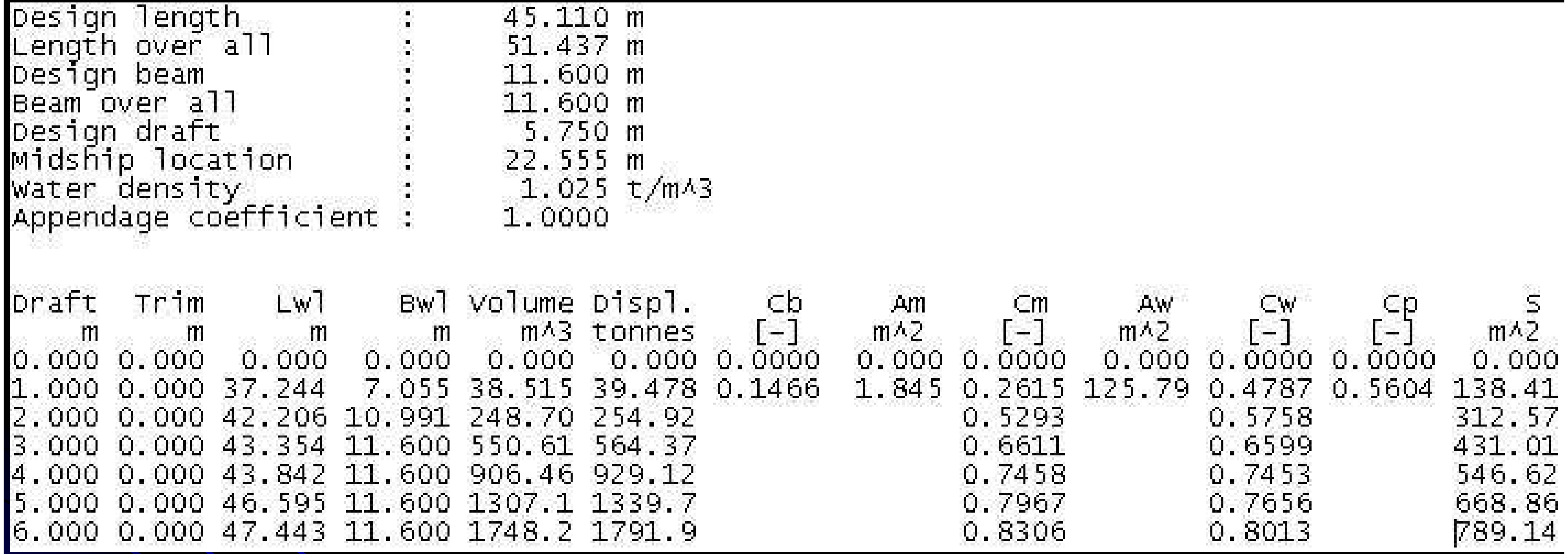
Example 2



-2000 0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000 22000 24000 26000 28000 30000 32000 34000 36000 38000 40000 42000 44000 46000 48000
10000
9000
8000
7000
6000
DWL 5750
5000
4000
3000
2000
1000
Base 0
Center

Example 2

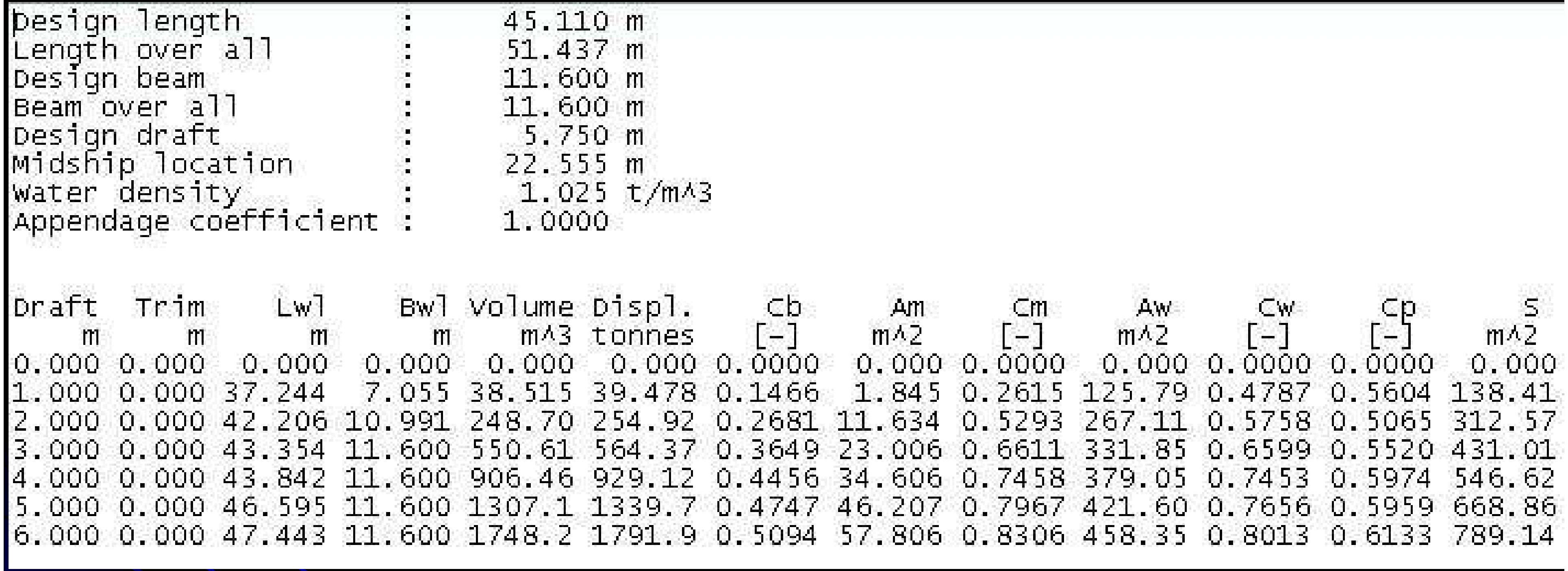
Completed the table calculation



```
Design length          :     45.110 m
Length over all        :     51.437 m
Design beam            :     11.600 m
Beam over all          :     11.600 m
Design draft           :      5.750 m
Midship location       :     22.555 m
Water density          :      1.025 t/m^3
Appendage coefficient :      1.0000


Draft   Trim     Lwl      Bwl Volume Displ.      Cb       Am      Cm      Aw      Cw      Cp       S
    m      m       m        m    m^3 tonnes     [-]     m^2     [-]     m^2     [-]     [-]     m^2
0.000  0.000   0.000    0.000  0.000  0.000  0.0000   0.000  0.0000   0.000  0.0000  0.0000   0.000
1.000  0.000  37.244    7.055 38.515 39.478  0.1466   1.845  0.2615  125.79  0.4787  0.5604  138.41
2.000  0.000  42.206   10.991 248.70 254.92                  0.5293          0.5758          312.57
3.000  0.000  43.354   11.600 550.61 564.37                  0.6611          0.6599          431.01
4.000  0.000  43.842   11.600 906.46 929.12                  0.7458          0.7453          546.62
5.000  0.000  46.595   11.600 1307.1 1339.7                  0.7967          0.7656          668.86
6.000  0.000  47.443   11.600 1748.2 1791.9                  0.8306          0.8013          789.14
```

Example 2



```
Design length           :      45.110 m
Length over all         :      51.437 m
Design beam             :      11.600 m
Beam over all           :      11.600 m
Design draft            :       5.750 m
Midship location        :      22.555 m
Water density           :       1.025 t/m^3
Appendage coefficient :      1.0000


Draft   Trim     Lwl      Bwl  Volume Displ.    Cb       Am      Cm      Aw      Cw      Cp       S
    m      m       m        m     m^3 tonnes   [-]      m^2     [-]     m^2     [-]     [-]     m^2
0.000  0.000   0.000    0.000   0.000  0.000 0.0000   0.000  0.0000   0.000  0.0000  0.0000   0.000
1.000  0.000  37.244    7.055  38.515 39.478 0.1466   1.845  0.2615  125.79  0.4787  0.5604  138.41
2.000  0.000  42.206   10.991  248.70 254.92 0.2681  11.634  0.5293  267.11  0.5758  0.5065  312.57
3.000  0.000  43.354   11.600  550.61 564.37 0.3649  23.006  0.6611  331.85  0.6599  0.5520  431.01
4.000  0.000  43.842   11.600  906.46 929.12 0.4456  34.606  0.7458  379.05  0.7453  0.5974  546.62
5.000  0.000  46.595   11.600  1307.1 1339.7 0.4747  46.207  0.7967  421.60  0.7656  0.5959  668.86
6.000  0.000  47.443   11.600  1748.2 1791.9 0.5094  57.806  0.8306  458.35  0.8013  0.6133  789.14
```

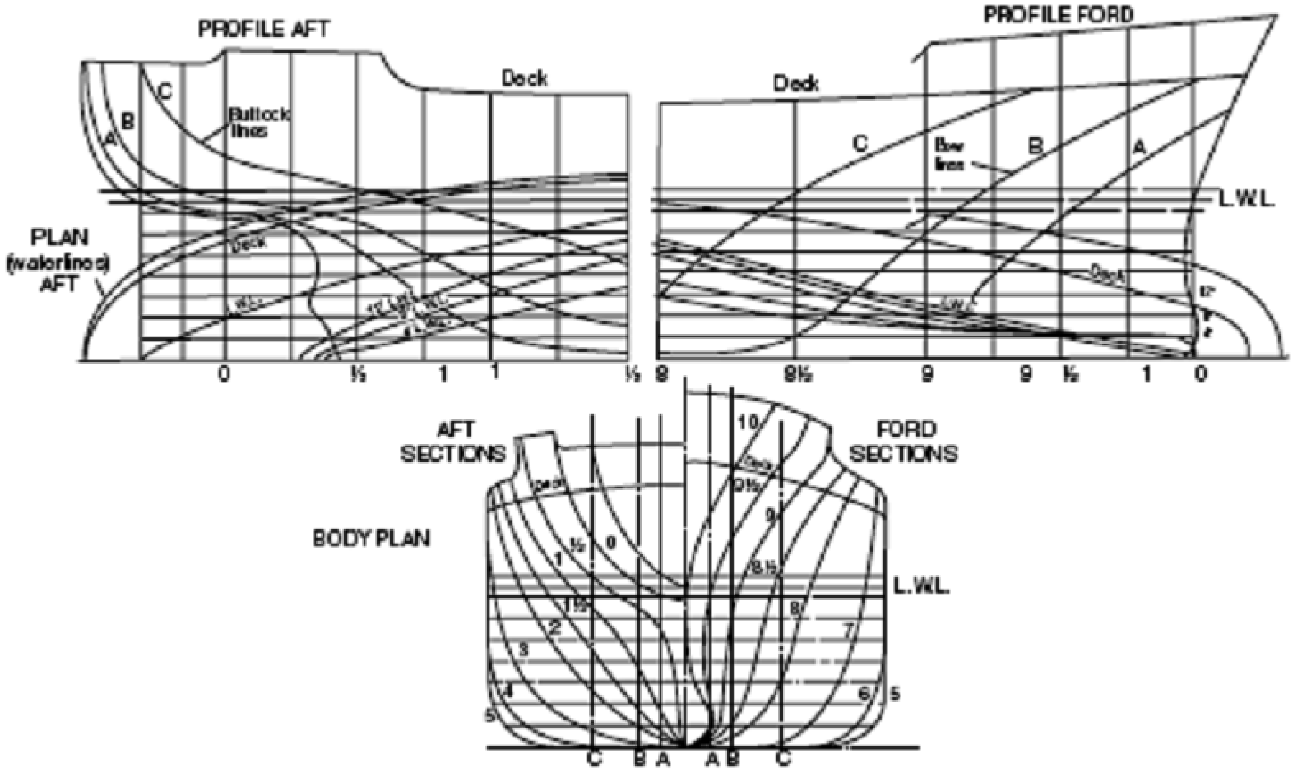
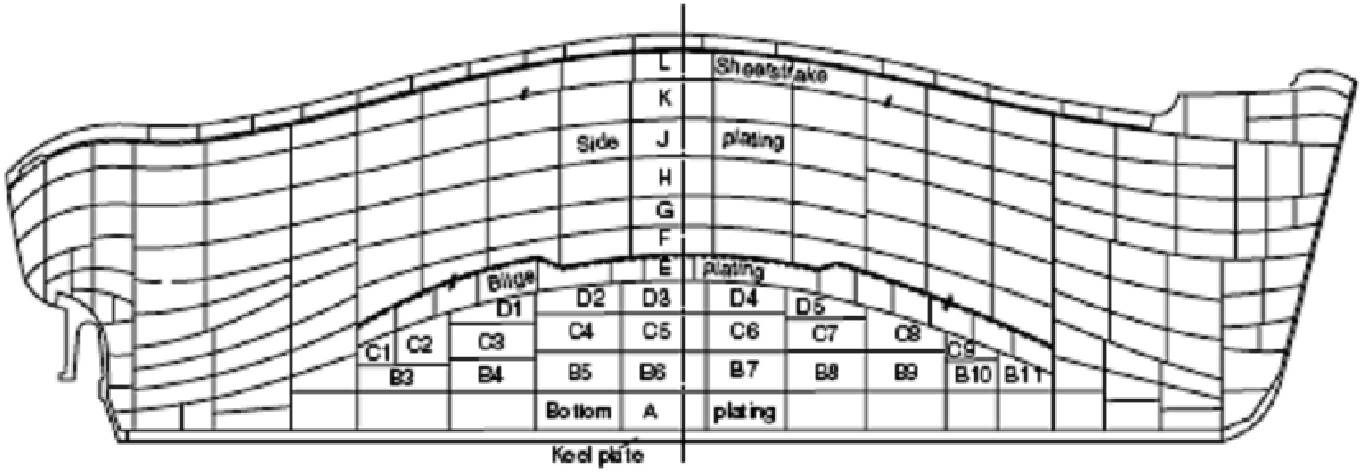


FIGURE 12.1 Linesplan



FRAMING, STRINGERS, DECKS AND OPENINGS INSIDE SHELL ARE ALSO SHOWN ON THE SHELL EXPANSION BUT HAVE BEEN OMITTED FOR CLARITY

FIGURE 12.2 Shell expansion