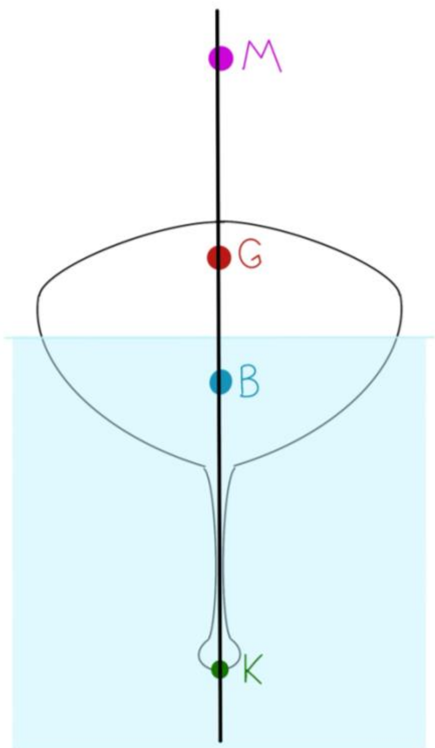
Naval Architecture / Stability

Assignment No. 3

Task No. 2 – Part 2a

Ship stability refers to the movement of a vessel after being disturbed from a state of equilibrium, such as by waves, wind or load distribution. A ship is considered to be in stable equilibrium when, upon slight inclination or disturbance from its resting position, it returns to its original orientation. Conversely, a ship is deemed to be in unstable equilibrium if, upon inclination or disturbance, it moves further away from its original position without returning. A ship is in neutral equilibrium when its new position is maintained without further movement after inclination. The image below shows a simplified midship cross section of a sailing yacht hull, where:

- K = Keel
- B = Centre of Buoyancy (CB)
- G = Centre of Gravity (CG)
- M = Metacentre (Considered a fixed position for Small Angle Stability)



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To calculate small angle stability, there are five data points that need to be known; and it is the shape of the ships hull, the forces acting upon it, and the resultant location and distances between each data point, that determine stability.

- G to M (GM) = Metacentric Height, used as a measure of small angle stability
- K to M (KM) = The distance between the keel and the Metacentre
- K to G (KG) = Vertical Centre of Gravity (VCG)
- K to B (KB) = Vertical Centre of Buoyancy (VCB)
- B to M (BM) = Metacentric Radius – Inertia / Volume of Displacement (I/V)

Metacentric Height (GM) is a key parameter used to measure a ship's initial stability. Simply, it represents the distance between the metacentre (M), which is the point of intersection of the vertical line passing through the centre of buoyancy, and the centre of gravity (G). A larger GM number indicates greater stability, whilst a smaller GM suggests reduced stability:

- GM > 0 = Positive Stability or Stable Equilibrium
- GM <=> 0 = Neutrally Stable
- GM < 0 = Negative (Poor) Stability or Unstable Equilibrium

GM is calculated by subtracting KG from KM:

- GM = KM – KG

  = (KB + BM) – KG

Therefore, the data required for calculating GM includes determining KB and BM. KM data points are found in a ship's hydrostatic tables, at which point an incline experiment can be used, whereas KG is calculated using weights and moments calculations with GM as one of the inputs.

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Task No. 2 – Part 2b

To calculate the displacement, underwater volume (V), and the waterplane area for a vessel with a current waterline length (W_L) of 29.5m, Simpsons Rule no.1, the 1/3 rule, can be applied to the data given in the table in the question as there are 10 ordinates with equally sized intervals that are divisible by 2 (10/2).

Displacement

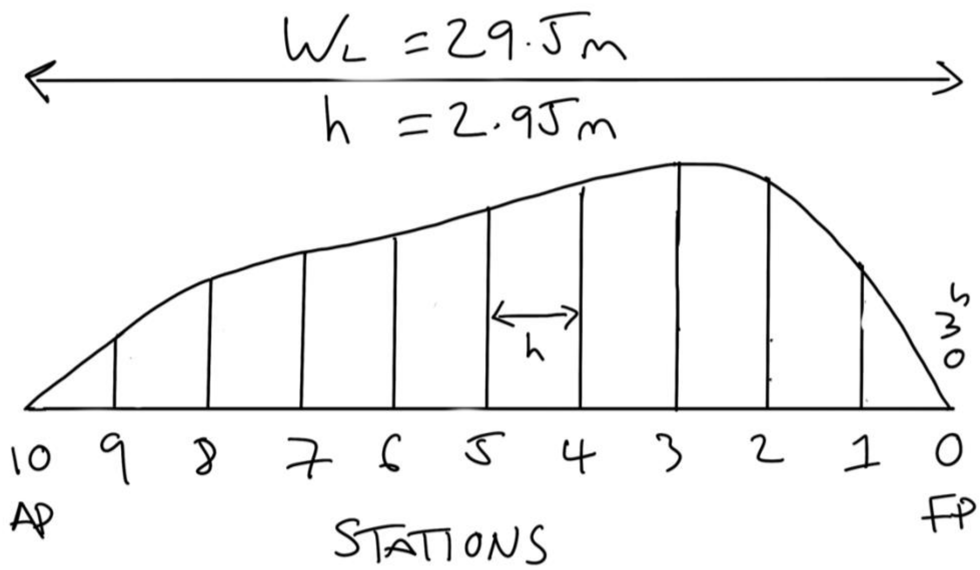
To calculate the total volume and convert this to displacement, it is necessary to follow the formula:

- V = 1/3 x h x Simpsons Rule Product Sum x 2 (as half areas are being used)

Whereby, 1/3 is Simpsons external multiplier; 'h' equals the distance between ordinates; and the product sum is found using Simpsons internal multipliers for the first rule (SM).

Sketched Curve of Cross SectionalAreas

Note. The FP has been placed at station 0, as typically in body plans and line drawings the first forward most station at the bow is 0 (Nudelman, 1990, p. 4).



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The following table shows the half areas, the internal multiplier and the resultant product.

Station	Half Area m²	SM	Product
0	0.00	1	0.00
1	3.04	4	12.16
2	4.90	2	9.80
3	5.02	4	20.08
4	4.62	2	9.24
5	4.21	4	16.84
6	3.80	2	7.60
7	3.38	4	13.52
8	2.93	2	5.86
9	1.79	4	7.16
10	0.00	1	0.00
TOTAL			102.26

Therefore:

- V = 1/3 x 2.95 x 102.26 x 2

  = <u>201.11 m^3</u>

To convert cubic metres of volume into displacement in tonnes, in salt water, it is necessary to multiply the volume by the generally accepted average density of sea water, which is 1.025 tonnes/m^3. Using this formula the displacement for the small vessel in question equals:

- <u>Displacement in Salt Water = 201.11 x 1.025 = 206.14 tonnes</u>

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Waterplane Area

Using the same Simpsons Rule, it is possible to calculate the waterplane area (WPA) of the vessel using the given half breadths.

The table below shows the resultant product from multiplying the half breadths by their corresponding Simpsons internal multiplier (SM).

Station	Half Breadths	SM	Product
0	0.00	1	0.00
1	1.7	4	6.8
2	2.6	2	5.2
3	3.4	4	13.6
4	3.4	2	6.8
5	3.4	4	13.6
6	3.4	2	6.8
7	3.4	4	13.6
8	3.4	2	6.8
9	2.9	4	11.6
10	0.00	1	0.00
TOTAL			84.8

Similar to the calculation for displacement, for waterplane area the sum of the products is multiplied x the Simpson external multiplier, 1/3, and by the distance between stations, to give a half waterplane area in m^2. The solution is then multiplied by 2 to get the total area:

- <u>WPA = 1/3 x 2.95 x 84.8 = 83.39</u>

  <u>= 83.39 x 2 = 166.78 m^2</u>

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Longitudinal Centre of Buoyancy (LCB)

The longitudinal centre of buoyancy (LCB) is the longitudinal midpoint on a vessel where all buoyant forces are said to act vertically upwards. To calculate the LCB, the vessels underwater volume and half areas need to be known, as well as the total longitudinal moment (LM). To calculate moments, it is necessary to define a datum from which the LCB centroid will be relative to; this is typically either from amidships or the aft perpendicular (AP). The distance from this datum point to the relating ordinate of area is described as the lever, measured in metres. The LCB will then be equal to the sum of LM divided by the sum of the area Products, with the resultant answer being a distance in metres from the datum point along the centreline of the vessel.

For the small vessel in question the datum point shall be the AP, starting at station 10.

Station	**Half Area m² ***	**SM =**	**Product ***	**Lever =**	**LM**
0	0.00	1	0.00	29.50	0.00
1	3.04	4	12.16	26.55	322.85
2	4.90	2	9.80	23.60	231.28
3	5.02	4	20.08	20.65	414.65
4	4.62	2	9.24	17.70	163.55
5	4.21	4	16.84	14.75	248.39
6	3.80	2	7.60	11.80	89.68
7	3.38	4	13.52	8.85	119.65
8	2.93	2	5.86	5.90	34.57
9	1.79	4	7.16	2.95	21.12
10	0.00	1	0.00	0.00	0.00
TOTAL			102.26		1645.74

- <u>LCB = 1645.7 / 102.26</u>

  <u>= 16.09m forward of AP</u>

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Calculation of Metacentric Radius (BM)

The metacentric radius BM relates to the vessels underwater geometry, and can be determined using the formula:

- BM = I / V

Where 'I' represents the transverse moment of inertia along the waterplane about the centreline axis, and V, as before, describes the total immersed volume of the hull. For the vessel in question, Simpsons rules, the displacement in salt water, and the given half breadths, can all be used to determine the second moment of inertia of the waterplane (I).

Station	Half Breadths	Half Breadths^{3}*	SM	Product
0	0.00	0.00	1	0.00
1	1.7	4.91	4	19.64
2	2.6	17.58	2	35.16
3	3.4	39.30	4	157.20
4	3.4	39.30	2	78.60
5	3.4	39.30	4	157.20
6	3.4	39.30	2	78.60
7	3.4	39.30	4	157.20
8	3.4	39.30	2	78.60
9	2.9	24.39	4	97.56
10	0.00	0.00	1	0.00
TOTAL				859.76

- Using Simpsons first rule:

  I = 1/3 x 859.76 x 1/3 x 2.95 x 2

  = 563.62

  <u>BM = 563.62 / 206.14</u>

  <u>= 2.73m</u>

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Tons Per Centimetre (TCP)

The TPC for any given draught is the weight which must be added or taken away from a vessel to change a vessel's mean draught by one centimetre. Normally TCP data sets are found in a hydrostatic table, however providing the waterplane area (WPA) and the density of the water in which the vessel is immersed are known, it is possible to calculate TCP using the following formula:

- TCP = WPA x Density x 0.01

For the example vessel, at the draught that provided the waterplane half areas and half breadths:

- TCP = 166.78 x 1.025 x 0.01
  = 1.71 tonnes / cm

Calculation of GM & KG

Using the data provided from the incline experiment, it is possible to calculate GM, and KG.

It is already known that GM = KM – KG; where KM equals the sum of KB and BM. The data of KB and BM is already known, therefore KM is equal to:

- KM = KB + BM
  = 0.737m + 2.73m
  KM = 3.567m

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The angle of heel, i.e. the angle between the cross section centre line and the intersection of a vertical line running through the new G (G_1) and CB (B_1), can be determined by dividing the distance moved by the plumb weight, by the length of the plumb line; being that it is the angle of a tangent:

- 0.075m / 3m = 0.025°

It is also possible to work out the distance moved by the centre of gravity (G) towards the position of weights A+B. These weights, a combined total of 3.6 tonnes, are 2.2m to one side of the LCB. To calculate GG_1, the distance moved by G ending at G_1, the following formula can be used:

- w x d / displacement

Where 'w' is the combined weight of the added incline experiment weights, and 'd' is the distance from the LCB.

- GG_1 = 3.6 x 2.2 / 206.14
  = 0.038m

GG_1 and GM are opposite and adjacent lengths of a right angled triangle, and therefore:

- Tan 0.025° = GM / GG_1, and therefore, GM = 0.038m / 0.025°
  <u>GM = 1.52m – Positive Stability</u>
  &
- KG = KB + BM (=KM) – GM
  = 0.737 + 2.73 – 1.52
  <u>KG = 2.047m</u>

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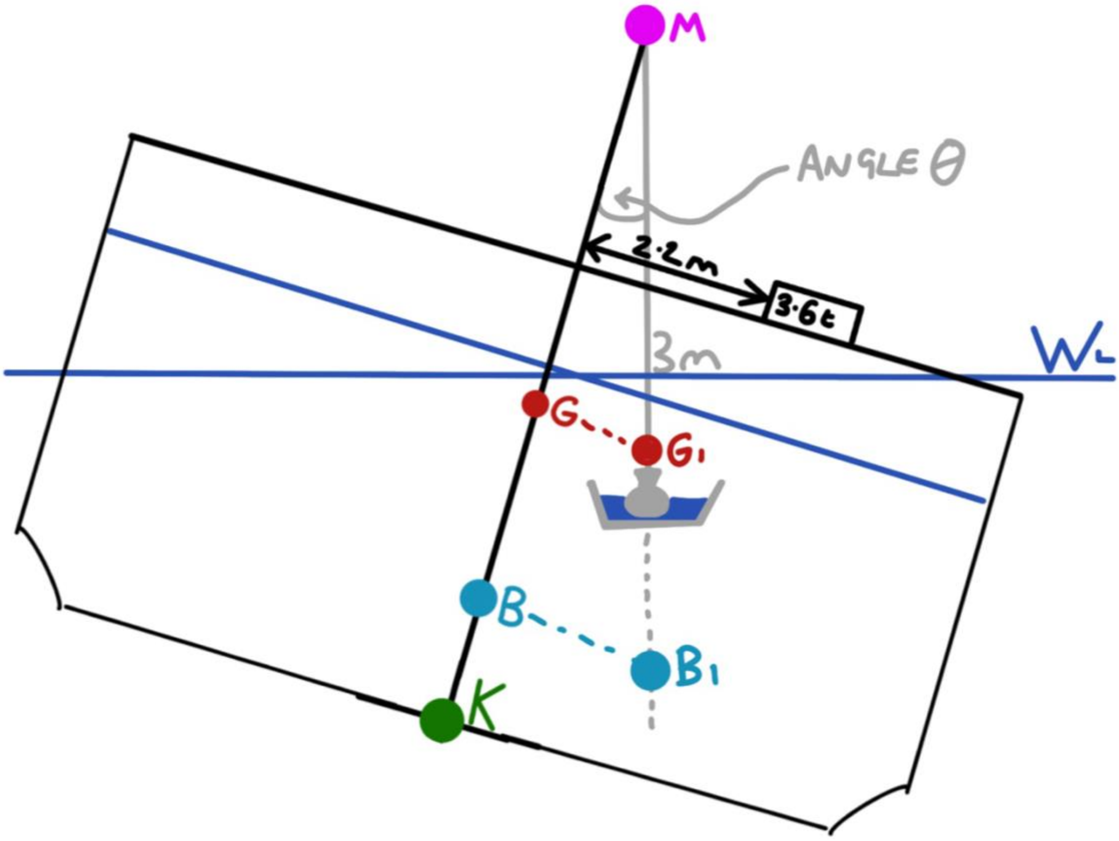
The below image shows an overly exaggerated example of an incline experiment, showing for example the movement of GG_1, the movement of B, the change in distances for KB, KG, and KM.

A more accurate illustration would also show the change in GM, either positively or negatively.



When one of the 1.8t weights is returned to its original position, I.e. 2.2m to the opposite side of the LCB to where it was stationed, the vessel will return to a state of stable and vertical equilibrium. This is confirmed by the positive GM number of +1.52.

When an additional 10 ton weight is added amidships, a number of changes in stability will take place.

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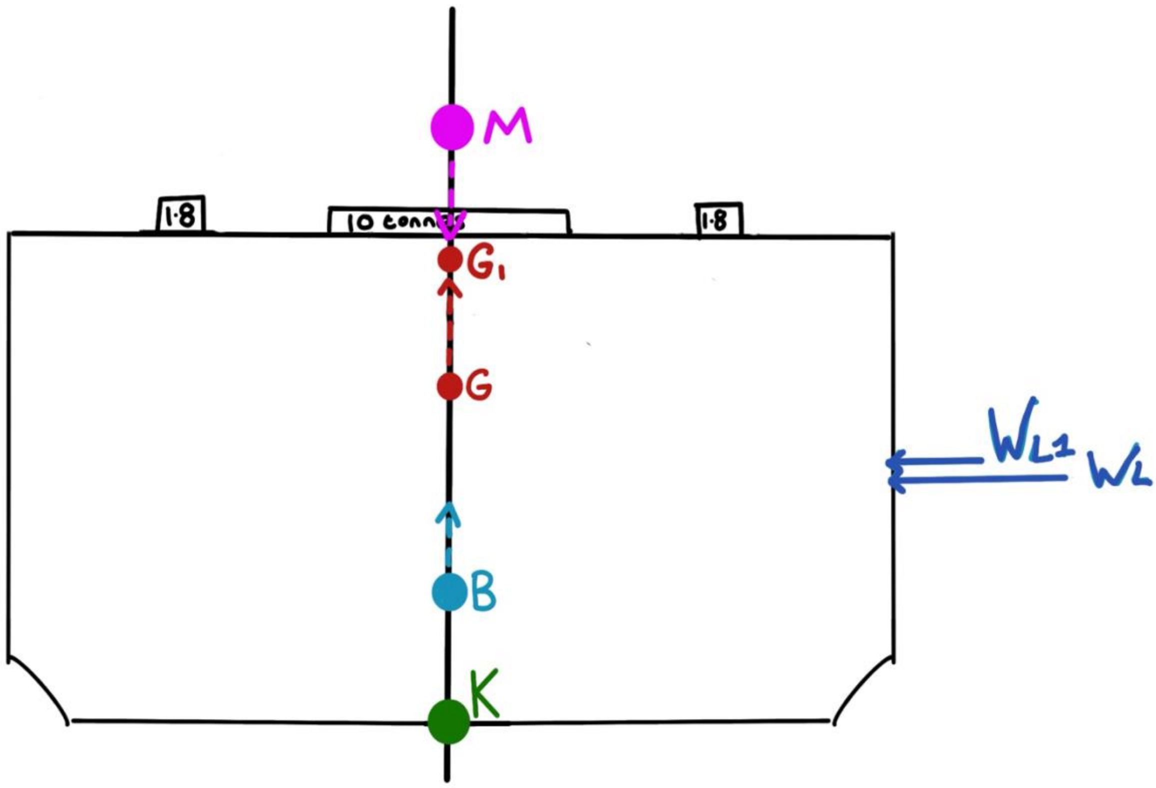

Firstly, the draught of the vessel will change. The TCP data shows that for each 1.71 tons, the vessel will sit 1 cm deeper in the water, I.e. the draught will increase by 1 cm. With an additional 10 tons added amidships, there will be an additional 5.85cm of draught, (W_L to W_{L1}). Without additional hydrostatic data, such as the waterplane hull geometry, half breadths and half areas for additional draughts, it is not possible to calculate a new displacement. Therefore the current displacement will be used. With the addition of a weight amidships, there will be significant changes to the KG as G will move towards the new weight. This movement will will be vertical, increasing KG and reducing GM.

The new KG can be calculated by using the formula to work out GG_1:

- (w (added weights) x d (distance of weights) / displacement (W)) + KG_{old}
    - As there is no d, it is simply w / W
- KG_{new} = 13.6 / 206.14 + 2.047
- <u>KG_{new} = 2.113m</u>

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Task No. 2 – Part 2c

KN curves are graphical representations of a vessel's statical stability. KN curves show the relationship between the angle of heel in degrees (°) and the righting arm in metres (m). The righting arm (KN) is the horizontal distance from the keel to the vertical line running through the centre of buoyancy and the center of gravity. This information is particularly important for working out stability at large angles where GM is no longer a measure that can be used reliably.

KN curves can therefore be used to assist with determining:

- **An Assessment of Initial Stability**
  - KN curves provide information about a ship's initial stability by showing how the righting arm changes with the angle of heel.

- **The Angle of Vanishing Stability (AVS)**
  - GZ curves can be derived from the KN curves, and therefore KN curves can be used to calculate the limiting heel angle, I.e. the point where stability becomes negative and a vessel will not return to its vertical position and therefore will capsize. The combined information from KN and GZ curves can also be used to determine the maximum moment admissible before instability in a vessel is reached for a particular displacement.

- **Evaluation of Stability at Varying Displacements**
  - Cross curves can show the the righting arm for a variety of displacements concurrently with the angles of heel. This greatly assists with determining stability at various angles of heel for equal displacements but undefined water planes. This is helpful for calculations during operations, such as during the loading and discharging of cargo.

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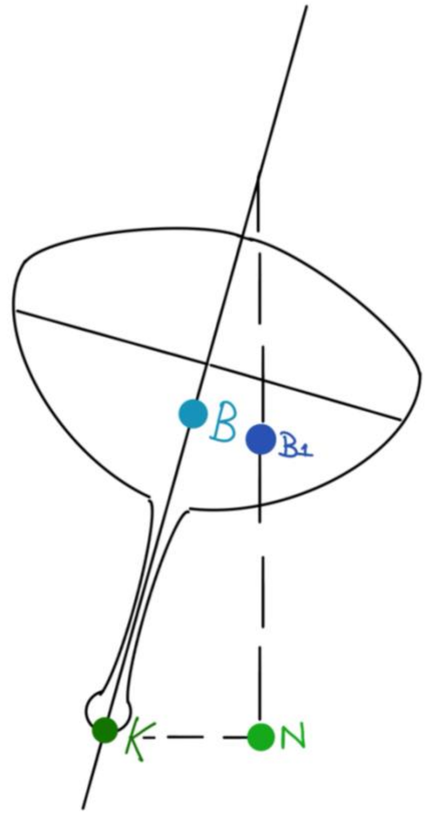
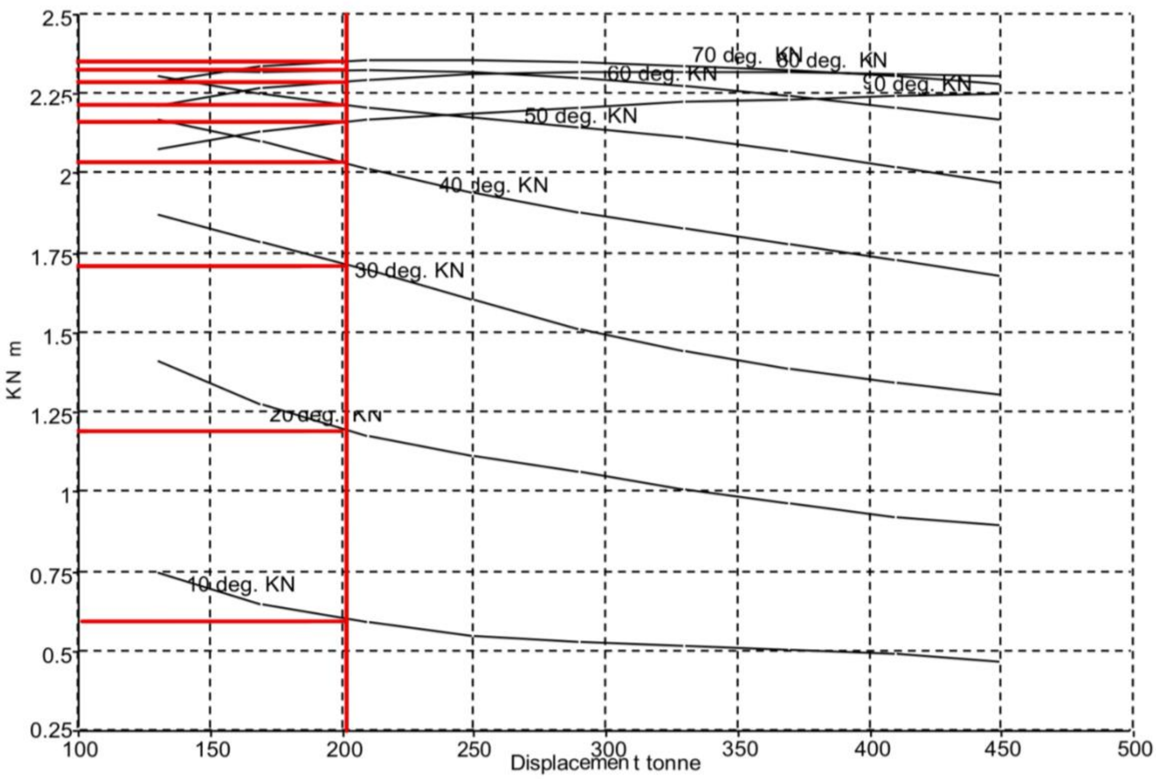


From the provided KN Curve graph, it is possible to extrapolate the righting arm for each angle of heel at the known displacement of 206.14 tonnes:



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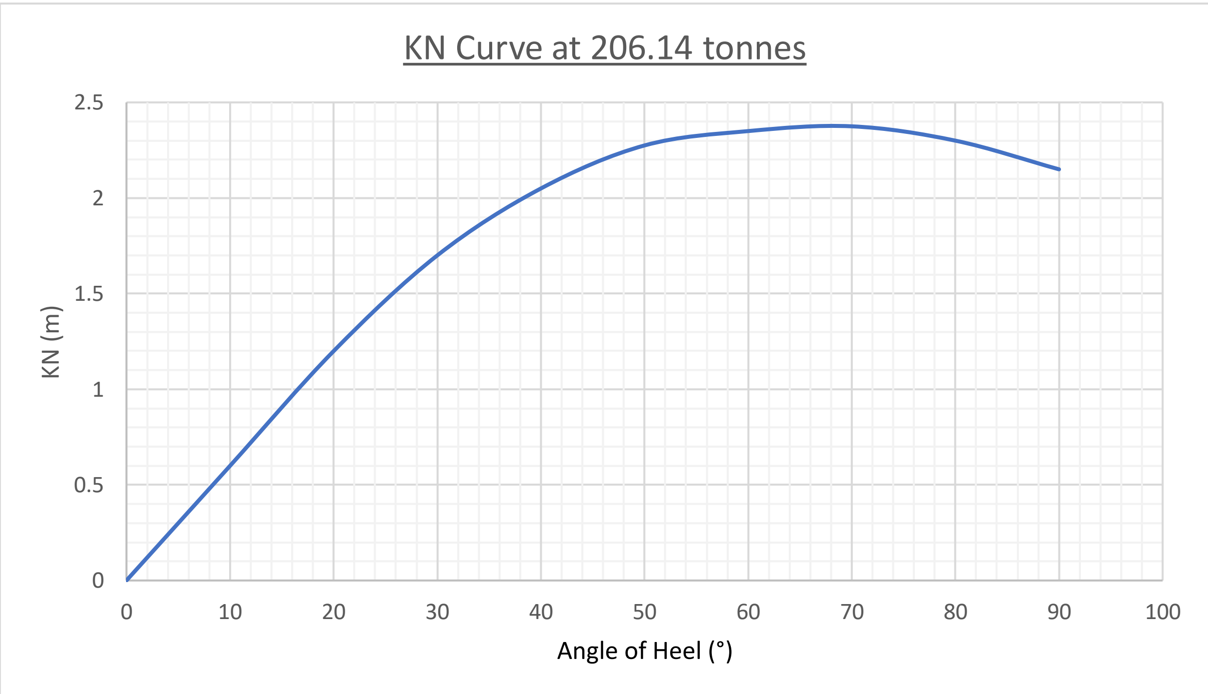
For this series of cross curves, the KN numbers extrapolated are:

Angle of Heel (°)	KN (m)
0	0
10	0.6
20	1.2
30	1.7
40	2.05
50	2.275
60	2.35
70	2.375
80	2.3
90	2.15

Where the largest KN number, KN_{MAX}, would be:

- KN_{MAX} = 2.375m

This data can then be used to formulate the KN curve of the known displacement:



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Task No. 2 – Part 2d

MCT 1cm describes the moment required to change the trim of a vessel by 1cm. This can be calculated by using the formula:

- MCT 1 = Displacement (W) x Longitudinal GM (GM_L)/ 100 x L (L = Vessels Length)

To work this equation it is necessary to know GM_L, W and L. The displacement of this particular vessel has been given as 6300 tonnes, and the length 100m, with a centre of floatation at the midships.

- $GM_L = KM_L – KG$, & $KM = KB + BM_L$

  = (3 + 104.7) – KG

  = 107.7 – 5.4

  = 102.3

- MCT 1cm = W x GM_L / 100L

  = 6300 x 102.3 / 10,000

  = 644,490 / 10,000

  = <u>64.449 tonne metres / cm</u>

Upon moving a weight of 60 tonnes, 50m towards the aft of the vessel, there will be a change in the trim due to a change in the position of the centre of flotation and the centre of buoyancy. This will cause a change in the draught at both the forward and aft ends of the vessel.

To calculate the change in draught, it will be necessary to calculate the change in trim. For this equation we need to know GG_1 (the shift of the centre of gravity after movement of the 60 tonne weight):

- GG_1 = w x d / W

  = 60 x 50 / 6300

  = 0.476m

It is now possible to work out the angle of trim, which, similar to transverse calculations, equals:

- Tan θ = GG_1 / GM_L

  = 0.476 / 102.3

  = 0.00465

  = 0.005°

Now, using the MTC 1cm, it is possible to calculate the trim change in cm at either end of this vessel by using the w x d divided by MTC 1cm.

- Change in Trim = 3000 / 64.449

  = 46.548 cm Fwd

  Therefore,

The change in Draught at each end of the vessel now equals the change in trim multiplied by the LCF / L (0.5) and either added or subtracted from the original mean draft. Therefore, the new Draughts are:

- Fwd = 600cm + (46.548cm x 0.5)

  = 6.233m

&

- Aft = 600cm – (46.548cm x 0.5)

  = 5.768m

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Assignment No. 3

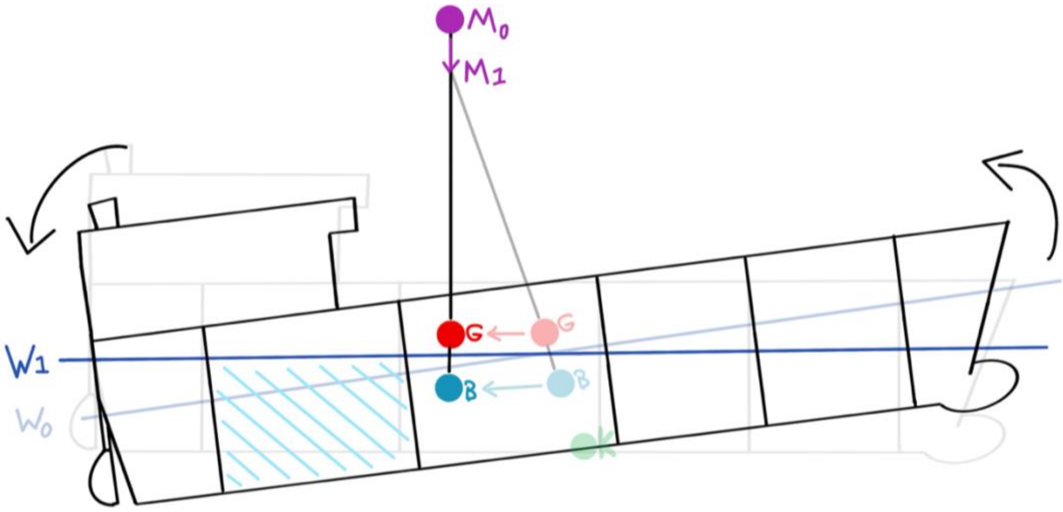
Task No. 3 – Part 3a

When discussing the effects of flooding or bilging to one or more compartments, or the ingress of water into any compartment following an incident such as a grounding, it is often longitudinal stability that is affected initially, followed by transverse stability depending on internal compartmentalisation, permeability and subdivision. This is typically true, except in the case of free-surface effect, which can induce severe changes in transverse stability very quickly. To assist in answering this question, the focus will be on the effect of water ingress on the longitudinal stability of a vessel.

Buoyancy and Stability

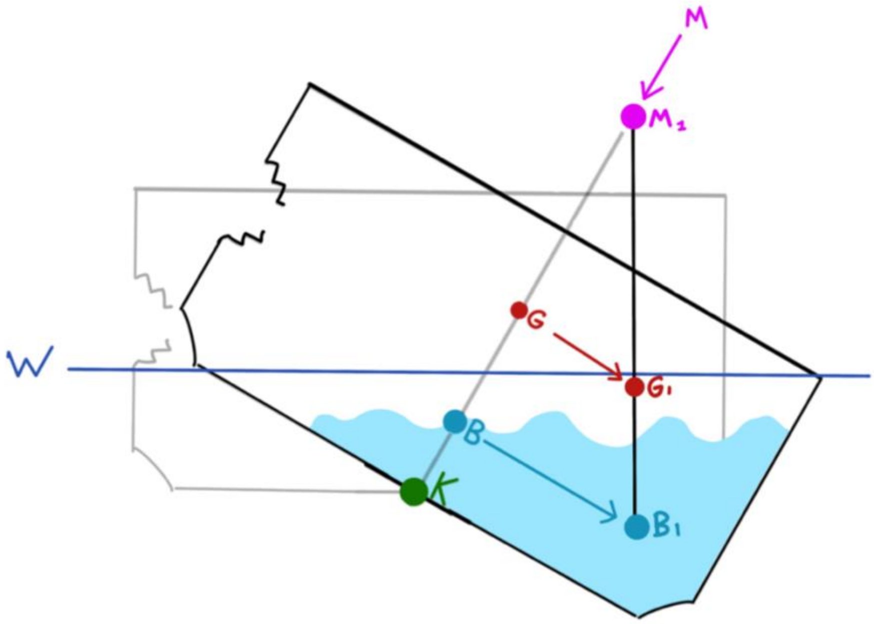
When a compartment floods, there is a reduction in the volume of buoyancy (B), which can lead to sinkage, a change in trim, and a subsequent change of waterplane and vessel stability. The position of the affected compartment, and its distance from the vessel's centre of floatation effects the location of the longitudinal centre of buoyancy (B), the location of the centre of gravity (G), the distance between the keel and the centre of buoyancy and gravity, and therefore the righting arm. As is the case of any added weight, the location G shifts towards the new weight, with B settling vertically in line with G, with the distance between each adjusting accordingly. As such, there may be a loss in Metacentric height (GM). For larger angles of trim, the effect of flooding and water ingress can be found by studying a vessels floodable length curve and hydrostatic data.

The diagram below, on page 18, shows the simplified effect of water ingress in an aft compartment, and the resultant sinkage, change in trim and exaggerated change in the location of B, G, and M. This example shows the state of equilibrium after the flooding event, on the presumption that only one watertight compartment has lost buoyancy. In the case of multiple compartments, the margin line may end up immersed, increasing the risk of down-flooding into additional compartments, especially should water broach the freeboard deck.



Free Surface Effect

In the case of partial compartment flooding, i.e. when a liquid does not completely fill the space, a free surface will form on the top of the liquid. This is more pronounced in spaces where there are large horizontal surfaces without vertical breaks, baffles or obstructions. Free surface effect is in essence the rapid movement of mass in liquid form from one location to another, creating moments that are in contrast to the general equilibrium of the vessel. This is particularly dangerous for vessels due to the changes in G and B that occur leading to unpredictable and rapid changes of GM and a loss of stability.



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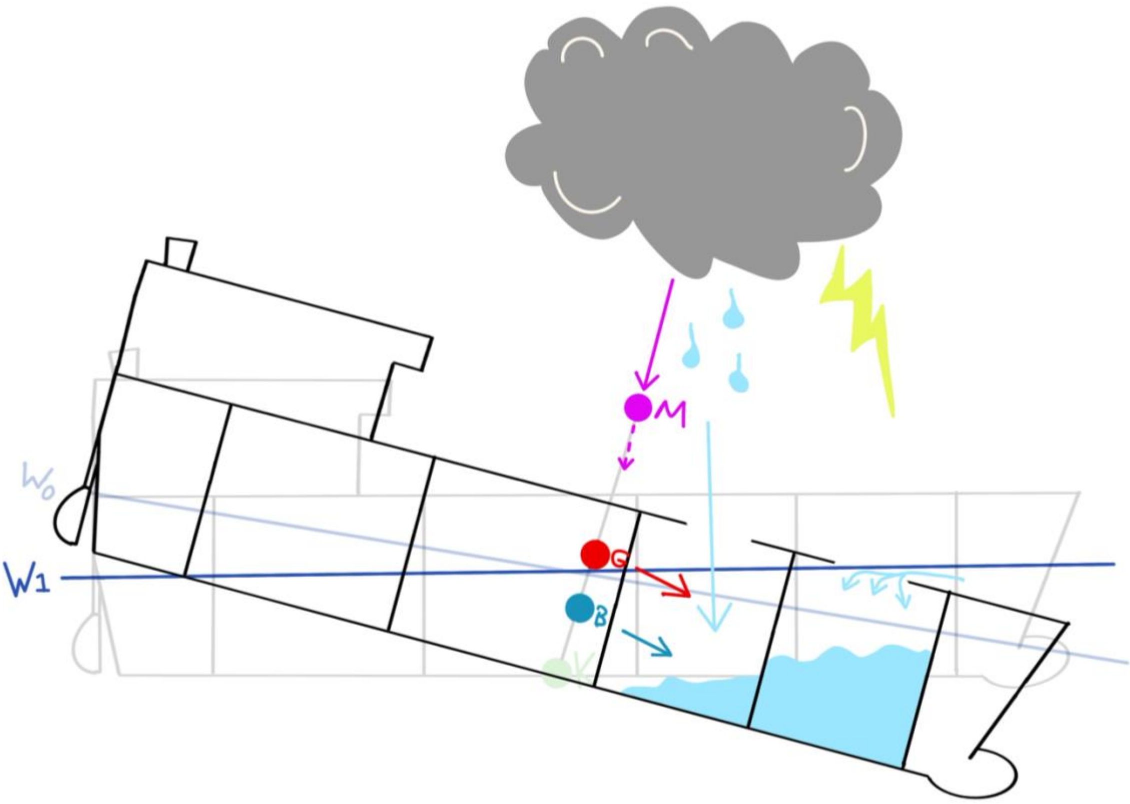
Down-flooding, Submersion and Sinkage

Down-flooding is the phenomena of water filling spaces from above through on deck down-flooding points, hatches, or areas of damage during inclement weather or when navigating through adverse sea conditions.

As water enters through openings, there will be an increase and redistribution of mass, and the vessel's transverse and longitudinal axis will be subjected to asymmetrical and un-ballasted loading. This will affect the location of G, the location of B and will force a change of GM and stability. When there is a reduction of buoyancy at either end of a vessel, sinkage can occur, which may lead to an increase in draft and a change of trim, resulting in reduced freeboard, further compromising seakeeping performance, and perpetuating the risk of down-flooding and submersion.



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Task No. 3 – Part 3b

"There is no danger that the Titanic will sink. The boat is unsinkable and nothing, but inconvenience, will be suffered by the passengers"
(Franklin, 1912)

Despite Mr Franklins boast, in 1912, a high-speed collision with an iceberg caused severe damage to the Titanic's hull, leading to rapid flooding and bilging of its underwater compartments. Bulkheads at the time did not extend to a bulkhead deck, and therefore the internal subdivision was not watertight, and the internal structure was in fact permeable. Once one compartment was flooded, water was able to flood freely to the next, from compartment to compartment, resulting in rapid loss of watertight integrity, buoyancy and stability. The presumed to be watertight subdivision of the ship was not as thought to be, and The Titanic foundered in the North Atlantic with the loss of approximately 1,500 lives.

In 1914, in direct response to the tragedy, a number of international bodies used the lessons learned to pen a global treaty aimed at improving the safety of merchant ships as the disaster had highlighted critical deficiencies in ship safety, particularly with the design and implementation of watertight subdivision. This treaty was named the International Convention for the Safety of Life at Sea (SOLAS), and since 1974 the International Maritime Organisation (IMO) has included SOLAS as one of its four pillars. In the modern era, the 175 IMO member states are required to adhere to and enforce the minimum standards as set out in SOLAS 1974.

Enforced by the signatory flag states and classification societies, the SOLAS 1974 convention establishes rigorous standards to govern the design, construction, and operation of ships. Integral to the SOLAS convention, and the more recent amendments including SOLAS 2009 and SOLAS 2014 / 2020 (the latter implemented as a direct result of the Costa Concordia incident), are provisions for subdivision and damage stability. These provisions are in place to ensure that a ship will remain stable and afloat after assumed damage.

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SOLAS Chapter II-1, 'Construction – Subdivision and Stability, Machinery and Electrical Installations', outlines, amongst other items, the regulations for mitigating the effects of flooding through the implementation of the following:

- Watertight Integrity and Subdivision
  - Ships shall be as efficiently subdivided as is possible, having regards to the service for which they are intended.
  - As per regulations 4-7 of SOLAS 1974 whereby Floodable lengths and factors of subdivision are used to calculate degrees of subdivision.
  - SOLAS 2009, and more recently SOLAS 2020, introduced parts B1-B4, to supersede the use of floodable lengths and factors of subdivision. SOLAS 2009 contains regulations on the use of Subdivision Lengths and probabilistic damage calculations for deterministic assessment of degrees of subdivision. The degrees of subdivision vary with the subdivision length of the ship and the highest degree of subdivision corresponds with those ships engaged in the transport of passengers.
  - Ships must be constructed with watertight compartments to restrict the effects of flooding in the event of hull damage. National bodies may impose restrictions on the number of compartments that are permissible to be flooded to maintain buoyancy and stability.
  - Watertight bulkheads must extend vertically to the bulkhead deck and remain watertight unless damaged, to contain flooding within the watertight compartment.
- Subdivision Load Lines
  - Criteria for assigning subdivision load lines based on the ship's length and service operations, such as in SOLAS 2009 Part B-3.
  - Subdivision load lines will indicate the maximum permissible draft corresponding to various loading conditions to ensure adequate reserve buoyancy and stability.

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- Damage Stability
  - Standards for maintaining stability in the event of flooding or hull damage.
  - Criteria for intact stability and damage stability.
- Cross-Flooding Arrangements
  - Provision of cross-flooding arrangements to manage free surface effect and maintain stability during flooding and water ingress incidents.
  - Controlled transfer of water / ballast between compartments to improve stability.
- Bilge Pumping Systems
  - Requirements for bilge pumping systems to remove water from flooded compartments.
  - Standards of minimum pumping capacities and redundancies to ensure effective evacuation of liquids in emergency situations.
- Permeability
  - Standards relating to the permissible permeability of general and cargo compartments.

Naval Architects, designers, and shipyards must also give consideration to the future flag state under which a proposed vessel will be registered, and to the sea areas upon which the ship is planning to sail.

A modern, large passenger cruise liner that is penned to operate under the United Kingdom flag registry, would not only be required to be designed and built in accordance with the international rules and regulations as laid out by the IMO, but will also be required to adhere to the rules and instructions as may be imposed by the United Kingdom's flag state authority. Which, in this example, would be the Maritime and Coastguard Agency (MCA). It would be the MCA who would issue certification, such as a Passenger Ship Safety Certificate, rather than the international body. The MCA also issues guidance for designers, naval architects and surveyors, such as the 'Instructions for the guidance of Surveyors on Damage Stability SOLAS 2020 – With Explanatory Notes, MSIS42'.

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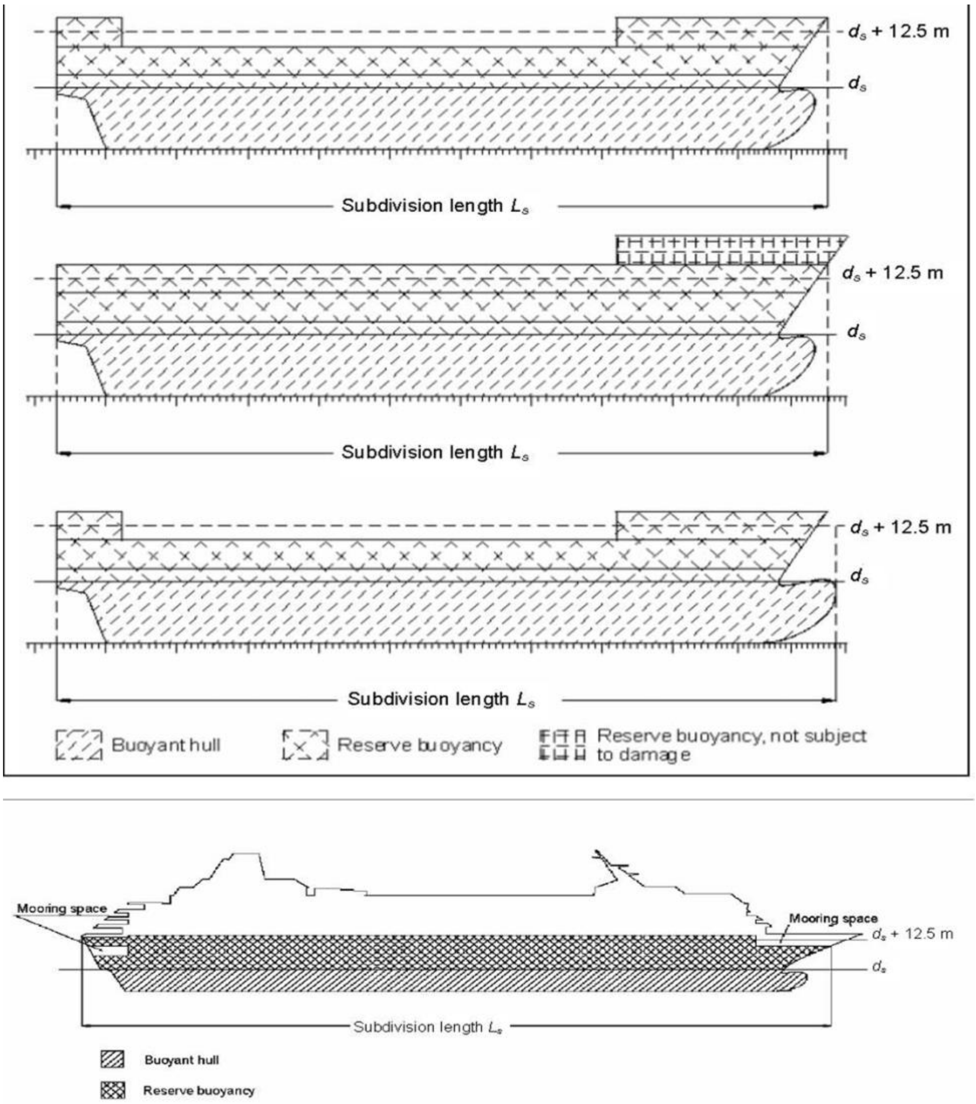
Furthermore, flag states often appoint and recognise organisations such as Classification Societies, to act on behalf of the flag state to carry out surveys and inspections. Those involved in the design of a new passenger vessel would therefore be required to follow class rules, whose rules will align with those of the flag state and international body.

In summary, international and national rules and regulations on subdivision and watertight integrity, play a crucial role in ensuring the safety of lives at sea, by reducing the risk of catastrophic incidents occurring such as the sinking of the Titanic and the foundering of the Costa Concordia.



(Subdivision Lengths and Reserve Buoyancy, MCA, 2023)

Naval Architecture / Stability

Task No. 3 – Part 3c

Methods to Determine the effects of Flooding

A vessel may flood in a variety of ways and for a variety of reasons. Bilging may occur after damage to the hull; water ingress can result from submersion and down flooding; there may be inwardly pumped water due to a mechanical fault; or for example, the installation of incorrect piping systems may lead to back siphoning when a vessel is heeled. Regardless of the cause, flooding will most notably affect a vessels buoyancy and stability, in turn affecting trim and draught. Therefore, during the design process for any vessel, the effects of flooding need to be calculated to ensure that the design will meet stability criteria. To determine how flooding may affect a vessel there are a number of methods in common use:

- Hydrostatic Calculations
  - There are are a number of common calculations in use:
    - The Lost Buoyancy Method – This method focuses on the loss in buoyancy resulting from the flooding of a compartment, and the impact on the vessel's hydrostatic properties, where the position of G is assumed to remain unchanged.
    - The Added Weight Method – This method regards any water entering a compartment as an added weight, and initial calculations follow the same format as for any added weight.
      - Challenges occur as free surface effects need to be accounted for, using Steiners Theorem.
    - Stability in the Damaged Condition – Both of the previous methods only determine changes in the flooded waterplane, i.e. changes to draught and trim.
      - Therefore, calculations need to be made for changes in stability through estimating a loss of GM.

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- Computational Fluid Dynamics (CFD) & Computerised Damage Simulations
    - CFD and dynamic computer simulations can be used to model the behaviour of water inside a flooded compartment, and provide accurate predictions of changes in draft, trim, and stability under various flooding conditions.
    - Computerised simulations require modern and expensive computational resources, and specific expertise is required to design a simulation and interpret the findings.
    - The loss of buoyancy method is typically used for computerised calculations.

- Model Testing
    - Model testing involves constructing a scaled-down physical model of a vessel and subjecting it to a controlled flooding experiments in a wave tank or towing tank and provides real time, visible, data on the effects of flooding to draft, trim, stability and manoeuvrability in the damaged condition.
    - This method is extremely useful to validate theoretical predictions.
    - Model testing can be time consuming and costly, and the results are dependant on the accuracy of the scaled model.

(Scale Model of a Large Cruise Ship, Yuura, 2020)

Naval Architecture / Stability

Case Study

To explain how to manually calculate the effects of water ingress on a vessel, I will use the example a fictional 1000 DWT box shaped short-sea trading vessel / coaster. All drawings are for illustration purposes only, and are not to be used for calculations.

MV Malheureuse – General Characteristics

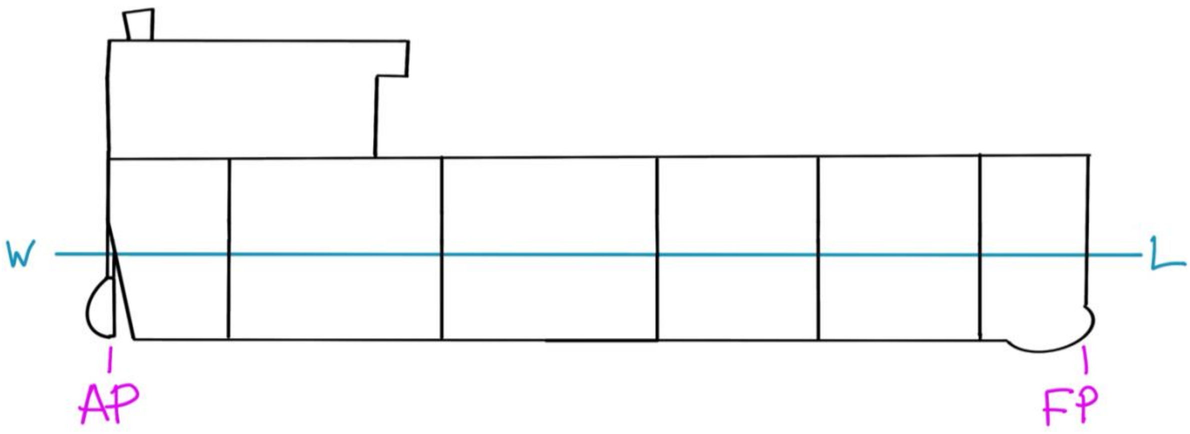
Length (L) – 50.0m

Breadth (B) – 10.0m

Max Draught – 3.0m

DWT Capacity – 1000 tonnes

Lightship Displacement – 300 tonnes



Current Draught (D) – 2.95m

Current Total Underwater Volume (UV) – 1,475m^3

Current Displacement in Salt Water – 1,475 x 1.025 = 1,511.875 tonnes

KG of the Vessel – 2.25m

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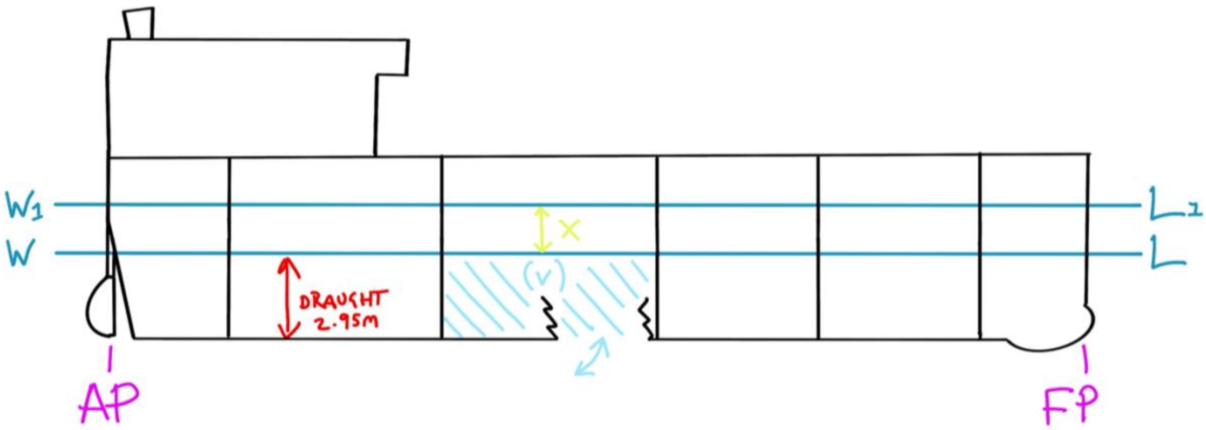
Changes in Draught

Due to a collision, whilst underway on an even keel, with an unidentified floating object, the coaster has been holed in its midships compartment and is bilged. Due to a loss in buoyancy, the vessel has settled at a new waterline (WL_1) and the change in draught needs to be calculated. The lost buoyancy method will be used in the first instance, the length of the midships compartment (Lc) is 14m and the compartment has 100% permeability.



- Increase in Draught (x) = Vol. of Lost Buoyancy (v) / Area of Intact Waterplane (A-a)
  - Increase in Draught (x) = Lc x B x D / A - a
  - x = 14 x 10 x 2.95 / A – a
  - x = 413 / (L x B) – (Lc x B)
  - x = 413 / (50 x 7) - (14 x 7)
  - x = 413 / 350 – 98
  - x = 413 / 252
  - x = 1.639m
- Therefore, the New Draught = 2.95 + 1.147 = 4.589m

In this example, there has been no change in trim, as the vessel remains on an even keel due to having been bilged amidships.

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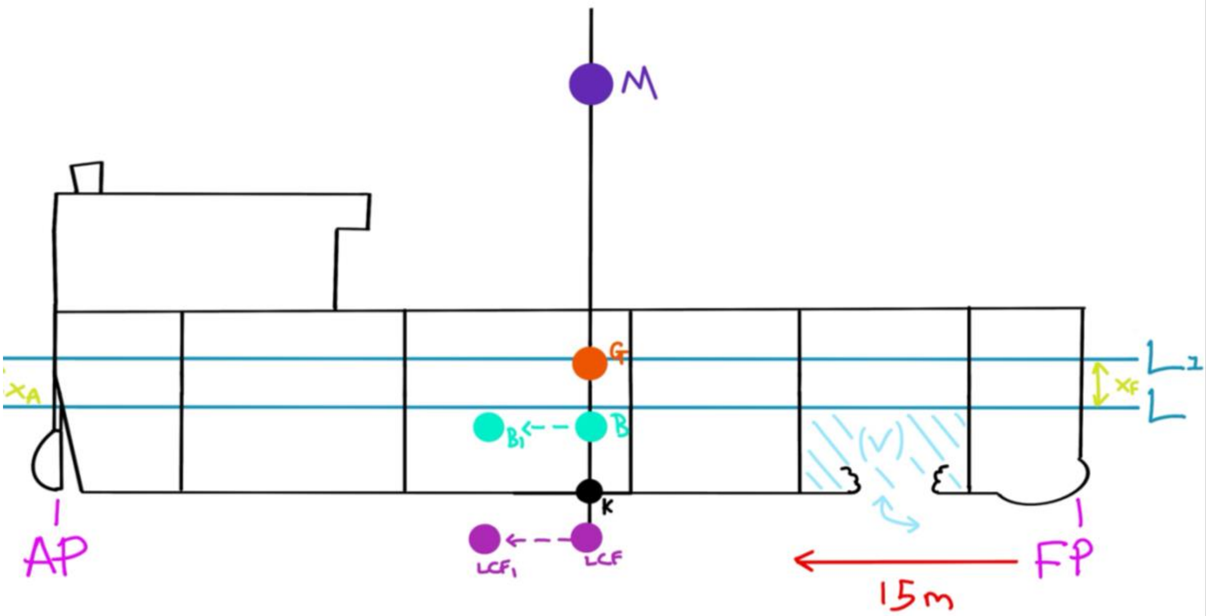
<u>Changes to Trim</u>

The MV Malheureuse had been repaired and was underway on an even keel, but unfortunately struck another floating object, holing a forward compartment that has become bilged. The forward compartment has an aft bulkhead 15m from the FP; the length of the compartment (Lc) is 7m; and the permeability (P) is 60%. As the loss of buoyancy is forward of the original longitudinal centre of floatation (LCF), the longitudinal centre of buoyancy and LCF will move aft (B_1 + LCF1) to compensate as the vessel finds equilibrium at the new area of intact waterplane.



- Sinkage (S) = Vol. of Lost Buoyancy (v) / Area of Intact Waterplane (A-a)
  - Vol. of Lost Buoyancy (v) = 0.6 x 7 x 10 x 2.95
  - v = 123.9
  - Area of Intact Waterplane (A-a) = (50 x 7) – (7 x 7 x 0.6)
  - A-a = 350 – 29.4
  - A-a = 320.6
  - S = 123.9 / 320.6
  - <u>Sinkage = 0.386m</u>
  - Mean Draft = 2.95 + 0.386
  - <u>Mean Draft @WL_1 = 3.336m</u>

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- LCF_1 = P x Lc x B x Dist. Between LCF and Centroid of Lost Buoyancy / A-a
  - Dist. Between LCF and Centroid of Lost Buoyancy = (0.5 x L) – 15 + (0.5 x Lc)
  - Dist. Between LCF and Centroid of Lost Buoyancy = 25 -15 + 3.5
  - Dist. Between LCF and Centroid of Lost Buoyancy = 13.5m
  - 0.6 x 7 x 10 x 13.5 / 320.6
  - 567 / 320.6 = 1.769
  - LCF_1 = 1.769m Aft of midships or 23.231m forward of AP

- To calculate the change of trim it is necessary to calculate the new hydrostatics, and parallel axis theorem can be used to help calculate BM_L, KM_L, and GM_L. KG has already been given at 2.25m.
  - BM_L of (A-a) = Longitudinal moment of Inertia (I_L) of (A-a) about LCF_1
    /
    Total Underwater Volume (UV)
  - I_L Centroid of Damaged Compartment = $P(BxL^3 / 12) + B \times L \times 1.769^2$
  - I_L Centroid of Damaged Compartment = (10 x 125,000/12) + 1564.68
  - I_L Centroid of Damaged Compartment = 104,166.67 + 1564.68
  - I_L Centroid of Damaged Compartment = 105,731.35m^4
  - I_L Lost waterplane area = $P(BxLc^3 / 12 + B \times Lc \times 15.269^{2)})$
  - I_L Lost waterplane area = 0.6 (10 x 343 / 12 + 10 x 7 x 233.14)
  - I_L Lost waterplane area = 0.6 (285.83 + 16319.8)
  - I_L Lost waterplane area = 9,963.378m^4
  - I_L about LCF1 = 105,731.35 - 9,963.378
  - I_L about LCF1 = 95,767.972 m^4
  - BM_L = 95,767.972 / 1475
  - BM_L = 64.927m
  - $KM_L = KB_1 + BM_L$
  - KM_L = (3.336/2) + 64.927

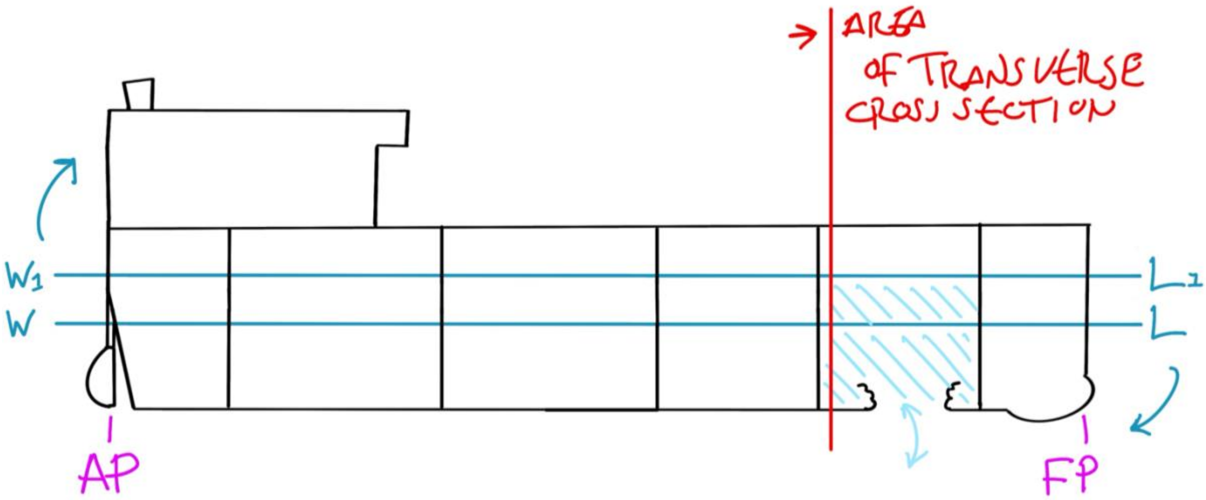
- <u>KM_L = 66.595m</u>
- $GM_L = KM_L – KG$
- GM_L = 66.595 – 2.25
- <u>GM_L = 64.345</u>

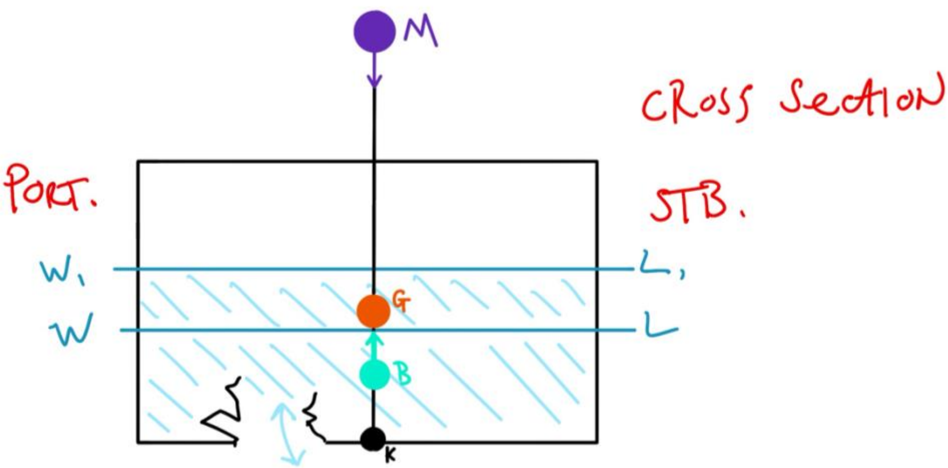
- Knowing GM_L, it is now possible to calculate MCTC.
  - MCTC = W x GM_L / 100 x L
  - MCTC = 1,511.875 x 64.345 / 100 x 50
  - <u>MCTC = 19.456 tonne metres</u>
- Then to calculate the change of trim (Tc).
  - Tc = Trimming Moment (Tm) / MCTC
  - Tc = Volume of Loss of Buoyancy x 1.025 x Centroid Distance from LCF1
    /
    MCTC
  - Tc = 123.9 x 1.025 x 15.269 / 19.456
  - <u>Tc = 99.667cm or 0.997m</u>
- Therefore, to calculate the change of trim by the head, it is necessary to use the LCF_1 distance from the AP as calculated earlier.
  - Change of Trim aft = Tc x LCF_1 AP / LBP
  - Change of Trim aft = 0.997 x 23.231 / 50
  - <u>Change of Trim aft = 0.463m</u>
  - Change of Trim fwd = Tc – Ta
  - <u>Change of Trim fwd = 0.534m</u>
- Finally, the change in Draught at either end of the vessel can be calculated.
  - Original Draught aft = 2.95m
  - Original Draught fwd = 2.95m
  - Sinkage = 0.386m
  - Change in Draught fwd = 2.95 + 0.386 + 0.534
  - <u>New Draught fwd = 3.87m</u>
  - Change in Draught aft = 2.95 + 0.386 - 0.463
  - <u>New Draught aft = 2.873 m</u>

Naval Architecture / Stability

Effect of Bilging on Stability

In order to ascertain how bilging may affect stability in the damaged condition, it is essential to estimate for the loss of GM. The the below drawings show a transverse cross section of the MV Malheureuse after having been holed in the fwd compartment as described in the previous section.





To determine concern, there needs to be a comparison between the Damaged GM and the Intact GM. Note that KG on the centreline has already been given and is assumed to remain constant given the use of the loss of buoyancy method.

- Intact GM = KM (KB+BM) – KG
    - GM = (KB+BM) – 2.25
    - KB = 0.5 x D (2.95)
    - KB = 1.475m
    - BM = LB^3 / 12UV
    - BM = 50,000 / 12x1475
    - BM = 2.825m
    - GM = (1.475+2.825)-2.25
    - <u>GM = 2.05m</u>
- Damaged GM_d = KM_d (KB_d+BM_d) – KG
    - GM_d = (KB_d+BM_d) – 2.25
    - KB_d = 0.5 x D (3.336)
    - KB_d = 1.668m
- Calculations for KB have shown a rise in the position of the center of buoyancy on the centreline, which will affect GM in the damaged state.
    - GM_d = (1.668+BM_d) – 2.25
    - BM_d = P(LB^3 / 12UV)
    - BM_d = 0.6 x (50,000 / 12x1475)
    - BM_d = 1.695m
    - GM_d = (1.668+1.695)-2.25
    - <u>GM_d = 1.133m</u>

The calculations for GM show that the damaged GM, 1.133m, is significantly reduced when compared to that for the intact hull, 2.05m. Therefore, it can be said that when having a bilged fwd compartment, the MV Malheureuse will experience a loss in stability.

<u>Preferred Methods</u>

Using the Loss of buoyancy method provides a systematic approach to calculating changes in draft, trim, and stability for vessels that have experienced flooding. However, my preferred method would be to use computer models and formula to ensure highly accurate results.