

▽ NON DIMENSIONAL FORM COEFFICIENTS

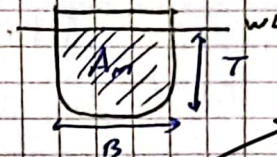
C_B : Block coefficient: Determines the fullness of underwater form.

$$C_B = \frac{\nabla}{L_{WL} \cdot B \cdot T}$$

$C_B \uparrow$ Speed $\downarrow$

C_m : Midship area coefficient: Indicates the fullness of the midship section.

$$C_m = \frac{A_m}{B \cdot T}$$



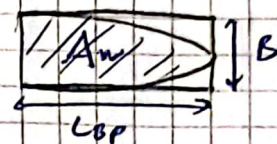
fullness of waterline

C_p : Prismatic coefficient:

$$C_p = \frac{C_B}{C_m}$$

C_{wp} : Waterplane coefficient:

$$C_{wp} = \frac{A_w}{L_{wp} \cdot B}$$



Displacement Tonnage: Weight of the volume of water a ship displaces when it is sitting in the water.



Standard Displacement Tonnage: (Displacement Tonnage) - (Weight of fuel and potable water)

Light weight Tonnage: Weight of the ship without any consumables like oil, water.

Dead weight Tonnage: Weight of everything carried on the ship.
(Displacement Tonnage) - (Lightweight Tonnage)

Gross Registered Tonnage: Measurement of volume of all enclosed spaces with 100 cubic feet = 1 ton



Net Registered Tonnage: Measurement of volume of cargo storage areas with 100 cubic feet = 1 ton

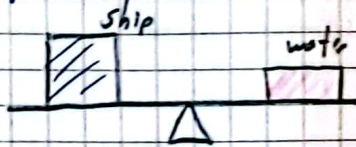
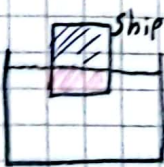


HYDROSTATIC CALCULATIONS AND CURVES



density of fluid
 $F_B = \rho g \nabla$
Archimedes' principle

"Buoyant force acting on a floating body in the fluid is equal to the weight of the displaced fluid by the body."



FREEBOARD MARK



- TF - Tropical Fresh Water → lightest water ($\rho = 0.9997 \text{ g/cm}^3$)
- F - Fresh water
- T - Tropical Sea water
- S - Summer Sea water
- W - Winter Sea water
- WNA - Winter North Atlantic → heaviest water ($\rho = 1.025 \text{ g/cm}^3$)



STATE OF EQUILIBRIUM

Buoyant force on the ship = Weight

Displacement = Weight

$$F_B = \rho g \nabla = mg$$

$$\frac{\rho \nabla}{V_T} = \frac{m}{V_T} \Rightarrow \frac{\rho \nabla}{V_T} = \rho_{\text{ship}}$$

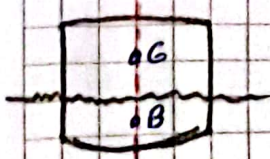
$$\frac{\rho_{\text{ship}}}{\rho_{\text{fluid}}} = \frac{\nabla}{V_T} \Rightarrow \rho_{\text{ship}} \leq \rho_{\text{fluid}}$$

Static Equilibrium:

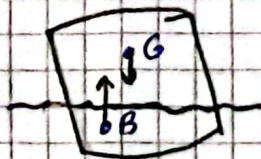
condition 1: $\sum F = 0 \rightarrow F_B = \Delta$

condition 2: $\sum M = 0$

total weight
of ship



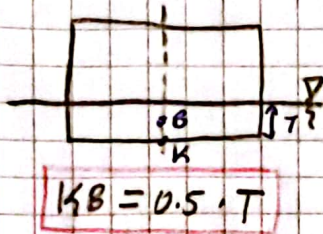
$\sum F = 0$
 $\sum M = 0$



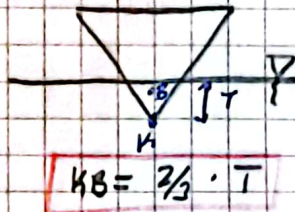
$\sum F = 0$
 $\sum M \neq 0$

$$0.5 \quad 100 \quad X = \frac{100 \cdot 0.5}{0.5}$$

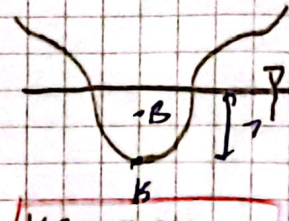
VERTICAL POSITION OF CENTRE OF BUOYANCY (KB or VCB)



$$KB = 0.5 \cdot T$$



$$KB = \frac{2}{3} \cdot T$$

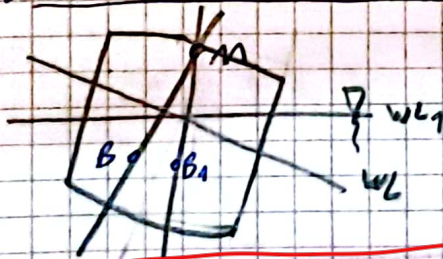


$$KB = 0.535 \cdot T$$

$$\frac{KB}{T} = \frac{1}{3} \left[2.5 - \frac{C_b}{C_w} \right]$$

Approximate Formula (Morris's formula)

METACENTRIC RADIUS (BM)



$$BM = \frac{I}{V}$$

Moment of inertia with respect to centerline (m^4)

Underwater volume (m^3)

For a box shaped portion:

$$I = \frac{LB^3}{12}$$

$$BM = \frac{B^2}{T} \cdot \frac{C_w^3}{2C_b(1+C_w)(1+2C_w)}$$

Approximate Formula (Munro-Smith)

$$BM = \frac{LB^3}{12V} \quad \text{or} \quad BM = \frac{B^2}{12T}$$

$$(V = L \cdot B \cdot T)$$

HYDROSTATIC CURVES

(continued)

same amount of change in forward and aft draft.

TPC: Tons Per Cent immersion: Tons required to obtain one cm. of parallel sinkage
(ton/cm) in salt water. Trim: difference between forward and aft draft

$$Trim = T_{aft} - T_{fwd}$$

$$TPC = \frac{A_{wp}(m^2) \rho}{100} \left(\frac{ton}{cm} \right)$$

$$\delta Tps = \frac{w}{TPC}$$

amount of weight added or removed (tons)

change in draft (cm)

(cm/m)

MCT, Moment to Change Trim one cm: Ship will rotate around the center of flotation when a moment is applied to it.



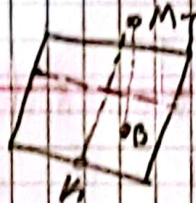
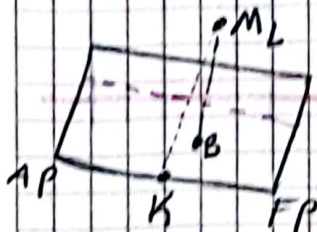
$$\Delta \text{Trim} = \frac{W \cdot d}{MCT}$$

distance weight was moved if shifted
or
distance from weight to F if added or removed

change in trim due to weight addition/removal

LONGITUDINAL

LONGITUDINAL AND TRANSVERSE METACENTRIC HEIGHTS

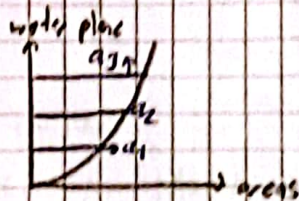


$K M_L$ → Distance from keel to M_L (m)

$K M_T$ → Distance from keel to M_T (m)

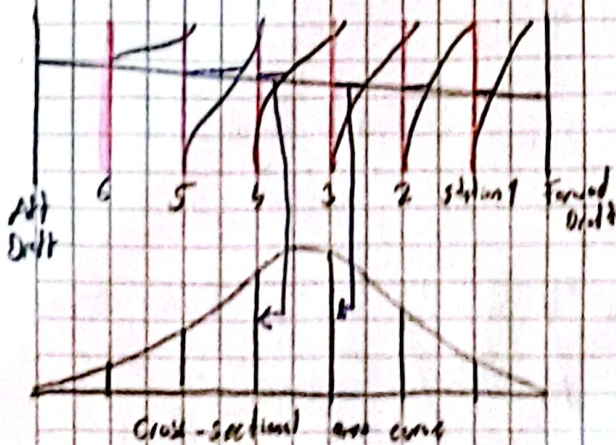
BENJAMIN SECTIONAL AREA CURVES

to show the sectional areas below a certain draft of the given section.



CROSS-SECTIONAL AREA CURVE

Obtained by using Benjamin sectional area curves at any draft.



DISPLACEMENT

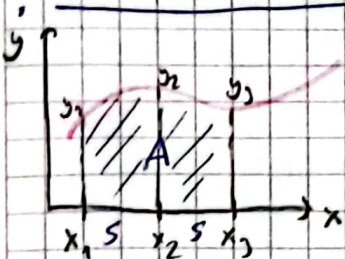
Integration of cross sectional area curve yields the displacement of the ship.

~ NUMERICAL INTEGRATION ~

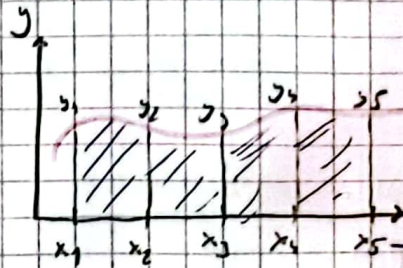
< Simpson's Rule is used when a curve is irregular and not easily defined mathematically. It is an approximation.

the one generally used.

▽ SIMPSON'S 1st RULE



$$A \approx \frac{\Delta x}{3} (y_1 + 4y_2 + y_3)$$



$$A \approx \frac{\Delta x}{3} (y_1 + 4y_2 + 2y_3 + \dots + 2y_{n-2} + 4y_{n-1} + y_n)$$

odd number!!
even space!!

▽ SIMPSON'S 2nd RULE

$$A \approx \frac{3\Delta x}{8} (y_0 + 3y_1 + 3y_2 + 2y_3 + 3y_4 + 3y_5 + 2y_6 + \dots + 3y_{n-1} + y_n) \rightarrow \text{even number!!}$$

pattern: 1 3 3 2 3 3 2 3 3 1

▽ CALCULATION OF WATERPLANE AND SECTIONAL AREAS

$$2 A_{wp} = 2 \cdot \int y(x) dx$$

the dots you have
is for a hold-section

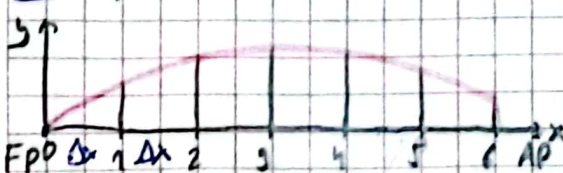
$$A_{wp} = 2 \cdot \frac{\Delta x}{5} (y_0 + 4y_1 + 2y_2 + \dots + 2y_{n-2} + 4y_{n-1} + y_n)$$

waterplane area

$$A_{sect} = 2 \int y(z) dz$$

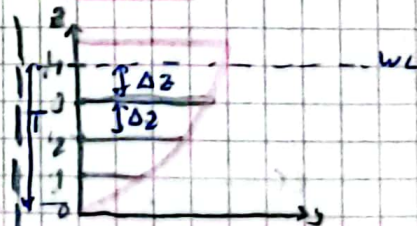
$$A_{sect} = 2 \cdot \frac{\Delta z}{5} (y_0 + 4y_1 + 2y_2 + \dots + 2y_{n-2} + 4y_{n-1} + y_n)$$

Note: You will always know the value of y from the offset table.



$$A_{wp} = 2 \cdot \frac{\Delta x}{3} [y_0 + 4y_1 + 2y_2 + 4y_3 + 2y_4 + 4y_5 + y_6]$$

for the other side



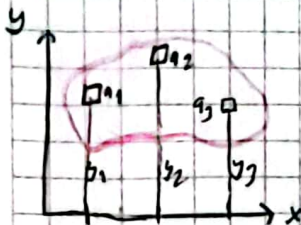
$$A_{sect} = 2 \cdot \frac{\Delta z}{5} [y_0 + 4y_1 + 2y_2 + 4y_3 + y_4]$$

for the other side

geometric center center of gravity

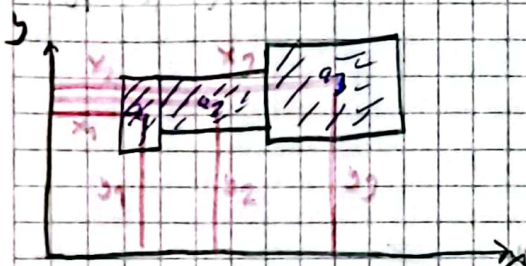
▼ CENTROID AND CENTER OF MASS

Both can be found using a weighted average



$$y_{ave} = \frac{y_1 a_1 + y_2 a_2 + \dots + y_n a_n}{a_1 + a_2 + \dots + a_n} \quad \text{Centroid}$$

↓ differential area



$$\bar{x} = \frac{x_1 a_1 + x_2 a_2 + \dots + x_n a_n}{A_T}$$

Center of mass

$$\bar{y} = \frac{y_1 a_1 + y_2 a_2 + \dots + y_n a_n}{A_T}$$

x_i : distance from x to dif. area center

y_i // // y to dif. area center

▼ LONGITUDINAL CENTER OF FLUTATION (LCF)

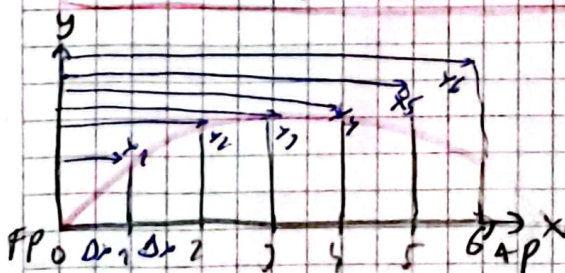


Geometric center of waterline plane.

Ship trims around this point.



$$LCF = \frac{2}{A_{wp}} \cdot \frac{\Delta x}{3} [y_0 y_1 + 4x_1 y_1 + 2x_2 y_2 + \dots + 4x_{n-1} y_{n-1} + x_n y_n]$$



CALCULATION OF VOLUMES

$$V_{\text{submerged}} = \int A_{\text{sect}}(x) dx$$

$$V_{\text{sub}} = \frac{\Delta x}{3} [A_0 + 4A_1 + 2A_2 + \dots - 2A_{n-2} + 4A_{n-1} + A_n]$$

term becomes area as we are summing areas.

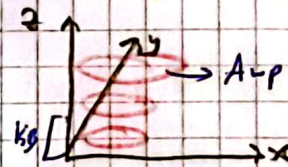


VERTICAL CENTER OF BUOYANCY (KB, VCB)

* LCF was centroid of A_{wp} , similarly KB is centroid of the submerged volume

$$KB = \int z A_{wp}(z) dz$$

$\nearrow$ volume element at distance z from keel
 $\nearrow$ spacing between A_{wp} sections
 $\nearrow$ distance of A_{wp} from z -axis

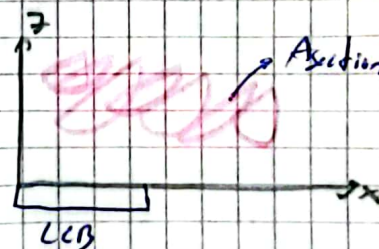


$$KB = A_{wp} \cdot \frac{\Delta z}{3} [(z_0 A_{wp0}) + 4(z_1 A_{wp1}) + 2(z_2 A_{wp2}) + \dots + (z_n A_{wpn})]$$

LONGITUDINAL CENTER OF BUOYANCY (LCB)

$$LCB = \int x \cdot A_{\text{sect}}(x) dx$$

$\nearrow$ spacing between A_{sect} s
 $\nearrow$ area of section at distance x from FP
 $\nearrow$ distance of A_{sect} from x -axis



$$LCB = A_{\text{sect}} \cdot \frac{\Delta x}{3} [(x_0 A_{wp0}) + 4(x_1 A_{wp1}) + 2(x_2 A_{wp2}) + \dots + (x_n A_{wpn})]$$

~ INTACT STABILITY ~ (Stable stability)

Stability: Tendency of a ship to rotate one way or another (tilt, sway)

Initial stability: Stability of a ship in the range 0° to $9^\circ-10^\circ$.

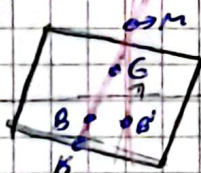
Overall stability: Ability to resist capsizing in a given loading condition.

Dynamic stability: Work done in heeling a ship to a given angle.

Heel: Semi-permanent angle of inclination, caused by external forces (waves, wind)

List: Permanent inclinations caused by the centre of gravity.

Roll: Action of a vessel involving recurrent motion around longitudinal axis.

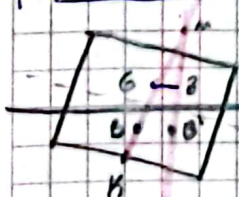


$\sim 10^\circ$ sınırlar içinde M noktasına göre denge

$\sim 10^\circ$ kadar olan eğilme için M noktasına göre denge.

B yükü kayar, **M ağırlığı** kayar
B ağırlığı kayar, **M yükü** kayar

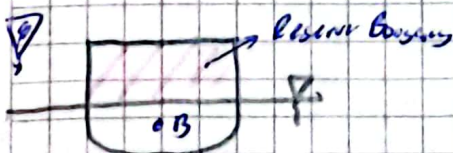
INITIAL TRANSVERSE STABILITY



GZ : righting arm

$\Delta \times GZ = \text{Righting Moment}$

$\rightarrow$ Replasma

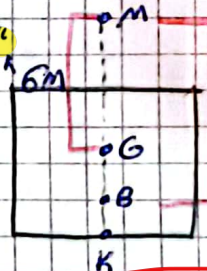


Reserve Buoyancy

$\sim B$ noktası su hattına bittikçe kayar ve su hattı azalır. B de aşağı.



metacentre height



metacentre radius

GZ stable moment

$$BM = \frac{I}{\Delta}$$

Displacement

$$KG + GM = KM = KB + BM$$

Depend on loading

$$GM = KM - KG$$

Calculation of G_M

$GM > 0$ stable

$GM = 0$ neutrally stable

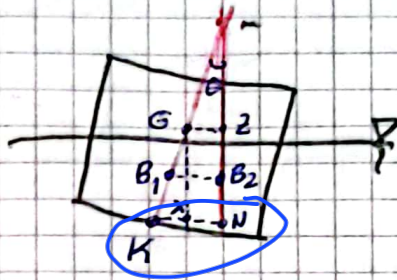
$GM < 0$ unstable

$\sim JMA \rightarrow GM > 0.15m$ olmalı

$\sim GM$ çok yüksek olursa fazla direnç olur (stiff ship)

Class Curves of Stability

- In some cases, the curves are constructed for an assumed $KG = 0$
- These kind of curves are called **KN curves**.



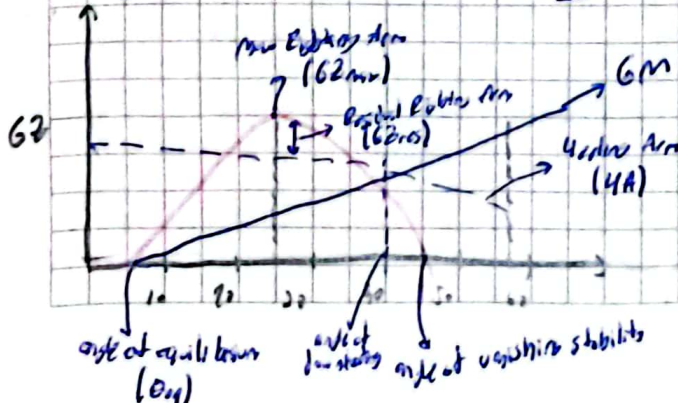
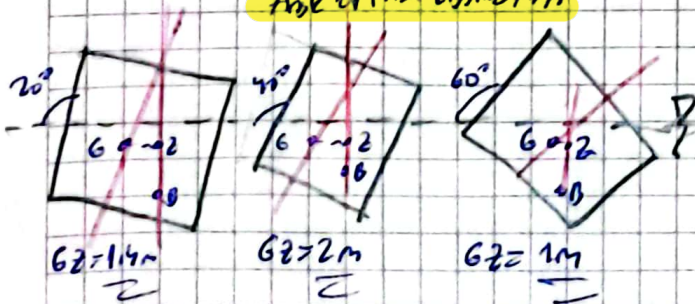
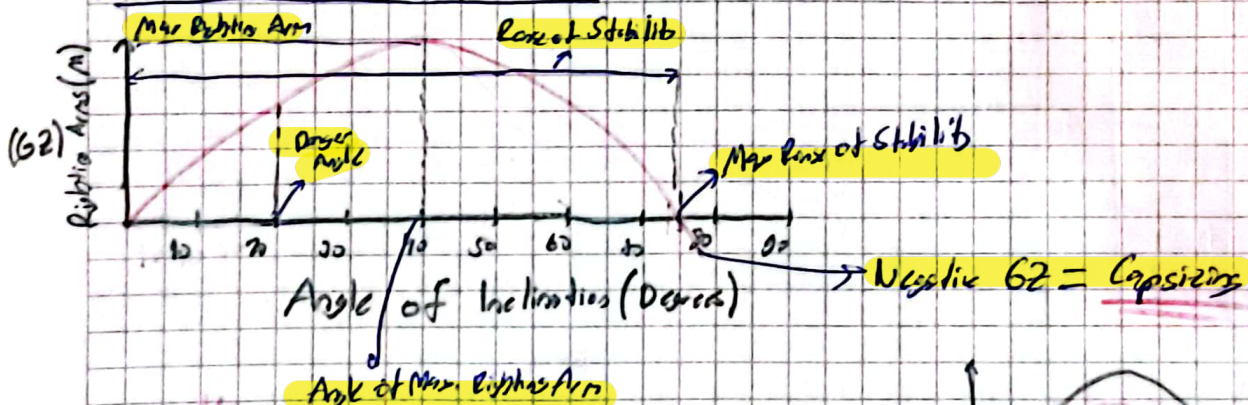
Righting lever measured horizontally

- KN represents the ordinate (x) obtained from the curves.
- KG is the actual height of center of gravity
- GZ is the length of righting lever,

$$GZ = XN = KN - KG \cdot \sin \theta$$

$$GZ = KN - KG \cdot \sin \theta$$

Righting Arms (GZ) Curve



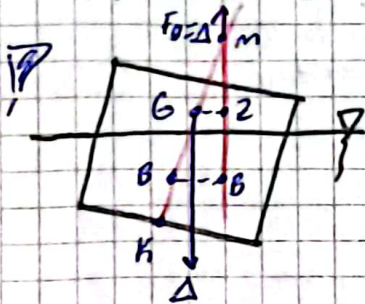
GZ curves can be drawn for different combinations of draft, displacement, trim etc.

For up to $\theta < 6^\circ \rightarrow GZ = GM \cdot \sin \theta$
 Initial GM has nothing to do with the rest of the curve.

IMO Stability Standards

< For intact stability, rules are outlined in IMO 2008 IS Code

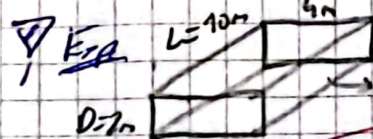
< After receiving approval and calculation from IMO, ship construction can proceed



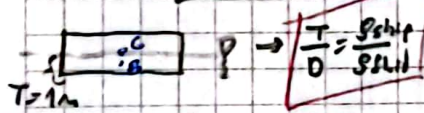
$\Delta \times GZ = \text{Righting Moment}$

$\theta < 6^\circ \rightarrow GZ \approx GM \cdot \sin \theta$

$F_0 = \Delta$



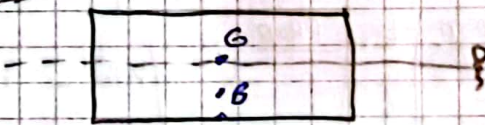
Expt. this block's initial transverse stability by calculating its GM.



$$I_T = \frac{LB^3}{12} = \frac{10 \cdot 4^3}{12} = 53.33 \text{ m}^4$$

$$\nabla = LBT = 10 \cdot 4 \cdot 7 = 280 \text{ m}^3$$

$$BM = \frac{I_T}{\nabla} = \frac{53.33}{280} = 0.19 \text{ m}$$

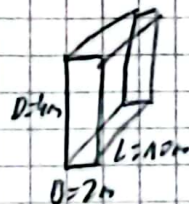
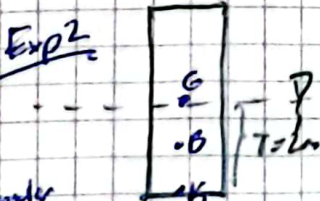


$$KB = \frac{D}{2} = 3.5 \text{ m}$$

$$KB = \frac{I}{\nabla} = 0.50 \text{ m}$$

Only for a block or rectangular body!!

$$GM = KB + BM - KG = 0.50 + 0.19 - 3.5 = -2.81 \text{ m} \quad \boxed{GM < 0} \quad \text{Block is unstable}$$



rectangular

$$KG = \frac{D}{2} = \frac{7}{2} = 3.5 \text{ m}$$

$$KB = \frac{I}{\nabla} = \frac{2}{2} = 1 \text{ m}$$

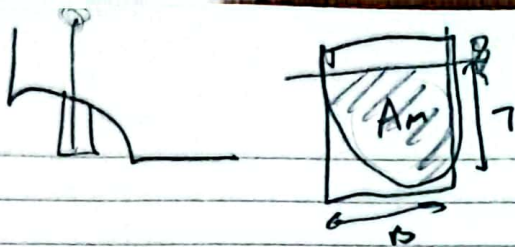
$$I_T = \frac{LB^3}{12} = \frac{10 \cdot 2^3}{12} = 6.67 \text{ m}^4$$

$$\nabla = LBT = 10 \cdot 2 \cdot 7 = 140 \text{ m}^3$$

$$BM = \frac{I_T}{\nabla} = \frac{6.67}{140} = 0.048 \text{ m}$$

$$GM = KB + BM - KG$$

$$GM = 1 + 0.048 - 3.5 = -2.452 \text{ m} \quad \boxed{GM < 0} \quad \text{unstable}$$



$$C_m = \frac{A_m}{T \cdot B}$$

~ SOLID WEIGHT SHIFTS, ADDITION AND REMOVALS ~

GENERAL CATEGORIES OF SHIFTS

< Lightship (hull, machinery, outfitting) < Personnel
 < Cargo < Fresh water
 < Fuel < Ballast tanks

= Total Ship Weight (Δ)

CALCULATIONS OF THE CENTERS

$$KG = \frac{\sum (w_i \times k_{gi})}{\Delta}$$

Δ ← sum of all individual loads
 ← vertical center of gravity

$$TCG = \frac{\sum (w_i \times t_{gi})}{\Delta}$$

Δ ← transverse center of gravity

$$LCG = \frac{\sum (w_i \times l_{gi})}{\Delta}$$

Δ ← longitudinal center of gravity

$$LCG = \frac{\text{sum of all individual loads} \times \text{their length to the CG}}{\Delta}$$

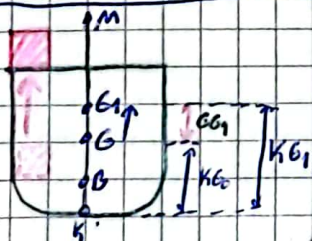
CALCULATING KG

Item	Weight (w_i)	k_{gi} (m)	$(w_i \times k_{gi})$ moment
Lightship	1	1	1
Cargo	1	1	1
Fuel	1	1	1
Freshwater	1	1	1
Crew	1	1	1
	<u>20420</u>		<u>182400</u>

$$KG = \frac{\sum (w_i \times k_{gi})}{\Delta}$$

$$KG = \frac{182400}{20420} = 8.93 \text{ m}$$

VERTICAL WEIGHT SHIFT



$$GG_1 = KG_1 - KG_0$$

$$KG_1 = \frac{(W_0 \times KG_0) \pm (w \times k_g)}{W_f \rightarrow \text{Final } \Delta}$$

Original Δ weight shifted Distance shifted

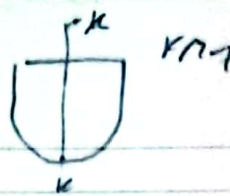
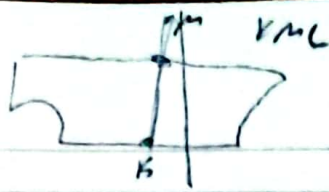
VERTICAL WEIGHT ADDITION



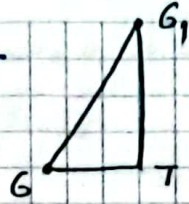
$$GG_1 = KG_1 - KG_0$$

$$KG_1 = \frac{(W_0 \times KG_0) \pm (w \times k_g)}{W_f}$$

weight added/removed



! Sine Correction



$$GT = GG_1 \cdot \sin \theta$$

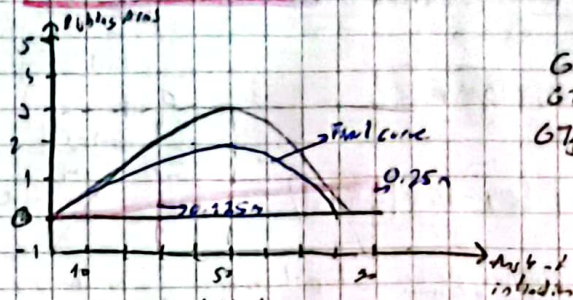
$$KG_1 = 2m, KG_2 = 2.25m$$

$$GG_1 = 0.25m$$

$$GT_0 = 0.25 \cdot 0 = 0m$$

$$GT_1 = 0.25 \cdot 0.5 = 0.125m$$

$$GT_2 = 0.25 \cdot 1 = 0.25m$$



! Horizontal Weight Shift



$$GG_2 = \frac{W \times d}{W_f} \rightarrow \text{distance shifted}$$

! Horizontal Weight Addition/Removal



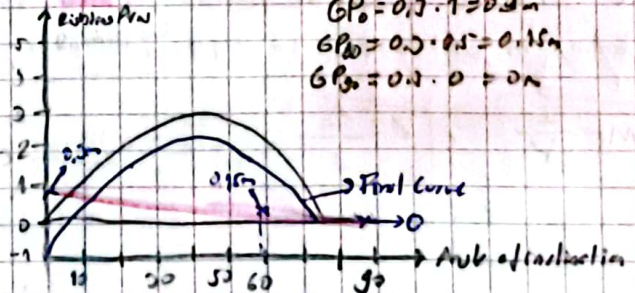
$$GG_2 = \frac{W \times d}{W_f} \rightarrow \text{distance added/removed from } C_L$$

$$GG_2 = 0.25m$$

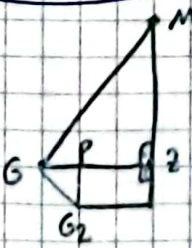
$$GP_0 = 0.25 \cdot 1 = 0.25m$$

$$GP_1 = 0.25 \cdot 0.5 = 0.125m$$

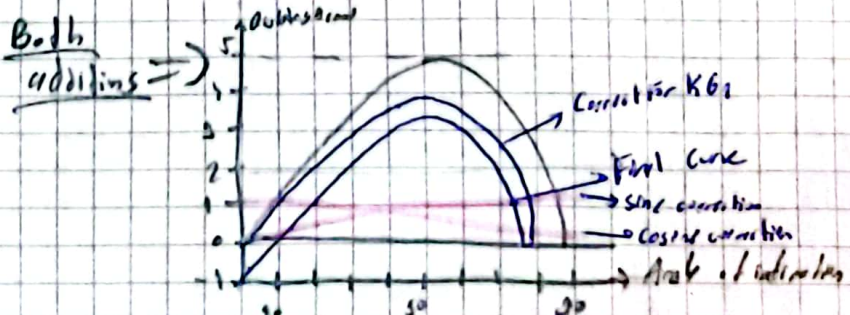
$$GP_2 = 0.25 \cdot 0 = 0m$$



! Cosine Correction



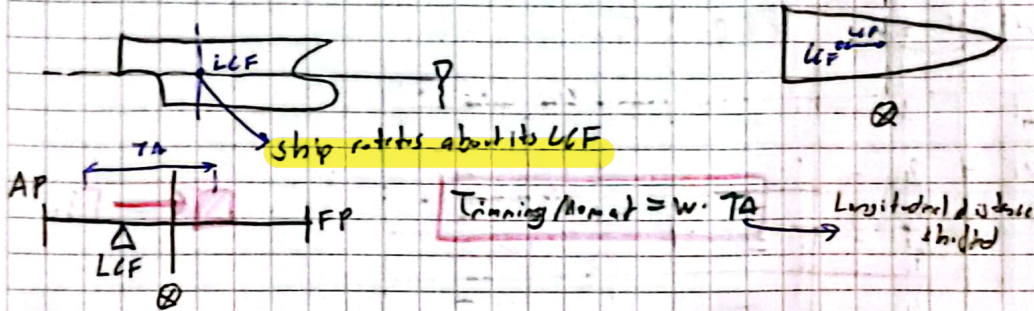
$$GP = GG_2 \times \cos \theta$$



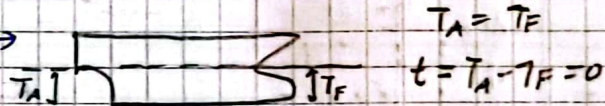
Note: Apply second curve to the first corrected curve
Doesn't matter which one you do first.

LONGITUDINAL STABILITY AND TRIM

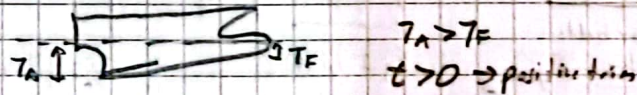
▽ Trim: Difference between drafts fore and aft



▽ Zero Trim = Even Keel $\rightarrow$

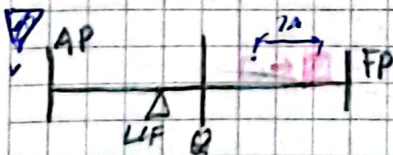
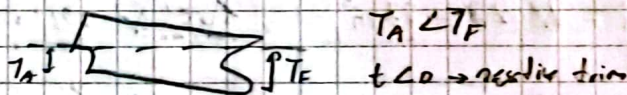


△ Trim by the Stern

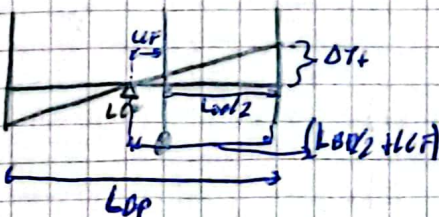
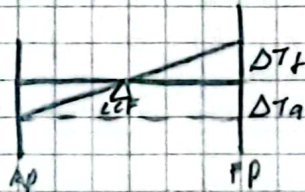
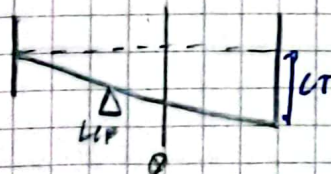


△ Trim by the Bow

Not ideal
(reverse drafts)

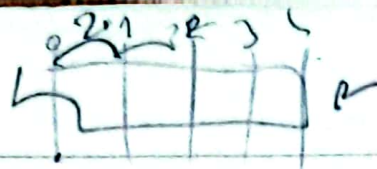


$$\text{Change in Trim (CT)} = \frac{TM}{MCT} \rightarrow \text{Trimming Moment} = TA \cdot w$$



$$\Delta T_L = \frac{(LOP/2 + LCF)}{LOP} \times CT$$

$$\Delta T_A = CT - \Delta T_L$$

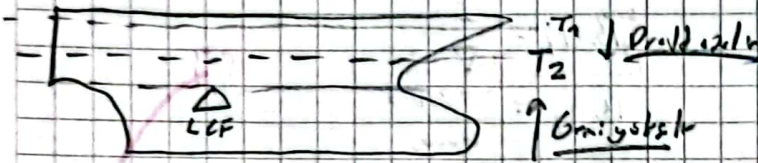


Parallel Sinkage and Rise



Parallel Sinkage (PS): Distance that the drafts fore and aft increase due to weight addition

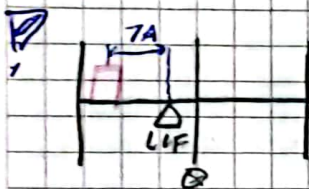
$$PS = \frac{W}{TPC}$$



Parallel Rise (PR): Distance that the drafts fore and aft decrease due to weight removal

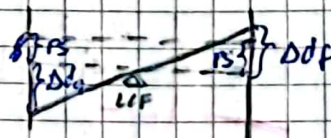
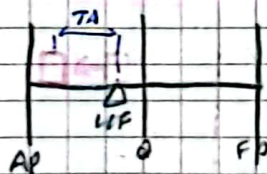
$$PR = -\frac{W}{TPC}$$

→ Tons per centimetre
Number of tons required to sink the ship by one centimetre



For a weight addition, Trimming Arm is equal to the distance from LCF to the center of weight.

Any weight addition can be equated to an addition of LCF and a shift.

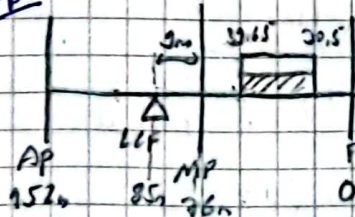


$$\text{Total } \Delta \text{draft} = \frac{PS}{PR} + \Delta d_L$$

or

$$= \frac{PS}{PR} + \Delta d_0$$

Exp



$D = 2.20m$
 $L = 9.15m$
 $H = 3.65m$
 $W_0 = 4500t$

No. 5 compartment is damaged.

1.05m high water in tank.

$TPC = 15.95 t/cm$

$MTC = 126.7 t/cm$

$$W_{water} = B \times L \times D \times \rho$$

$$W_{water} = 2.20 \times 9.15 \times 1.05 \times 1.025 = 126.7 t \rightarrow W_f = 126.7 + W_0 = 126.7 + 4500 = 4626.7 t$$

$$PS = \frac{W}{TPC} = \frac{126.7 t}{15.95 t/cm} = 8.05 cm$$

$$TA = 85 - (30.5 + \frac{9.15}{2}) = 49.92 m$$

$$TM = 49.92 \times 126.7 t$$

$$TM = 6325.6 t$$

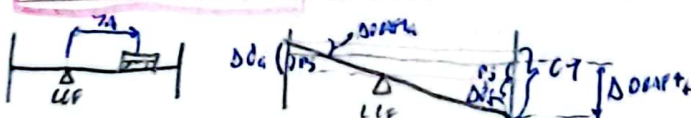
$$CT = \frac{TM}{MTC} = \frac{6325.6 t}{126.7 t/cm} = 50.2 cm$$

$$\Delta d_L = \frac{(400/2 + LCF)}{L_{BP}} \times CT = \frac{(76 + 9)}{152} \times 50.2 = 28.07 cm$$

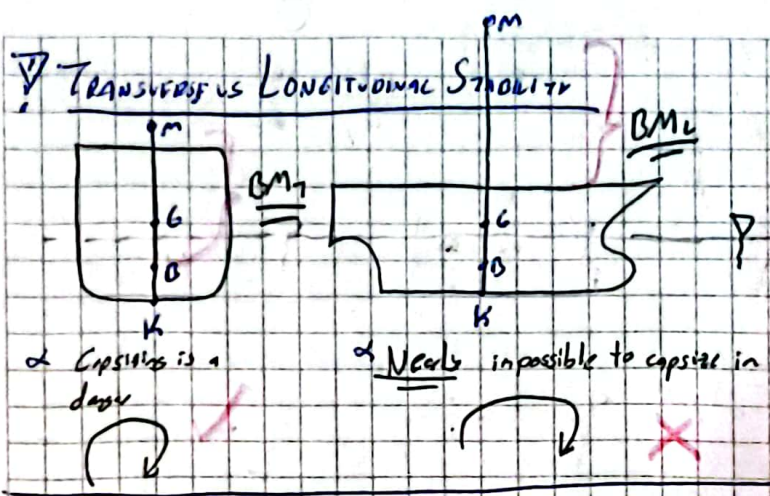
$$\Delta d_0 = CT - \Delta d_L = 50.2 - 28.07 = 22.13 cm$$

$$\Delta \text{DRAFT}_0 = PS + \Delta d_0 = 8.05 + 22.13 = 30.18 cm$$

$$\Delta \text{DRAFT}_f = PS + \Delta d_L = 8.05 + 28.07 = 36.12 cm$$



MCQ 7PC

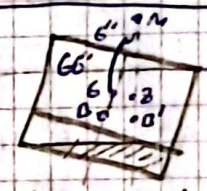


$$BM = \frac{I}{\nabla}$$

$$I_L \gg I_T \rightarrow BM_L \gg BM_T$$

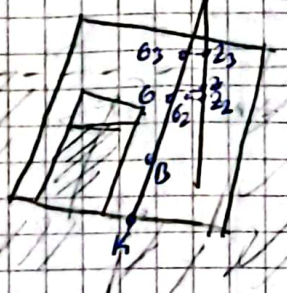
Capstern is a device

Nearly impossible to capsize in this way.



Within a tab the fluid surface has incline, Table incline decreases GM

FREE SURFACE EFFECT



$$G_2 = G_3$$

$$FSE = \frac{B^3 \times L \times 1.025}{12 \cdot W_f} = \frac{\text{Tab's Moment of inertia}}{\text{Ship's displacement}}$$

Free surface correction (m) → final displacement

$$GG'' = \frac{g_1 \cdot g_2 \cdot i_2}{\Delta} \rightarrow \text{inclin of the vessel due to tab}$$

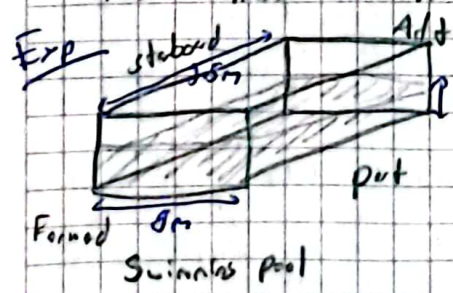
Free Surface Correction

FSE is not dependent on the water depth.

FSE increases with increasing length and breadth of tab

FSE decreases with decreasing draft (bottle diameter)

L	FSE ↑
B	FSE ↑
T	FSE ↓



W₀ = 3500t FSE = ?

$$FSE = \frac{B^3 \times L \times 1.025 \times 1.2}{12 \cdot W_f} = \frac{9^3 \cdot 7.5 \cdot 1.025}{12 \cdot 3601.25t} = 0.17m$$

$$W_{water} = L \times B \times H \times \rho_w = 25 \cdot 9 \cdot 1.5 \cdot 1 = 101.25t$$

$$W_f = W_0 + W_{water} = 3500 + 101.25 = 3601.25t$$

$$FSE = \frac{I}{W_f} \cdot \rho \cdot \frac{1}{2}$$



Free Surface Moment METHODS TO DECREASE FSE



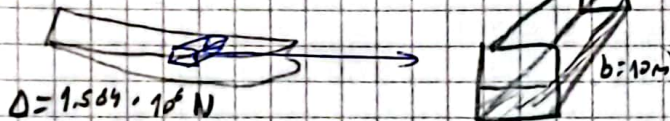
Longitudinal Subdivision of hull

$$GM_{corrected} = GM_0 - \frac{\rho_f \cdot J_{xf}}{\rho_s \cdot \nabla}$$

$$KG_{corrected} = KG_0 + \frac{\rho_f \cdot J_{xf}}{\rho_s \cdot \nabla}$$

	Number of longitudinal bulkheads in hull		
	0	1	2
I_{xf}	$\frac{1b^3}{12}$	$\frac{2(1/6)b^3}{12}$	$\frac{3(1/6)b^3}{12}$
FSE Index	1	$\frac{1}{3}$	$\frac{1}{9}$

Ex 1 (wide Tabb)



$$I_t = \frac{1b^3}{12} = \frac{1 \cdot 10^3}{12} = 333.33 m^4$$

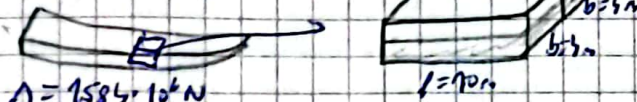
$$GG'' = \frac{\rho_f \cdot g \cdot I_t}{\Delta} \rightarrow \frac{1020 \cdot 9.81 \cdot 333.33}{1.584 \cdot 10^6} = 2.12 m$$

Virtual shift of centre of gravity (Free surface correction)

Free surface correction?

$$\frac{I}{\nabla} \cdot \frac{\rho_f}{\rho_s} \cdot \frac{1}{n}$$

Ex 2 (Two Divided Tabb)



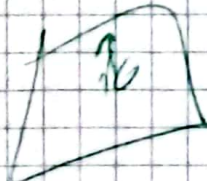
Total free surface correction?

$$I_{t1} = \frac{10 \cdot 4^3}{12} = 53.33 m^4 \quad I_{t2} = I_{t1} = 53.33 m^4$$

$$GG''_1 = GG''_2 = \frac{1020 \cdot 9.81 \cdot 53.33}{1.584 \cdot 10^6} = 0.34 m$$

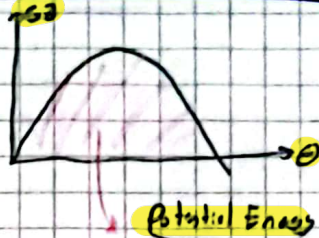
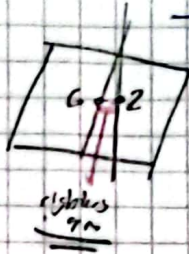
$$GG''_{total} = GG''_1 + GG''_2 = 0.68 m$$

$I_{t1} \quad I_{t2}$



Still doesn't mean it's stable

DYNAMICAL STABILITY



$$\text{Dynamic Stability} = \int_0^{\theta} W \times GZ \times d\theta$$

$$= W \cdot \int_0^{\theta} GZ d\theta$$

Ex 1

A ship of 5000 tons displacement has righting lever as:

θ	10°	20°	30°	40°
GZ	0.21	0.33	0.40	0.43

Calculate dynamic stability up to 40° heel.

Depends on sum of

①

GZ	SM	PROD
0	1	0
0.21	4	0.84
0.33	2	0.66
0.40	4	1.60
0.43	1	0.43
	Σ	

$\Sigma = 3.53$

②

$$\text{Area} = \frac{1}{3} \cdot \theta \cdot \Sigma$$

$$= \frac{1}{3} \cdot 10 \cdot \frac{\pi}{180} \cdot 3.53 = 0.2053$$

→ radian

③

$$\text{D.S.} = W \cdot \text{Area}$$

$$\text{D.S.} = 5000 \cdot 0.2053$$

$$= 1026.5 \text{ ton.m}$$

Ex 2

A box shaped vessel 45x10x6m is floating in salt water & draft of 7=4m. GM=0.6m. Calculate the dynamic stability up to 20°.

①

$$\Delta = 45 \cdot 10 \cdot 4 \cdot 1.025 = 1845 \text{ tons}$$

Assumption → The ship is wall-sided
 UGAW → Valid until draft abn immersion
 → create some given body

②

$$10^\circ \rightarrow GZ = GM \cdot \sin \theta \rightarrow GZ = 0.6 \cdot \sin 10^\circ = 0.104 \text{ m}$$

$$20^\circ \rightarrow GZ = \left(GM + \frac{1}{2} B M \sin^2 \theta \right) \cdot \sin \theta = \left(0.6 + \frac{1}{2} \cdot 2.08 \cdot \sin^2 20^\circ \right) \cdot \sin 20^\circ$$

→ wall-sided formula at large angle!

$$GZ_{20^\circ} = 0.252 \text{ m}$$

$$BM = \frac{B^2}{12T} = \frac{10^2}{12 \cdot 4} = 2.08 \text{ m}$$

③

θ	GZ	SM	PROD
0°	0	1	0
10°	0.104	4	0.416
20°	0.252	1	0.252
		Σ	

$\Sigma = 0.668$

④

$$\text{Area} = \frac{1}{3} \cdot \theta \cdot \Sigma$$

$$= \frac{1}{3} \cdot 10^\circ \cdot \frac{\pi}{180} \cdot 0.668 = 0.039$$

⑤

$$\text{D.S.} = 1845 \cdot 0.039$$

$$\text{D.S.} = 71.77 \text{ ton.m}$$

~ ANGLE OF LOLL ~



IMO → GZ has same positive slope

$$GZ = (GM + \frac{1}{2}BM + ta^2\theta) \cdot \sin\theta$$

duffy-bird formula

At the angle of loll: $GZ = 0$

$$(GM + \frac{1}{2}BM + ta^2\theta) \cdot \sin\theta = 0$$

i) $GM + \frac{1}{2}BM + ta^2\theta = 0$ ✓

ii) $\sin\theta = 0$ ✗

$$\tan\theta = \sqrt{\frac{-2GM}{BM}}$$

GM is negative value
sin theta is positive value

$$\tan\theta = \sqrt{\frac{2 \cdot 6m}{8m}}$$

angle of loll

Exp Will a homogeneous log $6 \times 3 \times 3$ m with density of 0.4 t/m^3 float in fresh water with a side perpendicular to the waterline? If not, what will be the angle of loll?

② $\frac{T_{log}}{D_{log}} = \frac{\gamma_{log}}{\gamma_{FW}}$

① $KG = 1.5 \text{ m}$
(3/2)

③ $T_{log} = \frac{0.4 \cdot 3}{1} = 1.2 \text{ m}$

③ $KB = \frac{T}{2} = \frac{1.2}{2} = 0.6 \text{ m}$

$BM = \frac{B^2}{12T} = \frac{3^2}{12 \cdot 1.2} = 0.625 \text{ m}$

④ $GM = KB + BM - KG = -0.225 \text{ m}$

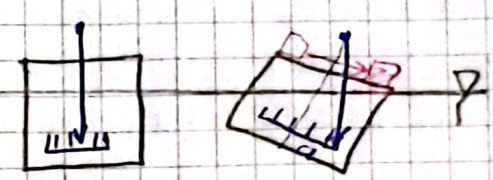
⑤ $\tan\theta = \sqrt{\frac{-2 \cdot (-0.225)}{0.625}}$ ← duffy-bird

$\theta = \arctan \sqrt{\frac{2 \cdot 0.225}{0.625}} \rightarrow \theta \approx 43^\circ$

INCLINING EXPERIMENT



$$GM = \frac{w \cdot d}{W \cdot \tan \phi}$$



ANGLE OF LEEF

$$\tan \phi = \frac{g}{\text{length of pendulum wire}}$$

↓
radius

$$GM = \frac{w \cdot d}{\Delta \cdot \tan \phi}$$

→ small angle

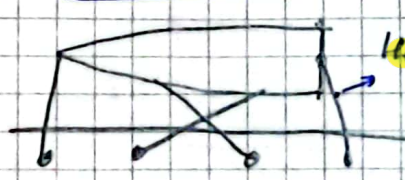
$$KG = KB + BM - GM$$

↓
height

PROCEDURE

- Experiment should be performed in calm weather
- Calculated GM is fluid GM → should be corrected for FSE to find solid GM.
- Time of arc read before and after the test
- All personnel on board not be at their allocated locations → Personnel assigned to each location
- 3 readings
- Q shall be measured

MEASUREMENT OF THE SHIP



Height of center of buoyancy,
 center of gravity

TRIM FLUZZ

- Sufficient enough to cause 1.5°-3° heel each
- $GZ = GM \cdot \sin \phi$ → heel out by lateral asymmetry

W FIGHT SURFS

< Test weight consist of 4m test, 2m each side → 11 W part → starboard
 21 2w P → S
 31 2w S → P
 41 W S → P
 51 2w S → P
 61 2w P → S

SAMPLE CALCULATION

$\times \text{W} = 87.20 \text{ kg (carb)}$
 $\times \text{d} = 2.708$
 $\times \text{length of keelson} = \text{L} = 1.690 \text{ m}$
 $\times \text{Disp} = \text{D} = 29.5 \text{ t}$

$\rightarrow \text{GM} = \frac{w \cdot d}{D \cdot \sin \theta} = \frac{w \cdot d \cdot L}{D \cdot Y}$

$\text{GM} = 0.002 \text{ m}$
 $\text{KG} = \text{KM} - \text{GM}$
 $\rightarrow \text{Keelson}$

ROLL PERIOD TEST (SALTIN)

Approximate method to determine GM

Alternative to inclining experiment, for small ships, inclining experiment is impossible.

Roll period is time elapsed for an entire cycle from port to starboard.

$\text{GM} = \left(\frac{F \cdot B}{T_r^2} \right)^2$

$\rightarrow \text{roll period factor}$
 $\rightarrow \text{Brads}$
 $\rightarrow \text{roll period (sec)}$

Ex: An inclining experiment is conducted on a vessel. Following data is noted:

As inclined: 9550 t

Inclining weights: 10 t

Distance shifted: 4.8 m

Length of keelson: 9.5 m

max deflection: 100 mm

(kg) of inclining weights: 92.5

KM: 8.135 m

GM as inclined = ?

A 150 t test weight is put on the keelson.

Calculate shift ship KG?

$\text{GM} = \frac{w \cdot d}{W \cdot \sin \theta}$

$\text{KG} = \frac{a}{1}$

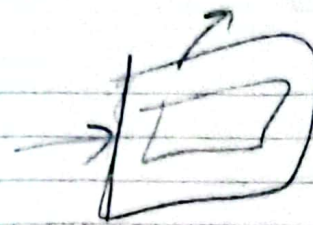
$\text{GM} = \frac{10 \cdot 18 \cdot 9.5}{9550 \cdot 0.1} = 1.724 \text{ m (as inclined)}$

$\text{KG} = 9.25 - 1.724 = 7.526 \text{ m}$

W	KG	max
9550	8.135	6.2642.2
-10	17.5	-12.5
-150	1	-150
D = 9380		6.2367

$\text{KG}_{\text{inclined}} = \frac{6.2012}{9.38} = 6.61 \text{ m}$

$\text{KG} = \frac{F_c}{F_n}$



Draft 0.4 m

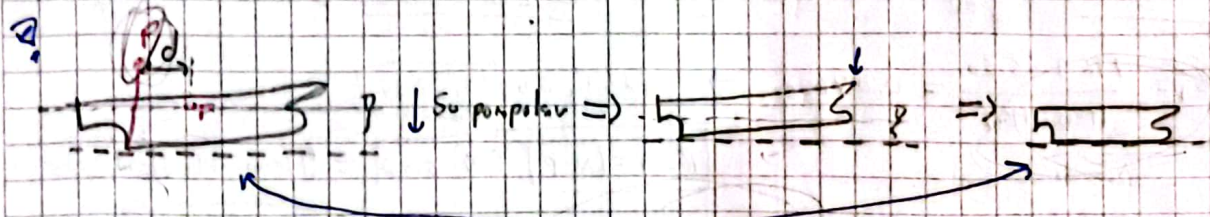
DR Docking

Before entering the dry dock, vessel must have:

- Positive initial GM
- Slight trim by stern if possible
- DB tanks full or empty $\rightarrow$ No FSE
- If initial GM is small $\rightarrow$ DB tanks to be filled to increase GM



GM+
Trim $\rightarrow$ by stern



REACTION FORCE P

$$\Delta t = \frac{T_m}{m \cdot g}$$

$$T_m = W \cdot d = P \cdot d$$

Get on sea $\rightarrow$ Critical Point

$$\Delta t = \frac{P \cdot d}{m \cdot g} \rightarrow P = \frac{\Delta t \cdot m \cdot g}{d} \quad (\text{tms})$$

VIRTUAL LOSS OF GM

ME14001 - Weight Transferred

$$GG_1 = \frac{P \cdot KG_1}{W - P}$$

ME14002 - Buoyancy Transferred

$$MM_1 = \frac{P \cdot KM_1}{W}$$

Note: If the ship has zero trim

$$\Delta t = 0 \rightarrow P = 0 \rightarrow GG_1 = 0$$

Virtual loss of GM will be 200

$$\text{Righting Moment} = (W - P) \cdot GM \cdot \sin \theta$$

attraction!

$$\text{Righting Moment} = W \cdot GM \cdot \sin \theta$$

Ex: 1

$D = 8000 \text{ tms}$ takes the ground on a sand bed

even bed, draft = 5.2m, $KG = 4.0 \text{ m}$, predicted depth of water over sand is 3.2m

Calculate GM assuming $KM = 5.0$, $TPC = 15 \text{ tms}$

$$P = TPC \cdot \Delta T = 15 (5.2 - 3.2) = 300 \text{ tms}$$

$$MM_1 = \frac{P \cdot KM}{W} = \frac{300 \cdot 5}{8000} = 1.88$$

$$\text{Virtual } KM = 3.42 \rightarrow 5 - 1.88$$

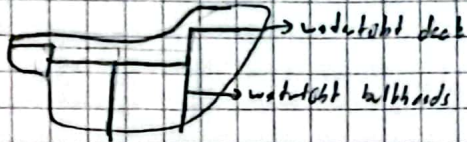
$$KG = 4.0$$

$$GM = KM - KG = -0.88$$

Keros otundesu
ign - gilebik

DAMAGE STABILITY

↳ Ship is divided to watertight compartments by transverse and longitudinal bulkheads.



↳ Main deck and main bulkheads must be watertight. Also called bulkhead deck

↳ Watertight bulkheads must extend to main deck.

IMO sızdırmazlık testleri

↳ Su geçirmez perdeler kayıp perde gibi açıklıklar su geçirmez olmalı

Wartschick: Hava koşullarıyla gelen suyu içeri geçirmez. Sadece dışarıdan içeri girer. Sızdırma.

Types of Watertight Doors

↳ TYPE A: Acık durabilir

↳ TYPE B: Geçici olarak kullanılabilir

↳ TYPE C: Kapalıdır, sadece giriş için açılır.

TERMINOLOGY

↳ Fouling: Diğer yağ yağ yağ yağ



↳ Crippling: Alabora, yan dönme



↳ Plating: Başta yağ yağ yağ yağ



eg. RMS Titanic

↳ Margin Line: After damage, ship shall not submerge beyond a line 76mm below the deck at side. → Ana güverte su girmesi olması isim.

↳ Flammable Length: Yakıcı saat margin line geçilmesinin pada giriş yağ yağ yağ yağ

↳ Extent of damage (length, depth, height) is calculated according to SOLAS rules

EFFECT OF FLOODING

Q



Compartment 2 damage → Invasion
Compartment 1 or 3 damage → Invasion + Trim

x



Compartment 4 damage → Invasion + Trim + Heel

Q



Last Avg due to flooding



→ Last ∇ due to flooding

→ KB

New ∇ = Old ∇ but shape will be much different

Q

T
G
BM
BML
Met C

All will change

Amount of ∇ that floods depends on permeability at the space (gasiness)

Amount of given space that is able to be flooded (if it is not too heavy)

$$BM = \frac{I}{\nabla}$$

$$GM = KB + OM - KG$$

Ex: Cog. hold $L=15.24$, $w=9.14$, $h=6.1$, Permeability = %60

Volume and flooded volume = ?

$$15.24 \cdot 9.14 \cdot 6.1 = 849.2 \text{ m}^3$$

$$\text{Volume} \times \%60 = \text{Flooded Volume}$$

METHODS OF DAMAGE STABILITY CALCULATIONS

① Lost Buoyancy Method → More efficient when calculating final state.
Flooded compartment does not bilge to the ship } Assumptions
Also known as method of const. displacement } does not have FSE

② Added Weight Method → Considers flooding as a weight added to ship

Give it a downward bulge



Extra volume that contributes to buoyancy

Added weight due to damage

ADDED WEIGHT METHOD

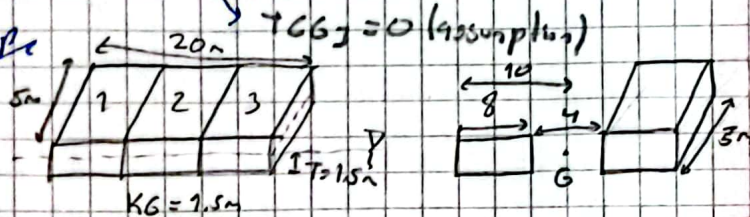
$$\Delta_F = \Delta_I + \rho \cdot V$$

f: Flooded
I: Intact

$$LCG_F \cdot \Delta_F = LCG_I + l_{CG} \cdot \rho \cdot V$$

$$TLCG_F \cdot \Delta_F = l_{CG} \cdot \rho \cdot V$$

Ex:



Given Conditions

$$V_I = L \cdot B \cdot T_I = 20 \cdot 5 \cdot 1.5 = 150 m^3$$

$$\Delta_I = \rho \cdot V_I = 1.025 \cdot 150 = 153.75 \text{ tons}$$

$$I_I = \frac{B^3 L}{12} = \frac{5^3 \cdot 20}{12} = 208.33 m^4$$

moment of inertia
of the waterplane
about CL

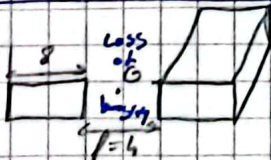
$$BM_I = \frac{I_I}{V_I} = \frac{208.33}{150} = 1.389 m$$

$$KB_I = \frac{T_I}{2} = \frac{1.5}{2} = 0.75 m$$

$$GM_I = KB_I + BM_I - KG_I = 0.75 + 1.389 - 1.5 = 0.639 m$$

$$MR_I = \Delta_I \cdot GM_I \cdot \sin \phi = 153.75 \cdot 0.639 = 98.225 \cdot \sin \phi \text{ tons}$$

LOST BUOYANCY METHOD



After losing the central compartment, A_{wp} is =

$$A_{wp} = (L - l) \cdot B = (20 - 4) \cdot 5 = 80 m^2$$

$$T_L = \frac{V_L}{A_L} = \frac{150}{80} = 1.875 m$$

$$KB_L = \frac{T_L}{2} = \frac{1.875}{2} = 0.938 m$$

$$I_L = \frac{(L - l)^3 \cdot B^3}{12} = \frac{(20 - 4)^3 \cdot 5^3}{12} = 166.67 m^4$$

$$BM_L = \frac{I_L}{V_L} = \frac{166.67}{150} = 1.111 m$$

$$GM_L = KB_L + BM_L - KG_I = 0.938 + 1.111 - 1.5 = 0.549 m$$

$$MR_L = \Delta_I \cdot GM_L \cdot \sin \phi = 153.75 \cdot 0.549 = 84.349 \cdot \sin \phi$$

ADDED WEIGHT METHOD

$$V = L \cdot B \cdot (T_1 + \partial T)$$

$$\partial V = L \cdot B \cdot \partial T$$

additional
buoyant volume

draft
designing

$$V = \partial V, \quad \partial T = \frac{T_2}{L-1} = \frac{4 \cdot 1.5}{20-4} = 0.375 \text{ m}$$

draft added
+ flooding

$$T_A = T_1 + \partial T = 1.5 + 0.375 = 1.875 \text{ m}$$

$$V = L \cdot B \cdot T_A = 4 \cdot 5 \cdot 1.875 = 37.5 \text{ m}^3$$

volume of
flooded water

$$k_b = \frac{T_A}{2} = \frac{1.875}{2} = 0.9375 \text{ m}$$

$$\nabla_A = L \cdot B \cdot T_A = 20 \cdot 5 \cdot 1.875 = 187.5 \text{ m}^3$$

$$I_A = 208.333 \text{ m}^4 \text{ (same as initial)}$$

$$BM_A = \frac{I_A}{\nabla_A} = \frac{208.333}{187.5} = 1.111 \text{ m}$$

$$i = \frac{LB^3}{12} = \frac{4 \cdot 5^3}{12} = 41.667 \text{ m}^4$$

moment of inertia of free surface in flooded compartment

$$r_F = \frac{i}{\nabla_A} = \frac{41.667}{187.5} = 0.222 \text{ m}$$

lever arm of free surface

$$KB_A = \frac{T_A}{2} = \frac{1.875}{2} = 0.9375 \text{ m}$$

$$GM_A = KB_A + BM_A - KB_G - r_F = 0.9375 + 1.111 - 1.088 - 0.222 = 0.439 \text{ m}$$

$$\Delta_A = \rho \cdot \nabla_A = 1.025 \cdot 187.5 = 192.188 \text{ t}$$

$$M_{RA} = \Delta_A \cdot GM_A \cdot \sin \phi \rightarrow 192.188 \cdot 0.439 \rightarrow 84.343 \cdot \sin \phi \text{ t.m}$$

ADDED W. vs. LAST B. SUMMATION

Item	Added Weight Method	Last Buoyancy Method
Change in disp.	✓	✗
" volume of exp.	✓	✗
" draft design	✓	✓
Shifted center of gravity	✓	✗
" " buoyancy	✓	✓
" metacenter	✓	✓
Free Surface Correction required	✓	✗

MEASURING DAMAGE STABILITY

- ① Deterministic Method: Calculation of survivability based on position & stability in damaged condition
- ② Probabilistic Method: " " " " probability of damage

DETERMINISTIC DAMAGE STABILITY

- ① Determination of regulations according to ship type.
- ② Assumption of location of damage according to ship length.
- ③ Assumption of the extent of damage.
- ④ Assumption of permeability for each compartment.
- ⑤ Evaluation of required damage stability of international regulations.

PROBABILISTIC DAMAGE STABILITY

P_i → probability of damage
 a compartment or group of compartments may be flooded at the level of the deepest subdivision draft (ds) → waterline which corresponds to the summer load line of the ship.

S_i → probability of survival

$A = \sum P_i \times S_i = P_1 \times S_1 + P_2 \times S_2 + P_3 \times S_3 + \dots + P_i \times S_i$
 Summation of the probability of all damage cases.

$R = 1 - \frac{128}{L_s + 154}$

Required subdivision index

L_s = subdivision length

$A \geq R$!!

STORAGE FACTOR

Ratio of weight to storage space required

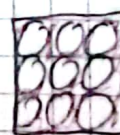
1 ton bulkhead top bays long no go bays?

Ex: Iron Ore 0.4-0.5 m³/ton

Broken Storage = $\frac{\text{Used Cargo Space}}{\text{Total Cargo Space}}$

Lost cargo space as a result of not being fully utilized.

& Flare keel.



PERMEABILITY

$$P = \frac{B.S}{S.F} \cdot 100(\%)$$

$\xrightarrow{\text{broken stowage}} B.S = S.F - \text{Space occupied by 1 ton of cargo}$
 $\xrightarrow{\text{stowage factor}} S.F$

• Increase in Draft $\rightarrow \Delta T = \frac{M \cdot \gamma}{A - M \gamma}$

Ex: Box shaped vessel is 64m long, floating on even keel $T=2m$. A compartment amidships is 12m long and contains cargo with permeability 92.5. Calculate the increase in draft if the compartment is bilged?

$$\Delta T = \frac{M \cdot \gamma}{A - M \gamma} = \frac{0.25 \cdot 12 \cdot B \cdot \gamma}{(64 \cdot B) - (0.25 \cdot 12 \cdot B)} = 0.15m$$

Ex 2: Box shaped vessel $150 \times 20 \times 12m$ is floating on even keel $T=5m$. A compartment amidships is 15m long and contains timber with density $0.8 t/m^3$ and stowage factor $1.5 m^3/t$. Calculate the draft if this compartment is bilged?

Space occupied by 1 ton of timber $= \frac{1}{S.F} = \frac{1}{1.5} = 0.667 m^3$

$$B.S = S.F - \text{Space occupied}$$

$$B.S = 1.5 - 0.667 = 0.833 m^3$$

$$M = \frac{B.S}{S.F} \cdot 100(\%) = \frac{0.833}{1.5} \cdot 100 = 55.53\%$$

$$\Delta T = \frac{M \cdot \gamma}{A - M \gamma} = \frac{0.5553 \cdot 15 \cdot 20 \cdot 5}{(150 \cdot 20) - (0.5553 \cdot 15 \cdot 20)} = 0.085m$$

New draft $= 5 + 0.085 = 5.085m$

• When a bilged compartment does not extend above waterline, the area of intact waterline remains constant.

$$M \gamma = A \cdot \Delta T$$

$$M \gamma \times \gamma = A \cdot \Delta T \times \gamma$$

$M \gamma \times \gamma$: weight of extra water lost
 $A \cdot \Delta T \times \gamma$: weight of extra water lost
 (Note: The original text has some confusion in the labels, but the equations are correct.)