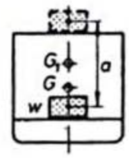
SHIP AND CARGO CALCULATIONS

Shifting weights

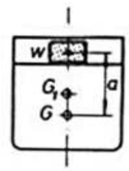
$$GG_1 = \frac{w \cdot a}{\Delta}$$



GG_1	distance *G* is shifted
G	gravity of ship
w	weight
a	distance the weight is shifted
Δ	displacement

Loading/discharging of weights

$$GG_1 = \frac{w \cdot a}{\Delta \pm w}$$



a distance of gravity of weight to initial gravity of ship, G

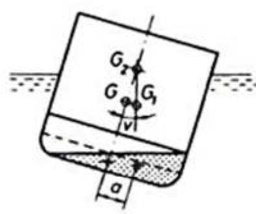
\+ by loading, – by discharging

$$w = \frac{GG_1 \cdot \Delta}{a \mp GG_1}$$

– by loading, + by discharging

Slack tank
Slack tank is a broader term than *free surface* of liquid.

$$GG_2 = \frac{w \cdot a}{\Delta} \cdot \cot v$$



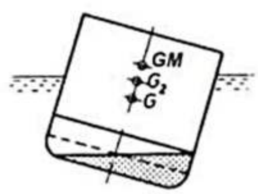
GG_2	gravity center *G*'s apparent raise in the formula must not be used as a reduction of *GM*
w	estimated tons in the tank
a	distance the point of gravity of liquid will shift when rolling
v	angle of heeling (roll)

v may often be too big for assessing *GM*.

Free surface effect of liquid

$$GG_2 = \frac{l \cdot b^3}{12 \cdot SF \cdot \Delta}$$

$$GG_2 = \frac{\;\frac{l \cdot b^3 \cdot \rho}{12 \cdot Depl}\;}{\Delta}$$



GG_2	reduction of *GM*
l	length of tank
b	breath/width of tank
SF	stowage factor of liquid
ρ	density of liquid
Δ	displacement

Water-line area

$$A_w = l \cdot b \cdot C_w$$

A_w water line area
l length of water line plane
b breath of water line plane
C_w correctness coefficient of water line plane

If C_w is unknown, A_w should be calculated by Simpson's formula.

Tons per 1" submergence

$$TPI = \frac{A_w}{12 \cdot 35}$$

TPI tons per 1" in sea water
A_w water line area in ft^2

Tons per 1 cm submergence

$$TPC = \frac{A_w \cdot 1.025}{100}$$

TPC ton per 1 cm in sea water
A_w water line area in m^2

Block coefficient

$$C_B = \frac{\nabla}{L \cdot B \cdot D}$$

∇ volume of displacement
C_B block coefficient
L length
B breath
D draught (depth)

For long tons and measures in feet

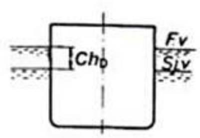
$$C_B = \frac{\Delta \cdot 35}{L \cdot B \cdot D}$$

Δ displacement

Change of draught due to salinity

When ship is at load line

$$Ch_D = \frac{f \cdot \rho_s}{0.025}$$



Ch_D change of draught
f distance from seawater to fresh water on load line
ρ density of seawater
ρ_s $1.025 - \rho$

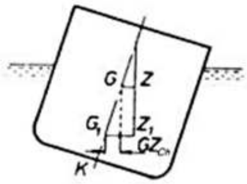
When ship is not on load line, independent of draught

$$Ch_D = \frac{\rho_s \cdot \Delta}{TPI}$$

TPI tons per inch
Δ displacement

Improving GZ-curve on coasters

$$GZ_{Ch} = \pm\ GG_1 \cdot \sin v$$



GZ_{Ch} change of GZ extracted from GZ-curve

+ when $KG > KG_1$
– when $KG < KG_1$

GG_1 KG difference between ship's actual loading condition and condition/ prerequisites of curve

KG extracted from curve
KG_1 is KG for the actual loading condition

v angle of inclination

Metacenter height and the period of roll

$$T = \frac{f \cdot B}{\sqrt{G_0M}}$$

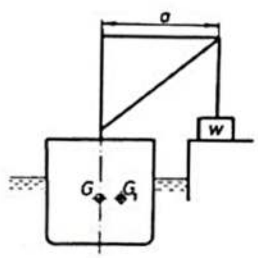
T complete period of roll
B breath in meter or feet
G_0M metacenter height in meter or feet

$$G_0M = \left(\frac{f \cdot B}{T}\right)^2$$

$f \approx 0.8$ (depending on type of ship)
$f = 0.44$ when B and G_0M is stated in feet

Establishing necessary GZ when handling heavy weights

$$GG_1 = \frac{w \cdot a}{\Delta} \approx GZ$$

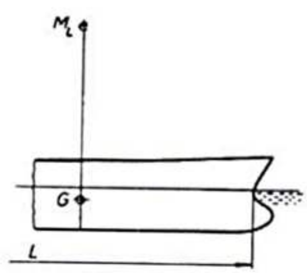


GG_1 approximate BZ required to stop inclination
w weight to be lifted
a distance from weight to midship
Δ displacement
a and GG_1 (GZ) in equal units
w and Δ in equal units

Moment per unit change of trim

$$MTC = \frac{GM_L \cdot \Delta}{100 \cdot L}$$

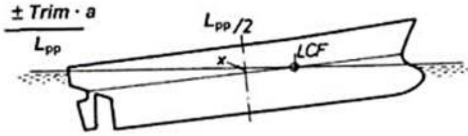
$$MTI = \frac{GM_L \cdot \Delta}{12 \cdot L}$$



MTC moment per 1 cm change of trim
GM_L longitude metacenter height in m
L length of waterplane in m

MTC will be given in ton-meter

MTI moment per 1 inch change of trim
Δ displacement
GM_L and L in equal units
MTI will be given in foot-tons

Moment per unit change of trim	$M = \frac{31 \cdot T^2}{B}$	*M* moment per 1" Δ trim *T* tons per 1" immersion *B* ship's breath in feet This formula is very approximate and must be used with great care.
Change of trim by sailing from seawater to brackish/fresh water	${}_{Ch}Trim = \frac{BB_1 \cdot \Delta}{MTI \text{ or } MTC}$	${}_{Ch}Trim$ change of trim BB_1 longitudinal shift of center of bouyancy *MTI* or *MTC* moment per unit change of trim Δ displacement
Change of trim	Distribution of the 2 parts of trimchange $= \frac{Trim\left(\frac{L_{pp}}{2} \pm a\right)}{L_{pp}}$	L_{pp} length between perpendiculars *a* distance of *LCF* from $L_{pp}/2$ The formula gives the two parts of trim to be applied forward and aft – the smallest part towards *LCF* related to $L_{pp}/2$.
Effect of trim on midship draught	$x = \frac{\pm Trim \cdot a}{L_{pp}}$ 	*x* change of draught midship owing to trim related to even keel. *Trim* ship's trim *a* distance from *LCF* to $L_{pp}/2$ L_{pp} length between perpendiculars – when *LCF* is forward, + when *LCF* is aftward in order to arrive at even keel draught when ship has aft ward trim. By forward trim the opposite prefixes shall be used. LCF water-plane's center of gravity

Effect of trim on displacement extracted from curve for mean draught

$$\Delta corr = \frac{Trim \cdot a \cdot TPI}{L_{pp}}$$

$\Delta corr$	displacement correction
$Trim$	ship's trim
a	distance from LCF to $^{L}/_{2}$
TPI	tons per unit immersion
L_{pp}	length between perpendiculars

$\Delta corr$ has negative (–) prefix when LCF is forward of $^{L_{pp}}/_{2}$ and afterward trim.

Correction of displacement owing to hogging and sagging

$$\Delta corr = \pm \frac{2x \cdot TPI}{3}$$

$\Delta corr$	displacement correction + for sagging – for hogging
x	hogging/sagging
TPI	tons per unit immersion

Displacement is extracted for mean draught $^{(F+A)}/_{2}$

$$\Delta corr = \mp \frac{x \cdot TPI}{3}$$

$\Delta corr$	displacement correction – for sagging + for hogging
x	hogging/sagging
TPI	tons per unit immersion

Displacement is extracted for mean draught midship $^{(SB+BB)}/_{2}$

Increase of midship draught owing to list or inclination

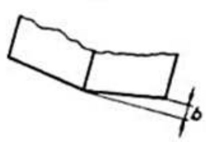
$$_{Mid}D_1 = \frac{B}{2} \sin v + {}_{Mid}D \cos v$$

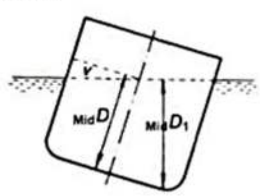
$_{Mid}D_1$	midship draught when listing
B	ship's breadth
$_{Mid}D$	midship's draught on even keel (without listing)
v	angle of inclination

With raise of bilge

$$_{Mid}D_1 = \frac{B}{2} \sin v + ({}_{Mid}D - b) \cos v$$

b ship's raise of bilge

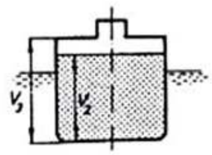




Ship's raise of bilge must be used with great care.

Tank loading

Maximum weight $T = \frac{V_3}{SF_3}$



T maximum tons
V_3 maximum volume of tank
SF_3 stowage factor at maximum temperature

Maximum volume $V_2 = T \cdot SF_2$

V_2 volume of cargo
SF_2 stowage factor at temperature of port of loading

Metric units may be used provided that *T*, *V* and *SF* are coordinated.

Percentage (%) ullage needed for temperature raise $\gamma = \frac{x}{\rho_2}$

γ volume expansion coefficient
x density coefficient
ρ_2 oil density at loading temperature

$$ullage = \gamma \cdot \Delta t \cdot 100\%$$

$$= \frac{x \cdot \Delta t \cdot 100}{\rho_2} \%$$

Highest rise of temperature for applied ullage

$$\Delta t = \frac{\% ullage \cdot \rho_2}{x \cdot 100}$$

$$= \frac{\% ullage}{\gamma \cdot 100}$$

Δt temperature raise

Stability requirements related to loading of grain

$$GG_2 = \frac{l \cdot b^3}{5 \cdot SF \cdot \Delta}$$

GG_2 reduction of *GM* caused by eventual shifting of grain
l length grain may be shifted
b breath grain may be shifted
SF stowage factor of grain
Δ displacement
This formula is applicable for USA.

$$M = \frac{l \cdot b^3 \cdot \sin v}{12 \cdot SF}$$

M upsetting moment
v required angle of inclination for the computations

$$\operatorname{tg} q = \frac{M}{G_2M \cdot \Delta}$$

q angle of inclination at eventual shifting

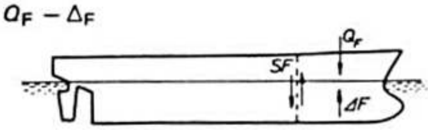
G_2M metacenter height after reduction for free liquid surface

As stability requirements vary, the actual applicable rules must be used.

Shear force

Shear force in section

$$SF = Q_F - \Delta_F$$



SF shear force

Q_F weight of ship's part to section (in this case from forward/ the bow)

Δ_F buoyancy of ship's part to section

Bending moment midship ($^L/_2$)

$$M_{SV} = M_Q - M_\Delta$$

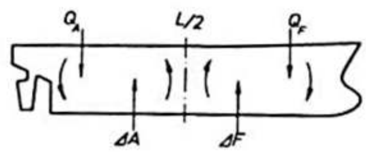
M_{SV} bending moment midship

$$M_Q = \frac{1}{2}\,(M_{QF} + M_{QA})$$

M_Q mean weight moment of half ships related to $^L/_2$

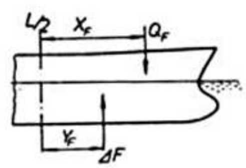
$$M_\Delta = \frac{1}{2}\,(M_{\Delta F} + M_{\Delta A})$$

M_Δ mean buoyancy moment of half ships related to $^L/_2$



$$M_{QF} = Q_F \cdot X_F$$

$$M_{\Delta F} = \Delta_F \cdot Y_F$$

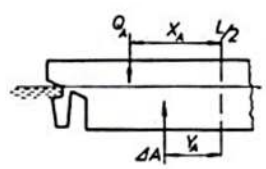


M_{QF} weight moment forward related to $^L/_2$

$M_{\Delta F}$ buoyancy moment forward related to $^L/_2$

$$M_{QA} = Q_A \cdot X_F$$

$$M_{\Delta A} = \Delta_A \cdot Y_A$$



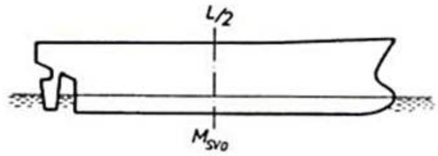
M_{QA} weight moment aft related to $^L/_2$

$M_{\Delta A}$ buoyancy moment aft related to $^L/_2$

When mean M_Q > mean M_Δ, the ship has a hogging condition.

Bending moment of empty ship

$$M_{SV0} = M_{Q0}\, M_{\Delta 0}$$



M_{SV0} bending moment of empty ship

M_{Q0} mean weight moment related to $^L/_2$ for the half ships for empty ship

$M_{\Delta 0}$ mean buoyancy moment related to $^L/_2$ for the half ships for empty ship

$$M_{Q0} = k \cdot L \cdot \Delta$$

$$M_{\Delta 0} = \frac{y}{2} \cdot \Delta$$

k factor varying from 0.102 to 0.125, depending of ship type

L length of ship, L_{pp}

y factor depending on ship shape, in special C_B.

Δ displacement

Cargo's influence on M_{SV0}

$$m = \frac{x}{2} - \frac{7{,}33 \cdot L}{100} \quad (C_B + 0{,}648)$$

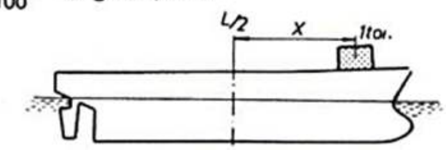
m Δmoment per 1 ton

x distance of cargo from $^L/_2$

$^x/_2$ is hogging element.

C_B block coefficient at summer load line

$$Y_1 = \frac{7{,}33 \cdot L}{100} \ (C_B + 0{,}648)$$



y_1 sagging element

If $^x/_2 > y_1$, the cargo resulted in hogging.

If distance to cargo is 0 m, the distance to neutral spot is $2y_1$ from $^L/_2$.

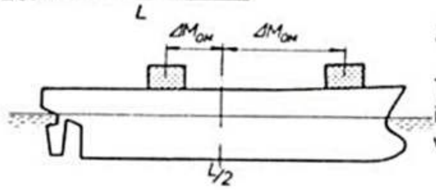
$y_2 = {}^L/_4 - y_1$ is m at the perpendiculars will give hogging.

The calculations are usually made in ton · meter.

Bending moment at $^L/_2$ related to *DW*'s influence

Empty ship	M_{Sw0}
+ Influence of DW	M
Loaded ship	M_{Sw}
± Eventual correction for *LCF*	
Corrected	M_{Sw}

$$\text{Correction for LCF} = \frac{1.5 \cdot f \cdot Tr.mom.}{L}$$



$$\text{Influence of DW} = \Sigma\,(m \cdot DW)$$

M_{Sw0} empty ship calm water moment
M moment from *DW* to hogging (+) or sagging (–)
M_{Sw} loaded ship calm water moment
LCF water-plane's point of gravity
f *LCF*'s distance from $^L/_2$.

$L = L_{pp}$

The correction is to hogging when f is forward of $^L/_2$ and the opposite when f is aftward.

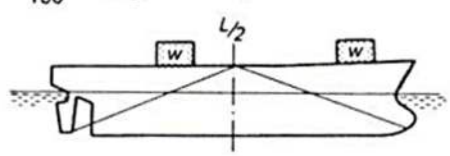
m moment per 1 ton

DW's location is decisive for whether the ship will be hogging or sagging.

Bending moment at $^L/_2$ (M_{SV}) related to the neutral point of the curve of influence

DW's $\frac{1}{2}(M_{QF} + M_{QA})$	$= M_Q$
+ $Y_1 \cdot DW$	$= M_\Delta$
Influence of DW	$= \Delta M_{Sw}$
± Empty ship	$= M_{Sw0}$
Result	M_{Sw}
Eventual correction for *LCF*	

$$Y_1 = \frac{7.33 \cdot L}{100}(C_B + 0.648)$$



M_Q mean weight moment on $^L/_2$ for the half ships. Extracted from trim calculations.
M_Δ mean neutral moment for the half ships on $^L/_2$

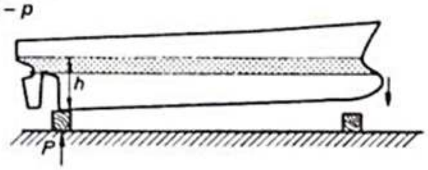
Sum = difference when prefixes are used.

When $M_\Delta > M_Q$, *DW* results in sagging, the opposite when $M_Q > M_\Delta$

Y_1 element of sagging
w weight of the various parts of *DW*

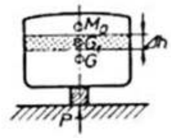
Reduction of stability when docking

$$GG_1 = \frac{p \cdot KG}{\Delta - p}$$



GG_1 reduction of *GM*
KG when docking
P pressure from the block aft

$$P_1 = \frac{2\ Tr \cdot e.Tr.mom}{L}$$



P_1 pressure when ship touch the forward block

Tr trim when docking

$e.\ Tr.mom$ trim moment per unit

Δ trim

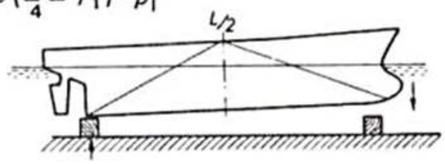
$$p = \Delta h \cdot T$$

T tons per unit immersion

Δh reduced water in the dock after the block aft touch

Change of bending moment at $^{L}/_{2}$ by docking

$$\Delta BM \approx \left(\frac{L}{4} - Y_1\right) \cdot p_1$$



ΔBM change of bending moment at $^{L}/_{2}$ when ship touches the forward block.

ΔBM will result in sagging

L L_{PP} (length between perpendiculars)

Y_1 element of sagging

Influence of pressure on M_{SV} when docking

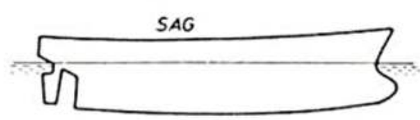
$$Y_1 = \frac{7.33 \cdot L}{100}\,(C_B + 0.648)$$

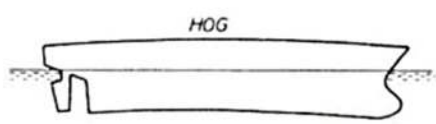
C_B block coefficient at summer load line

These formulas are approximate only, but still useful in addition to practical assessment based on experience.

Bending moment at $^{L}/_{2}$ based on using hydrostatic data for the ship

$$\frac{1}{2}(M_{QF} + M_{QA}) = M_{QLS}$$
$$+\ \frac{1}{2}(M_{QF} + M_{QA}) = M_{QDW}$$
$$\frac{1}{2}(M_{QF} + M_{QA}) = M_Q$$
$$-\ \frac{1}{2}(M_{\Delta F} + M_{\Delta A}) = M_\Delta$$
$$\text{Loaded ship} = M_{SV}$$





M_{QLS} empty ship's mean weight moment on $^{L}/_{2}$. Extracted from ship's data

M_{QDW} DW's mean weight moment on $^{L}/_{2}$. Derived from trim calculation

M_Q total mean weight moment for the two half ships on $^{L}/_{2}$.

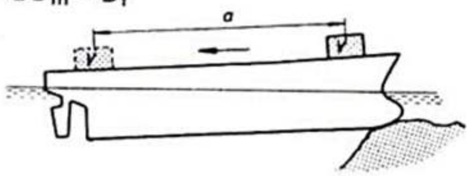
M_Δ mean difference of moment for the two half ships on $^{L}/_{2}$. The figures to be extracted from ship's data.

$M_\Delta > M_Q$ will result in sagging.

Eventual correction for LCF (water-plane's point of gravity) may be done. The formulas are approximate. Ton-meter is most commonly used.

Necessary change of trim and weight shifting if grounding occurs

$D_a = 2\,D_m - D_f$



D_a desired draught aft after grounding
D_m mean draught before grounding
D_f forward draught after grounding

$Tr_\varnothing = D_a - D_f$

$Tr_\varnothing$ desired trim after grounding

$\Delta Tr_\varnothing = Tr_\varnothing - Tr_f$

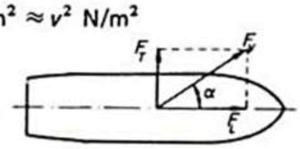
$\Delta Tr_\varnothing$ desired change of trim
Tr_f trim before grounding

$$w = \frac{\Delta Tr_\varnothing \cdot e.Tr.mom}{a}$$

w weight needed to shift
a distance the weight must be shifted

Effect of wind force on moorings

$F_V \approx 0{,}1\,v^2\ \text{kp/m}^2 \approx v^2\ \text{N/m}^2$

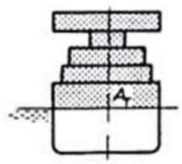


F_V wind force
v velocity of wind in m/sec

Coefficient 0.1 may vary between 0.08 and 0.10

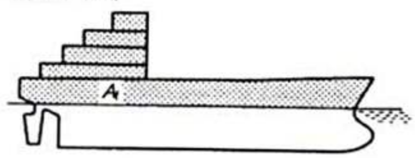
Distribution of wind force

$F_a = F_V \cdot \sin\alpha \cdot A_f$



F_a abeam component of wind force
α angle of wind direction related to fore-and-aft
A_f fore-and-aft area of section above water

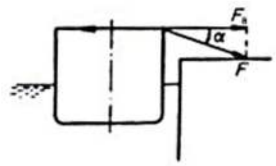
$F_f = F_V \cdot \cos\alpha \cdot A_T$



F_f fore-and-aft component of wind force
A_T abeam area of section above water

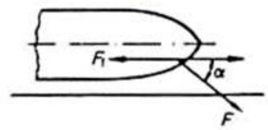
Force on moorings related to the angle of the moorings

Abeam $F = F_a \cdot \sec \alpha$



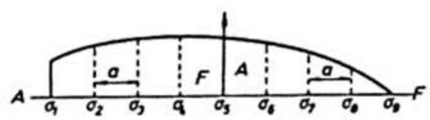
F abeam force on moorings
F_a abeam wind force
α horizontal angle

Fore-and-aft $F = F_f \cdot \sec \alpha$



F fore-and-aft force on moorings
F_f fore-and-aft wind force
α fore-and-aft angle

Simpson's formula for calculating areas and the point of gravity of areas from a selected axis



SM Simpson's factor
σ ordinate

Always an odd number of ordinates.

ord. no.	ord.	SM	prod.	ord.	A-Mom	F-Mom
1	σ_1	1	σ_1	4	$4\sigma_1$	
2	σ_2	4	$4\sigma_2$	3	$12\sigma_2$	
3	σ_3	2	$2\sigma_3$	2	$4\sigma_3$	
4	σ_4	4	$4\sigma_4$	1	$4\sigma_4$	
5	σ_5	2	$2\sigma_5$	axis		
6	σ_6	4	$4\sigma_6$	1		$4\sigma_6$
7	σ_7	2	$2\sigma_7$	2		$4\sigma_7$
8	σ_8	4	$4\sigma_8$	3		$12\sigma_8$
9	σ_9	1	σ_9	4		$4\sigma_9$
		Σ	prod.	Σ	A-Mom	F-Mom
				Σ	F-Mom	
				Σ	Mom	

Area $A = \frac{\Sigma \text{prod} \cdot a}{3}$

A area
a distance between ordinates (must always be constant)

Point of gravity $F = \frac{\Sigma \text{mom} \cdot a}{\Sigma \text{prod}}$

F point of gravity from fore-and-aft axis (σ_5 selected as axis)

Use same system for volume calculations. Number of ordinates should never be less than 5. Even ordinates = 0 must be included.