# KESEIMBANGAN BENDA TERAPUNG

$F_G$ = gaya berat sendiri (vertical ke bawah)

$F_B$ = gaya apung (vertical ke atas)

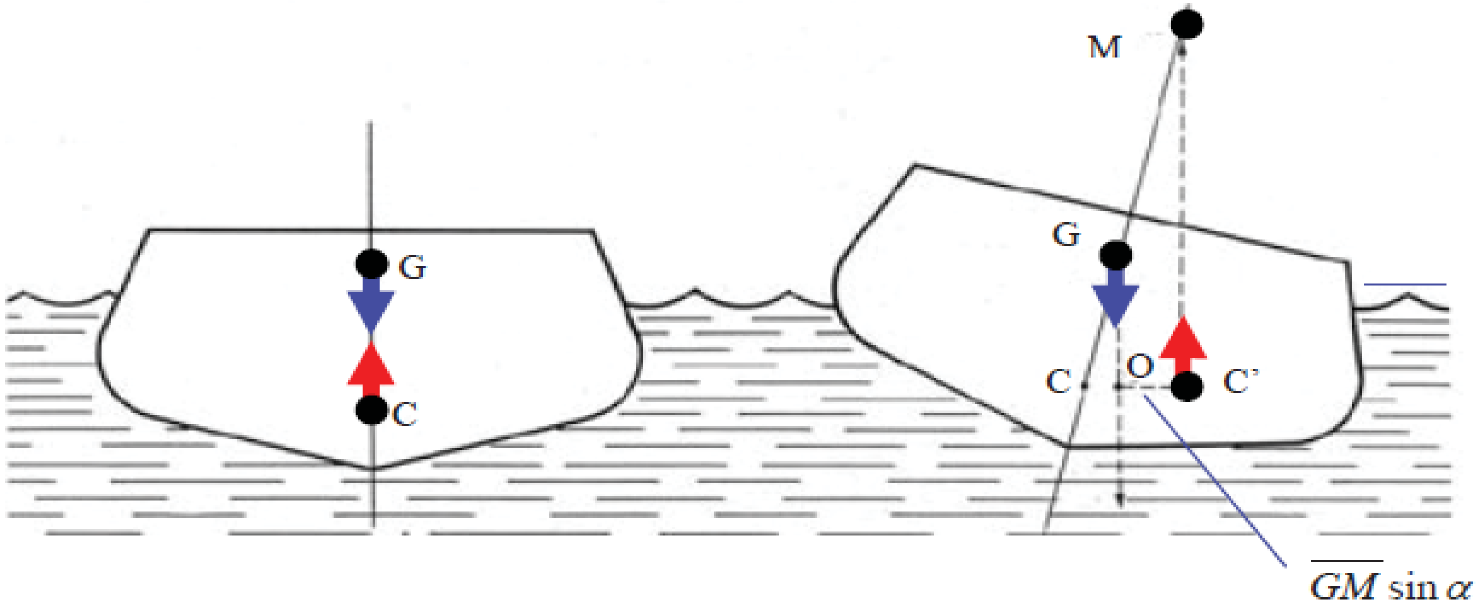
$G$ = pusat berat benda

$B$ = pusat apung benda

# Hubungan G dan B, metasentrum (kestabilan)

- Tenggelam → $F_G > F_B$
- Melayang (terendam) → $F_G = F_B$
- Mengapung → $F_G < F_B$
  - $GM > 0$ → benda stabil
  - $GM = 0$ → benda stabilitas netral
  - $GM < 0$ → benda tidak stabil
- $GM = BM - BG$
- $BM = \frac{I_0}{V}$
  - $BG = OG - OB$
  - $GM$ = tinggi metasentrum
- $I_0$ = momen inersia tampang benda yang terpotong permukaan zat cair
- $V$ = vol.zat cair yang dipindahkan benda
- $BG$ = jarak pusat berat dan pusat apung
- $OG$ = jarak pusat berat benda dan dasar
- $OB$ = jarak pusat apung dan dasar

A floating object is stable if it tends to return to its original position after an angular displacement. This can be illustrated by the following example. When a vessel is tipped, the centre of buoyancy moves from *C* to *C'*. This is because the volume of displaced water at the left of *G* has been decreased while the volume of displaced water to the right is increased. The centre of buoyancy, being at the centre of gravity of the displaced water, moves to point *C'*, and a vertical line through this point passes *G* and intersects the original vertical at *M*. The distance $\overline{GM}$ is known as the *metacentric height*. This illustrates the fundamental law of stability. *When M is above G, the metacentric height is positive and the floating body is stable*, otherwise it is unstable.




There are two ways to find the metacentre: experiment and analytical method.

a) Metacentre by experiment (if a ship is already built, the experiment method is easy to apply)

Shift a known weight ω from the centre of the ship by a distance *l* to create a turning moment $P=\omega l$ and the ship (with a total weight of *W*) is tilted by an angle $\alpha$. The metacentre can be derived by the balance of moments at the point G.

$$\overline{GM} = \frac{P}{W \sin \alpha} = \frac{\omega l}{W \sin \alpha} \approx \frac{\omega}{W} \frac{l}{\alpha}$$

b) Metacentre by analytical method

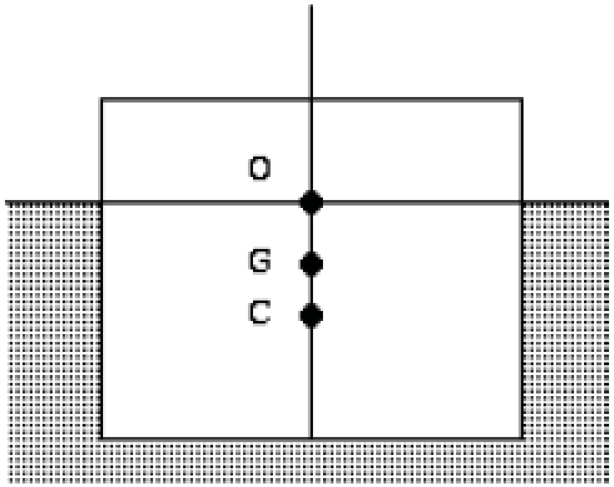
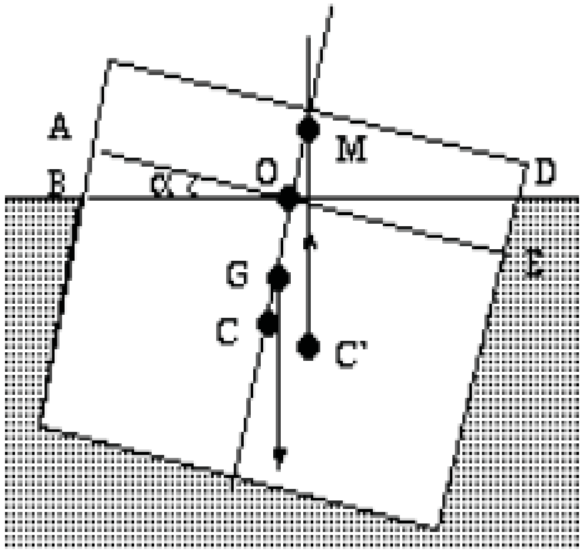



Image the displacement centre (centroid of the buried body) is moved by *x* due to a turning moment. This centroid displacement is contributed from only the top two triangles (worked out one triangle and the other one is doing the same thing, with either added buoyancy and reduced buoyancy). If the ship's displacement volume is V, length is *L* and width is *D*, we can derive around *C* point the following,

$$Vx = 2\int_0^{D/2} L(x\tan\alpha)x\,dx = (\tan\alpha)I_o\,,\quad (I_o \text{ is the 2}^{nd}\text{ moment of the area})$$

So $x = \dfrac{(\tan\alpha)I_o}{V}$




Therefore

$$\overline{CM} = \frac{x}{\tan\alpha} = \frac{I_o}{V}$$

From the centre of gravity and buoyancy,

$$\overline{GM} = \overline{CM} - \overline{CG}$$

Contoh 1

Batu di udara mempunyai berat 500N, sedang beratnya di dalam air adalah 300N. Hitung volume dan rapat relatif batu.

Pnyelesaian:

$$F_B = W_{di\ udara} - W_{di\ air} \rightarrow = 500 - 300 = 200\ N$$

$$F_B = \gamma V = \rho G v \rightarrow 200 = 9810V \dashrightarrow V = 0{,}0204\ m^3$$

$$W_{di\ udara} = \gamma V = \rho g V \rightarrow 500 = \rho . 9{,}81 . 0{,}0204$$

$$\rho = 2500 \frac{kg}{m^3} \dashrightarrow S = \frac{\rho}{\rho_{air}} = \frac{2500}{1000} = 2{,}5$$

Catatan :

Hk. Archimedes: gaya apung FB = berat air yang dipindahkan

Berat air yang dipindahkan = Vol.air (V) x berat jenis (ρ.g)

Contoh 5

Suatu balok ponton, lebar B= 6,0 m, panjang L=12 m, dan sarat d=1,5 m mengapung di dalam air tawar ($\rho_2$=1000 kg/m$^3$).

Hitung:

1. Berat balok ponton,
2. Sarat apabila berada di air laut ($\rho_2$=1025 kg/m$^3$).
3. Beban yang dapat didukung oleh ponton di air tawar apabila sarat maksimum yang diijinkan adalah 2,0 m.

Penyelesaian:

1. $F_G = F_B = \rho_1 gBLd$

$$= 1000 \,.\, 9{,}81 \,.\, 6{,}0 \,.\, 12{,}0 \,.\, 1{,}5$$

$$= 1059480\ N$$

$$F_G = 1059{,}48\ kN$$

Ctt : Berat benda = berat zat cair yang dipindahkan

2. $\rho_2 = 1025\ kg/m^3; F_G = F_B = \rho_2 gBLd$

$$d = \frac{F_G}{\rho_2 gBL} = \frac{1059480}{1025\ .\ 9{,}81\ .\ 6{,}0\ .\ 12{,}0} = 1{,}463\ m$$

3. Sarat maks, $d_{maks}$ = 2,0 m

Gaya apung total:

$$F_{B\ maks} = \rho gBLd_{maks}$$
$$= 1000\ .\ 9{,}81\ .\ 6{,}0\ .\ 12{,}0\ .\ 2{,}0 = 1412640\ N = 1412{,}64\ kN$$

Jadi beban yang dapat didukung:

$$B_{maks} = gaya\ apung\ maks - berat\ ponton$$
$$= 1412{,}64 - 1059{,}48 = 353{,}16\ kN$$

Contoh 6

Silinder berdiameter 3 m, tinggi 3 m terbuat dari bahan dengan rapat relatif 0,8. benda mengapung dengan sumbu vertikal. Hitung tinggi metasentrum dan selidiki stabilitas benda.

Penyelesaian:

$S = \frac{\gamma_{benda}}{\gamma_{air}}$ =0,8 → $\gamma_{benda} = 0{,}8 \,.\, 1000 = 800\ kkf/m^3$

Berat benda: $F_B = \frac{1}{4}\pi D^2 \,.\, H \,.\, \gamma_{benda}$

Berat air yang dipindahkan: $F_B = \frac{1}{4}\pi D^2 \,.\, H \,.\, \gamma_{air}$

Dalan kondisi mengapunga: $F_G = F_B$

Maka: $F_B = \frac{1}{4}\pi D^2 \,.\, H \,.\, \gamma_{benda}$ = $F_B = \frac{1}{4}\pi D^2 \,.\, H \,.\, \gamma_{air}$

Kedalaman benda terendam: $d = \frac{\gamma_{benda}}{\gamma_{air}} \,.\, H = 0{,}8 \,.\, 3 = 2{,}4\ m$

Jarak pusat apungterhadap dasar silinder: $OB = \frac{2{,}4}{2} = 1{,}2\ m$

Jarak pusat berat terhadap silinder: $OG = \frac{3{,}0}{2} = 1{,}5\ m$

Jarak pusat benda dan pusat apung: $BG = OG - OB = 1{,}5 - 1{,}2 = 0{,}3\ m$

Momen Inersia tampang lingkaran: $I_o = \frac{\pi}{64}\,.\,D^4 = \frac{\pi}{64}\,.\,3^4 = 3{,}9761\ m^4$

Volume air yang dipindahkan: $V = \frac{\pi}{4}\,.\,3^2\,.\,2{,}4 = 16{,}9646\ m^3$

$$BM = \frac{I_o}{V} = \frac{3{,}9761}{16{,}9646} = 0{,}234\ m$$

Tinggi Metasentrum: $GM = BM - BG = 0{,}234 - 0{,}3 = -0{,}066\ m$

Ctt: tanda negatip menunjukkan bahwa metasentrum M berada di bawah pusat berat G, → benda tidak stabil