$$\text{New displacement} = 7650 \text{ tonne}$$

$$\text{New centre of gravity} = \frac{25\,350}{7650}$$

$$= 3{\cdot}313 \text{ m above keel}$$

7.

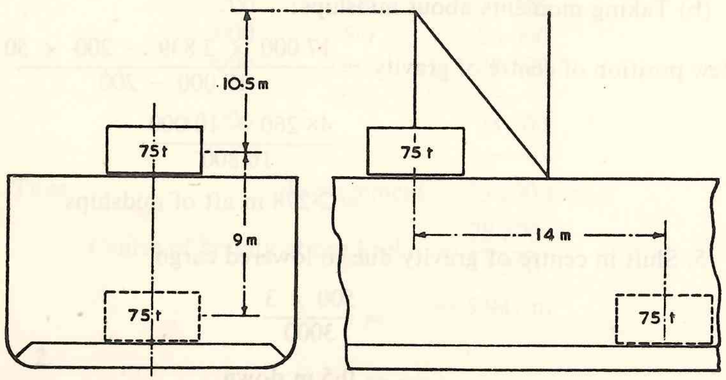

Fig. 92

(a) Since the centre of gravity of a suspended mass is at the point of suspension, the mass is virtually raised to the derrick head.

$$\text{Rise in centre of gravity} = \frac{75 \times 10{\cdot}5}{8000}$$

$$= 0{\cdot}0984 \text{ m}$$

(b) When the mass is at the derrick head there is no further movement of the centre of gravity.

i.e. rise in centre of gravity $= 0{\cdot}0984$ m

(c) When the mass is in its final position the centre of gravity moves down and forward.

$$\text{Vertical shift in centre of gravity} = \frac{75 \times 9}{8000}$$

$$= 0{\cdot}0844 \text{ m down}$$

$$\text{Longitudinal shift in centre of gravity} = \frac{75 \times 14}{8000}$$

$$= 0{\cdot}1313 \text{ m forward}$$

SOLUTIONS TO TEST EXAMPLES 5

1.

$$GM = KB + BM - KG$$

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

$$= \frac{42{\cdot}5 \times 10^3 \times 1{\cdot}025}{12\,000}$$

$$= 3{\cdot}630 \text{ m}$$

$$GM = 3{\cdot}60 + 3{\cdot}63 - 6{\cdot}50$$

$$= 0{\cdot}73 \text{ m}$$

2.

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

$$= \frac{60 \times 10^3 \times 1{\cdot}025}{10\,000}$$

$$= 6{\cdot}150 \text{ m}$$

$$KG = \frac{4000 \times 6{\cdot}30 + 2000 \times 7{\cdot}50 + 4000 \times 9{\cdot}15}{4000 + 2000 + 4000}$$

$$= \frac{25\,200 + 15\,000 + 36\,600}{10\,000}$$

$$= \frac{76\,800}{10\,000}$$

$$= 7{\cdot}680 \text{ m}$$

$$GM = 2{\cdot}750 + 6{\cdot}150 - 7{\cdot}680$$

$$= 1{\cdot}22 \text{ m}$$

3.

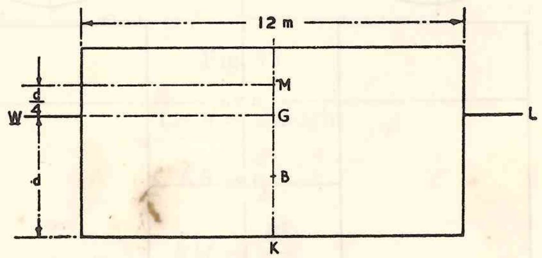

Fig. 93

Let $d = \text{draught}$

Then $KB = \dfrac{d}{2}$

$$BM = \frac{B^2}{12d}$$

$$= \frac{12}{d}$$

$$KG = d$$

$$GM = \frac{d}{4}$$

$$KG + GM = KB + BM$$

$$d + \frac{d}{4} = \frac{d}{2} + \frac{12}{d}$$

$$\tfrac{3}{4}d = \frac{12}{d}$$

$$d^2 = \frac{4}{3} \times 12$$

$$= 16$$

$\therefore$ Draught $d = 4$ m

4.

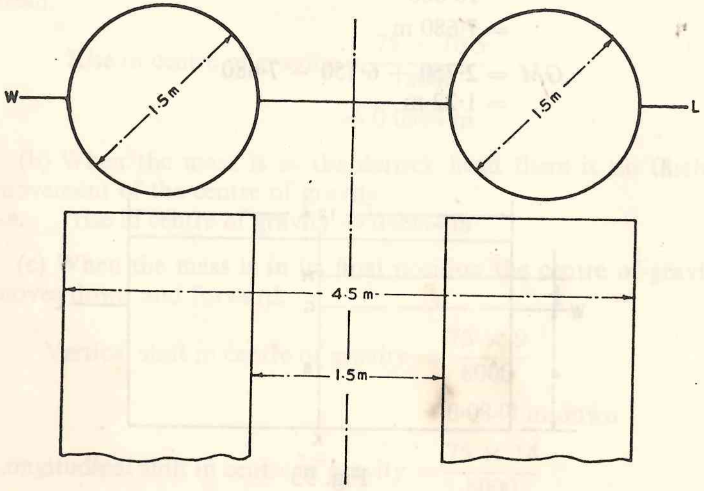

Fig. 94

Although the raft is formed by cylinders, the waterplane consists of two rectangles, a distance of 1·5 m apart.

Second moment of area of waterplane about centreline

$$I = \frac{1}{12} \times 6 \times 4{\cdot}5^3 - \frac{1}{12} \times 6 \times 1{\cdot}5^3$$

$$= \frac{1}{12} \times 6\,(4{\cdot}5^3 - 1{\cdot}5^3)$$

$$= \tfrac{1}{2} \times 87{\cdot}75$$

$$= 43{\cdot}875 \text{ m}^4$$

$$\text{Volume of displacement } \nabla = 2 \times 6 \times \frac{\pi}{4} \times 1{\cdot}5^2 \times \tfrac{1}{2}$$

$$= 10{\cdot}603 \text{ m}^3$$

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

$$= \frac{43{\cdot}875}{10{\cdot}603}$$

$$= 4{\cdot}138 \text{ m}$$

5.

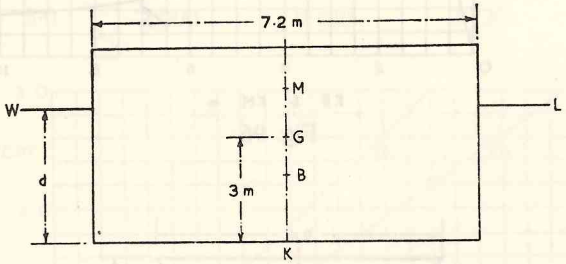

Fig. 95

(a) Let $d = \text{draught}$

$$KB = \frac{d}{2}$$

$$BM = \frac{B^2}{12d}$$

$$= \frac{4{\cdot}32}{d}$$

d	*KB*	*BM*	*KM*
0	0	∞	∞
0·5	0·25	8·640	8·890
1·0	0·50	4·320	4·820
1·5	0·75	2·880	3·630
2·0	1·00	2·160	3·160
2·5	1·25	1·728	2·998
3·0	1·50	1·440	2·940
3·5	1·75	1·234	2·984
4·0	2·00	1·080	3·080

(b) Between draughts of 2·4 m and 3·6 m the vessel will be unstable.

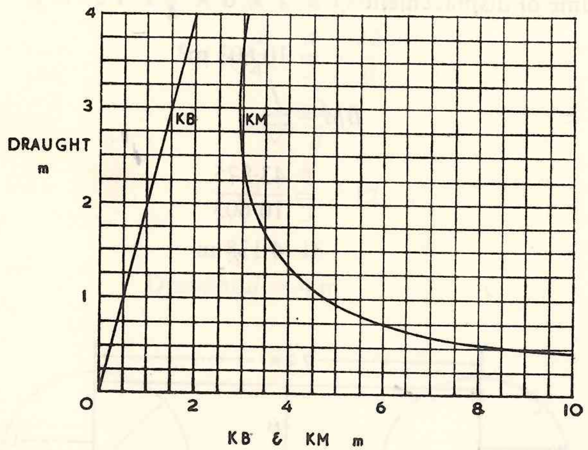

Fig. 96

6.

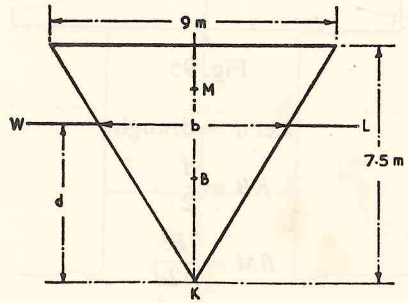

Fig. 97

Let d = draught

b = breadth at waterline

By similar triangles $b = \frac{9}{7 \cdot 5} \times d$

$= 1 \cdot 2d$

$KB = \frac{2}{3}d$

$BM = \frac{b^2}{6d}$

$= \frac{(1 \cdot 2d)^2}{6d}$

$= 0 \cdot 24d$

d	*KB*	*BM*	*KM*
0	0	0	0
0·5	0·333	0·120	0·453
1·0	0·667	0·240	0·907
1·5	1·000	0·360	1·360
2·0	1·333	0·480	1·813
2·5	1·667	0·600	2·267
3·0	2·000	0·720	2·720

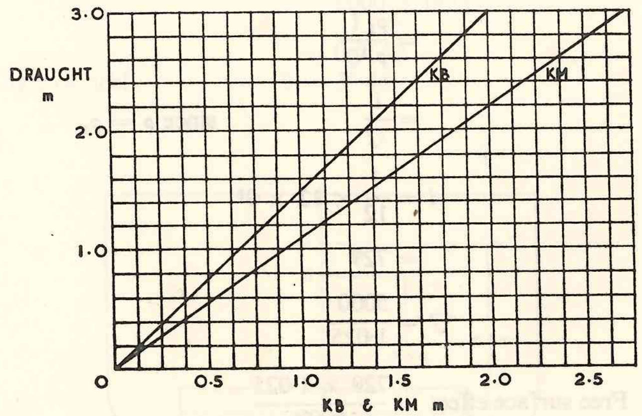

Fig. 98

7.
$$GM = \frac{m \times d}{\triangle \tan \theta}$$

$$\tan \theta = \frac{\text{deflection of pendulum}}{\text{length of pendulum}}$$

$$= \frac{0{\cdot}110}{8{\cdot}50}$$

$$GM = \frac{10 \times 14 \times 8{\cdot}50}{8000 \times 0{\cdot}110}$$

$$= 1{\cdot}352 \text{ m}$$

$$KG = KM - GM$$
$$= 7{\cdot}150 - 1{\cdot}352$$
$$= 5{\cdot}798 \text{ m}$$

8. Mean deflection

$$= \tfrac{1}{8}(81 + 78 + 85 + 83 + 79 + 82 + 84 + 80)$$
$$= 81{\cdot}5 \text{ mm}$$

$$GM = \frac{6 \times 13{\cdot}5 \times 7{\cdot}5}{4000 \times 0{\cdot}0815}$$

$$= 1{\cdot}863 \text{ m}$$

9. Virtual reduction in GM due to free surface

$$= \frac{\rho_1}{\rho}\frac{i}{\nabla}$$

$$= \frac{i}{\nabla} \qquad \text{since } \rho = \rho_1$$

$$i = \frac{1}{12} \times 12 \times 9^3$$

$$= 729$$

$$\nabla = \frac{5000}{1{\cdot}025}$$

$$\text{Free surface effect} = \frac{729 \times 1{\cdot}025}{5000}$$

$$= 0{\cdot}149 \text{ m}$$

10. (a)
$$GM = KM - KG$$
$$= 5{\cdot}00 - 4{\cdot}50$$
$$= 0{\cdot}50 \text{ m}$$

But
$$GM = \frac{m \times d}{\triangle \tan \theta}$$

$$\therefore \quad \tan \theta = \frac{m \times d}{\triangle \times GM}$$

$$= \frac{10 \times 12}{8000 \times 0{\cdot}50}$$

$$= 0{\cdot}030$$

Angle of heel $\theta = 1° \, 43'$

(b) Free surface effect $= \dfrac{i}{\nabla}$

$$= \frac{7{\cdot}5 \times 15^3 \times 1{\cdot}025}{12 \times 8000}$$

$$= 0{\cdot}270 \text{ m}$$

Virtual $GM = 0{\cdot}50 - 0{\cdot}27$
$$= 0{\cdot}23 \text{ m}$$

$$\tan \theta = \frac{10 \times 12}{8000 \times 0{\cdot}23}$$

$$= 0{\cdot}0652$$

Angle of heel $\theta = 3° \, 44'$

11.

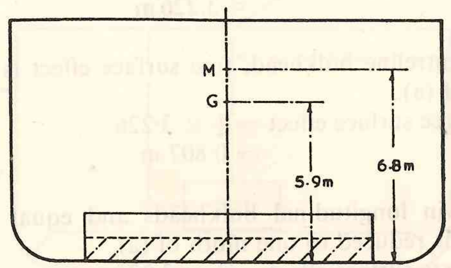

Fig. 99

$$\text{Mass of water added} = 10.5 \times 12 \times 0.6 \times 1.025 = 77.49 \text{ tonne}$$

$$\text{New } KG = \frac{6000 \times 5.9 + 77.49 \times 0.3}{6000 + 77.49} = \frac{35\,400 + 23.25}{6077.49} = 5.829 \text{ m}$$

$$\text{Free surface effect} = \frac{\rho i}{\Delta} = \frac{1.025 \times 10.5 \times 12^3}{12 \times 6077.49} = 0.255 \text{ m}$$

$$\text{Virtual } KG = 5.829 + 0.255 = 6.084 \text{ m}$$

$$GM = 6.80 - 6.084 = 0.716 \text{ m}$$

12 (a)

$$\text{Free surface effect} = \frac{\rho i}{\Delta} = \frac{0.8 \times 9 \times 10 \times 24^3}{12 \times 25\,000} = 3.226 \text{ m}$$

(b) With centreline bulkhead, free surface effect is reduced to one quarter of (a).

$$\text{Free surface effect} = \tfrac{1}{4} \times 3{\cdot}226 = 0{\cdot}807 \text{ m}$$

(c) With twin longitudinal bulkheads and equal tanks, free surface effect is reduced to one ninth of (a).

$$\text{Free surface effect} = \tfrac{1}{9} \times 3{\cdot}226 = 0{\cdot}358 \text{ m}$$

(d) The only change is in the second moment of area.

For centre tank $$i = \frac{9 \times 10 \times 12^3}{12} = \frac{9 \times 10}{12} \times 1728$$

For wing tanks $$i = \frac{9 \times 10 \times 6^3}{12} \times 2 = \frac{9 \times 10}{12} \times 432$$

Thus for both tanks $$i = \frac{9 \times 10}{12}(1728 + 432) = \frac{30}{4} \times 2160$$

$$\text{Total free surface effect} = \frac{0.8 \times 30 \times 2160}{4 \times 25\,000} = 0{\cdot}518 \text{ m}$$

13.

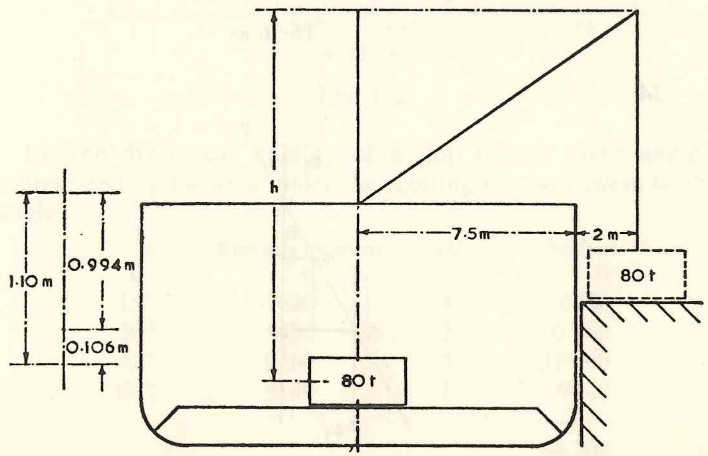

Fig. 100

$$GM = \frac{m \times d}{\triangle \tan \theta}$$

$$= \frac{80 \times 9{\cdot}5}{12\,500 \times \tan 3{\cdot}5^\circ}$$

$$= 0{\cdot}994 \text{ m}$$

Thus the metacentric height is reduced from 1·10 m to 0·994 m when the mass is suspended over the quay. Since the draught does not alter, and hence the transverse metacentre remains in the same position, this reduction in metacentric height must be due to a rise in the centre of gravity. This rise is due to the effect of the suspended mass.

$$\text{Rise in centre of gravity} = 1{\cdot}10 - 0{\cdot}994$$
$$= 0{\cdot}106 \text{ m}$$

Let h be the distance from the centre of gravity of the mass to the derrick head.

$$\text{Then} \quad \text{rise in centre of gravity} = \frac{\text{mass} \times h}{\text{displacement}}$$

$$0{\cdot}106 = \frac{80 \times h}{12\,500}$$

$$h = \frac{0{\cdot}106 \times 12\,500}{80}$$

$$= 16{\cdot}56 \text{ m}$$

14.

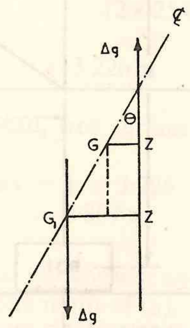

Fig. 101

Since the actual centre of gravity G_1 is *below* the assumed centre of gravity G, the ship is *more* stable, and

$$G_1Z = GZ + GG_1 \sin \theta$$
$$GG_1 = 3{\cdot}50 - 3{\cdot}00$$
$$= 0{\cdot}50 \text{ m}$$

θ	$\sin \theta$	$GG_1 \sin \theta$	GZ	G_1Z
0	0	0	0	0
15°	0·2588	0·129	0·25	0·379
30°	0·500	0·250	0·46	0·710
45°	0·7071	0·353	0·51	0·863
60°	0·8660	0·433	0·39	0·823
75°	0·9659	0·483	0·10	0·583
90°	1·000	0·500	−0·38	0·120

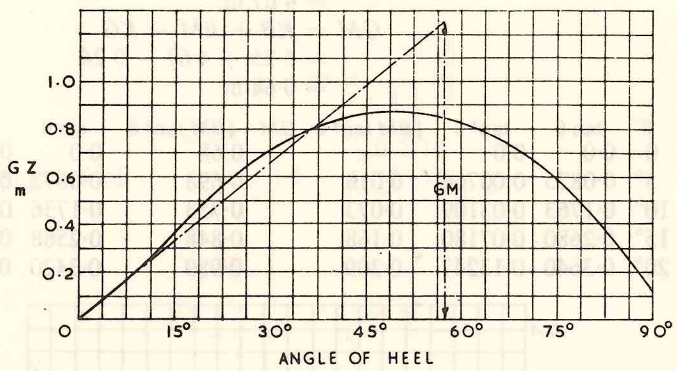

Fig. 102

15. The dynamical stability of a ship to any given angle is represented by the area under the righting moment curve to that angle.

θ	Righting moment	SM	Product
0	0	1	0
15°	1690	4	6760
30°	5430	2	10 860
45°	9360	4	37 440
60°	9140	1	9140
			64 200

$$\text{Common interval} = 15^\circ$$
$$= \frac{15}{57 \cdot 3} \text{ radians}$$
$$\text{Dynamical stability} = \frac{1}{3} \times \frac{15}{57 \cdot 3} \times 64\,200$$
$$= 5602 \text{ kJ}$$

16. Wall-sided formula $GZ = \sin\theta\,(GM + \frac{1}{2}BM \tan^2\theta)$

$$BM = \frac{I}{\nabla}$$
$$= \frac{82 \times 10^3 \times 1 \cdot 025}{18\,000}$$
$$= 4 \cdot 67 \text{ m}$$
$$GM = KB + BM - KG$$
$$= 5 \cdot 25 + 4 \cdot 67 - 9 \cdot 24$$
$$= 0 \cdot 68 \text{ m}$$

θ	$\tan\theta$	$\tan^2\theta$	$\frac{1}{2}BM \tan^2\theta$	$GM + \frac{1}{2}BM \tan^2\theta$	$\sin\theta$	GZ
0	0·0	0·0	—	0·68	0·0	0
5°	0·0875	0·00766	0·018	0·698	0·0872	0·061
10°	0·1763	0·03109	0·073	0·753	0·1736	0·131
15°	0·2680	0·07180	0·168	0·848	0·2588	0·219
20°	0·3640	0·13247	0·309	0·989	0·3420	0·338

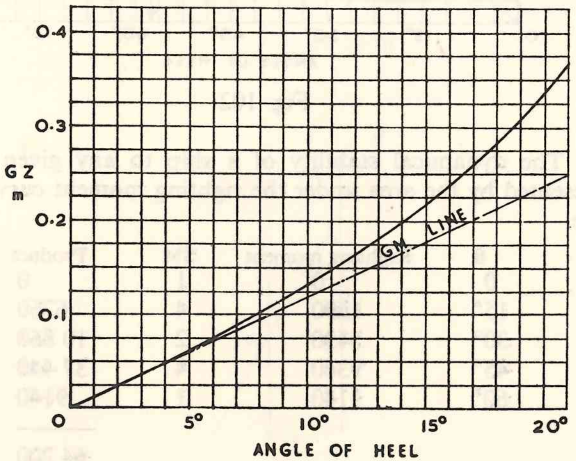

Fig. 103

17. $$\text{New } KG = \frac{7200 \times 5 \cdot 20 - 300 \times 0 \cdot 60}{7200 - 300}$$
$$= \frac{37\,260}{6900}$$
$$= 5 \cdot 40 \text{ m}$$
$$GM = KM - KG$$
$$= 5 \cdot 35 - 5 \cdot 40$$
$$= -\,0 \cdot 05 \text{ m}$$
$$BM = KM - KB$$
$$= 5 \cdot 35 - 3 \cdot 12$$
$$= 2 \cdot 23 \text{ m}$$
$$\tan\theta = \pm\sqrt{\frac{-2GM}{BM}}$$
$$= \pm\sqrt{\frac{0 \cdot 10}{2 \cdot 23}}$$
$$= \pm\,0 \cdot 2118$$

Angle of loll $\theta = \pm\,11^\circ\,57'$

SOLUTIONS TO TEST EXAMPLES 6

1. (a) $$\text{Change in trim} = \frac{\text{trimming moment}}{\text{MCT1 cm}}$$

$$\therefore \quad \text{MCT1 cm} = \frac{100 \times 75}{65}$$

$$= 115{\cdot}4 \text{ tonne m}$$

(b) $$\text{MCT1 cm} = \frac{\triangle \times GM_L}{100L}$$

$$\therefore \quad GM_L = \frac{115{\cdot}4 \times 100 \times 125}{12\,000}$$

$$= 120{\cdot}2 \text{ m}$$

(c) $$GG_1 = \frac{m \times d}{\triangle}$$

$$= \frac{100 \times 75}{12\,000}$$

$$= 0{\cdot}625 \text{ m}$$

2. $$\text{Bodily sinkage} = \frac{\text{mass added}}{\text{TPC}}$$

$$= \frac{110}{3}$$

$$\text{Change in trim} = \frac{110 \times (24 + 2{\cdot}5)}{80}$$

$$= 36{\cdot}44 \text{ cm by the stern}$$

$$\text{Change forward} = -\frac{36{\cdot}44}{120}\left(\frac{120}{2} - 2{\cdot}5\right)$$

$$= -17{\cdot}46 \text{ cm}$$

$$\text{Change aft} = +\frac{36{\cdot}44}{120}\left(\frac{120}{2} + 2{\cdot}5\right)$$

$$= +18{\cdot}98 \text{ cm}$$

$$\text{New draught forward} = 5{\cdot}50 + 0{\cdot}085 - 0{\cdot}175$$
$$= 5{\cdot}410 \text{ m}$$
$$\text{New draught aft} = 5{\cdot}80 + 0{\cdot}085 + 0{\cdot}190$$
$$= 6{\cdot}075 \text{ m}$$

3. $$\text{Bodily rise} = \frac{180}{18}$$

$$= 10 \text{ cm}$$

$$\text{MCT1 cm} = \frac{14\,000 \times 125}{100 \times 130}$$

$$= 134{\cdot}6 \text{ tonne m}$$

$$\text{Change in trim} = -\frac{180 \times (40 - 3)}{134{\cdot}6}$$

$$= -49{\cdot}48 \text{ cm by the stern}$$
$$= +49{\cdot}48 \text{ cm by the head}$$

$$\text{Change forward} = +\frac{49{\cdot}48}{130}\left(\frac{130}{2} + 3\right)$$

$$= +25{\cdot}88 \text{ cm}$$

$$\text{Change aft} = -\frac{49{\cdot}48}{130}\left(\frac{130}{2} - 3\right)$$

$$= -23{\cdot}60 \text{ cm}$$

$$\text{New draught forward} = 7{\cdot}50 - 0{\cdot}10 + 0{\cdot}259$$
$$= 7{\cdot}659 \text{ cm}$$
$$\text{New draught aft} = 8{\cdot}10 - 0{\cdot}10 - 0{\cdot}236$$
$$= 7{\cdot}764 \text{ cm}$$

4. If the draught aft remains constant, the reduction in draught aft due to change in trim must equal the bodily sinkage.

$$\text{Bodily sinkage} = \frac{180}{11}$$

$$= 16{\cdot}36 \text{ cm}$$

$$\text{Change in trim aft} = -\frac{t}{L}\text{WF}$$

$$16{\cdot}36 = \frac{t}{90}\left(\frac{90}{2} - 2\right)$$

$$t = \frac{16{\cdot}36 \times 90}{43}$$

$$= 34{\cdot}24 \text{ cm by the head}$$

But $$\text{Change in trim } t = \frac{m \times d}{\text{MCT1 cm}}$$

$$34{\cdot}24 = \frac{180 \times d}{50}$$

$$d = \frac{34{\cdot}24 \times 50}{180}$$

$$= 9{\cdot}511 \text{ m}$$

Thus the mass must be placed 9·511 m forward of the centre of flotation or 7·511 m forward of midships.

$$\text{Change in trim forward} = +\frac{34{\cdot}24}{90}\left(\frac{90}{2} + 2\right)$$

$$= 17{\cdot}88 \text{ cm}$$

$$\text{New draught forward} = 5{\cdot}80 + 0{\cdot}164 + 0{\cdot}179$$
$$= 6{\cdot}143 \text{ m}$$

5. $$\text{Change in trim required} = 8{\cdot}90 - 8{\cdot}20$$
$$= 0{\cdot}70 \text{ m}$$
$$= 70 \text{ cm by the head}$$

$$\therefore \quad 70 = \frac{m \times d}{\text{MCT1 cm}}$$

$$= \frac{m \times (60 + 1{\cdot}5)}{260}$$

$$m = \frac{70 \times 260}{61{\cdot}5}$$

$$= 296 \text{ tonne}$$

$$\text{Bodily sinkage} = \frac{296}{28}$$

$$= 10{\cdot}57 \text{ cm}$$

$$\text{Change forward} = +\frac{70}{150}\left(\frac{150}{2} + 1{\cdot}5\right)$$

$$= +\ 35{\cdot}70 \text{ cm}$$

$$\text{Change aft} = -\frac{70}{150}\left(\frac{150}{2} - 1{\cdot}5\right)$$

$$= -\ 34{\cdot}30 \text{ cm}$$

$$\text{New draught forward} = 8{\cdot}20 + 0{\cdot}106 + 0{\cdot}357$$
$$= 8{\cdot}663 \text{ m}$$

$$\text{New draught aft} = 8{\cdot}90 + 0{\cdot}106 - 0{\cdot}343$$
$$= 8{\cdot}663 \text{ m}$$

(It is not necessary to calculate both draughts but this method checks the calculation.)

6.

Mass	distance from F	moment forward	moment aft
20	41·5A	—	830
50	24·5A	—	1225
30	3·5A	—	105
70	4·5F	315	—
15	28·5F	427·5	—
185		742·5	2160

$$\text{Bodily sinkage} = \frac{185}{9} = 20{\cdot}55 \text{ cm}$$

$$\text{Excess moment aft} = 2160 - 742{\cdot}5 = 1417{\cdot}5 \text{ tonne m}$$

$$\text{Change in trim} = \frac{1417{\cdot}5}{55} = 25{\cdot}77 \text{ cm by the stern}$$

$$\text{Change forward} = -\frac{25{\cdot}77}{110}\left(\frac{110}{2} - 1{\cdot}5\right) = -12{\cdot}53 \text{ cm}$$

$$\text{Change aft} = +\frac{25{\cdot}77}{110}\left(\frac{110}{2} + 1{\cdot}5\right) = +13{\cdot}24 \text{ cm}$$

$$\text{New draught forward} = 4{\cdot}20 + 0{\cdot}205 - 0{\cdot}125 = 4{\cdot}280 \text{ m}$$

$$\text{New draught aft} = 4{\cdot}45 + 0{\cdot}205 + 0{\cdot}132 = 4{\cdot}787 \text{ m}$$

7.

Mass	distance from F	moment forward	moment aft
+160	66·5A	—	+10 640
+200	23·5F	+4700	—
−120	78·5A	—	− 9420
− 70	19·5A	—	− 1365
+170		+4700	− 145

$$\text{Bodily sinkage} = \frac{170}{28} = 6{\cdot}07 \text{ cm}$$

$$\text{Excess moment forward} = 4700 - (-145) = 4845 \text{ tonne m}$$

$$\text{Change in trim} = \frac{4845}{300} = 16{\cdot}15 \text{ cm by the head}$$

$$\text{Change forward} = \frac{16{\cdot}15}{170}\left(\frac{170}{2} - 3{\cdot}5\right) = +7{\cdot}74 \text{ cm}$$

$$\text{Change aft} = -\frac{16{\cdot}15}{170}\left(\frac{170}{2} + 3{\cdot}5\right) = -8{\cdot}41 \text{ cm}$$

$$\text{New draught forward} = 6{\cdot}85 + 0{\cdot}061 + 0{\cdot}077 = 6{\cdot}988 \text{ m}$$

$$\text{New draught aft} = 7{\cdot}50 + 0{\cdot}061 - 0{\cdot}084 = 7{\cdot}477 \text{ m}$$

8.

Item	mass	Lcg	moment forward	moment aft
Lightweight	1050	4·64A	—	4872·0
Cargo	2150	4·71F	10 126·5	—
Fuel	80	32·55A	—	2604·0
Water	15	32·90A	—	493·5
Stores	5	33·60F	168·0	—
	3300		10 294·5	7969·5

$$\text{Excess moment forward} = 10\,294{\cdot}5 - 7969{\cdot}5 = 2325 \text{ tonne m}$$

$$\text{LCG of loaded ship} = \frac{2325}{3300}$$

$$= 0{\cdot}704 \text{ m forward of midships}$$

The mean draught, MCT1 cm, LCB and LCF may be found by interpolation from the tabulated values.

Displacement difference 4·50 m to 5·00 m

$$= 3533 - 3172$$
$$= 361 \text{ tonne}$$

$$\text{Actual difference required} = 3300 - 3172$$
$$= 128 \text{ tonne}$$

$$\text{Proportion of draught difference} = \frac{128}{361}$$

$$\text{Actual draught difference} = 0{\cdot}50 \times \frac{128}{361}$$

$$= 0{\cdot}50 \times 0{\cdot}355$$
$$= 0{\cdot}177 \text{ m}$$

$$\therefore \quad \text{mean draught} = 4{\cdot}50 + 0{\cdot}177$$
$$= 4{\cdot}677 \text{ m}$$

MCT1 cm difference 4·50 m to 5·00 m

$$= 43{\cdot}10 - 41{\cdot}26$$
$$= 1{\cdot}84 \text{ tonne m}$$

$$\text{Actual difference} = 1{\cdot}84 \times 0{\cdot}355$$
$$= 0{\cdot}65 \text{ tonne m}$$

$$\therefore \quad \text{MCT1 cm} = 41{\cdot}26 + 0{\cdot}65$$
$$= 41{\cdot}91 \text{ tonne m}$$

$$\text{LCB difference 4·50 m to 5·00 m} = -\ 0{\cdot}24 \text{ m}$$

$$\text{Actual difference} = -\ 0{\cdot}24 \times 0{\cdot}355$$
$$= -\ 0{\cdot}085$$

$$\therefore \quad \text{LCB} = 1{\cdot}24 - 0{\cdot}085$$
$$= 1{\cdot}155 \text{ m forward of midships}$$

$$\text{LCF difference 4·50 m to 5·00 m} = 0{\cdot}43 \text{ m}$$

$$\text{Actual difference} = 0{\cdot}43 \times 0{\cdot}355$$
$$= 0{\cdot}153$$

$$\therefore \quad \text{LCF} = 0{\cdot}84 + 0{\cdot}153$$
$$= 0{\cdot}993 \text{ m aft of midships}$$

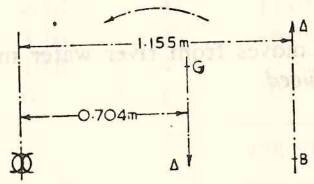

Fig. 104

$$\text{Trimming lever} = 1{\cdot}155 - 0{\cdot}704$$
$$= 0{\cdot}451 \text{ m by the stern}$$

$$\text{Trimming moment} = 3300 \times 0{\cdot}451$$

$$\text{Trim} = \frac{3300 \times 0{\cdot}451}{41{\cdot}91}$$

$$= 35{\cdot}51 \text{ cm by the stern}$$

$$\text{Change forward} = -\frac{35{\cdot}51}{80}\left(\frac{80}{2} + 0{\cdot}993\right)$$

$$= -\ 18{\cdot}20 \text{ cm}$$

$$\text{Change aft} = +\frac{35{\cdot}51}{80}\left(\frac{80}{2} - 0{\cdot}993\right)$$

$$= +\ 17{\cdot}31 \text{ cm}$$

$$\text{Draught forward} = 4{\cdot}677 - 0{\cdot}182$$
$$= 4{\cdot}495 \text{ m}$$

$$\text{Draught aft} = 4{\cdot}677 + 0{\cdot}173$$
$$= 4{\cdot}850 \text{ m}$$

9. Change in mean draught $= \dfrac{100\Delta}{A_w}\left(\dfrac{\rho_S - \rho_R}{\rho_S \times \rho_R}\right)$

$$= \frac{100 \times 15\,000}{1950}\left(\frac{1{\cdot}022 - 1{\cdot}005}{1{\cdot}005 \times 1{\cdot}022}\right)$$

$$= 12{\cdot}73 \text{ cm}$$

Since the vessel moves from river water into sea water, the draught will be *reduced*.

10. Let ρ_S = density of sea water in kg/m³

$$10 = \frac{7000 \times 100}{1500}\left(\frac{\rho_S - 1005}{1005 \times \rho_S}\right) \times 1000$$

$$\frac{\rho_S - 1005}{1005\rho_S} = \frac{10 \times 1500}{7000 \times 100 \times 1000}$$

$$\rho_S - 1005 = \frac{10 \times 1500 \times 1005\rho_S}{7000 \times 100 \times 1000}$$

$$= 0{\cdot}02153\ \rho_S$$

$$\rho_S(1 - 0{\cdot}02153) = 1005$$

$$\rho_S = \frac{1005}{0{\cdot}97847}$$

$$= 1027 \text{ kg/m}^3$$

11.

½ ordinate	SM	product
0	1	0
2·61	4	10·44
3·68	2	7·36
4·74	4	18·96
5·84	2	11·68
7·00	4	28·00
7·30	2	14·60
6·47	4	25·88
5·35	2	10·70
4·26	4	17·04
3·16	2	6·32
1·88	4	7·52
0	1	0
		158·50

Common interval $= \dfrac{90}{12}$ m

Waterplane area $= \dfrac{2}{3} \times \dfrac{90}{12} \times 158{\cdot}50$

$$= 792{\cdot}5 \text{ m}^2$$

(a) TPC $= \dfrac{792{\cdot}5 \times 1{\cdot}024}{100}$

$$= 8{\cdot}115$$

(b) Mass required $= 12 \times 8{\cdot}115$
$= 97{\cdot}38$ tonne

(c) Change in mean draught $= \dfrac{8200 \times 100}{792{\cdot}5}\left(\dfrac{1{\cdot}024 - 1{\cdot}005}{1{\cdot}005 \times 1{\cdot}024}\right)$

$= 19{\cdot}10$ cm increase

12. Let $\triangle$ = displacement in sea water
Then $(\triangle - 360)$ = displacement in fresh water

Volume of displacement in sea water

$$= \frac{\triangle}{1{\cdot}025}\ \text{m}^3$$

Volume of displacement in fresh water

$$= \frac{\triangle - 360}{1{\cdot}000}\ \text{m}^3$$

Since the draught remains constant, these two volumes must be equal

$$\frac{\triangle - 360}{1{\cdot}000} = \frac{\triangle}{1{\cdot}025}$$

$$1{\cdot}025\,\triangle - 1{\cdot}025 \times 360 = \triangle$$

$$0{\cdot}025\triangle = 1{\cdot}025 \times 360$$

$$\triangle = \frac{1{\cdot}025 \times 360}{0{\cdot}025}$$

Displacement in sea water = 14 760 tonne

13. Change in mean draught

$$= \frac{5200 \times 100}{1100}\left(\frac{1{\cdot}023 - 1{\cdot}002}{1{\cdot}002 \times 1{\cdot}023}\right)$$

$$= 9{\cdot}68 \text{ cm increase}$$

$$\text{MCT1 cm} = \frac{5200 \times 95}{100 \times 90}$$

$$= 54{\cdot}88 \text{ tonne nm}$$

$$FB = 0{\cdot}6 + 2{\cdot}2$$
$$= 2{\cdot}8 \text{ m}$$

$$\text{Change in trim} = \frac{\triangle \times FB\,(\rho_S - \rho_R)}{\text{MCT1 cm} \times \rho_S}$$

$$= \frac{5200 \times 2{\cdot}8\,(1{\cdot}023 - 1{\cdot}002)}{54{\cdot}88 \times 1{\cdot}023}$$

$$= 5{\cdot}45 \text{ cm by the head}$$

$$\text{Change forward} = +\frac{5{\cdot}45}{90}\left(\frac{90}{2} + 2{\cdot}2\right)$$

$$= +\,2{\cdot}86 \text{ cm}$$

$$\text{Change aft} = -\frac{5{\cdot}45}{90}\left(\frac{90}{2} - 2{\cdot}2\right)$$

$$= -\,2{\cdot}59 \text{ cm}$$

$$\text{New draught forward} = 4{\cdot}95 + 0{\cdot}097 + 0{\cdot}029$$
$$= 5{\cdot}076 \text{ cm}$$

$$\text{New draught aft} = 5{\cdot}35 + 0{\cdot}097 - 0{\cdot}026$$
$$= 5{\cdot}421 \text{ cm}$$

14. Change in mean draught

$$= \frac{22\,000 \times 100}{3060}\left(\frac{1{\cdot}026 - 1{\cdot}007}{1{\cdot}007 \times 1{\cdot}026}\right)$$

$$= 13{\cdot}22 \text{ cm reduction}$$

$$\text{Change in trim} = \frac{22\,000 \times 3\,(1{\cdot}026 - 1{\cdot}007)}{280 \times 1{\cdot}007}$$

$$= 4{\cdot}45 \text{ cm by the stern}$$

$$\text{Change forward} = -\frac{4{\cdot}45}{160}\left(\frac{160}{2} + 4\right)$$

$$= -\,2{\cdot}34 \text{ cm}$$

$$\text{Change aft} = +\frac{4{\cdot}45}{160}\left(\frac{160}{2} - 4\right)$$

$$= +\,2{\cdot}11 \text{ cm}$$

$$\text{New draught forward} = 8{\cdot}15 - 0{\cdot}132 - 0{\cdot}023$$
$$= 7{\cdot}995 \text{ m}$$

$$\text{New draught aft} = 8{\cdot}75 - 0{\cdot}132 + 0{\cdot}021$$
$$= 8{\cdot}639 \text{ m}$$

15. (a)

$$\text{Volume of lost buoyancy} = 12 \times 10 \times 4 \text{ m}^3$$

$$\text{Area of intact waterplane} = (60 - 12) \times 10 = 48 \times 10 \text{ m}^2$$

$$\text{Increase in draught} = \frac{12 \times 10 \times 4}{48 \times 10} = 1 \text{ m}$$

$$\therefore \text{ New draught} = 4 + 1 = 5 \text{ m}$$

(b)

$$\text{Volume of lost buoyancy} = 0{\cdot}85 \times 12 \times 10 \times 4 \text{ m}^3$$

$$\text{Area of intact waterplane} = (60 - 0{\cdot}85 \times 12) \times 10 = 49{\cdot}8 \times 10 \text{ m}^2$$

$$\text{Increase in draught} = \frac{0{\cdot}85 \times 12 \times 10 \times 4}{49{\cdot}8 \times 10} = 0{\cdot}819 \text{ m}$$

$$\therefore \text{ New draught} = 4 + 0{\cdot}819 = 4{\cdot}819 \text{ m}$$

(c)

$$\text{Volume of lost buoyancy} = 0{\cdot}60 \times 12 \times 10 \times 4 \text{ m}^3$$

$$\text{Area of intact waterplane} = (60 - 0{\cdot}60 \times 12) \times 10 = 52{\cdot}8 \times 10 \text{ m}^2$$

$$\text{Increase in draught} = \frac{0{\cdot}60 \times 12 \times 10 \times 4}{52{\cdot}8 \times 10} = 0{\cdot}545 \text{ m}$$

$$\therefore \text{ New draught} = 4 + 0{\cdot}545 = 4{\cdot}545 \text{ m}$$

16.

$$\text{Density of coal} = 1{\cdot}000 \times 1{\cdot}28 = 1{\cdot}28 \text{ t/m}^3$$

Volume of 1 tonne of solid coal

$$= \frac{1}{1{\cdot}28} = 0{\cdot}781 \text{ m}^3$$

Volume of 1 tonne of stowed coal

$$= 1{\cdot}22 \text{ m}^3$$

$\therefore$ in every $1{\cdot}22$ m³ of volume, $0{\cdot}439$ m³ is available for water

Hence

$$\text{Permeability } \mu = \frac{0{\cdot}439}{1{\cdot}22} = 0{\cdot}3598$$

$$\text{Increase in draught} = \frac{0{\cdot}3598 \times 9 \times 8 \times 3}{(50 - 0{\cdot}3598 \times 9) \times 8} = 0{\cdot}208 \text{ m}$$

$$\therefore \text{ New draught} = 3 + 0{\cdot}208 = 3{\cdot}208 \text{ m}$$

17.

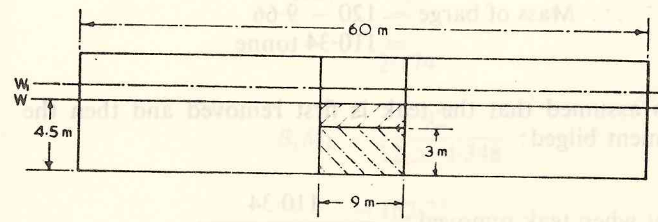

Fig. 105

(a) Volume of lost buoyancy $= 9 \times 12 \times 3 \text{ m}^3$

Area of intact waterplane $= 60 \times 12 \text{ m}^2$

(Since the water is restricted at the flat, the whole of the waterplane is intact.)

$$\text{Increase in draught} = \frac{9 \times 12 \times 3}{60 \times 12}$$

$$= 0{\cdot}45 \text{ m}$$

$$\text{New draught} = 4{\cdot}5 + 0{\cdot}45$$
$$= 4{\cdot}95 \text{ m}$$

(b) Volume of lost buoyancy $= 9 \times 12 \times (4{\cdot}5 - 3) \text{ m}^3$

Area of intact waterplane $= (60 - 9) \times 12 \text{ m}^2$

$$\text{Increase in draught} = \frac{9 \times 12 \times 1{\cdot}5}{51 \times 12}$$

$$= 0{\cdot}265 \text{ m}$$

$$\text{New draught} = 4{\cdot}5 + 0{\cdot}265$$
$$= 4{\cdot}765 \text{ m}$$

18. Mass of barge and teak $= 25 \times 4 \times 1{\cdot}2 \times 1{\cdot}000$
$= 120$ tonne

$$\text{Mass of teak} = 25 \times 4 \times 0{\cdot}120 \times 0{\cdot}805$$
$$= 9{\cdot}66 \text{ tonne}$$

$$\therefore \text{Mass of barge} = 120 - 9{\cdot}66$$
$$= 110{\cdot}34 \text{ tonne}$$

If it is assumed that the teak is first removed and then the compartment bilged:

$$\text{Draught when teak removed} = \frac{110{\cdot}34}{1{\cdot}000 \times 25 \times 4}$$

$$= 1{\cdot}1034$$

Increase in draught due to bilging

$$= \frac{5 \times 4 \times 1{\cdot}1034}{(25 - 5)\,4}$$

$$= 0{\cdot}2758 \text{ m}$$

$$\text{Final draught} = 1{\cdot}1034 + 0{\cdot}2758$$
$$= 1{\cdot}379 \text{ m}$$

19. It has been convenient to consider this as a three-part question, but any *one* part could constitute an examination question.

(a)

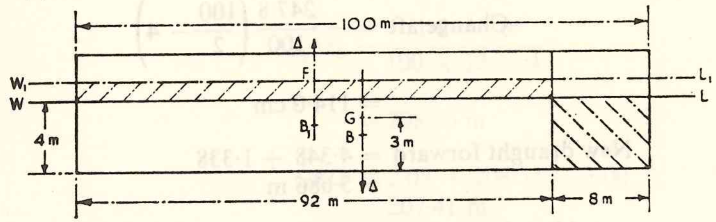

Fig. 106

$$\text{Increase in mean draught} = \frac{8 \times 12 \times 4}{(100 - 8) \times 12}$$

$$= 0{\cdot}348 \text{ m}$$

$$\text{New mean draught} = 4 + 0{\cdot}348$$
$$= 4{\cdot}348$$

$$KB_1 = \frac{4{\cdot}348}{2}$$

$$= 2{\cdot}174$$

$$B_1M_L = \frac{92^2}{12 \times 4{\cdot}348}$$

$$= 162{\cdot}22$$

$$GM_L = 2{\cdot}17 + 162{\cdot}22 - 3{\cdot}00$$
$$= 161{\cdot}39$$

$$\text{Change in trim} = \frac{50\,L\,l}{GM_L}$$

$$= \frac{50 \times 100 \times 8}{161{\cdot}39}$$

$$= 247{\cdot}8 \text{ cm by the head}$$

$$\text{Change forward} = +\frac{247{\cdot}8}{100}\left(\frac{100}{2} + 4\right)$$

$$= +\,133{\cdot}8 \text{ cm}$$

$$\text{Change aft} = -\frac{247{\cdot}8}{100}\left(\frac{100}{2} - 4\right)$$

$$= 114{\cdot}0 \text{ cm}$$

$$\text{New draught forward} = 4{\cdot}348 + 1{\cdot}338$$
$$= 5{\cdot}686 \text{ m}$$

$$\text{New draught aft} = 4{\cdot}348 - 1{\cdot}140$$
$$= 3{\cdot}208 \text{ m}$$

(b)

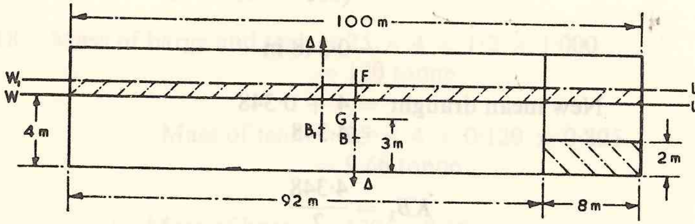

Fig. 107

$$\text{Volume of lost buoyancy} = 8 \times 12 \times 2 \text{ m}^3$$

$$\text{Area of intact waterplane} = 100 \times 12 \text{ m}^2$$

$$\text{Increase in draught} = \frac{8 \times 12 \times 2}{100 \times 12}$$

$$= 0{\cdot}16 \text{ m}$$

$$\text{New draught} = 4{\cdot}16 \text{ m}$$

$$KB_1 = 2{\cdot}08 \text{ m (approx.)}$$

$$I_F = \frac{1}{12} L^3 B$$

$$= \frac{1}{12} \times 100^3 \times 12$$

$$= 1{\cdot}0 \times 10^6 \text{ m}^4$$

$$\nabla = L\,B\,d$$
$$= 100 \times 12 \times 4$$

$$B_1M_L = \frac{1{\cdot}0 \times 10^6}{100 \times 12 \times 4}$$

$$= 208{\cdot}33 \text{ m}$$

$$GM_L = 2{\cdot}08 + 208{\cdot}33 - 3{\cdot}00$$
$$= 207{\cdot}41 \text{ m}$$

To find the longitudinal shift in the centre of buoyancy, consider the volume of lost buoyancy moved to the centre of the intact waterplane, which in this case is midships.

$$BB_1 = \frac{8 \times 12 \times 2 \times (50 - 4)}{100 \times 12 \times 4}$$

$$= 1{\cdot}84 \text{ m}$$

$$\text{Trimming moment} = \Delta . BB_1$$

$$\text{MCT1 cm} = \frac{\Delta \times GM_L}{100\,L}$$

$$= \frac{\Delta \times 209{\cdot}49}{100 \times 100}$$

$$\text{Change in trim} = \frac{1{\cdot}84 \times 100 \times 100}{207{\cdot}41}$$

$$= 88{\cdot}71 \text{ cm by the head}$$

$$\text{Change forward} = +\frac{88 \cdot 71}{100} \times 50$$
$$= +44 \cdot 36 \text{ cm}$$

$$\text{Change aft} = -\frac{88 \cdot 71}{100} \times 50$$
$$= -44 \cdot 36 \text{ cm}$$

$$\text{New draught forward} = 4 \cdot 16 + 0 \cdot 444$$
$$= 4 \cdot 604 \text{ m}$$

$$\text{New draught aft} = 4 \cdot 16 - 0 \cdot 444$$
$$= 3 \cdot 716 \text{ m}$$

(c)

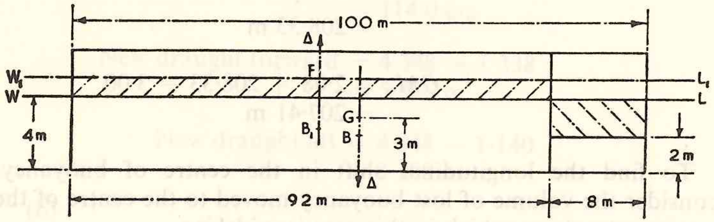

Fig. 108

$$\text{Volume of lost buoyancy} = 8 \times 12 \times 2 \text{ m}^3$$

$$\text{Area of intact waterplane} = (100 - 8) \times 12 \text{ m}^2$$

$$\text{Increase in draught} = \frac{8 \times 12 \times 2}{(100 - 8) \times 12}$$
$$= 0 \cdot 174 \text{ m}$$

$$\text{New draught} = 4 \cdot 174 \text{ m}$$

$$KB_1 = 2 \cdot 087 \text{ m}$$

$$I_F = \frac{1}{12} \times 92^3 \times 12$$
$$= 778\,688$$

$$\nabla = 100 \times 12 \times 4$$

$$B_1M_L = \frac{778\,688}{4800}$$
$$= 162 \cdot 22 \text{ m}$$

$$GM_L = 2 \cdot 09 + 162 \cdot 22 - 3 \cdot 00$$
$$= 161 \cdot 31 \text{ m}$$

$$\text{Shift in centre of buoyancy } BB_1 = \frac{8 \times 12 \times 2 \times (46 + 4)}{100 \times 12 \times 4}$$
$$= 2 \cdot 00 \text{ m}$$

$$\text{Change in trim} = \frac{2 \cdot 00 \times 100 \times 100}{161 \cdot 31}$$
$$= 124 \text{ cm by the head}$$

$$\text{Change forward} = +\frac{124}{100}\left(\frac{100}{2} + 4\right)$$
$$= +67 \text{ cm}$$

$$\text{Change aft} = -\frac{124}{100}\left(\frac{100}{2} - 4\right)$$
$$= -57 \text{ cm}$$

$$\text{New draught forward} = 4 \cdot 174 + 0 \cdot 670$$
$$= 4 \cdot 844 \text{ m}$$

$$\text{New draught aft} = 4 \cdot 174 - 0 \cdot 570$$
$$= 3 \cdot 604 \text{ m}$$

SOLUTIONS TO TEST EXAMPLES 7

1. $$R_f = f S V^n$$
$$= 0{\cdot}424 \times 3200 \times 17^{1{\cdot}825}$$
$$= 238\,900 \text{ N}$$
$$= 238{\cdot}9 \text{ kN}$$
$$\text{Power} = R_f \times v$$
$$= 238{\cdot}9 \times 17 \times \frac{1852}{3600}$$
$$= 208{\cdot}93 \text{ kW}$$

2. At 3 m/s $$R_f = 13 \text{ N/m}^2$$

At 15 knots $$R_f = 13 \times \left(\frac{15}{3} \times \frac{1852}{3600}\right)^{1{\cdot}97}$$
$$= 83{\cdot}605 \text{ N/m}^2$$
$$\therefore \quad R_f = 83{\cdot}605 \times 3800$$
$$= 317\,700 \text{ N}$$
$$\text{Power} = 317\,700 \times 15 \times \frac{1852}{3600}$$
$$= 2\,451\,500 \text{ W}$$
$$= 2451{\cdot}5 \text{ kW}$$

3. At 180 m/min $$R_f = 12 \text{ N/m}^2$$

At 14 knots $$R_f = 12 \times \left(\frac{14}{180} \times \frac{1852}{60}\right)^{1{\cdot}9}$$
$$= 63{\cdot}36 \text{ N/m}^2$$
$$\therefore \quad R_f = 63{\cdot}36 \times 4000$$
$$= 253\,400 \text{ N}$$
$$R_t = \frac{R_f}{0{\cdot}7}$$
$$= \frac{253\,400}{0{\cdot}7}$$
$$= 362\,000 \text{ N}$$

$$\text{Effective power} = R_t \times v$$
$$= 362\,000 \times 14 \times \frac{1852}{3600}$$
$$= 2\,547\,800 \text{ W}$$
$$= 2547{\cdot}8 \text{ kW}$$

4. Wetted surface area $$S = c\sqrt{\triangle L}$$
$$= 2{\cdot}55\sqrt{125 \times 16 \times 7{\cdot}8 \times 0{\cdot}72 \times 1{\cdot}025 \times 125}$$
$$= 3059 \text{ m}^2$$
$$R_f = f S V^n$$
$$= 0{\cdot}423 \times 3059 \times 17{\cdot}5^{1{\cdot}825}$$
$$= 240\,140 \text{ N}$$
$$\text{Power} = 240\,140 \times 17{\cdot}5 \times \frac{1852}{3600}$$
$$= 2\,161\,900 \text{ W}$$
$$= 2161{\cdot}9 \text{ kW}$$

5. $$R_r \propto L^3$$
$$\therefore \quad R_r = 36 \times \left(\frac{20}{1}\right)^3$$
$$= 288\,000 \text{ N}$$
$$V \propto \sqrt{L}$$
$$\therefore \quad V = 3 \times \sqrt{\frac{20}{1}}$$
$$= 13{\cdot}417 \text{ knots}$$
$$\text{Power} = 288\,000 \times 13{\cdot}417 \times \frac{1852}{3600}$$
$$= 1\,987\,800 \text{ W}$$
$$= 1987{\cdot}8 \text{ kW}$$

6.
$$V \propto \sqrt{L}$$
$$\propto \triangle^{\frac{1}{6}}$$
$$\therefore \quad V = 16 \times \left(\frac{24\,000}{14\,000}\right)^{\frac{1}{6}}$$
$$= 17{\cdot}503 \text{ knots}$$

$$R_r \propto \triangle$$
$$\therefore \quad R_r = 113 \times \left(\frac{24\,000}{14\,000}\right)$$
$$= 193{\cdot}7 \text{ kN}$$

7. Let v = speed in m/s

At 3 m/s
$$R_f = 11 \times 1{\cdot}025$$
$$= 11{\cdot}275 \text{ N/m}^2 \text{ in sea water}$$
$$\therefore \quad R_f = 11{\cdot}275 \times 2500$$
$$= 28\,190 \text{ N}$$

At v m/s
$$R_f = 28{\cdot}19 \left(\frac{v}{3}\right)^{1{\cdot}92} \text{ kN}$$

and
$$R_t = \frac{R_f}{0{\cdot}72}$$

$$\text{effective power} = R_t \times v$$
$$= 1100 \text{ kW}$$
$$\frac{R_f}{0{\cdot}72} \times v = 1100$$
$$\frac{28{\cdot}19}{0{\cdot}72}\left(\frac{v}{3}\right)^{1{\cdot}92} \times v = 1100$$
$$v^{2{\cdot}92} = 1100 \times \frac{0{\cdot}72}{28{\cdot}19} \times 3^{1{\cdot}92}$$
$$v = 6{\cdot}454 \text{ m/s}$$
$$V = 6{\cdot}454 \times \frac{3600}{1852}$$
$$= 12{\cdot}545 \text{ knots}$$

8. Model:
$$R_t = 35 \text{ N in fresh water}$$
$$= 35 \times 1{\cdot}025$$
$$= 35{\cdot}875 \text{ N}$$
$$f = 0{\cdot}417 + \frac{0{\cdot}773}{6 + 2{\cdot}862}$$
$$= 0{\cdot}417 + 0{\cdot}0872$$
$$= 0{\cdot}5042$$
$$R_f = 0{\cdot}5042 \times 7 \times 3^{1{\cdot}825}$$
$$= 26{\cdot}208 \text{ N}$$
$$R_r = R_t - R_f$$
$$= 35{\cdot}875 - 26{\cdot}208$$
$$= 9{\cdot}667 \text{ N}$$

Ship:
$$R_r \propto L^3$$
$$\therefore \quad R_r = 9{\cdot}667 \times \left(\frac{120}{6}\right)^3$$
$$= 77\,336 \text{ N}$$
$$S \propto L^2$$
$$\therefore \quad S = 7 \times \left(\frac{120}{6}\right)^2$$
$$= 2800 \text{ m}^2$$
$$V \propto \sqrt{L}$$
$$\therefore \quad V = 3 \times \sqrt{\frac{120}{6}}$$
$$= 13{\cdot}416 \text{ knots}$$
$$f = 0{\cdot}417 + \frac{0{\cdot}773}{120 + 2{\cdot}862}$$
$$= 0{\cdot}417 + 0{\cdot}0063$$
$$= 0{\cdot}4233$$
$$R_f = 0{\cdot}4233 \times 2800 \times 13{\cdot}416^{1{\cdot}825}$$
$$= 135\,400 \text{ N}$$
$$R_t = 77\,336 + 135\,400$$
$$= 212\,736 \text{ N}$$

$$\text{Effective power (naked)} = 212\,736 \times 13{\cdot}416 \times \frac{1852}{3600}$$
$$= 1468{\cdot}2 \text{ kW}$$

$$\text{Effective power} = ep_n \times \text{SCF}$$
$$= 1468{\cdot}2 \times 1{\cdot}15$$
$$= 1688{\cdot}4 \text{ kW}$$

9.
$$sp = \frac{\Delta^{\frac{2}{3}} V^3}{C}$$
$$= \frac{12\,000^{\frac{2}{3}} \times 16^3}{550}$$
$$= 3903 \text{ kW}$$

10. (a)
$$2800 = \frac{\Delta^{\frac{2}{3}} \times 14^3}{520}$$
$$\Delta^{\frac{2}{3}} = \frac{2800 \times 520}{14^3}$$
$$\Delta = 12\,223 \text{ tonne}$$

(b)
$$\text{New speed} = 0{\cdot}85V$$
$$= 0{\cdot}85 \times 14$$
$$sp \propto V^3$$
$$\therefore \quad \frac{sp_1}{sp_2} = \left(\frac{V_1}{V_2}\right)^3$$
$$sp_2 = 2800 \times \left(\frac{0{\cdot}85 \times 14}{14}\right)^3$$
$$= 1720 \text{ kW}$$

11.
$$2100 = \frac{8000^{\frac{2}{3}} \times V^3}{470}$$
$$V^3 = \frac{2100 \times 470}{8000^{\frac{2}{3}}}$$
$$V = 13{\cdot}51 \text{ knots}$$

12. (a)
$$\Delta = 150 \times 19 \times 8 \times 0{\cdot}68 \times 1{\cdot}025$$
$$= 15\,890 \text{ tonne}$$
$$sp = \frac{15\,890^{\frac{2}{3}} \times 18^3}{600}$$
$$= 6143 \text{ kW}$$

(b)
$$sp \propto R_t \times V$$
$$\propto V^3 \times V$$
$$\propto V^4$$
$$\therefore \quad sp = 6143 \times \left(\frac{21}{18}\right)^4$$
$$= 11\,382 \text{ kW}$$

Note: In practice there will be a gradual increase in the index of speed.

13. Fuel cons/day
$$= \frac{\Delta^{\frac{2}{3}} V^3}{\text{fuel coefficient}} \text{ tonne}$$
$$= \frac{15\,000^{\frac{2}{3}} \times 14{\cdot}5^3}{62\,500}$$
$$= 29{\cdot}67 \text{ tonne}$$

14.
$$25 = \frac{9000^{\frac{2}{3}} V^3}{53\,500}$$
$$V^3 = \frac{25 \times 53\,500}{9000^{\frac{2}{3}}}$$
$$V = 14{\cdot}57 \text{ knots}$$

15. At 16 knots: time taken
$$= \frac{2000}{16 \times 24}$$
$$= 5{\cdot}209 \text{ days}$$
$$\text{total consumption} = 28 \times 5{\cdot}209$$
$$= 145{\cdot}8 \text{ tonne}$$

But $\quad \text{total consumption} \propto V^2$

∴ at 14 knots, total consumption

$$= 145{\cdot}8 \times \left(\frac{14}{16}\right)^2$$
$$= 111{\cdot}6 \text{ tonne}$$

∴ Saving in fuel $= 145{\cdot}8 - 111{\cdot}6$
$= 34{\cdot}2$ tonne

16. Total fuel used $= 115 - 20$
$= 95$ tonne

At 15 knots; total consumption for 1100 nautical miles

$$= 40 \times \frac{1100}{15 \times 24}$$
$$= 122{\cdot}3 \text{ tonne}$$

But total consumption $\propto V^2$

$$\frac{95}{122{\cdot}3} = \frac{V^2}{15^2}$$
$$V = 15\sqrt{\frac{95}{122{\cdot}3}}$$
$$= 13{\cdot}22 \text{ knots}$$

$$\text{Time taken} = \frac{1100}{13{\cdot}22}$$
$$= 83{\cdot}18 \text{ hours}$$

17 (a)

$$\frac{\text{cons}_1}{\text{cons}_2} = \left(\frac{V_1}{V_2}\right)^3$$
$$V_2^3 = V_1^3\left(\frac{\text{cons}_2}{\text{cons}_1}\right)$$
$$V_2 = V_1\sqrt[3]{\frac{\text{cons}_2}{\text{cons}_1}}$$
$$= 14\sqrt[3]{\frac{1{\cdot}15 \times 23}{23}}$$
$$= 14{\cdot}67 \text{ knots}$$

(b)
$$V_2 = 14\sqrt[3]{\frac{0{\cdot}88 \times 23}{23}}$$
$$= 13{\cdot}42 \text{ knots}$$

(c)
$$V_2 = 14\sqrt[3]{\frac{18}{23}}$$
$$= 12{\cdot}90 \text{ knots}$$

18. Fuel consumption/hour $= 0{\cdot}12 + 0{\cdot}001V^3$ tonne
$= 0{\cdot}12 + 0{\cdot}001 \times 14^3$
$= 2{\cdot}864$ tonne

(a) Over 1700 nautical miles;

$$\text{total fuel consumption} = 2{\cdot}864 \times \frac{1700}{14}$$
$$= 347{\cdot}7 \text{ tonne}$$

(b) Saving in fuel $= 10$ t/day

$$= \frac{10}{24} \text{ t/h}$$

$$\therefore \text{new fuel consumption} = 2{\cdot}864 - \frac{10}{24}$$
$$= 2{\cdot}447 \text{ t/h}$$
$$2{\cdot}447 = 0{\cdot}12 + 0{\cdot}001\,V^3$$
$$0{\cdot}001\,V^3 = 2{\cdot}447 - 0{\cdot}12$$
$$V^3 = 2327$$
$$V = 13{\cdot}25 \text{ knots}$$

19. Let C = normal consumption per hour
V = normal speed.

For first 8 hours:

speed $= 1{\cdot}2V$

$$\text{cons/h} = C \times \left(\frac{1{\cdot}2V}{V}\right)^3$$
$$= 1{\cdot}728C$$
$$\text{cons for 8 hours} = 8 \times 1{\cdot}728C$$
$$= 13{\cdot}824C$$

For next 10 hours:

$$\text{speed} = 0{\cdot}9V$$

$$\text{cons/h} = C \times \left(\frac{0{\cdot}9V}{V}\right)^3$$

$$= 0{\cdot}729C$$

$$\text{cons for 10 hours} = 10 \times 0{\cdot}729C$$
$$= 7{\cdot}29C$$

For remaining 6 hours:

$$\text{speed} = V$$

$$\text{cons for 6 hours} = 6C$$

$$\text{Total cons for 24 hours} = 13{\cdot}824C + 7{\cdot}29C + 6C$$
$$= 27{\cdot}114C$$

$$\text{Normal cons for 24 hours} = 24C$$

$$\therefore \quad \text{Increase in cons} = 27{\cdot}114C - 24C$$
$$= 3{\cdot}114C$$

$$\%\ \text{increase in cons} = \frac{3{\cdot}114C}{24C} \times 100$$

$$= 12{\cdot}97\%$$

20. Let C = consumption per day at 18 knots

Then $C - 22$ = consumption per day at 14·5 knots

$$\frac{C}{C-22} = \left(\frac{18}{14{\cdot}5}\right)^3$$

$$= 1{\cdot}913$$

$$C = 1{\cdot}913C - 1{\cdot}913 \times 22$$

$$0{\cdot}913C = 1{\cdot}913 \times 22$$

$$C = \frac{1{\cdot}913 \times 22}{0{\cdot}913}$$

$$= 46{\cdot}09\ \text{tonne/day}$$

21. At 17 knots: cons/day = 42 tonne

At V knots: cons/day = 28 tonne

But at V knots: cons/day = 1·18C

Where $$C = 42 \times \left(\frac{V}{17}\right)^3$$

$$1{\cdot}18C = 28$$

$$\therefore \quad 28 = 1{\cdot}18 \times 42 \times \left(\frac{V}{17}\right)^3$$

$$V^3 = \frac{17^3 \times 28}{1{\cdot}18 \times 42}$$

$$V = 17\sqrt[3]{\frac{28}{1{\cdot}18 \times 42}}$$

$$= 14{\cdot}06\ \text{knots}$$

SOLUTIONS TO TEST EXAMPLES 8

1. $$\text{Theoretical speed } V_T = \frac{P \times N \times 60}{1852}$$

$$= \frac{5 \times 105 \times 60}{1852}$$

$$= 17{\cdot}01 \text{ knots}$$

$$\text{Apparent slip} = \frac{V_T - V}{V_T} \times 100$$

$$= \frac{17{\cdot}01 - 14}{17{\cdot}01} \times 100$$

$$= 17{\cdot}70\%$$

$$\text{Speed of advance } V_a = V(1 - w)$$
$$= 14(1 - 0{\cdot}35)$$
$$= 9{\cdot}10 \text{ knots}$$

$$\text{Real slip} = \frac{V_T - V_a}{V_T} \times 100$$

$$= \frac{17{\cdot}01 - 9{\cdot}10}{17{\cdot}01} \times 100$$

$$= 46{\cdot}50\%$$

2. $$p = \frac{P}{D}$$

$$\therefore \quad \text{Pitch } P = p \times D$$
$$= 0{\cdot}8 \times 5{\cdot}5$$
$$= 4{\cdot}4 \text{ m}$$

$$\text{Theoretical speed } V_T = \frac{4{\cdot}4 \times 120 \times 60}{1852}$$

$$= 17{\cdot}11 \text{ knots}$$

$$\text{Real slip} = \frac{V_T - V_a}{V_T} \times 100$$

$$0{\cdot}35 = \frac{17{\cdot}11 - V_a}{17{\cdot}11}$$

$$\therefore \text{Speed of advance } V_a = 17{\cdot}11(1 - 0{\cdot}35)$$
$$= 11{\cdot}12 \text{ knots}$$

But $$V_a = V(1 - w)$$

$$\therefore \quad \text{Ship speed } V = \frac{V_a}{1 - w}$$

$$= \frac{11{\cdot}12}{1 - 0{\cdot}32}$$

$$= 16{\cdot}35 \text{ knots}$$

$$\text{Apparent slip} = \frac{V_T - V}{V_T} \times 100$$

$$= \frac{17{\cdot}11 - 16{\cdot}35}{17{\cdot}11} \times 100$$

$$= 4{\cdot}44\%$$

3. $$C_b = \frac{\triangle}{L \times B \times d \times \rho}$$

$$= \frac{12\,400}{120 \times 17{\cdot}5 \times 7{\cdot}5 \times 1{\cdot}025}$$

$$= 0{\cdot}768$$

$$w = 0{\cdot}5 \times 0{\cdot}768 - 0{\cdot}05$$
$$= 0{\cdot}334$$

$$\text{Speed of advance } V_a = V(1 - w)$$
$$= 12(1 - 0{\cdot}334)$$
$$= 7{\cdot}992 \text{ knots}$$

$$\text{Real slip} = \frac{V_T - V_a}{V_T} \times 100$$

$$0{\cdot}30 V_T = V_T - 7{\cdot}992$$

$$V_T = \frac{7{\cdot}992}{0{\cdot}7}$$

$$= 11{\cdot}42 \text{ knots}$$

But $$V_T = \frac{P \times N \times 60}{1852}$$

$\therefore$ Pitch $$P = \frac{11{\cdot}42 \times 1852}{100 \times 60}$$

$$= 3{\cdot}52 \text{ m}$$

$$\text{Diameter } D = \frac{P}{p}$$

$$= \frac{3{\cdot}52}{0{\cdot}75}$$

$$= 4{\cdot}70 \text{ m}$$

$$\text{Apparent slip} = \frac{11{\cdot}42 - 12}{11{\cdot}42} \times 100$$

$$= -\ 5{\cdot}08\%$$

4. Theoretical speed $$V_T = \frac{4{\cdot}8 \times 110 \times 60}{1852}$$

$$= 17{\cdot}11 \text{ knots}$$

Apparent slip $$-s = \frac{V_T - V}{V_T} \times 100 \quad \ldots(1)$$

Real slip $$+1{\cdot}5s = \frac{V_T - V_a}{V_T} \times 100$$

$$V_a = V(1 - w)$$
$$= 0{\cdot}75V$$

$\therefore$ Real slip $$+1{\cdot}5s = \frac{V_T - 0{\cdot}75V}{V_T} \times 100 \quad \ldots(2)$$

Multiply (1) by 1·5

$$-1{\cdot}5s = 1{\cdot}5 \times \frac{V_T - V}{V_T} \times 100 \quad \ldots(3)$$

Adding (2) and (3)

$$\frac{V_T - 0{\cdot}75V}{V_T} \times 100 + 1{\cdot}5 \times \frac{V_T - V}{V_T} \times 100 = 0$$

Hence $$V_T - 0{\cdot}75V + 1{\cdot}5V_T - 1{\cdot}5V = 0$$

$$2{\cdot}25V = 2{\cdot}5V_T$$

$$V = \frac{2{\cdot}5}{2{\cdot}25} \times 17{\cdot}11$$

$$= 19{\cdot}01 \text{ knots}$$

Substitute for V in (1)

$$-s = \frac{17{\cdot}11 - 19{\cdot}01}{17{\cdot}11} \times 100$$

$$\text{Apparent slip} = -\ 11{\cdot}10\%$$

$$\text{Real slip} = -\ 1{\cdot}5 \times (-\ 11{\cdot}10)$$
$$= +\ 16{\cdot}66\%$$

5. Theoretical speed $$V_T = \frac{4{\cdot}3 \times 95 \times 60}{1852}$$

$$= 13{\cdot}23 \text{ knots}$$

$$\text{Real slip } 0{\cdot}28 = \frac{13{\cdot}23 - V_a}{13{\cdot}23}$$

$$V_a = 13{\cdot}23\,(1 - 0{\cdot}28)$$
$$= 9{\cdot}53 \text{ knots}$$

$$\text{Effective disc area } A = \frac{\pi}{4}(D^2 - d^2)$$

$$= \frac{\pi}{4}(4{\cdot}6^2 - 0{\cdot}75^2)$$

$$= 16{\cdot}18 \text{ m}^2$$

$$\text{Thrust } T = \rho A s P^2 n^2$$

$$= 1{\cdot}025 \times 16{\cdot}18 \times 0{\cdot}28 \times 4{\cdot}3^2 \times \left(\frac{95}{60}\right)^2$$

$$= 215{\cdot}2 \text{ kN}$$

$$\text{Thrust power} = T \times v_a$$

$$= 215{\cdot}2 \times 9{\cdot}53 \times \frac{1852}{3600}$$

$$= 1055 \text{ kW}$$

6. $$T_1 N_1 = T_2 N_2$$

$$17{\cdot}5 \times 115 = T_2 \times 90$$

$$T_2 = \frac{17{\cdot}5 \times 115}{90}$$

$$\text{Thrust pressure} = 22{\cdot}36 \text{ b}$$

7. $$\frac{tp_1}{tp_2} = \frac{T_1 V_1}{T_2 V_2}$$

$$T_2 = \frac{T_1 V_1 tp_2}{V_2 tp_1}$$

$$= 19{\cdot}5 \times \frac{V_1}{0{\cdot}88 V_1} \times \frac{2900}{3400}$$

$$\text{Thrust pressure} = 18{\cdot}9 \text{ b}$$

8. $$\text{tp} = 2550 \text{ kW}$$

$$\text{dp} = \frac{\text{tp}}{\text{propeller efficiency}}$$

$$= \frac{2550}{0{\cdot}65}$$

$$\text{sp} = \frac{\text{dp}}{\text{transmission efficiency}}$$

$$= \frac{2550}{0{\cdot}65 \times 0{\cdot}94}$$

$$\text{ip} = \frac{\text{sp}}{\text{mechanical efficiency}}$$

$$= \frac{2550}{0{\cdot}65 \times 0{\cdot}94 \times 0{\cdot}83}$$

$$\text{Indicated power} = 5028 \text{ kW}$$

$$\text{ep} = \text{dp} \times \text{QPC}$$

$$= \frac{2550}{0{\cdot}65} \times 0{\cdot}71$$

$$\text{Effective power} = 2785 \text{ kW}$$

$$\text{sp} = \frac{\Delta^{\frac{2}{3}} V^3}{\text{C}}$$

$$V^3 = \frac{\text{sp} \times \text{C}}{\Delta^{\frac{2}{3}}}$$

$$= \frac{2550}{0{\cdot}65 \times 0{\cdot}94} \times \frac{420}{15\,000^{\frac{2}{3}}}$$

$$\text{Ship speed } V = 14{\cdot}23 \text{ knots}$$

9. $$\text{Theoretical speed } v_T = 4 \times \frac{125}{60}$$

$$= 8{\cdot}33 \text{ m/s}$$

$$\text{Real slip} = \frac{v_T - v_a}{v_T}$$

$$0{\cdot}36 = \frac{8{\cdot}33 - v_a}{8{\cdot}33}$$

$$v_a = 8{\cdot}33\,(1 - 0{\cdot}36)$$
$$= 5{\cdot}33 \text{ m/s}$$

$$\text{tp} = \text{dp} \times \text{propeller efficiency}$$
$$= 2800 \times 0{\cdot}67$$
$$= 1876 \text{ kW}$$

But $$\text{tp} = T \times v_a$$

$$\therefore \quad 1876 = T \times 5{\cdot}33$$

$$T = \frac{1876}{5{\cdot}33}$$

$$\text{Propeller thrust} = 351{\cdot}8 \text{ kN}$$

10. $$\frac{pm_1}{pm_2} = \left(\frac{N_1}{N_2}\right)^2$$

$$\therefore \quad pm_2 = pm_1 \left(\frac{N_2}{N_1}\right)^2$$

$$= 4{\cdot}5 \times \left(\frac{105}{130}\right)^2$$

$$= 2{\cdot}94 \text{ b}$$

11. Since the power is reduced, the rev/min may be found from the Admiralty Coefficient formula.

The displacement and Admiralty Coefficient are constant, hence: power $\propto$ speed^3

$$P \propto \text{revs}^3$$

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$$

$$N_2 = 120 \sqrt[3]{\frac{0{\cdot}8P_2}{P_1}}$$

$$= 111{\cdot}4 \text{ rev/min}$$

Also $$P \propto p_m \times N$$

$$\therefore \quad \frac{P_1}{P_2} = \frac{p_{m1}}{p_{m2}} \times \frac{N_1}{N_2}$$

$$p_{m2} = p_{m1} \times \frac{N_1}{N_2} \times \frac{P_2}{P_1}$$

$$= 5{\cdot}5 \times \frac{120}{111{\cdot}4} \times \frac{0{\cdot}8P_1}{P_1}$$

$$= 4{\cdot}74 \text{ b}$$

12. $$\text{Pitch} = \tan\theta \times 2\pi R$$
$$= \tan 21{\cdot}5° \times 2\pi \times 2$$
$$= 4{\cdot}95 \text{ m}$$

13. $$\tan\theta = \frac{40}{115}$$

$$= 0{\cdot}3478$$

$$\theta = 19°\ 10'$$

$$\text{Pitch} = 0{\cdot}3478 \times 2\pi \times 2{\cdot}6$$
$$= 5{\cdot}682 \text{ m}$$

$$\sin\theta = \frac{\text{horizontal ordinate}}{\text{blade width}}$$

$$\therefore \quad \text{width} = \frac{40}{\sin\ 19°\ 10'}$$

$$= 121{\cdot}8 \text{ cm}$$
$$= 1{\cdot}218 \text{ m}$$

SOLUTIONS TO TEST EXAMPLES 9

1. Ship speed $= 18$ knots

$$= 18 \times \frac{1852}{3600}$$

$$= 9{\cdot}26 \text{ m/s}$$

$$\text{Torque } T = F \sin\alpha \times b$$
$$= 580A\, v^2 \sin\alpha \times b$$
$$= 580 \times 25 \times 9{\cdot}26^2 \times 0{\cdot}5736 \times 1{\cdot}2$$
$$= 855\,816 \text{ N m}$$

But
$$\frac{T}{J} = \frac{q}{r}$$

and
$$J = \frac{\pi r^4}{2}$$

$$\therefore \quad T = \frac{\pi r^4 q}{2r}$$

$$r^3 = \frac{T \times 2}{\pi \times q}$$

$$= \frac{855\,816 \times 2}{\pi \times 85 \times 10^6}$$

$$r = 0{\cdot}1858 \text{ m}$$

$$\text{Diameter} = 0{\cdot}3716 \text{ m}$$
$$= 372 \text{ mm}$$

2. $\text{Torque } T = 580\, A\, v^2 \sin\alpha \times b$

$$= 580 \times 13 \times \left(\frac{14 \times 1852}{3600}\right)^2 \times 1{\cdot}1 \sin\alpha$$

$$= 430\,226 \sin\alpha$$

Angle α	sin α	T	SM	product
0°	0	0	1	0
10°	0·1736	74 690	4	298 760
20°	0·3420	147 140	2	294 280
30°	0·5000	215 110	4	860 440
40°	0·6428	276 550	1	276 550
				1 730 030

$$\text{Common interval} = \frac{10}{57{\cdot}3}$$

$$\text{Work done} = \frac{1}{3} \times \frac{10}{57{\cdot}3} \times 1\,730\,030$$

$$= 100\,640 \text{ J}$$
$$= 100{\cdot}64 \text{ kJ}$$

3. $\text{Rudder area} = \dfrac{L \times d}{60}$

$$= \frac{150 \times 8{\cdot}5}{60}$$

$$= 21{\cdot}25 \text{ m}^2$$

$$\text{Torque } T = \frac{J q}{r}$$

$$= \frac{\pi r^4 q}{2r}$$

$$= \frac{\pi r^3 q}{2}$$

$$= \frac{\pi}{2} \times 0{\cdot}16^3 \times 70 \times 10^6$$

$$= 0{\cdot}4504 \times 10^6 \text{ N m}$$

$$\therefore \quad 0{\cdot}4504 \times 10^6 = 580 \times 21{\cdot}25 \times v^2 \times 0{\cdot}9 \times \sin 35^\circ$$

$$v^2 = \frac{0{\cdot}4504 \times 10^6}{580 \times 21{\cdot}25 \times 0{\cdot}9 \times 0{\cdot}5736}$$

$$v = 8{\cdot}414 \text{ m/s}$$

$$\text{Ship speed } V = 8{\cdot}414 \times \frac{3600}{1852}$$

$$= 16{\cdot}35 \text{ knots}$$

4. Normal force on rudder F_n

$$= 580\,A\,v^2 \sin\alpha$$

Transverse force on rudder F_t

$$= 580\,A\,v^2 \sin\alpha\cos\alpha$$

$$= 580 \times 12 \times \left(\frac{16 \times 1852}{3600}\right)^2 \times \sin 35^\circ \cos 35^\circ$$

$$= 221\,600 \text{ N}$$

$$= 221{\cdot}6 \text{ kN}$$

$$\tan\theta = \frac{F_t \times NL}{\triangle \times g \times GM}$$

$$= \frac{221{\cdot}6 \times 1{\cdot}6}{5000 \times 9{\cdot}81 \times 0{\cdot}24}$$

$$= 0{\cdot}0301$$

Angle of heel $\theta = 1^\circ\,43'$

5. Speed of ship $V = 17$ knots

$$v = 17 \times \frac{1852}{3600}$$

$$= 8{\cdot}746 \text{ m/s}$$

$$\tan\theta = \frac{v^2 \times GL}{g \times \rho \times GM}$$

$$= \frac{8{\cdot}746^2 \times (7{\cdot}00 - 4{\cdot}00)}{9{\cdot}81 \times 450 \times (7{\cdot}45 - 7{\cdot}00)}$$

$$= 0{\cdot}1155$$

Angle of heel $\theta = 6^\circ\,35'$

SELECTION OF EXAMINATION QUESTIONS
SECOND CLASS

** Questions marked with an asterisk have been selected from Department of Trade papers and are reproduced by kind permission of The Controller of Her Majesty's Stationary Office.*

1. A box barge is 15 m long, 6 m wide and floats in water of 1.016 t/m³ at a draught of 3 m. 150 tonne cargo is now added. Calculate the load exerted by the water on the sides, ends and bottom.

2. A ship has a load displacement of 6000 tonne and centre of gravity 5.30 m above the keel. 1000 tonne are then removed 2.1 m above the keel, 300 tonne moved down 2.4 m, 180 tonne placed on board 3 m above the keel and 460 tonne placed on board 2.2 m above the keel. Find the new position of the centre of gravity.

3. A ship of 8000 tonne displacement floats in sea water of 1.025 t/m³ and has a TPC of 14. The vessel moves into fresh water of 1.000 t/m³ and loads 300 tonne of oil fuel. Calculate the change in mean draught.

4. The wetted surface area of one ship is 40% that of a similar ship. The displacement of the latter is 4750 tonne more than the former. Calculate the displacement of the smaller ship.

5. A ship of 9000 tonne displacement floats in fresh water of 1.000 t/m³ at a draught 50 mm below the sea water line. The waterplane area is 1650 m². Calculate the mass of cargo which must be added so that when entering sea water of 1.025 t/m³ it floats at the sea water line.

6. A thin plate drawn through the water at 3 m/s has a frictional resistance of 14 N/m² and its resistance varies as (speed)$^{1{\cdot}97}$.

A ship 90 m long has a breadth of 16.7 m, draught of 7.5 m and block coefficient of 0.87. If the total frictional resistance is 300 kN, calculate the speed of the ship. The wetted surface area may be found from the formula.

$$S = 1.7\,Ld + \frac{\nabla}{d}$$

7. The effective power of ship is 1400 kW at 12 knots, the propulsive efficiency 65% and the fuel consumption 0.3 kg/kW h, based on shaft power. Calculate the fuel required to travel 10 000 nautical miles at 10 knots.

8. A ship is 60 m long, 16 m beam and has a draught of 5 m in sea water, block coefficient 0.7 and waterplane area coefficient 0.8. Calculate the draught at which it will float in fresh water.

9. A tank top manhole 0.50 m wide and 0.65 m long has semi-circular ends. The studs are pitched 30 mm outside the line of hole and 100 mm apart. The cross-sectional area of the studs between the threads is 350 mm^2. The tank is filled with salt water to a height of 7.5 m up the sounding pipe. Calculate the stress in the studs.

10. A small vessel has the following particulars before modifications are carried out. Displacement 150 tonne, *GM* 0.45 m, *KG* 1.98 m, *KB* 0.9 m, TPC 2.0 and draught 1.65 m.

After modification, 20 tonne has been added, *Kg* 3.6 m. Calculate the new *GM* assuming constant waterplane area over the change in draught.

11. A ship displacing 10 000 tonne and travelling at 16 knots has a fuel consumption of 41 tonne per day. Calculate the consumption per day if the displacement is increased to 13 750 tonne and the speed is increased to 17 knots. Within this speed range, fuel consumption per day varies as (speed)$^{3.8}$.

12. The ½ ordinates of a waterplane 320 m long are 0, 9, 16, 23, 25, 25, 22, 18 and 0 m respectively. Calculate:

(a) waterplane area
(b) TPC
(c) waterplane area coefficient.

13. A double bottom tank is filled with sea water to the top of the air pipe. The pressure on the outer bottom is found to be 1.20 bar while the pressure on the inner bottom is found to be 1.05 bar. Calculate the height of the air pipe above the inner bottom and the depth of the tank.

14. A ship 125 m long and 17.5 m beam floats in sea water of 1.025 t/m^3 at a draught of 8 m. The waterplane area coefficient is 0.83, block coefficient 0.759 and midship section area coefficient 0.98. Calculate:

(a) prismatic coefficient
(b) TPC
(c) change in mean draught if the vessel moves into river water of 1.016 t/m^3.

15. At 90 rev/min a propeller of 5 m pitch has an apparent slip of 15% and wake fraction 0.10. Calculate the real slip.

16. A hopper barge of box form 50 m long and 10 m wide floats at a draught of 2 m in sea water when the hopper, which is 15 m long and 5 m wide, is loaded with mud having relative density twice that of the sea water, to the level of the waterline.

Doors in the bottom of the hopper are now opened allowing the mud to be discharged. Calculate the new draught.

17. It is found that by reducing the fuel consumption of a vessel 43 tonne/day, the speed is reduced 2.2 knots and the saving in fuel for a voyage of 3500 nautical miles is 23%. Determine:

(a) the original daily fuel consumption, and
(b) the original speed.

18. A ship of 7000 tonne displacement, having *KG* 6 m and TPC 21, floats at a draught of 6 m. 300 tonne of cargo is now added at *Kg* 1.0 m and 130 tonne removed at *Kg* 5 m. The final draught is to be 6.5 m and *KG* 5.8 m. Two holds are available for additional cargo, one having *Kg* 5 m and the other *Kg* 7 m. Calculate the mass of cargo to be added to each hold.

19. A block of wood of uniform density has a constant cross-section in the form of a triangle, apex down. The width is 0.5 m and the depth 0.5 m. It floats at a draught of 0.45 m. Calculate the metacentric height.

20. The waterplane area of a ship at 8.40 m draught is 1670 m^2. The areas of successive waterplanes at 1.40 m intervals below this are 1600, 1540, 1420, 1270, 1080 and 690 m^2 respectively. Calculate the displacement in fresh water at 8.40 m draught and the draught at which the ship would lie in sea water with the same displacement.

21. A floating dock 150 m long, 24 m overall width and 9 m draught consists of a rectangular bottom compartment 3 m deep and rectangular wing compartments 2.5 m wide. A ship with a draught of 5.5 m is floated in. 4000 tonne of ballast are pumped out of the dock to raise the ship 1.2 m. Calculate the mean TPC of the ship.

22. A ship of 7500 tonne displacement has its centre of gravity 6.5 m above the keel. Structural alterations are made, when 300 tonne are added 4.8 m above the keel, 1000 tonne of oil fuel are then added 0.7 m above the keel.
(a) Calculate the new position of the centre of gravity.
(b) Calculate the final centre of gravity when 500 tonne of oil fuel are used.

23. A ship of 15 000 tonne displacement floats at a draught of 7 m in water of 1.000 t/m³. It is required to load the maximum amount of oil to give the ship a draught of 7 m in sea water of 1.025 t/m³. If the waterplane area is 2150 m², calculate the mass of oil required.

24. A bulkhead 12 m wide and 9 m high is secured at the base by an angle bar having 20 mm diameter rivets on a pitch of 80 mm. The bulkhead is loaded on one side only to the top edge with sea water. Calculate the stress in the rivets.

25. The ½ ordinates of a waterplane 96 m long are 1.2, 3.9, 5.4, 6.0, 6.3, 6.3, 6.3, 5.7, 4.5, 2.7 and 0 m respectively. A rectangular double bottom tank with parallel sides is 7.2 m wide, 6 m long and 1.2 m deep. When the tank is completely filled with oil of 1.15 m³/tonne the ship's draught is 4.5 m. Calculate the draught when the sounding in the tank is 0.6 m.

* 26. A ship 120 m in length has a wetted surface area of 2680 m² and operates at a speed of 14.5 knots. If the effective power is 2050 kW, calculate:
(a) the residuary resistance
(b) the ratio of frictional resistance to total resistance.

Frictional coefficient in water of density 1025 kg/m³ is 1.42.
Speed in m/s with index for ship 1.83.

27. A ship enters harbour and discharges 6% of its displacement. It then travels upriver to a berth and the total change in draught is found to be 20 cm. The densities of the harbour and berth water are respectively 1.023 t/m³ and 1.006 t/m³ and the TPC in the harbour water is 19. Calculate the original displacement and state whether the draught has been increased or reduced.

28. The fuel consumption of a vessel varies within certain limits as $(\text{speed})^{2.95}$. If, at 1.5 knots above and below the normal speed, the power is 9200 kW and 5710 kW respectively, find the normal speed.

29. The length of a ship is 7.6 times the breadth, while the breadth is 2.85 times the draught. The block coefficient is 0.69, prismatic coefficient 0.735, waterplane area coefficient 0.81 and the wetted surface area 7000 m². The wetted surface area S is given by:

$$S = 1.7\,Ld + \frac{\nabla}{d}$$

Calculate:
(a) displacement in tonne
(b) area of immersed midship section
(c) waterplane area

30. A ship 120 m long, 17 m beam and 7.2 m draught has a block coefficient of 0.76. A parallel section 6 m long is added to the ship amidships. The midship sectional area coefficient is 0.96. Find the new displacement and block coefficient.

31. State what is meant by the Admiralty Coefficient and what its limitations are.

A ship has an Admiralty Coefficient of 355, a speed of 15 knots and shaft power 7200 kW. Calculate its displacement.

If the speed is now reduced by 16%, calculate the new power required.

* 32. A ship of 8100 tonne displacement, 120 m long and 16 m beam floats in water of density 1025 kg/m³. In this condition the ship has the following hydrostatic data:

Prismatic coefficient	=	0.70
Midship area coefficient	=	0.98
Waterplane area coefficient	=	0.82

A full depth midship compartment, which extends the full breadth of the ship, is flooded. Calculate the length of the compartment if, after flooding, the mean draught is 7.5 m.

33. A double bottom tank 1.15 m deep has transverse floors 0.90 m apart connected to the tank top by rivets spaced 7 diameters apart. When the tank is filled with oil (*rd* 0.81) to the top of the sounding pipe, the pressure on the outer bottom is 1.06 bar, while the stress in the rivets in the tank top is 320 bar. Calculate:
(a) the height of the sounding pipe above the tank top
(b) the diameter of the rivets.

34. A ship of 22 000 tonne displacement has a draught of 9.00 m in river water of 1.008 t/m³. The waterplane area is 3200 m². The vessel then enters sea water of 1.026 t/m³. Calculate the change in displacement as a percentage of the original displacement in order to:

(a) keep the draught the same
(b) give a draught of 8.55 m.

* 35. A ship has a fuel consumption of 60 tonne per 24 hours when the displacement is 15 500 tonne and the ship speed 14 knots. Determine the ship speed during a passage of 640 nautical miles if the displacement is 14 500 tonne and the total fuel consumption is 175 tonne.

36. The TPC values of a ship at 1.2 m intervals of draught, commencing at the load waterline are 19, 18.4, 17.4, 16.0, 13.8, 11.0 and 6.6 respectively. If 6.6 represents the value at the keel, calculate the displacement in tonne and state the load draught.

37. If the density of sea water is 1.025 t/m³ and the density of fresh water is 1.000 t/m³, prove that the Statutory Fresh Water Allowance is $\frac{\Delta}{40\ TPC}$ cm.

A ship of 12 000 tonne displacement loads in water of 1.012 t/m³. By how much will the Summer Load Line be submerged if it is known that 130 tonne must be removed before sailing? The TPC in sea water is 17.7.

38. A ship of 2543 tonne displacement is 85 m long, 10.5 m beam, 5 m draught and has a speed of 14 knots. A similar ship has a displacement of 3000 tonne. Calculate the dimensions of the larger ship and its corresponding speed.

* 39. A collision bulkhead is in the form of an isosceles triangle and has a depth of 7.0 m and a width at the deck of 6.0 m. The bulkhead is flooded on one side with water of density 1025 kg/m³ and the resultant load on the bulkhead is estimated at 195 kN. Calculate the depth of water to which the bulkhead is flooded.

40. A ship of 8000 tonne displacement has a metacentric height of 0.46 m, centre of gravity 6.6 m above the keel and centre of buoyancy 3.6 m above the keel. Calculate the second moment of area of the waterplane about the centreline of the ship.

41. A ship has a displacement of 9800 tonne. 120 tonne of oil fuel are moved from an after tank to a tank forward. The centre of gravity of the ship moves 0.75 m forward.

The forward tank already contains 320 tonne of oil fuel and after the transfer 420 tonne of fuel are used. The centre of gravity of the ship now moves to a new position 0.45 m aft of the vessel's original centre of gravity. Find the distance from the ship's original centre of gravity to the centre of gravity of each tank.

* 42. A ship of 18 000 tonne displacement carries 500 tonne of fuel. If the fuel coefficient is 47 250 when the ship's speed is 12 knots, calculate:

(a) the range of operation of the ship
(b) the percentage difference in range of the ship's operation if the speed of the ship is increased by 5%.

43. Before bunkering in harbour the draught of a vessel of 12 000 tonne displacement is 8.16 m, the waterplane area being 1625 m². After loading 1650 tonne of fuel and entering sea water of 1.024 t/m³, the draught is 9.08 m. Assuming that the waterplane area remains constant and neglecting any fuel etc. expended in moving the vessel, calculate the density of the harbour water.

44. Describe how an inclining experiment is carried out. A vessel of 8000 tonne displacement was inclined by moving 5 tonne through 12 m. The recorded deflections of a 6 m pendulum were 73, 80, 78 and 75 mm. If the *KM* for this displacement was 5.10 m, calculate *KG*.

45. A rectangular bulkhead 17 m wide and 6 m deep has a head of sea water on one side only, of 2.5 m above the top of the bulkhead. Calculate:

(a) the load on the bulkhead
(b) the pressure at the top and bottom of the bulkhead.

* 46. For a ship of 4600 tonne displacement the metacentric height *(GM)* is 0.77 m. A 200 tonne container is moved from the hold to the upper deck.

Determine the angle of heel developed if, during this process, the centre of mass of the container is moved 8 m vertically and 1.1 m transversely.

47. The load draught of a ship is 7.5 m in sea water and the corresponding waterplane area is 2100 m². The areas of parallel waterplanes at intervals of 1.5 m below the load waterplane are 1930, 1720, 1428 and 966 m² respectively.

Draw the TPC curve. Assuming that the displacement of the portion below the lowest given waterplane is 711 tonne, calculate the displacement of the vessel when:
(a) fully loaded, and
(b) floating at a draught of 4.5 m in sea water.

48. Define *centre of buoyancy* and show with the aid of sketches how a vessel which is stable will return to the upright after being heeled by an external force.

A vessel displacing 8000 tonne has its centre of gravity 1 m above the centre of buoyancy when in the upright condition. If the moment tending to right the vessel is 570 tonne m when the vessel is heeled over 7°, calculate the horizontal distance the centre of buoyancy has moved from its original position.

* 49. A propeller rotates at 2 rev/s with a speed of advance of 12 knots and a real slip of 0.30. The torque absorbed by the propeller is 250 kN m and the thrust delivered is 300 kN. Calculate:
(a) the pitch of the propeller
(b) the thrust power
(c) the delivered power.

50. A box barge 40 m long and 7.5 m wide floats in sea water with draughts forward and aft of 1.2 m and 2.4 m respectively. Where should a mass of 90 tonne be added to obtain a level keel draught?

* 51. For a box-shaped barge of 16 m beam floating at an even keel draught of 6 m in water of density 1025 kg/m³, the tonne per centimetre immersion (TPC) is 17. A full-depth midship compartment 20 m in length and 16 m breadth has a permeability of 0.80.

If the compartment is bilged, determine:
(a) the draught
(b) the position of the metacentre above the keel, if the second moment of area of the intact waterplane about the centreline is 75 000 m⁴.

52. A box barge is 7.2 m wide and 6 m deep. Draw the metacentric diagram using 1 m intervals of draught up to the deck line.

* 53. A propeller has a diameter of 4.28 m, pitch ratio of 1.1 and rotates at a speed of 2 rev/s. If the apparent and true slip are 0.7% and 12% respectively, calculate the wake speed.

$$\text{Pitch ratio} = \frac{\text{propeller pitch}}{\text{propeller diameter}}$$

* 54. At a ship speed of 12 knots the shaft power for a vessel is 1710 kW and the fuel consumption is 0.55 kg/kW h.

Determine for a speed of 10 knots:
(a) the quantity of fuel required for a voyage of 7500 miles
(b) the fuel coefficient if the ship's displacement is 6000 tonne.

55. A ship of 12 000 tonne displacement has a metacentric height of 0.6 m and a centre of buoyancy 4.5 m above the keel. The second moment of area of the waterplane about the centreline is 42.5×10^3 m⁴. Calculate height of centre of gravity above keel.

* 56. A box-shaped barge 37 m long, 6.4 m beam, floats at an even keel draught of 2.5 m in water of density 1025 kg/m³. If a mass is added and the vessel moves into water of density 1000 kg/m³, determine the magnitude of this mass if the forward and aft draughts are 2.4 m and 3.8 m respectively.

* 57. Calculate the effective power of a ship given the following information:

Length of ship	=	145 m
Wetted surface area	=	3400 m²
Ship speed	=	16 knots

The residuary resistance can be assumed to be 7.1 newtons per tonne displacement.

The frictional coefficient for the ship in water of density 1025 kg/m³ is 1.42. Speed in m/s with index for ship 1.83.

Note: $\textit{Wetted surface area} = 2.56\sqrt{\textit{displacement} \times \textit{length}}$

58. A ship of 7200 tonne displacement has two similar bunkers adjacent to each other, the capacity of each being 495 tonne and their depth 9.9 m. If one of the bunkers is completely full and the other completely empty, find how much fuel must be transferred to lower the ship's centre of gravity 120 mm.

59. The ½ ordinates of the waterplane of a ship 75 m long are:

Station	0	½	1	2	3	4	5	5½	6
½ ord	0.06	1.25	2.68	4.55	5.30	5.20	4.20	2.60	0 m

Calculate the tonne per cm immersion.

60. A ship of 7000 tonne displacement has *KM* 7.30 m. Masses of 150 tonne at a centre 3.0 m above and 60 tonne at a centre 5.5 m below the original centre of gravity of the ship are placed on board. A ballast tank containing 76 tonne of water at *Kg* 0.60 m is then discharged.

Calculate the original height of the ship's centre of gravity above the keel if the final metacentric height is 0.50 m and *KM* is assumed to remain constant.

SOLUTIONS TO SECOND CLASS EXAMINATION QUESTIONS

1.
$$TPC = \frac{A_W \times 1.016}{100}$$

$$= 15 \times 6 \times 0.01016$$
$$= 0.914$$

$$\text{Bodily sinkage} = \frac{150}{0.914}$$

$$= 164 \text{ cm}$$

$$\text{New draught} = 3.0 + 1.64$$
$$= 4.64 \text{ m}$$

$$\text{Load on side} = \rho g\, A\, H$$
$$= 1.016 \times 9.81 \times 15 \times 4.64 \times 2.32$$
$$= 1609 \text{ kN}$$

$$\text{Load on end} = 1.016 \times 9.81 \times 6 \times 4.64 \times 2.32$$
$$= 643.8 \text{ kN}$$

$$\text{Load on bottom} = 1.016 \times 9.81 \times 15 \times 6 \times 4.64$$
$$= 4162 \text{ kN}$$

2.

Mass	distance	moment
6000	3.30	31 800
− 1000	2.10	− 2100
(300)	2.40	− 720
180	3.00	+ 540
460	2.20	+ 1012
5640		30 532

Note: The 300 tonne remains on board and therefore does not alter the final displacement.

$$\text{Centre of gravity above keel} = \frac{30\,532}{5640}$$
$$= 5.413 \text{ m}$$

3. Change in mean draught

$$= \frac{\Delta \times 100 \times 1.025}{TPC \times 100}\left(\frac{1.025 - 1.000}{1.000 \times 1.025}\right)$$

$$= \frac{8000 \times 0.025}{14}$$

$$= 14.29 \text{ cm increase}$$

$$\text{TPC in fresh water} = 14 \times \frac{1.000}{1.025}$$

$$\text{Bodily sinkage} = \frac{300}{TPC}$$

$$= \frac{300 \times 1.025}{14}$$

$$= 21.96 \text{ cm}$$

$$\text{Total increase} = 14.29 + 21.96$$
$$= 36.25 \text{ cm}$$

4. Let S = wetted surface area of small ship

Δ = displacement of small ship

Then $\frac{S}{0.4}$ = wetted surface area of large ship

$\Delta + 4750$ = displacement of large ship

Now $\Delta \propto S^{\frac{3}{2}}$

$$\frac{\Delta}{\Delta_1} = \left(\frac{S}{S_1}\right)^{\frac{3}{2}}$$

$$\frac{\Delta}{\Delta + 4750} = \left(\frac{S \times 0.4}{S}\right)^{\frac{3}{2}}$$

$$= 0.2523$$

$$\Delta = 0.2523\,(\Delta + 4750)$$

$$\Delta\,(1 - 0.2523) = 0.2523 \times 4750$$

$$\Delta = \frac{0.2523 \times 4750}{0.7477}$$

$$= 1603 \text{ tonne}$$

5. Change in mean draught $= \dfrac{9000 \times 100}{1650}\left(\dfrac{1.025 - 1.000}{1.000 \times 1.025}\right)$

$= 13.30$ cm

Thus new waterline $= 13.30 + 5.0$
$= 18.30$ cm below SW line

TPC $= 1650 \times 0.01025$
$= 16.91$

Mass of cargo $= 18.3 \times 16.91$
$= 309.5$ tonne

6. Volume of displacement $= 90 \times 16.7 \times 7.5 \times 0.87$
$= 9807\ m^3$

Wetted surface area $S = 1.7 \times 90 \times 7.5 + \dfrac{9807}{7.5}$

$= 1147.5 + 1307.6$
$= 2455.1\ m^2$

At 3 m/s $\quad R_f = 14 \times 2455.1$ N
$= 34.371$ kN

At v m/s $\quad R_f = 34.371 \times \left(\dfrac{v}{3}\right)^{1.97}$

$\therefore \quad 300 = 34.371 \times \left(\dfrac{v}{3}\right)^{1.97}$

$$v = 3 \sqrt[1.97]{\frac{300}{34.371}}$$

$= 9.010$ m/s

Ship speed $V = \dfrac{9.010 \times 3600}{1852}$

$= 17.51$ knots

7. At 12 knots: $\quad$ ep $= 1400$ kW

sp $= \dfrac{1400}{0.65}$

$= 2154$ kW

Cons/h $= 0.3 \times 2154$
$= 646.2$ kg

Cons/h $\propto$ speed^3

$\therefore$ at 10 knots: cons/h $= 646.2 \times \left(\dfrac{10}{12}\right)^3$

$= 374.0$ kg

Time on voyage $= \dfrac{10\,000}{10}$

$= 1000$ h

$\therefore \quad$ voyage consumption $= 374 \times 1000$
$= 374$ tonne

8. Displacement $\Delta = L\,B\,d \times C_b \times 1.025$

Area of waterplane $A_w = L\,B \times C_w$

$$\frac{\Delta}{A_w} = 1.025d \times \frac{C_b}{C_w}$$

Change in draught $= \dfrac{\Delta \times 100}{A_w}\left(\dfrac{\rho_S - \rho_R}{\rho_R \times \rho_S}\right)$

$= \dfrac{1.025 \times 5 \times 0.7 \times 100}{0.8}\left(\dfrac{1.025 - 1.000}{1.000 \times 1.025}\right)$

$= 10.94$ cm

New draught $= 5.0 + 0.109$
$= 5.109$ m

9.

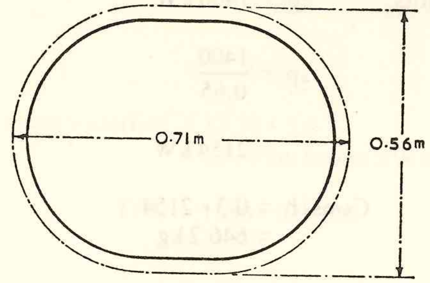

Fig. 109

Perimeter of stud line $= \pi \times 0.56 + 2 \times 0.15$
$= 2.059$ m

Number of studs $= \dfrac{2.059}{0.10}$

$= 21$

Cross-sectional area of studs $= 21 \times 350$
$= 7350\ \text{mm}^2$
$= 7.35 \times 10^{-3}\ \text{m}^2$

Effective area of door $= \dfrac{\pi}{4} \times 0.56^2 + 0.15 \times 0.56$

$= 0.2463 + 0.0840$
$= 0.3303\ \text{m}^2$

Load on door $= \rho g A H$
$= 1.025 \times 9.81 \times 0.3303 \times 7.5$
$= 24.91$ kN

Stress $= \dfrac{\text{load}}{\text{area}}$

$= \dfrac{24.91}{7.35 \times 10^{-3}}$

$= 3.389 \times 10^3\ \text{kN/m}^2$
$= 3.389\ \text{MN/m}^2$

10. $KM = 1.98 + 0.45$
$= 2.43$ m

$BM = 2.43 - 0.90$
$= 1.53$ m

$= \dfrac{I}{\nabla}$

$I = \dfrac{1.53 \times 150}{1.025}$

$= 223.9\ \text{m}^4$

$KG = \dfrac{150 \times 1.98 + 20 \times 3.6}{150 + 20}$

$= \dfrac{297.0 + 72}{170}$

$= 2.170$ m

Increase in draught $= \dfrac{20}{2}$

$= 10$ cm

$KB_1 = \dfrac{150 \times 0.9 + 20\,(1.65 + 0.05)}{170}$

$= \dfrac{135 + 34}{170}$

$= 0.994$ m

$BM_1 = \dfrac{223.9}{170} \times 1.025$

$= 1.350$ m

$KM_1 = 0.994 + 1.350$
$= 2.344$ m

$GM_1 = 2.344 - 2.170$
$= 0.174$ m

11. Fuel cons/day $\alpha\ \Delta^{\frac{2}{3}} V^{3.8}$

$$\therefore \quad \frac{C}{41} = \left(\frac{13\,750}{10\,000}\right)^{\frac{2}{3}} \times \left(\frac{17}{16}\right)^{3.8}$$

$$C = 41\left(\frac{13\,750}{10\,000}\right)^{\frac{2}{3}} \times \left(\frac{17}{16}\right)^{3.8}$$

Fuel cons/day = 63.81 tonne

12.

½ ordinate	SM	Product
0	1	—
9	4	36
16	2	32
23	4	92
25	2	50
25	4	100
22	2	44
18	4	72
0	1	—
		426

$$h = \frac{320}{8}$$

$$= 40 \text{ m}$$

(a) Waterplane area $= \frac{2}{3} \times 40 \times 426$
$= 11\,360 \text{ m}^2$

(b) TPC $= A_w \times 0.01025$
$= 116.44$

(c) Waterplane area coefficient

$$= \frac{11\,360}{320 \times 50}$$

$$= 0.710$$

13. Bottom pressure $= 1.2 \times 10^5 \text{ N/m}^2$
$= \rho g h$

$$h = \frac{1.2 \times 10^5}{1025 \times 9.81}$$

Height of air pipe above outer bottom
$= 11.93 \text{ m}$

Top pressure $= 1.05 \times 10^5 \text{ N/m}^2$

$$h_1 = \frac{1.05 \times 10^5}{1025 \times 9.81}$$

Height of air pipe above inner bottom
$= 10.44 \text{ m}$

Depth of tank $= 11.93 - 10.44$
$= 1.49 \text{ m}$

14. (a)

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

$$= \frac{0.759}{0.98}$$

$$= 0.7745$$

(b) Waterplane area $= 125 \times 17.5 \times 0.83$
$= 1815.6 \text{ m}^2$

TPC $= 1815.6 \times 0.01025$
$= 18.61$

(c) Displacement $= 125 \times 17.5 \times 8 \times 0.759 \times 1.025$
$= 13\,615$ tonne

$$\text{Change in draught} = \frac{13\,615 \times 100}{1815.6}\left(\frac{1.025 - 1.016}{1.016 \times 1.025}\right)$$

$$= 6.48 \text{ cm}$$

15. $$\text{Theoretical speed } V_t = \frac{5 \times 90 \times 60}{1852}$$

$$= 14.58 \text{ knots}$$

$$\text{Apparent slip } 0.15 = \frac{14.58 - V}{14.58}$$

$$V = 14.58(1 - 0.15)$$
$$= 12.39 \text{ knots}$$

$$\text{Wake fraction } 0.10 = \frac{12.39 - V_a}{12.39}$$

$$V_a = 12.39(1 - 0.10)$$
$$= 11.15 \text{ knots}$$

$$\text{Real slip} = \frac{14.58 - 11.15}{14.58}$$

$$= 0.2352$$
or 23.52%

16. Mass of mud in hopper $= 2 \times 1.025 \times 15 \times 5 \times 2$
Mass of buoyancy in hopper $= 1.025 \times 15 \times 5 \times 2$

When the doors are opened, the mud drops out, but at the same time the buoyancy of the hopper is lost. Since the reduction in displacement exceeds the reduction in buoyancy, there will be a reduction in draught.

Nett loss of displacement $= 1.025 \times 15 \times 5 \times 2$
Nett volume of lost displacement
$= 15 \times 5 \times 2 \text{ m}^3$

Area of intact waterplane $= 50 \times 10 - 15 \times 5$
$= 425 \text{ m}^2$

$$\text{Reduction in draught} = \frac{15 \times 5 \times 2}{425}$$

$$= 0.353 \text{ m}$$

New draught $= 2.0 - 0.353$
$= 1.647 \text{ m}$

17. Let C = original daily consumption
V = original speed
K = original voyage consumption
$C \propto V^3$
$K \propto V^2$

$$\frac{K}{(1 - 0.23)K} = \left(\frac{V}{V - 2.2}\right)^2$$

$$\frac{1}{0.77} = \left(\frac{V}{V - 2.2}\right)^2$$

$$\frac{1}{\sqrt{0.77}} = \frac{V}{V - 2.2}$$

$$V - 2.2 = \sqrt{0.77} \times V$$
$$= 0.8775V$$
$$V(1 - 0.8775) = 2.2$$
$$\text{Original speed } V = 17.97 \text{ knots}$$

$$\frac{C}{C - 43} = \left(\frac{V}{V - 2.2}\right)^3$$

$$= \left(\frac{17.97}{15.77}\right)^3$$

$$= 1.480$$
$$C = 1.480(C - 43)$$
$$0.48C = 1.48 \times 43$$

$$C = \frac{1.48 \times 43}{0.48}$$

Original consumption = 132.6 tonne/day

18. Total change in draught $= 6.5 - 6.0$
$= 0.50 \text{ m}$
Total change in displacement $= 50 \times 21$
$= 1050$ tonne
Let mass of additional cargo $= m$
Then $1050 = +300 - 130 + m$
$m = 1050 - 300 + 130$
$= 880$ tonne
Let mass of cargo in one hold $= x$

Then mass of cargo in other hold

$$= 880 - x$$

Taking moments about the keel.

Mass	Kg	moment
7000	6.0	42 000
+ 300	1.0	+ 300
− 130	5.0	− 650
+ x	5.0	+ 5x
+ (880 − x)	7.0	+ (6160 − 7x)
8050		47 810 − 2x

$$\text{Final } KG \qquad 5.8 = \frac{47\,810 - 2x}{8050}$$

$$5.8 \times 8050 = 47\,810 - 2x$$

$$2x = 47\,810 - 46\,690$$

$$x = 560 \text{ tonne}$$

∴ Mass of cargo in holds Kg 5.0 m and Kg 7.0 m respectively are 560 tonne and 320 tonne.

19.

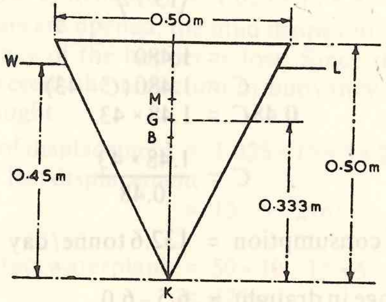

Fig. 110

$$\text{Width at waterline} = 0.45 \text{ m}$$

$$KB = \tfrac{2}{3}d$$

$$= 0.30 \text{ m}$$

$$KG = \tfrac{2}{3}D$$

$$= 0.333 \text{ m}$$

$$BM = \frac{b^2}{6d}$$

$$= \frac{0.45^2}{6 \times 0.45}$$

$$= 0.075 \text{ m}$$

$$KM = KB + BM$$

$$= 0.30 + 0.075$$

$$= 0.375 \text{ m}$$

$$GM = KM - KG$$

$$= 0.375 - 0.333$$

$$\text{Metacentric height} = 0.042 \text{ m}$$

20.

Waterplane area	SM	product
1670	1	1670
1600	4	6400
1540	2	3080
1420	4	5680
1270	2	2540
1080	4	4320
690	1	690
		24 380

$$h = 1.4 \text{ m}$$

$$\text{Displacement in fresh water} = \frac{1.4}{3} \times 24\,380 \times 1.000$$

$$= 11\,377 \text{ tonne}$$

$$\text{Reduction in draught} = \frac{11\,377 \times 100}{1670}\left(\frac{1.025 - 1.000}{1.000 \times 1.025}\right)$$

$$= 16.62 \text{ cm}$$

$$\text{Draught in sea water} = 8.40 - 0.166$$

$$= 8.234 \text{ m}$$

21.
The dock must rise 0.5 m before the ship touches. Thus if the ship rises 1.2 m, the dock must rise 1.70 m.

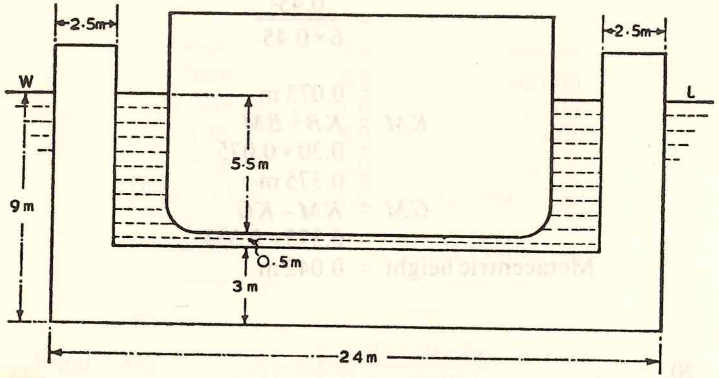

Fig. 111

Mass removed to raise dock 1.70 m

$= 150 \times (2.5 + 2.5) \times 1.70 \times 1.025$
$= 1307$ tonne

Mass removed to raise ship 1.20 m

$= 4000 - 1307$
$= 2693$ tonne

$\therefore 120 \times \text{TPC} = 2693$

$$\text{Mean TPC} = \frac{2693}{120}$$

$= 22.44$

22. (a)

Mass	Kg	moment
7500	6.5	48 750
300	4.8	1440
1000	0.7	700
8800		50 890

$$\text{New } KG = \frac{50\,890}{8800}$$

$= 5.783$ m

(b) After burning oil:

$$\text{New } KG = \frac{50\,890 - 500 \times 0.7}{8800 - 500}$$

$= 6.089$ m

23. With displacement of 15 000 tonne:

$$\text{Reduction in draught} = \frac{15\,000 \times 100}{2150}\left(\frac{1.025 - 1.000}{1.000 \times 1.025}\right)$$

$= 17.02$ cm

$\therefore$ Increase in draught required

$= 17.02$ cm

$\text{TPC} = 2150 \times 0.01025$
$= 22.04$

Mass of oil required $= 17.02 \times 22.04$
$= 375.1$ tonne

24. Load on bulkhead $= \rho g A H$
$= 1.025 \times 9.81 \times 12 \times 9 \times 4.5$
$= 4887$ kN

Shearing force at bottom $= \frac{2}{3} \times 4887$
$= 3258$ kN

$$\text{Number of rivets} = \frac{12}{0.080}$$

$= 150$

Total cross-sectional area of rivets

$$= 150 \times \frac{\pi}{4} \times 20^2 \times 10^{-6}$$

$= 47.13 \times 10^{-3}\,\text{m}^2$

$$\text{Stress in rivets} = \frac{\text{load}}{\text{area}}$$

$$= \frac{3258}{47.13 \times 10^{-3}}$$

$= 69.13 \times 10^3\,\text{kN/m}^2$
$= 69.13\,\text{MN/m}^2$

25.

½ ordinate	SM	product
1.2	1	1.2
3.9	4	15.6
5.4	2	10.8
6.0	4	24.0
6.3	2	12.6
6.3	4	25.2
6.3	2	12.6
5.7	4	22.8
4.5	2	9.0
2.7	4	10.8
0	1	—
		144.6

$h = 9.6$ m

Waterplane area $= \frac{2}{3} \times 9.6 \times 144.6$

$= 925.44$ m²

TPC $= 925.44 \times 0.01025$

$= 9.486$

Mass of oil in tank $= \dfrac{7.2 \times 6.0 \times 1.2}{1.15}$

$= 45.08$ tonne

∴ mass removed $= 22.54$ tonne

Reduction in draught $= \dfrac{22.54}{9.486}$

$= 2.38$ cm

Final draught $= 4.50 - 0.024$

$= 4.476$ m

26. Effective power $= R_t \times v$

$v = 14.5 \times \dfrac{1852}{3600}$

$= 7.459$ m/s

$2050 = R_t \times 7.459$

$R_t = 274.8$ kN

$R_f = fSv^n$

$= 1.42 \times 2680 \times 7.459^{1.83}$

$= 150.0$ kN

$R_r = R_t - R_f$

$= 274.8 - 150.0$

Residuary resistance $= 124.8$ kN

$\dfrac{R_f}{R_t} = \dfrac{150.0}{274.8}$

$= 0.546$

i.e. Frictional resistance 54.6% of total resistance.

27. Let Δ = original displacement

Change in draught due to removal of mass

$a = \dfrac{0.06\Delta}{\text{TPC}}$ cm

$= \dfrac{0.06\Delta}{19}$

$= 0.003158\,\Delta$ cm reduction

Change in draught due to change in density

$b = \dfrac{0.94\,\Delta \times 100 \times 1.023}{\text{TPC} \times 100} \left(\dfrac{1.023 - 1.006}{1.006 \times 1.023}\right)$

$= \dfrac{0.94\,\Delta \times 0.017}{19 \times 1.006}$

$= 0.000836\,\Delta$ cm increase

Assuming *a* to be greater than *b*

$20 = a - b$

$= 0.003158\Delta - 0.000836\Delta$

$= 0.002322\Delta$

Original displacement

$\Delta = \dfrac{20}{0.002322}$

$= 8613$ tonne

The draught will be *reduced* by 20 cm.

If the above assumption were wrong, the displacement would work out as a *negative* value.

28. Let V = normal speed in knots

$$\frac{9200}{5710} = \left(\frac{V+1.5}{V-1.5}\right)^{2.95}$$

$$\frac{V+1.5}{V-1.5} = \sqrt[2.95]{\frac{9200}{5710}}$$

$$= 1.176$$

$$V+1.5 = 1.176V - 1.176 \times 1.5$$

$$0.176V = (1+1.176)\,1.5$$

$$V = \frac{2.176 \times 1.5}{0.176}$$

Normal speed V = 18.55 knots

29.

$$L = 7.6 \times B$$

$$B = 2.85 \times d$$

$$\nabla = L \times B \times d \times C_b$$

$$= 7.6B \times B \times \frac{B}{2.85} \times 0.69$$

$$= \frac{7.6 \times 0.69\,B^3}{2.85}$$

$$S = 1.7\,Ld + \frac{\nabla}{d}$$

$$= 1.7 \times 7.6B \times \frac{B}{2.85} + \frac{7.6 \times 0.69}{2.85}B^3 \times \frac{2.85}{B}$$

$$7000 = 4.533B^2 + 5.244B^2$$

$$= 9.777B^2$$

$$B^2 = \frac{7000}{9.777}$$

$$B = 26.76 \text{ m}$$

$$L = 7.6 \times 26.76$$

$$= 203.38 \text{ m}$$

$$d = \frac{26.76}{2.85}$$

$$= 9.389 \text{ m}$$

(a) Displacement Δ

$$= 203.38 \times 26.76 \times 9.389 \times 0.69 \times 1.025$$

$$= 36\,140 \text{ tonne}$$

(b) Area of immersed midship section

$$A_m = B \times d \times \frac{C_b}{C_p}$$

$$= 26.76 \times 9.389 \times \frac{0.69}{0.735}$$

$$= 235.9 \text{ m}^2$$

(c) Waterplane area

$$A_w = L \times B \times C_w$$

$$= 203.38 \times 26.76 \times 0.81$$

$$= 4410 \text{ m}^2$$

30. Original displacement $= 120 \times 17 \times 7.2 \times 0.76 \times 1.025$

$= 11\,442$ tonne

Additional displacement $= 6 \times 17 \times 7.2 \times 0.96 \times 1.025$

$= 723$ tonne

New displacement $= 11\,442 + 723$

$= 12\,165$ tonne

New length $= 126$ m

$$\text{New block coefficient} = \frac{12\,165}{126 \times 17 \times 7.2 \times 1.025}$$

$$= 0.770$$

31.

$$\text{sp} = \frac{\Delta^{\frac{2}{3}} V^3}{C}$$

$$\Delta^{\frac{2}{3}} = \frac{7200 \times 355}{15^3}$$

Displacement Δ = 20 840 tonne

$\text{sp} \propto V^3$

$$\therefore \quad \text{sp}_1 = 7200 \times \left(\frac{0.84V}{V}\right)^3$$

$$= 4267 \text{ kW}$$

32.

$$\Delta \doteq L \times B \times d \times C_b \times \rho$$

$$C_b = C_p \times C_m$$

$$\therefore \quad 8100 = 120 \times 16 \times d \times 0.70 \times 0.98 \times 1.025$$

$$d = \frac{8100}{120 \times 16 \times 0.70 \times 0.98 \times 1.025}$$

$$= 6.00 \text{ m}$$

Let l = length of compartment

Volume of lost buoyancy = $l \times 16 \times 6.0 \times 0.98$

Area of intact waterplane = $120 \times 16 \times 0.82 - l \times 16$

Increase in draught = $7.5 - 6.0$

= 1.5 m

$$\therefore \quad 1.5 = \frac{l \times 16 \times 6 \times 0.98}{120 \times 16 \times 0.82 - l \times 16}$$

$$2361.6 - 24l = 94.08\,l$$

$$94.08\,l + 24\,l = 2361.6$$

$$l = \frac{2361.6}{118.08}$$

Length of compartment = 20 m

33.

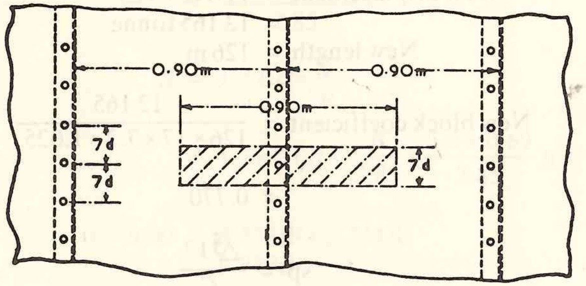

Fig. 112

(a) Pressure on outer bottom = $\rho g h$

$$1.06 \times 10^5 = 810 \times 9.81 \times h$$

$$h = \frac{1.06 \times 10^5}{810 \times 9.81}$$

$$= 13.34 \text{ m}$$

$\therefore$ Sounding pipe above tank top

$$= 13.34 - 1.15$$

$$= 12.19 \text{ m}$$

(b) Area supported by one rivet

$$= 0.90 \times 7d$$

$$= 6.3d \text{ m}^2$$

Load on one rivet = $\rho g A H$

$$= 810 \times 9.81 \times 6.3d \times 12.19$$

$$= 610\,240d \text{ N}$$

But stress = $\dfrac{\text{load}}{\text{area}}$

$\therefore$ load on one rivet = stress × area of one rivet

$$610\,240d = 320 \times 10^5 \times \frac{\pi}{4} d^2$$

$$d = \frac{610\,240 \times 4}{320 \times 10^5 \times \pi}$$

$$= 0.0243 \text{ m}$$

$$= 24 \text{ mm}$$

34 (a) Change in draught due to density

$$= \frac{22\,000 \times 100}{3200}\left(\frac{1.026 - 1.008}{1.008 \times 1.026}\right)$$

= 11.97 cm reduction

Change in displacement = $11.97 \times 3200 \times 1.026 \times 10^{-2}$

= 393 tonne

$$\% \text{ difference} = \frac{393}{22\,000} \times 100$$

= 1.79% increase

(b) New draught = $9.00 - 0.1197$

= 8.8803 m

Final draught = 8.55 m

Change in draught = 0.3303 m

Change in displacement = $0.3303 \times 3200 \times 1.026$

= 1084 tonne

$$\% \text{ difference} = \frac{1084}{22\,000} \times 100$$

= 4.93% reduction

35.
$$\text{Fuel cons/day} \propto \Delta^{\frac{2}{3}} V^3$$

Let V = new ship speed in knots

Then
$$\text{new cons/day} = \left(\frac{14\,500}{15\,500}\right)^{\frac{2}{3}} \times \left(\frac{V}{14}\right)^3 \times 60$$
$$= 0.02092\ V^3 \text{ tonne}$$
$$\text{Number of days} = \frac{640}{24V}$$
$$\therefore \quad \text{Voyage cons} = \frac{640}{24V} \times 0.02092 V^3$$
$$175 = \frac{640}{24} \times 0.02092\ V^2$$
$$V^2 = 313.7$$
$$\text{Ship speed} \quad V = 17.71 \text{ knot}$$

36.

TPC	SM	product
19.0	1	19.0
18.4	4	73.6
17.4	2	34.8
16.0	4	64.0
13.8	2	27.6
11.0	4	44.0
6.6	1	6.6
		269.6

$$h = 1.2 \text{ m}$$
$$\text{Displacement} = \frac{1.2}{3} \times 269.6 \times 100$$
$$= 10\,784 \text{ tonne}$$
$$\text{Load draught} = 1.2 \times 6$$
$$= 7.2 \text{ m}$$

37. Change in draught due to density
$$= \frac{12\,000 \times 100 \times 1.025}{17.7 \times 100}\left(\frac{1.025 - 1.012}{1.012 \times 1.025}\right)$$
$$= 8.71 \text{ cm reduction}$$

Change in draught due to removal of 130 tonne
$$= \frac{130}{17.7}$$

$$= 7.344 \text{ cm reduction}$$

Total change in draught
$$= 8.71 + 7.344$$
$$= 16.054 \text{ cm}$$

i.e. Summer Load Line would have been submerged 16.05 cm.

38. For similar ships
$$\Delta \propto L^3$$
$$L \propto \Delta^{\frac{1}{3}}$$
$$\therefore \quad \text{Length } L = 85\sqrt[3]{\frac{3000}{2543}}$$
$$= 85 \times 1.057$$
$$= 89.81 \text{ m}$$
$$\text{Breadth } B = 10.5 \times 1.057$$
$$= 11.09 \text{ m}$$
$$\text{Draught } d = 5 \times 1.057$$
$$= 5.28 \text{ m}$$
$$\text{Corresponding speed} \propto \Delta^{\frac{1}{6}}$$
$$\therefore \quad V = 14\sqrt[6]{\frac{3000}{2543}}$$
$$= 14.39 \text{ knots}$$

39.

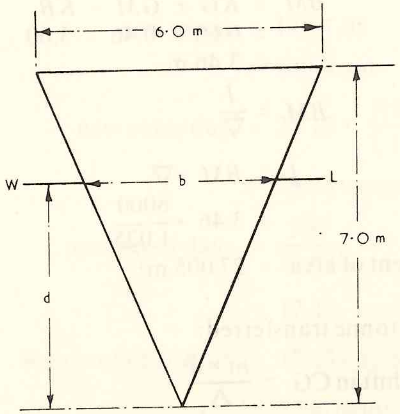

Fig. 113

The effective area of the bulkhead will depend upon whether the water level is above or below the top. Assume that the water is *at* the top.

$$\text{Load on bulkhead} = \rho g A H$$

$$= 1.025 \times 9.81 \times \frac{6 \times 7}{2} \times \frac{7}{3}$$

$$= 492.7 \text{ kN}$$

Thus the water must lie below the top.

Let d = depth of water;
b = width of bulkhead at water level.

$$b = \frac{6}{7} \times d$$

$$\text{Load on bulkhead} = 1.025 \times 9.81 \times \frac{b \times d}{2} \times \frac{d}{3}$$

$$195 = 1.025 \times 9.81 \times \frac{6}{7} d \times \frac{d}{2} \times \frac{d}{3}$$

$$d^3 = \frac{195 \times 7 \times 2 \times 3}{1.025 \times 9.81 \times 6}$$

Depth of water $d = 5.14$ m

40.

$$GM = KB + BM - KG$$

$$\therefore \quad BM = KG + GM - KB$$

$$= 6.60 + 0.46 - 3.60$$

$$= 3.46 \text{ m}$$

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

$$\therefore \quad I = BM \times \nabla$$

$$= 3.46 \times \frac{8000}{1.025}$$

Second moment of area $= 27\,005$ m^4

41. When 120 tonne transferred:

$$\text{Shift in CG} = \frac{m \times d}{\Delta}$$

$$d = \frac{\Delta \times GG_1}{m}$$

$$= \frac{9800 \times 0.75}{120}$$

Distance between tanks $= 61.25$ m

When 420 tonne used:

Let x = distance from original CG to cg of forward tank.

Taking moments about the original CG:

$$(9800 - 420)(-0.45) = 9800 \times 0.75 - 420 \times x$$

$$-4221 = 7350 - 420x$$

$$420x = 7350 + 4221$$

$$x = \frac{11\,571}{420}$$

$$= 27.55 \text{ m}$$

$$d - x = 61.25 - 27.55$$

$$= 33.70 \text{ m}$$

Thus the forward tank is 27.55 m from the vessel's original CG and the after tank is 33.70 m from the vessel's original CG.

42.

$$\text{Fuel cons day} = \frac{18\,000^{\frac{2}{3}} \times 12^3}{47250}$$

$$= 25.12 \text{ tonne}$$

$$\text{Number of days} = \frac{500}{25.12}$$

$$= 19.91$$

(a) Range of operation $= 19.91 \times 12 \times 24$

$= 5734$ nautical miles

(b) new speed $= 12 \times 1.05$

$= 12.6$ knot

$$\text{new cons/day} = 25.12 \times \left(\frac{12.6}{12}\right)^3$$

$$= 29.08 \text{ tonne}$$

$$\text{number of days} = \frac{500}{29.08}$$

$$= 17.19$$

Range of operation $= 17.19 \times 12.6 \times 24$

$= 5200$ nautical miles

$$\text{Percentage difference} = \frac{5734 - 5200}{5734} \times 100$$

$= 9.31\%$ reduction

43. TPC in sea water $= 1625 \times 0.01024$
$= 16.64$

$$\text{Bodily sinkage} = \frac{1650}{16.64}$$
$$= 99.16\ \text{cm}$$

Thus at 12 000 tonne displacement:

Mean draught in sea water $= 9.08 - 0.992$
$= 8.088\ \text{m}$

Thus change in draught due to density
$= 8.16 - 8.088$
$= 0.072\ \text{m}$

Let ρ_R = density of harbour water in t/m³

$$\text{Then} \qquad 7.2 = \frac{12\,000 \times 100}{1650}\left(\frac{1.024 - \rho_R}{1.024\rho_R}\right)$$

$$1.024\ \rho_R \times 7.2 = 727.3\,(1.024 - \rho_R)$$

$$\rho_R\,(7.37 + 727.3) = 727.3 \times 1.024$$

$$\rho_R = \frac{727.3 \times 1.024}{734.67}$$

Density of harbour water $= 1.014\ \text{t/m}^3$

44. Mean deflection $= \frac{1}{4}(73 + 80 + 78 + 75)$
$= 76.5\ \text{mm}$

$$GM = \frac{m \times d}{\Delta \tan\theta}$$
$$= \frac{5 \times 12 \times 6}{8000 \times 0.0765}$$
$$= 0.588\ \text{m}$$

$$KG = KM - GM$$
$$= 5.10 - 0.588$$
$$= 4.512\ \text{m}$$

45. (a) Load on bulkhead $= \rho g A H$
$= 1.025 \times 9.81 \times 17 \times 6 \times (3 + 2.5)$
$= 5641\ \text{kN}$

(b) Pressure at top of bulkhead

$= \rho g h$
$= 1.025 \times 9.81 \times 2.5$
$= 25.14\ \text{kN/m}^2$

Pressure at bottom of bulkhead

$= 1.025 \times 9.81 \times (6 + 2.5)$
$= 85.47\ \text{kN/m}^2$

46.

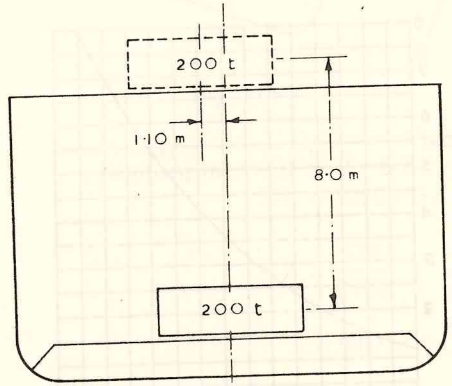

Fig. 114

$$\text{Rise in } G = \frac{200 \times 8}{4600}$$
$$= 0.348\ \text{m}$$

New $GM = 0.77 - 0.348$
$= 0.422\ \text{m}$

$$\tan\theta = \frac{200 \times 1.1}{4600 \times 0.422}$$
$$= 0.1133$$

Angle of heel $\theta = 6°\ 27'$

47. $TPC = A_W \times 0.01025$

Draught	A_W	TPC	SM_1	$product_1$	SM_2	$product_2$
7.5	2100	21.52	1	21.52		
6.0	1930	19.78	4	79.12		
4.5	1720	17.63	2	35.26	1	17.63
3.0	1428	14.64	4	58.56	4	58.56
1.5	966	9.90	1	9.90	1	9.90
				204.36		86.09

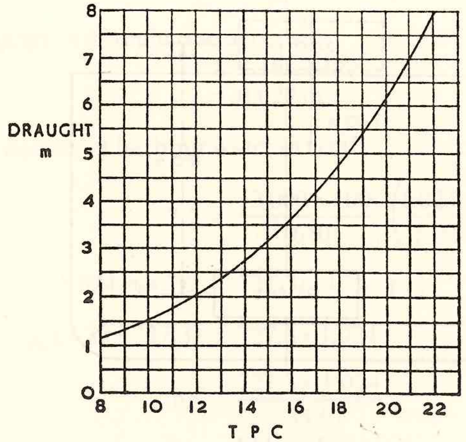

Fig. 115

(a) Displacement at 7.5 m draught

$$= 711 + \frac{1.5}{3} \times 100 \times 204.36$$

$$= 711 + 10\,218$$
$$= 10\,929 \text{ tonne}$$

(b) Displacement at 4.5 m draught

$$= 711 + \frac{1.5}{3} \times 100 \times 86.09$$

$$= 711 + 4305$$
$$= 5016 \text{ tonne}$$

48.

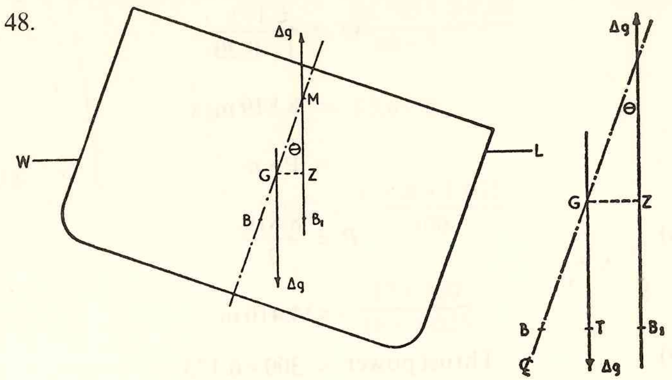

Fig. 116

$$\text{Righting moment} = \Delta \times GZ$$
$$570 = 8000 \times GZ$$

$$GZ = \frac{570}{8000}$$

$$= 0.0713 \text{ m}$$

$$BT = BG \sin\theta$$
$$= 1.0 \times 0.1219$$
$$= 0.1219 \text{ m}$$

$$\text{Horizontal movement of B} = BB_1$$
$$= BT + TB_1$$
$$= BT + GZ$$
$$= 0.1219 + 0.0713$$
$$= 0.1932 \text{ m}$$

49. $$\text{Speed of advance} = 12 \times \frac{1852}{3600}$$

$$= 6.173 \text{ m/s}$$

$$\text{Real slip} = \frac{vt - va}{vt}$$

$$0.30 = \frac{vt - 6.173}{vt}$$

$$vt = \frac{6.173}{1 - 0.30}$$

$$= 8.819\ \text{m/s}$$

$$= P \times n$$

(a) $$P = \frac{8.819}{2}$$

$$= 4.410\ \text{m}$$

(b) Thrust power $= 300 \times 6.173$
$= 1852\ \text{kW}$

(c) Delivered power $= 250 \times 2\pi \times 2$
$= 3142\ \text{kW}$

50.

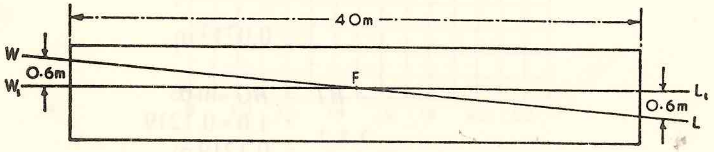

Fig. 117

If it is assumed that the mass is first added amidships, there will be a bodily increase in draught without change of trim.

To obtain a level keel draught the wedge of buoyancy WFW_1 must be transferred to L_1FL.

Mass of wedge $= 20 \times 7.5 \times 0.6 \times \frac{1}{2} \times 1.025$
$= 46.125$ tonne

Distance moved $= \frac{2}{3} \times 40$

Let x = distance moved forward by 90 tonne, then

$$90x = 46.125 \times \frac{2}{3} \times 40$$

$$x = \frac{46.125 \times 2 \times 40}{90 \times 3}$$

$$= 13.67\ \text{m}$$

51.

$$\text{TPC} = \frac{L \times B \times 1.025}{100}$$

$$L = \frac{17 \times 100}{16 \times 1.025}$$

$$= 103.6\ \text{m}$$

Volume of lost buoyancy $= 20 \times 16 \times 6 \times 0.80$
Area of intact waterplane $= 103.6 \times 16 - 20 \times 16 \times 0.8$

$$\text{Increase in draught} = \frac{20 \times 16 \times 6 \times 0.8}{103.6 \times 16 - 20 \times 16 \times 0.8}$$

$$= 1.096\ \text{m}$$

(a) New draught $= 6 + 1.096$

$$= 7.096\ \text{m}$$

(b) $$KB = \frac{7.096}{2}$$

$$= 3.548\ \text{m}$$

$$BM = \frac{75\,000}{103.6 \times 16 \times 6}$$

$$= 7.541\ \text{m}$$

$$KM = 3.548 + 7.541$$

$$= 11.089\ \text{m}$$

52.

$$KB = \frac{d}{2}$$

$$BM = \frac{B^2}{12d}$$

$$= \frac{7.2^2}{12d}$$

$$= \frac{4.32}{d}$$

Draught	KB	BM	KM
0	0	∞	∞
1	0.5	4.32	4.82
2	1.0	2.16	3.16
3	1.5	1.44	2.94
4	2.0	1.08	3.08
5	2.5	0.86	3.36
6	3.0	0.72	3.72

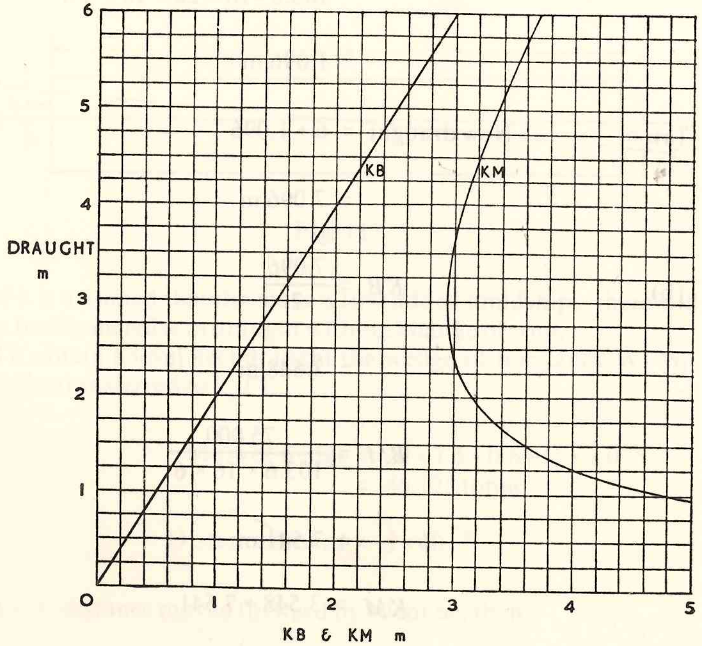

Fig. 118

53.

$$\text{Propeller pitch} = 1.1 \times 4.28$$
$$= 4.708\ \text{m}$$

$$vt = 4.708 \times 2$$
$$= 9.416\ \text{m/s}$$

$$\text{Apparent slip } 0.7 = \frac{9.416 - v}{9.416} \times 100$$

$$v = 9.416(1 - 0.007)$$
$$= 9.34\ \text{m/s}$$

$$\text{Real slip } 12 = \frac{9.416 - va}{9.416} \times 100$$

$$va = 9.416(1 - 0.12)$$
$$= 8.286\ \text{m/s}$$

$$\text{Wake speed} = 9.34 - 8.286$$
$$= 1.054\ \text{m/s}$$
$$= 2.05\ \text{knot}$$

54.

$$\text{At 12 knot; Cons/day} = \frac{0.55 \times 1710 \times 24}{1000}$$
$$= 22.572\ \text{tonne}$$

(a)

$$\text{At 10 knot: Cons/day} = 22.572 \times \left(\frac{10}{12}\right)^3$$
$$= 13.062\ \text{tonne}$$

$$\text{Number of days} = \frac{7500}{10 \times 24}$$
$$= 31.25$$

$$\text{Fuel required} = 13.062 \times 31.25$$
$$= 408.2\ \text{tonne}$$

(b)

$$\text{Fuel coefficient} = \frac{6000^{\frac{2}{3}} \times 12^3}{22.572}$$
$$= 25\,278$$

55.

$$KG = KB + BM - GM$$

$$KB = 4.5\,\text{m}$$

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

$$= \frac{42.5 \times 10^3 \times 1.025}{12\,000}$$

$$= 3.630\,\text{m}$$

$$GM = 0.6\,\text{m}$$

$$\therefore \quad KG = 4.50 + 3.63 - 0.60$$
$$= 7.53\,\text{m}$$

56.

Original displacement $= 37 \times 6.4 \times 2.5 \times 1.025$

$= 606.8$ tonne

New mean draught $= \dfrac{2.4 + 3.8}{2}$

$= 3.10$ m

New displacement $= 37 \times 6.4 \times 3.1 \times 1.00$

$= 734.08$ tonne

Mass added $= 734.08 - 606.8$

$= 127.28$ tonne

57.

Ship speed $= 16 \times \dfrac{1852}{3600}$

$= 8.231$ m/s

$$R_f = fSv^n$$

$$= 1.42 \times 3400 \times 8.231^{1.83}$$

$$= 228.58\,\text{kN}$$

$$S = 2.56\sqrt{\Delta L}$$

$$\Delta = \left(\frac{S}{2.56}\right)^2 \times \frac{1}{L}$$

$$= \left(\frac{3400}{2.56}\right)^2 \times \frac{1}{145}$$

$$= 12\,165\ \text{tonne}$$

$$R_r = 7.1 \times 12\,165$$

$$= 86.37\,\text{kN}$$

$$R_t = 228.58 + 86.37$$

$$= 314.95\,\text{kN}$$

Effective power $\quad ep = 314.95 \times 8.231$

$= 2592$ kW

58.

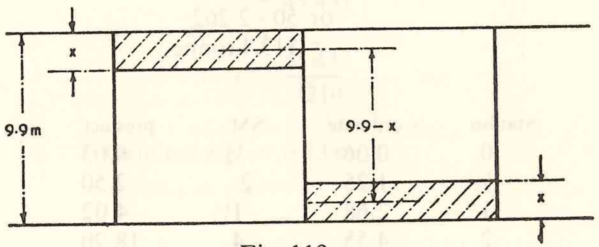

Fig. 119

Mass of fuel/m depth $= \dfrac{495}{9.9}$

$= 50$ tonne

Let x = depth of fuel which must be transferred

Then $50x$ = mass of fuel transferred

$9.9 - x$ = distance which fuel is transferred

$$\text{Shift in CG} = \frac{m \times d}{\Delta}$$

$$0.12 = \frac{50x \times (9.9 - x)}{7200}$$

$$= \frac{x \times (9.9 - x)}{144}$$

$$0.12 \times 144 = 9.9x - x^2$$

$$x^2 - 9.9x + 17.28 = 0$$

$$x = \frac{9.9 \pm \sqrt{9.9^2 - 4 \times 17.28}}{2}$$

$$= \frac{9.9 \pm 5.375}{2}$$

$$= 7.638 \text{ m or } 2.262 \text{ m}$$

$$\text{Mass of oil transferred} = 50 \times 7.638$$
$$= 381.9 \text{ tonne}$$
$$\text{or } 50 \times 2.262$$
$$= 113.1 \text{ tonne}$$

59.

Station	½ ordinate	SM	product
0	0.06	½	0.03
½	1.25	2	2.50
1	2.68	1½	4.02
2	4.55	4	18.20
3	5.30	2	10.60
4	5.20	4	20.80
5	4.20	1½	6.30
5½	2.60	2	5.20
6	0	½	0
			67.65

$$h = \frac{75}{6}$$
$$= 12.5 \text{ m}$$

$$\text{Waterplane area} = \tfrac{2}{3} \times 12.5 \times 67.65$$
$$= 563.75 \text{ m}^2$$

$$\text{TPC} = A_w \times 0.01025$$
$$= 563.75 \times 0.01025$$
$$= 5.778$$

60. $$\text{Final } KG = 7.30 - 0.50$$
$$= 6.80 \text{ m}$$

Let x = distance of original CG above the keel

mass	Kg	moment
7000	x	$7000x$
150	$x + 3$	$150x + 450$
60	$x - 5.5$	$60x - 330$
-76	0.6	-45.6
7134		$7210x + 74.4$

$$7134 \times 6.8 = 7210x + 74.4$$

$$7210x = 48\,511 - 74$$
$$= 48\,437$$

$$x = \frac{48\,437}{7210}$$

$$\text{Original } KG = 6.73 \text{ m}$$