BASIC NAVAL ARCHITECTURE
INSTRUCTOR'S GUIDE
AND PROBLEM SET

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16. Abstract

A video lecture course presenting the fundamentals of naval architecture was developed as part of the government-industry-supported National Shipbuilding Research Program (NSRP). This publication, along with Volumes I and II, contains the instructor syllabus, problem sets, and solutions that complement the videotapes. The notes include many of the slides used in the videotapes and are intended to be used by the instructor for overhead transparencies.

The following topics are covered in this volume: Ship Maneuverability and Control, Ship Motion, Strength and Structure of Ships, Ship Design Process, Shipbuilding Methods.

This material was developed to convey to trade school students the foundations of naval architecture. The level of material presented makes it suitable for engineers transferring into the field of naval architecture, a college level study course for students not majoring in the field (e.g. Ocean Engineering majors) or a naval or merchant marine officer candidate program.

The course consists of 45 videotapes (average length of 35 minutes each) presented in a classroom lecture format by Dr. Paul R. Van Mater Jr., of Giannotti and Associates Inc. An additional text is required for the course: *Modern Ship Design*, Second Edition, 1977, Thomas C. Gillmer, Naval Institute Press, Annapolis, MD 21402.

Inquiries regarding the purchase of the videotapes should be forwarded to the AVMAST Library, Marine Systems Division, University of Michigan Transportation Research Institute, 2901 Baxter Road, Ann Arbor, MI 48109, (313) 763-2465.

17. Key Words

Naval Architecture, Ship Maneuverability, Ship Motion, Ship Control, Strength and Structure of Ships, Ship Design Process, Shipbuilding Methods

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STATIC STABILITY

TRANSVERSE WEIGHT SHIFT EXAMPLE

A DD 692 DESTROYER IS FLOATING IS SALT WATER AT THE FOLLOWING DRAFTS AND KG:

T_f = 13' - 9"
T_a = 13' - 9"
KG = 16.30 FT A.K.

THE SHIP IS INITIALLY UPRIGHT.

A 20-TON WEIGHT IS SHIFTED HORIZONTALLY FROM PORT TO STARBOARD THROUGH A DISTANCE OF 30 FEET. FIND THE RESULTING ANGLE OF LIST.

STATIC STABILITY (CON'T)

WEIGHT SHIFT EXAMPLE - SOLUTION

1. FROM CURVES OF FORM AT

$$T_m = 13.75 \text{ FT.}$$

FIND,

DISPLACEMENT (CURVE 1): $\Delta = 3350$ LT.

KM (CURVE 10) = $965 \text{ T.} \times \frac{2 \text{ FT}}{100 \text{ T}} = 19.30$ FT. A.K.

2. GIVEN $\underline{KG = 16.30 \text{ FT. A.K.}}$

THEN $GM = 3.00$ FT

3. APPLY FORMULA, $GM \tan\phi = \frac{wt}{\Delta}$

FIND $\tan\phi$, THEN ϕ

STATIC STABILITY (CON'T)

WEIGHT SHIFT EXAMPLE - SOLUTION

4.

$$w = 20 \text{ LT}$$

$$t = 30 \text{ FT}$$

$$\Delta = 3350 \text{ LT}$$

$$GM = 3.00 \text{ FT}$$

$$\tan\phi = \frac{wt}{GM \cdot \Delta} = \frac{(20 \text{ LT})(30 \text{ FT})}{(3.00 \text{ FT})(3350 \text{ LT})}$$

$$\tan\phi = .0597$$

$$\underline{\underline{\phi = 3.4^\circ}}$$

STATIC STABILITY (CON'T)

INCLINING EXPERIMENT

THE PURPOSE OF THE INCLINING EXPERIMENT IS TO MEASURE THE HEIGHT OF CG (KG).

APPROACH

APPLY FORMULA: $GM \tan\phi = \frac{wt}{\Delta}$

MEASURE: $w,\ t,\ \Delta,\ \phi$

CALCULATE: GM

FIND KM FROM CURVES OF FORM.

THEN $KG = KM - GM$

STATIC STABILITY (CON'T)

INCLINING EXPERIMENT EXAMPLE

(VARIATION OF PREVIOUS EXAMPLE)

A DD 692 DESTROYER IS FLOATING IN SALT WATER AT THE FOLLOWING DRAFTS:

T_f = 13' - 9"

T_a = 13' - 9"

THE SHIP IS INITIALLY UPRIGHT. A 20-TON WEIGHT IS SHIFTED HORIZONTALLY FROM PORT TO STARBOARD THROUGH A DISTANCE OF 30 FEET. THE RESULTING ANGLE OF LIST IS 3.4°. FIND KG.

STATIC STABILITY (CON'T)

INCLINING EXPERIMENT - SOLUTION

1. **APPLY SAME FORMULA:**

$$GM \tan \phi = \frac{wt}{\Delta}$$

$$w = 20 \text{ LT}$$

$$t = 30 \text{ FT}$$

$$\Delta = 3350 \text{ LT}$$

$$\phi = 3.4^\circ$$

$$\tan \phi = .0597$$

$$GM = \frac{wt}{\tan \phi \cdot \Delta}$$

$$GM = \frac{(20 \text{ LT})(30 \text{ FT})}{(.0597)(3350 \text{ LT})}$$

$$GM = 3.00 \text{ FT}$$

STATIC STABILITY (CON'T)

INCLINING EXPERIMENT - SOLUTION

3. FROM CURVES OF FORM,

$$\begin{array}{l} KM = 19.30 \text{ FT A.K.} \\ \underline{GM = 3.00 \text{ FT}} \\ KG = 16.30 \text{ FT A.K.} \end{array}$$

$$\boxed{KG = 16.30 \text{ FT.}}$$

STATIC STABILITY (CON'T)

INCLINING EXPERIMENT PROCEDURE

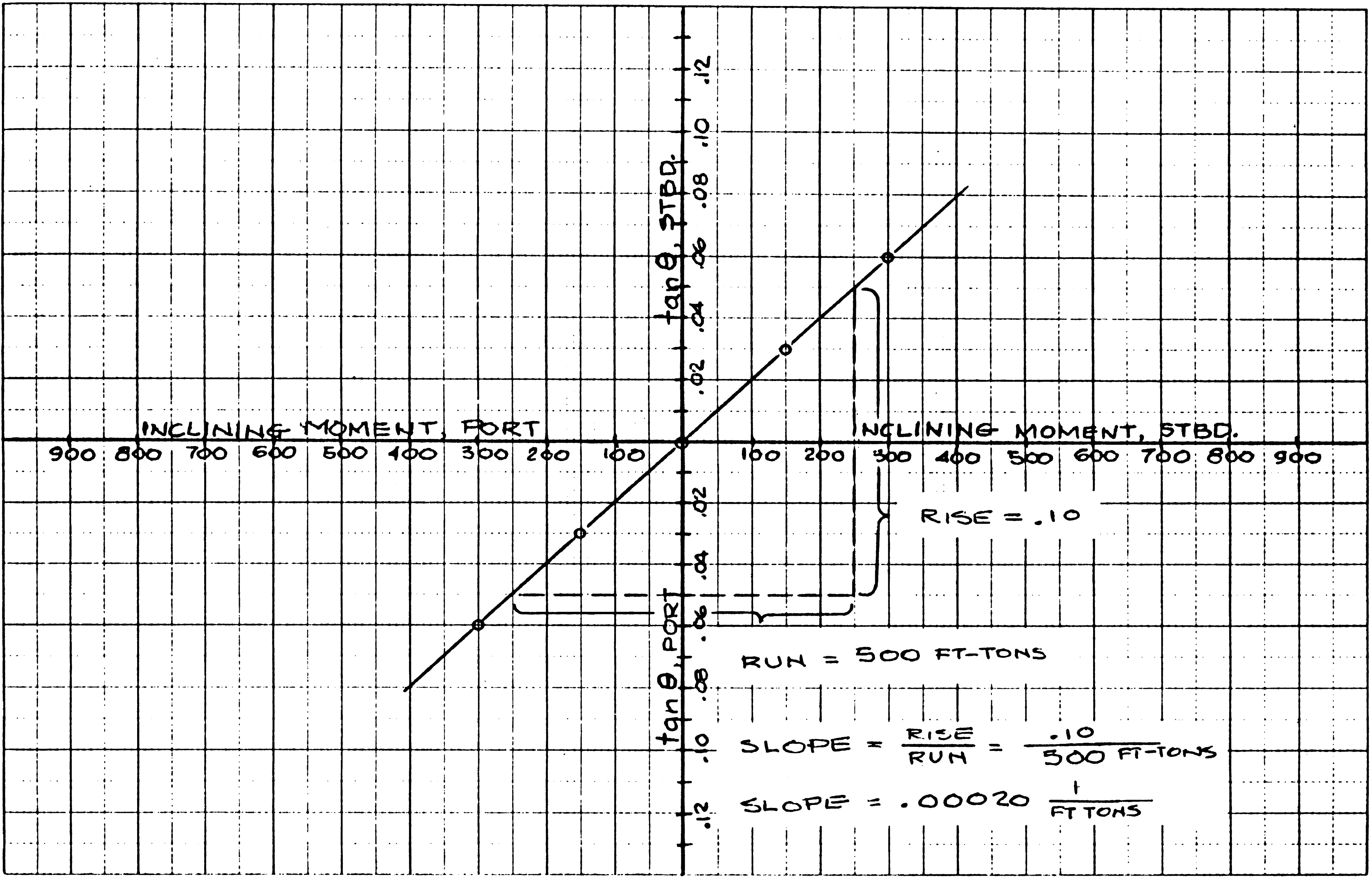
- INCLINING EXPERIMENTS ARE ROUTINELY CONDUCTED IN SHIPYARDS FOR NEW SHIPS AFTER LAUNCHING AND FOR OLDER SHIPS AFTER OVERHAUL

- THE SHIPYARD MAINTAINS LARGE CALIBRATED WEIGHTS. THE WEIGHTS ARE MOVED TRANSVERSLY EITHER BY CRANE OR BY A TROLLEY INSTALLED ON DECK.

STATIC STABILITY (CON'T)

INCLINING EXPERIMENT PROCEDURE:

- A NUMBER OF WEIGHT SHIFTS ARE MADE.
- INCLINATION IS MEASURED BY MEASURING PENDULUM DEFLECTIONS AT SEVERAL LOCATIONS.
- A PLOT IS MADE OF wt VERSUS $\tan\phi$
- THE SLOPE OF THE PLOT, $\frac{\tan\phi}{wt}$ IS THEN MEASURED.
- THEN, $GM = \frac{wt}{\tan\phi} = \frac{1}{SLOPE}$.



RISE = .10

RUN = 500 FT-TONS

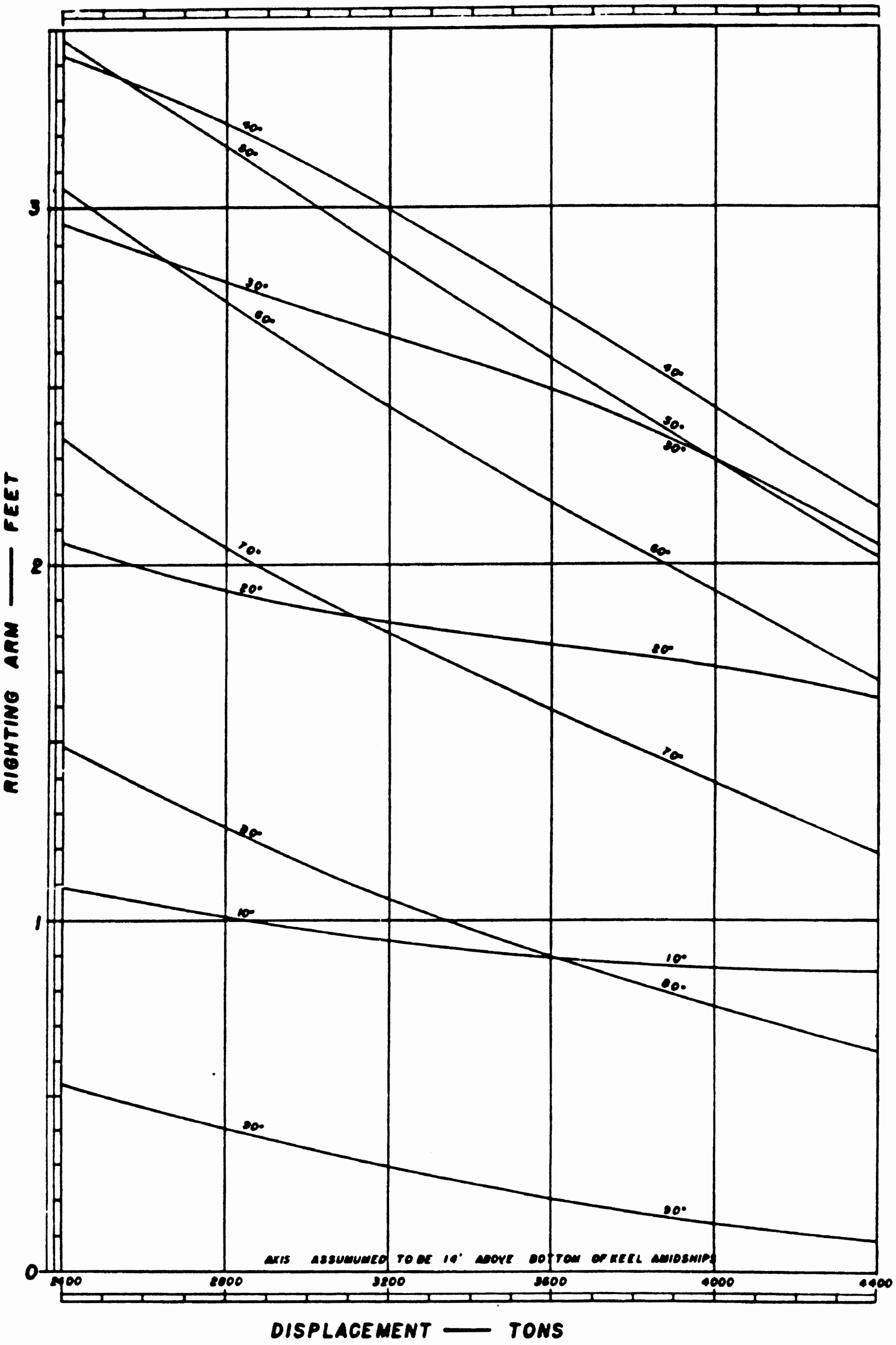
$\text{SLOPE} = \frac{\text{RISE}}{\text{RUN}} = \frac{.10}{500\ \text{FT-TONS}}$

$\text{SLOPE} = .00020\ \frac{1}{\text{FT TONS}}$

STATIC STABILITY (CON'T)

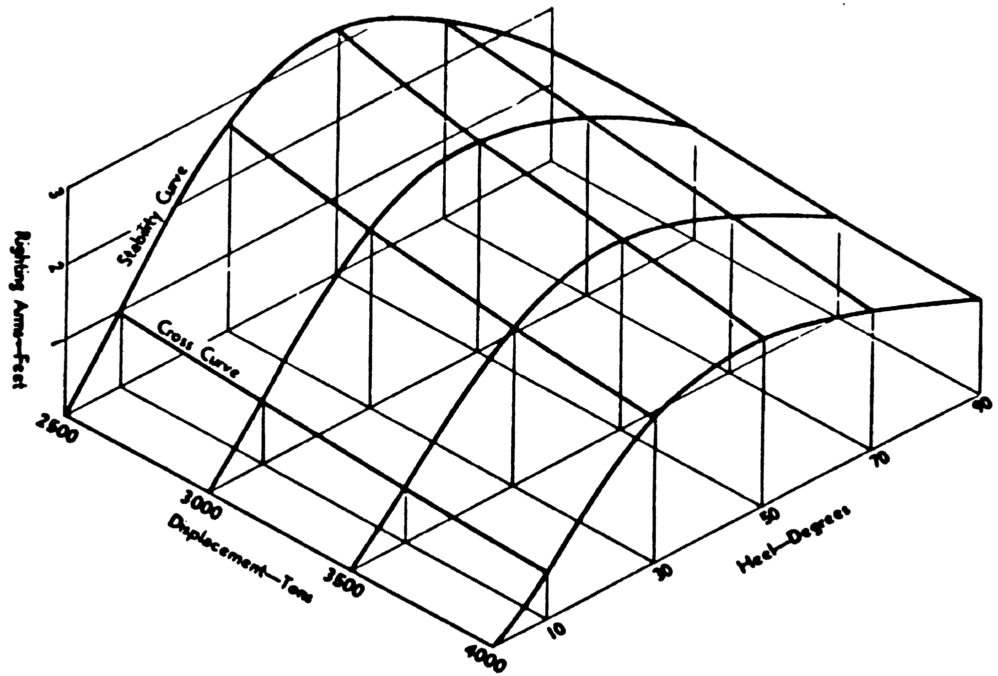
CROSS CURVES OF STABILITY

- CROSS CURVES ARE PLOTS OF GZ VERSUS DISPLACEMENT FOR VARIOUS ANGLES OF INCLINATION.
- READ MODERN SHIP DESIGN FOR DISCUSSION OF USE OF MECHANICAL INTEGRATOR, BUT-
- TODAY CROSS CURVES ARE ALWAYS GENERATED BY COMPUTER PROGRAM AT THE SAME TIME THE OTHER CURVES OF FORM ARE GENERATED


RIGHTING ARM —— FEET
0
1
2
3
40°
50°
30°
60°
70°
20°
80°
10°
90°
40°
50°
30°
60°
20°
70°
10°
80°
90°
AXIS ASSUMUMED TO BE 14' ABOVE BOTTOM OF KEEL AMIDSHIPS
2400
2800
3200
3600
4000
4400
DISPLACEMENT —— TONS

STATIC STABILITY (CON'T)

CROSS CURVES MAY BE VISUALIZED IN A THREE DIMENSIONAL VIEW



STATIC STABILITY (CON'T)

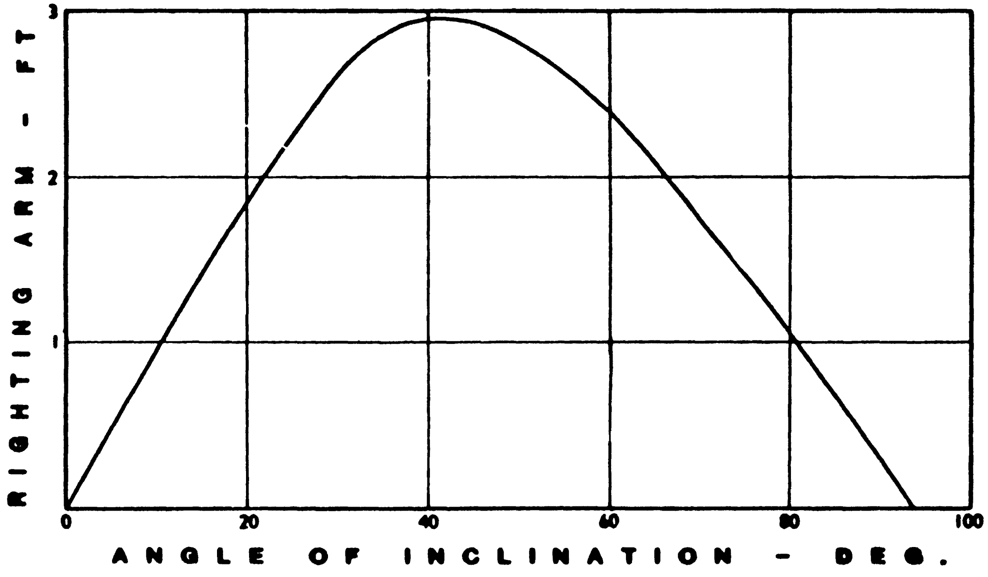
CROSS CURVES OF STABILITY

- ENTER CROSS CURVES WITH DISPLACEMENT. FIND GZ FOR VARIOUS ANGLES OF INCLINATION.
- CROSS CURVES ARE BASED ON AN ASSUMED KG (SOMETIMES CALLED THE AXIS OR THE POLE)
- THE VALUES OF GZ MUST BE CORRECTED FOR ACTUAL KG

STATIC STABILITY (CON'T)

THE STATIC STABILITY CURVE

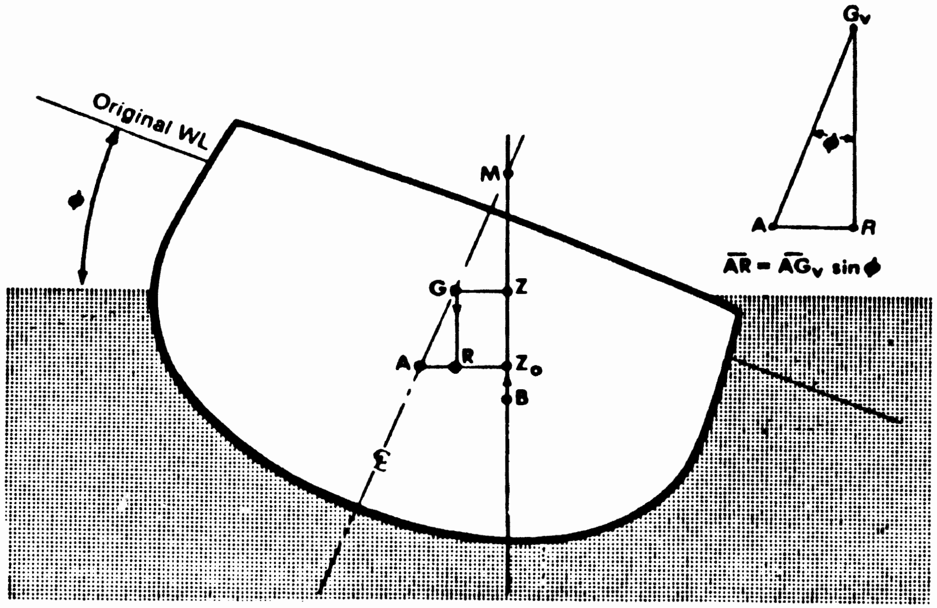
- WHEN THE VALUES OF GZ AND ϕ ARE OBTAINED FROM THE CROSS CURVES THE RESULT IS THE UNCORRECTED STATIC STABILITY CURVE



STATIC STABILITY (CON'T)

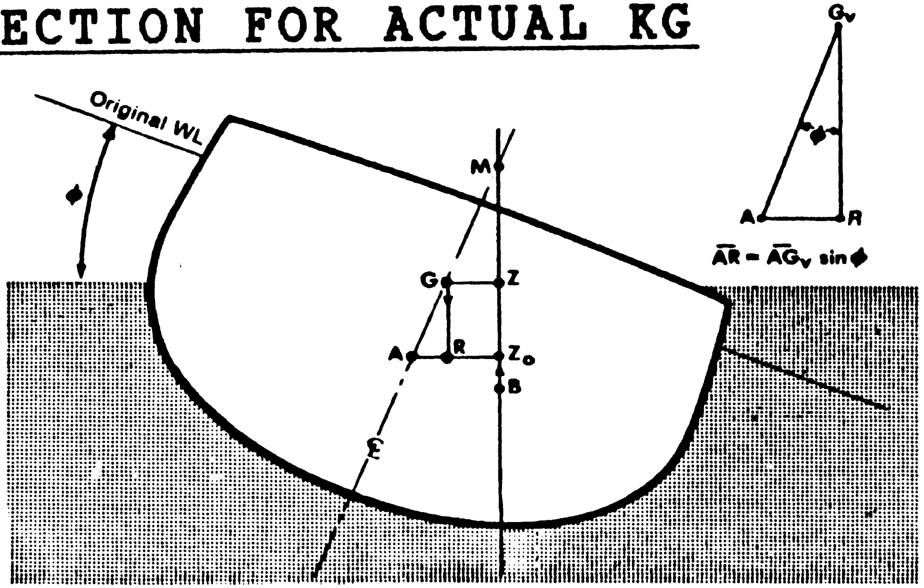
CORRECTION FOR ACTUAL KG

- THE ASSUMED KG IS AT A
- THE ACTUAL KG IS AT G
- THE VALUES READ FROM THE CROSS CURVES ARE AZ_O



STATIC STABILITY (CON'T)

CORRECTION FOR ACTUAL KG



$$GZ = AZ_o - AR$$

$$GZ = AZ_o - AG \sin \phi$$

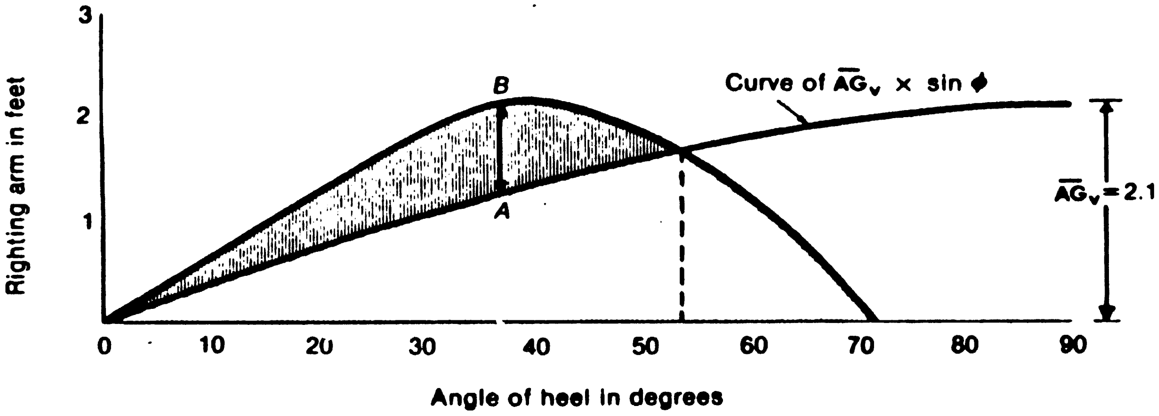
THUS THE CORRECTION TERM IS

$$AG \sin \phi$$

STATIC STABILITY (CON'T)

CORRECTION FOR ACTUAL KG

THE CORRECTED STATIC STABILITY CURVE IS THE DIFFERENCE BETWEEN THE UNCORRECTED CURVE AND SINE CURVE CORRECTION.



STATIC STABILITY (CON'T)

CORRECTION FOR ACTUAL KG

PROCEDURE

1. SUBTRACT ASSUMED KG (=KA) FROM ACTUAL KG

2. IF G IS HIGHER THAN A THE CORRECTION AT EACH ANGLE IS

   $- AG \sin \phi$

3. IF G IS BELOW A THE CORRECTION IS:

   $+ AG \sin \phi$

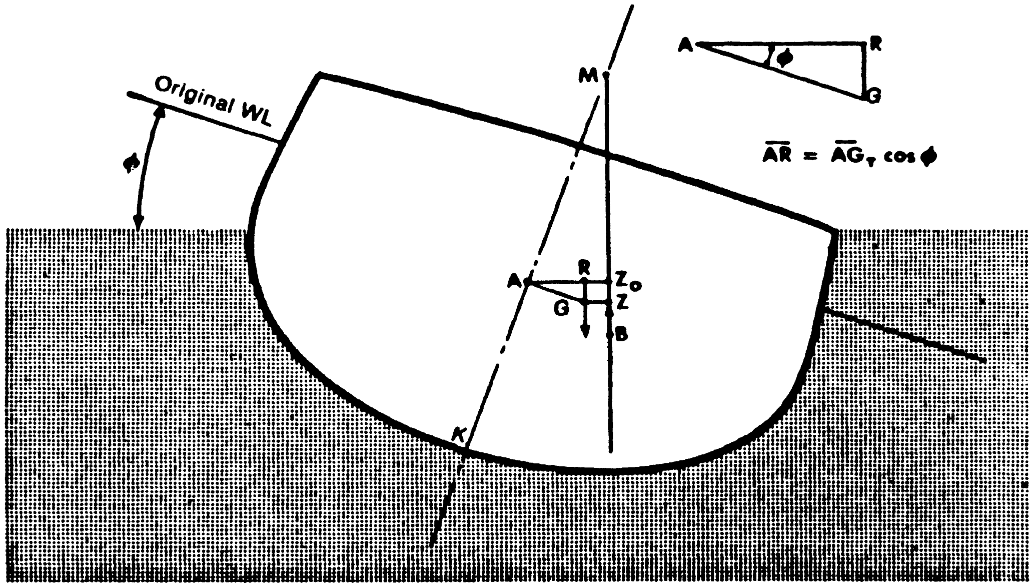
STATIC STABILITY (CON'T)

EFFECT OF TRANSVERSE SHIFT OF G:

- IF G IS OFF THE CENTERLINE, FOR EXAMPLE, DUE TO DAMAGE TO THE SHIP THERE WILL BE ANOTHER CORRECTION TO THE STATIC STABILITY CURVE

STATIC STABILITY (CON'T)

TRANSVERSE SHIFT OF G



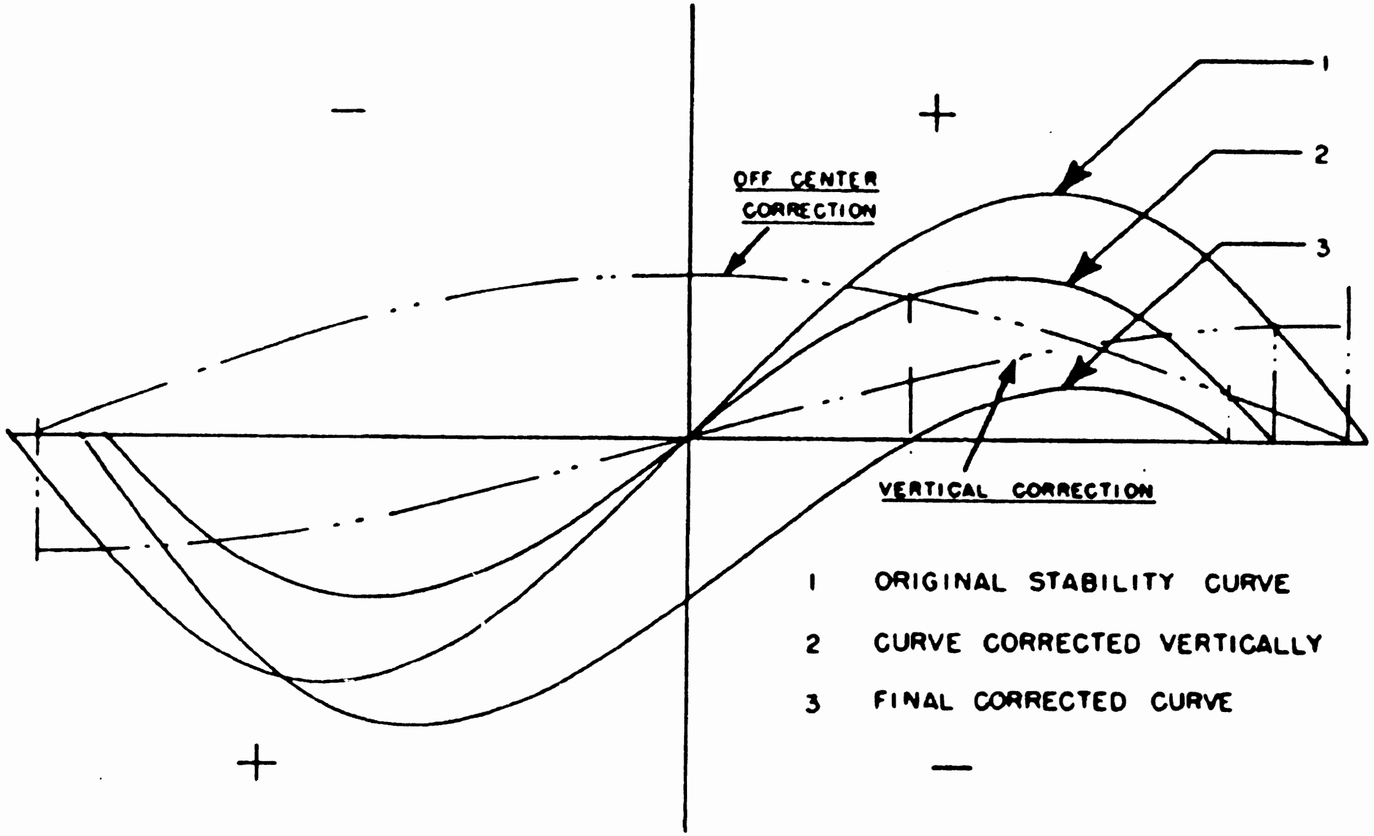
IN THIS CASE

$$GZ = AZ - AR$$

$$GZ = AZ - \underline{\underline{AG \cos \phi}}$$

STATIC STABILITY (CON'T)

FINAL CORRECTED CURVE



NOTE THAT THE TRANSVERSE CORRECTION IS <u>SUBTRACTED</u> ON THE SIDE TOWARD THE SHIFT AND <u>ADDED</u> ON THE SIDE AWAY FROM THE SHIFT.

STATIC STABILITY (CON'T)

GM FROM THE STATIC STABILITY CURVE

FOR SMALL ANGLES, $GZ = GM \sin\phi$

ALSO FOR SMALL ANGLES, $\sin\phi = \phi$ IN RADIANS

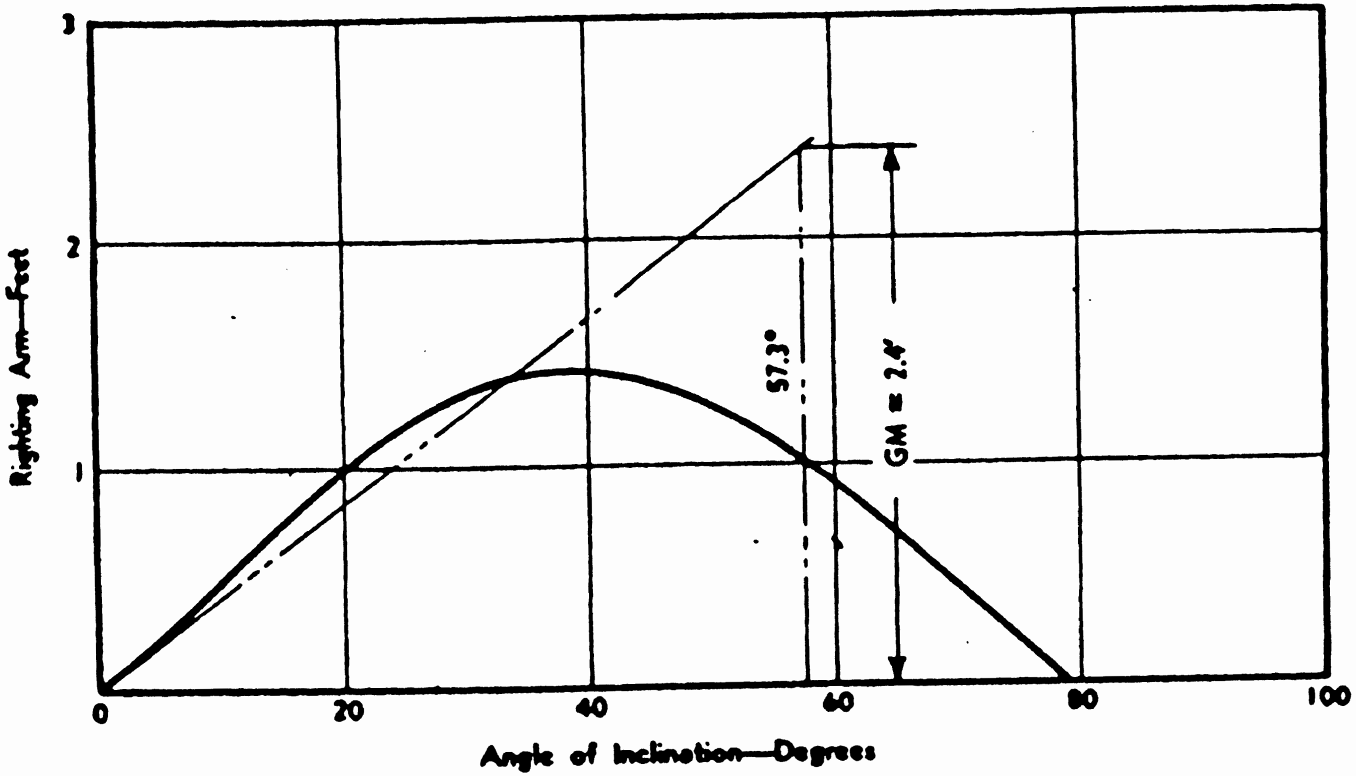
$\frac{GZ}{\phi} = \frac{RISE}{RUN}$ = SLOPE OF CURVE AT ORIGIN = $\frac{GM}{1}$

INTERPRETATION:

- PLOT TANGENT TO STABILITY CURVE AT ORIGIN
- READ $GM = GZ$ AT $\phi = 1$ RADIAN (1 RADIAN = 57.3°

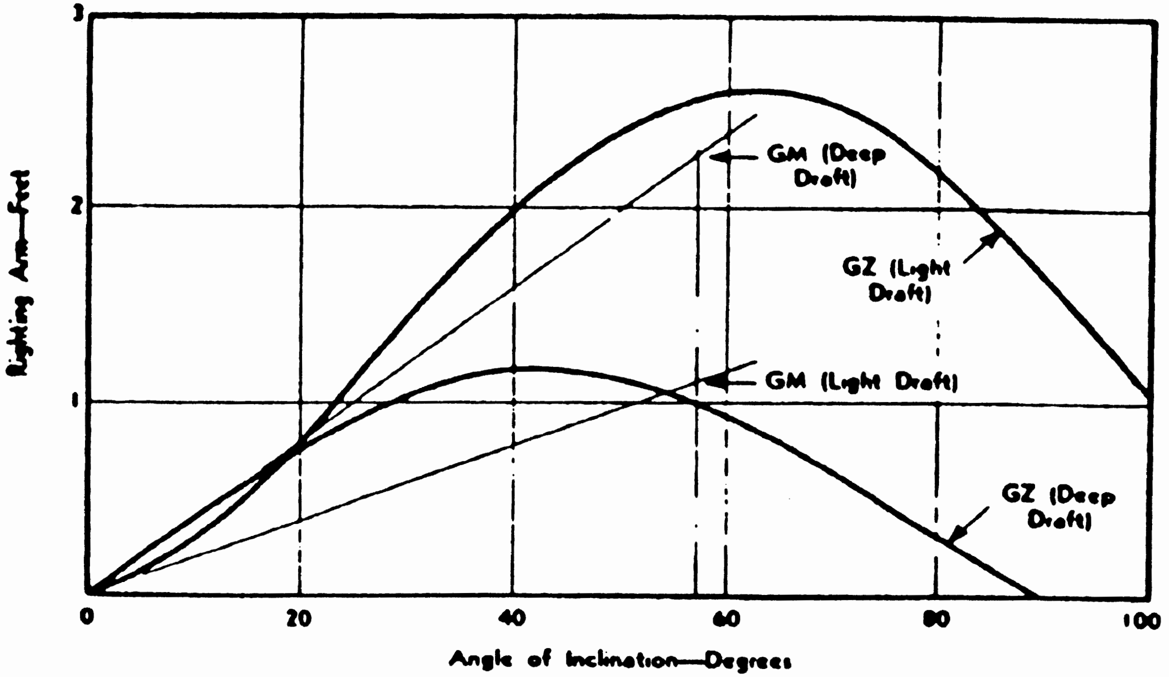
STATIC STABILITY (CON'T)

GM FROM THE STATIC STABILITY CURVE



STATIC STABILITY (CON'T)

HULL FORM EFFECTS



GZ CURVE LARGER AT LIGHT DRAFT THAN AT DEEP DRAFT, BUT

GM GREATER AT DEEP DRAFT THAN AT LIGHT DRAFT

BASIC NAVAL ARCHITECTURE

Problem 29

Problem Level: Basic

A rectangular barge is floating in salt water and has the following dimensions and drafts:

L_{pp} = 210'-0"

B = 48'-0"

D = 20'-0"

T_f = 12'-0"

T_a = 12'-0"

An inclining experiment is now conducted on the barge. Three twenty-ton weights initially on the centerline are shifted, first 20.00 ft. to port, then back to the centerline; then 20.00 ft. to starboard, then back to the centerline. A 100" long pendulum is used to measure the deflections.

The results are tabulated below:

Weight Position	Pendulum Deflection
℄	0.000
20.00' port	3.50" port
℄	0.000
20.00' stbd	3.50" stbd
℄	0.000

(1) On graph paper make a plot of Inclining Moment vs. Tangent of Angle of Inclination, both port and starboard.

(2) Compute GM_t from the plotted results

(3) Find KB and BM_t

(4) Find KG

BASIC NAVAL ARCHITECTURE

Problem 30

Problem Level: Basic

A rectangular barge is floating upright in salt water with no cargo on board.

L_{pp} = 175'-0"

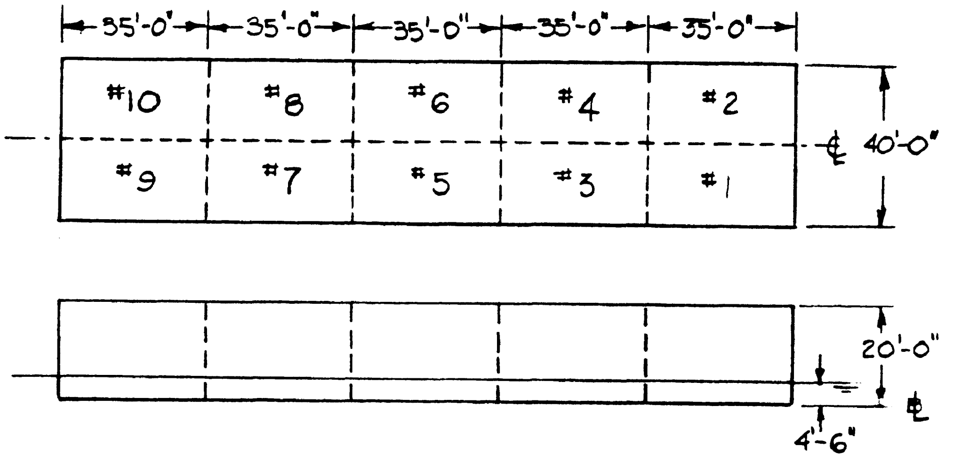
B = 40'-0"

T = 4'-6"

D = 20'=0"

KG = 10'-0"

Hold #5 is now filled with homogeneous cargo @ 140 ft^3/ton. Find the resulting Angle of list.



BASIC NAVAL ARCHITECTURE

Problem 31

Problem Level: Intermediate

The following specification for an early shipbuilding venture is cited:

> "Make thee an ark of gopher wood; rooms shalt thou make in the ark, and shalt pitch it within and without with pitch.
>
> And this is the fashion which thou shalt make it of: the length of the ark shall be three hundred cubits,* the breadth of it fifty cubits and the height of it thirty cubits.
>
> A window shalt thou make to the ark, and in a cubit shalt thou finish it above; and the door of the ark shalt thou set in the side thereof; with lower, second, and third stories shalt thou make it."
>
> (Genesis 6:14)

Assumptions

a) Assume that Noah constructed the ark in the form of a rectangular barge.

b) Assume that current Load Line Regulations for shelter deck ships would have represented good practice at that time. A freeboard-to-depth ratio of .40 may be taken.

c) For this type of construction and loading the height of the center of gravity is estimated to be located at 60% of the vessel's depth above the keel.

d) The ratio of the Light-ship weight to the Full Load Displacement for a wooden ship of this length is high because of the heavy structure involved. Take this ratio to be .40.

Find:

a) Full Load Displacement
b) Deadweight
c) Height of Center of Buoyancy
d) Metacentric Radius
e) Metacentric Height

Problem 31 (continued)

Problem Level: Intermediate

To examine the transverse stability of the ark assume the following weights initially distributed about the centerline have shifted to the extreme beam.

2 elephants @ 5 tons each
2 hippopotamuses @ 4 tons each
2 rhinoceroses @ 3 tons each
2 walruses @ 1 ton each
2 giraffes @ 1 ton each
2 yaks @ .5 ton each
2 horses @ .5 ton each
2 lions @ .25 ton each
2 tigers @ .25 each each

Miscellaneous 6.4 tons

Find:

f) The resulting angle of list.

* A cubit is unit of length = 18"

Problem 34

Problem Level: Intermediate

During a shipyard availability a DD692 (long hull) class destroyer is floating in *fresh* water with no list and at the following drafts:

$$T_f = 12'\text{-}6''$$

$$T_a = 11'\text{-}6''$$

In this condition the ship is inclined to measure KG. The Angles of inclination of the destroyer are measured by measuring the deflection of a pendulum 100" long. The destroyer is inclined, first to starboard then to port, by shifting a 39 ton weight through transverse distances of 10.00' and 20.00' off the centerline to each side. The data taken were:

Position of Weight	Deflection of Pendulum
℄	0.00"
10.00' stbd	4.80" stbd
20.00' stbd	10.20" stbd
℄	0.20" stbd
10.00' port	5.20" port
20.00' port	9.80" port
℄	0.20" port

Procedure

a) Compute the inclining moments, w x d, and the tangent of the angle of inclination:

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

b) Plot these values on the graph paper provided. Note that there is some experimental scatter in the data. With a straightedge draw the straight line which represents the best average of these points. Measure the slope of this average line.

Problem 34 (continued)

Problem Level: Intermediate

c) Solve the formula, $\frac{w \times d}{\Delta} = GM \tan \theta$, for GM.

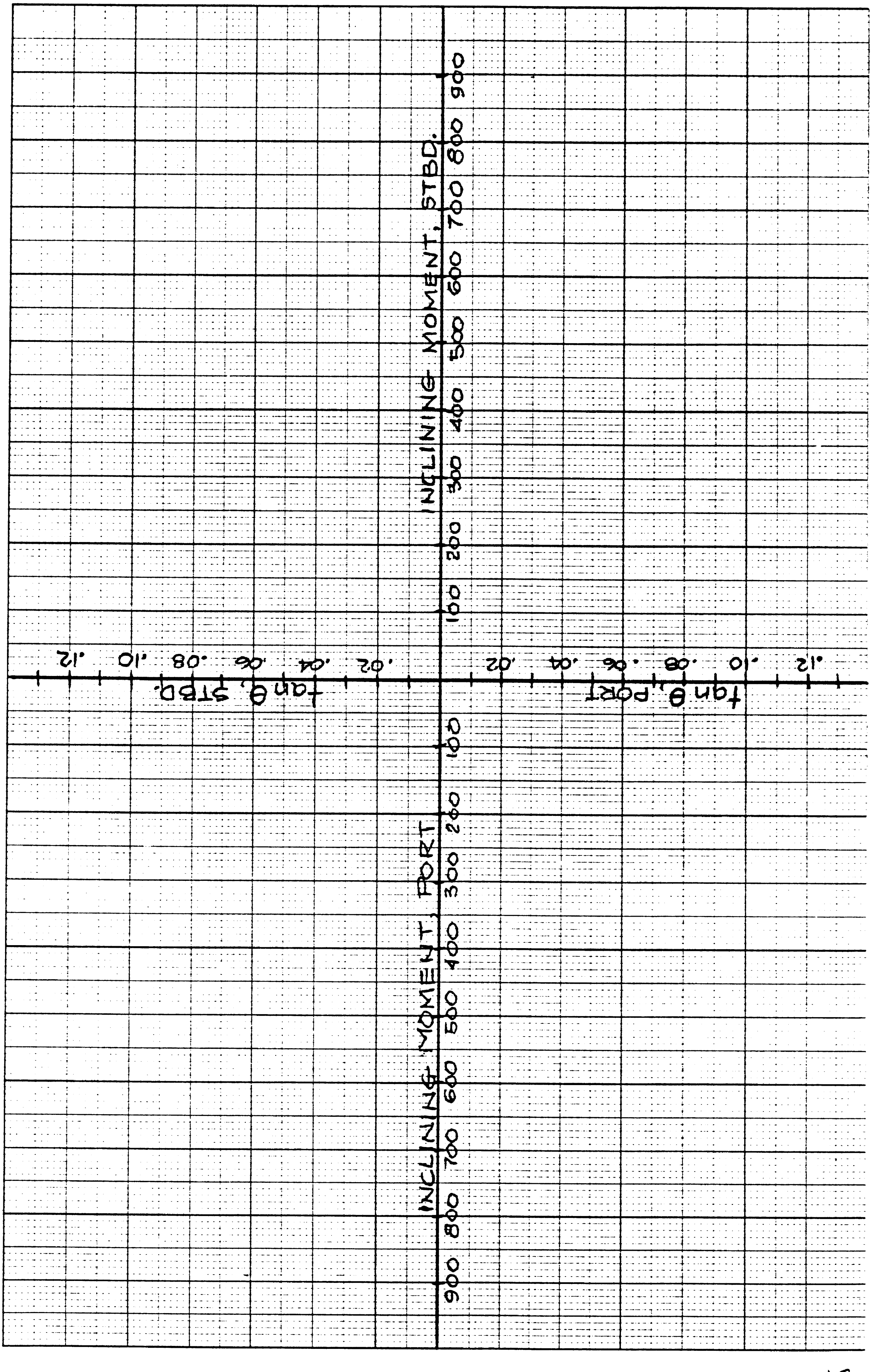
$$GM = \frac{w \times d}{\Delta \tan \theta} = \frac{1}{\Delta \times \text{slope}}$$

d) Find KG and LCG.

After completing the yard availability the ship fits out, fuels, and provisions for sea. The DCA keeps a record of all weight additions and deductions and their centers. The resultant of all these weight changes is:

Weight	Long'l Ctr.	Vert. Ctr.
+660 tons	34.00' aft ⊗	15.52' above K

e) Find the longitudinal and vertical location of the ship's center of gravity when ready for sea. Find the mean draft and GM in this condition.


INCLINING MOMENT, STBD.
100
200
300
400
500
600
700
800
900
tan θ, STBD.
.02
.04
.06
.08
.10
.12
tan θ, PORT
.02
.04
.06
.08
.10
.12
INCLINING MOMENT, PORT
100
200
300
400
500
600
700
800
900

REF: GILLMER, pp 58-60

CALCULATE DISPLACEMENT OF BARGE AS INCLINED.

$$\Delta = \frac{L \times B \times T \ \text{FT}^3}{35 \ \text{FT}^3/\text{TON}} = \frac{(\overset{6}{\cancel{210.0}})(48.0)(12.0)}{(\cancel{35.0})} \ ; \ \Delta = 3{,}456 \ \text{LT}$$

INCLINING DATA:

WEIGHT POSITION	INCLINING MOM'T FT-TONS	PENDULUM DEFL. IN.	$\tan\phi = \frac{\text{DEFL.}}{100''}$
℄	0.0	0.000	0.000
20.00' P	1200.0 P	3.50" P	0.035 P
℄	0.0	0.000	0.000
20.00 S	1200.0 S	3.50 S	0.035 S
℄	0.0	0.000	0.000

(1) NOTE: EITHER $\tan\phi$ CAN BE PLOTTED AS THE ORDINATE (AS ASSUMED IN GILLMER) OR, ALTERNATIVELY, INCLINING MOMENT CAN BE PLOTTED AS ORDINATE. IN THE FIRST CASE ~

$$\text{SLOPE} = \frac{\delta(\tan\phi)}{\delta(\text{INCL. MOM'T})}$$

IN THE SECOND CASE, AS PLOTTED ON PP 2,

$$\text{SLOPE} = \frac{\delta(\text{INCL. MOM'T})}{\delta(\tan\phi)}$$

IN THIS CASE ~

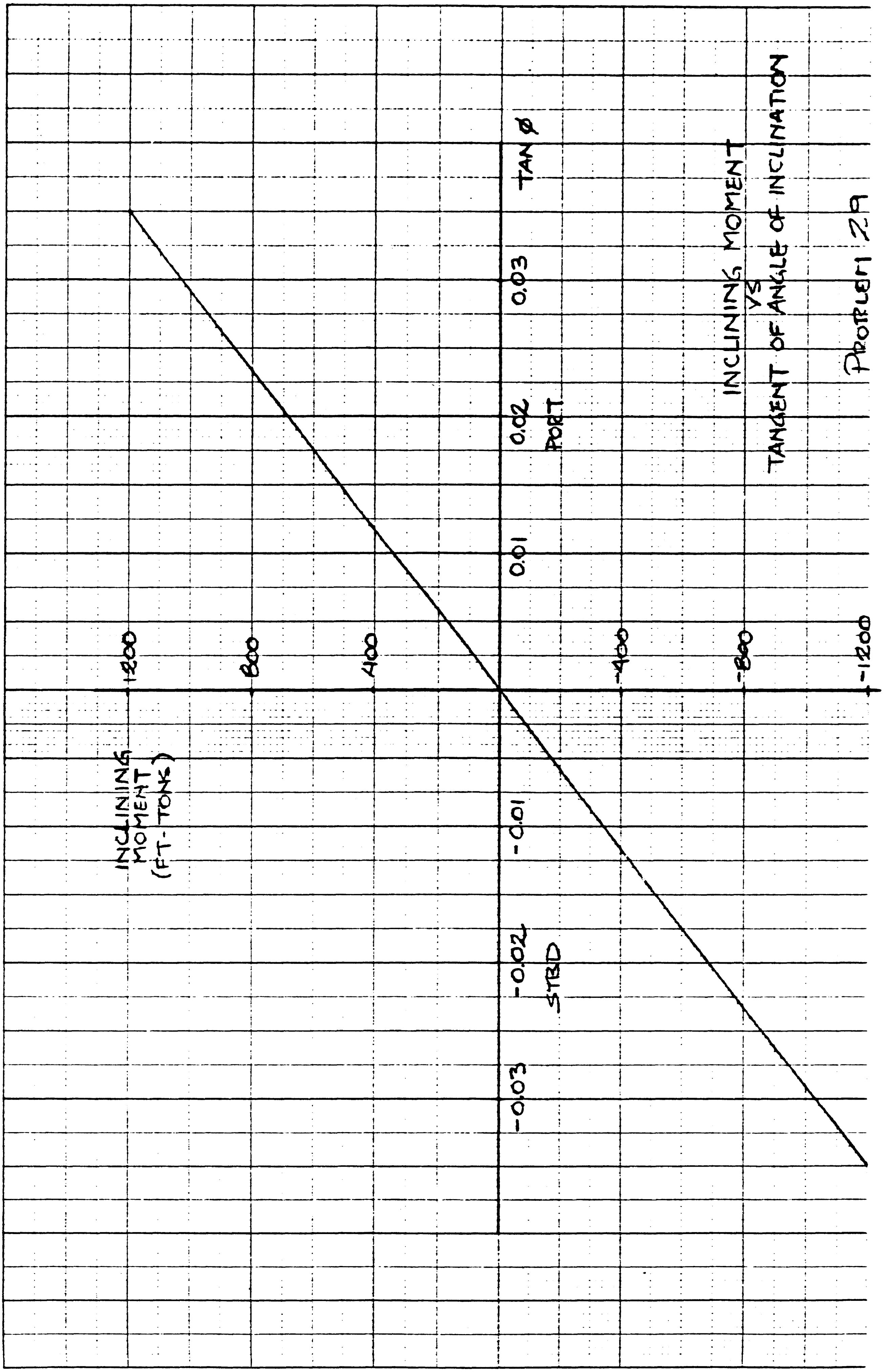
$$GM = \frac{wt}{\Delta \tan\phi} = \frac{\text{SLOPE}}{\Delta}$$

TAKE TWO POINTS ON THE STRAIGHT LINE TO DETERMINE THE SLOPE, SAY,

(1200.0 P, 0.035 P) AND (1200.0 S, 0.035 S)

$$\text{THEN, SLOPE} = \frac{2400.0 \ \text{FT-TONS}}{0.0700} = 34{,}286 \ \text{FT-TONS}$$

(2) AND, $GM_t = \frac{\text{SLOPE}}{\Delta} = \frac{34{,}286 \ \text{FT-TONS}}{3{,}456 \ \text{TONS}}$; $\boxed{GM_t = 9.92 \ \text{FT}}$



INCLINING MOMENT VS TANGENT OF ANGLE OF INCLINATION

PROBLEM 29

(CON'T)

(3) SINCE THE BARGE IS RECTANGULAR, $KB = \frac{T_m}{2}$,

$$KB = \frac{12.00'}{2} = 6.00' \text{ a ℄}$$

$$BM_t = \frac{B^3 L}{12\nabla} = \frac{\overset{4\cdot4}{\cancel{(48)}}{}^3\cancel{(210)}}{\cancel{(42)}\cancel{(210)}\cancel{(48)}\cancel{(12)}} = 16.00 \text{ FT}$$

$$\boxed{\begin{array}{l} KB = 6.00 \text{ FT a ℄} \\ BM_t = 16.00 \text{ FT} \end{array}}$$

(4)

$$\begin{array}{l} KB = 6.00 \text{ FT a ℄} \\ \underline{BM_t = 16.00 \text{ FT}} \\ KM_t = 22.00 \text{ FT a ℄} \\ \underline{GM_t = 9.92 \text{ FT}} \\ KG = 12.08 \text{ FT a ℄} \end{array}$$

$$\boxed{KG = 12.08 \text{ FT a ℄}}$$

(1) FIND INITIAL CONDITIONS OF THE BARGE.

$$\Delta_0 = \frac{L \times B \times T \ \text{FT}^3}{35 \ \text{FT}^3/\text{TON}} = \frac{(\overset{5.0}{\cancel{175.0}})(40.0)(4.50)}{(\cancel{35.0})} \frac{\text{FT}^3}{\text{FT}^3/\text{TON}}$$

$$\Delta_0 = 900 \ \text{LT}$$

$$KB_0 = 2.25 \ \text{FT a ℄}$$

$$KG_0 = 10.00 \ \text{FT a ℄}$$

(2) FIND WEIGHT OF CARGO ADDED.

$$w = \frac{(\cancel{35.0})(\overset{5}{\cancel{20.0}})(20.0) \ \text{FT}^3}{(\underset{4}{\cancel{140.0}}) \ \text{FT}^3/\text{TON}} = 100 \ \text{LT}$$

THE CG OF THE CARGO WILL BE 10.00 FT S. AND 10.00 FT a ℄.

ITEM	WEIGHT LT	VCG FT a ℄	MOM'T FT-TONS
ORIGINAL BARGE	900.0	10.00	9,000
CARGO	100.0	10.00	1,000
BARGE W/ CARGO	1,000	10.00	10,000

THE NEW MEAN DRAFT WILL BE, $T_{m_1} = \frac{35\,\Delta_1}{L \times B}$

$$T_{m_1} = \frac{(\cancel{35.0})(\overset{5.0}{\cancel{1000.0}})}{(\underset{5.0}{\cancel{175.0}})(\cancel{40.0})} = 5.0$$

AND $KB_1 = \frac{T_{m_1}}{2} = \quad 2.50 \ \text{FT a ℄}$

$$BM_{t_1} = \frac{B^3 L}{12 \nabla_1} = \frac{B^3 L}{12 LBT_1} = \frac{B^2}{12 T_1} = \frac{(40)^2}{(12)(5)}$$

$$BM_{t_1} = \quad = 26.67 \ \text{FT.}$$

(CON'T)

$$KB_1 = 2.50 \text{ FT a. BL}$$

$$BM_{t_1} = 26.67 \text{ FT}$$

$$KM_{t_1} = 29.17 \text{ FT a BL}$$

$$KG_1 = 10.00 \text{ FT a BL}$$

$$GM_{t_1} = 19.17 \text{ FT.}$$

THINK OF THE ADDED CARGO BEING ADDED ON THE ℄, THEN SHIFTED 10.00 FT TO STBD.

$$GM \tan\theta = \frac{w \cdot t}{\Delta}$$

HERE, $GM = GM_{t_1} = 19.17$ FT

$w = 100.0$ LT

$t = 10.0$ FT S

$\Delta = 1000.0$ LT

$$\tan\theta = \frac{(100.0 \text{ LT})(10.00 \text{ FT})}{(19.17 \text{ FT})(1000.0 \text{ LT})}$$

$$\tan\theta = .0522$$

$$\theta = 2.9866^\circ \simeq 3.0^\circ$$

$$\boxed{\text{ANGLE OF LIST, } \theta = 3.0^\circ}$$

NOAH'S ARK PROBLEM

NOTE: A CUBIT, TRADITIONALLY, IS THE DISTANCE FROM THE ELBOW OF THE RIGHT ARM TO THE TIP OF THE LONGEST FINGER, USUALLY TAKEN AS 18".

$$1 \text{ CUBIT} = 18'' = 1.50 \text{ FT.}$$

THEN,

$$L_{PP} = 300 \text{ CUBITS} \times 1.50 \frac{\text{FT}}{\text{CUBIT}}$$

$$L_{PP} = 450.0 \text{ FT}$$

$$B = 50 \text{ CUBITS} \times 1.50 \frac{\text{FT}}{\text{CUBIT}}$$

$$B = 75.0 \text{ FT.}$$

$$D = 30 \text{ CUBITS} \times 1.50 \frac{\text{FT}}{\text{CUBIT}}$$

$$D = 45.0 \text{ FT}$$

$$\frac{FBD}{D} = .40$$

$$FBD = .40 \times 45.0 = 18.0 \text{ FT}$$

$$T_M = D - FBD = 45.0 - 18.0$$

$$T_M = 27.0 \text{ FT.}$$

FOR A RECTANGULAR BARGE, $KB = \frac{T}{2}$,

$$KB = 13.50 \text{ FT a } ℄.$$

$$KG = .60 D = .60 \times 45.0$$

$$KG = 27.00 \text{ FT a } ℄.$$

(a) $$\Delta_{fl} = \frac{L \times B \times T_M \text{ FT}^3}{35 \text{ FT}^3/\text{TON}} = \frac{(450.0)(75.0)(27.0)}{(35.0)} \frac{\text{FT}^3}{\text{FT}^3/\text{TON}}$$

$$\Delta_{fl} = 26{,}036 \text{ LT}$$

$$\Delta_{ls} = .40 \times 26{,}036 \text{ LT}$$

$$\Delta_{ls} = 10{,}414 \text{ LT}$$

(b) $$DWT = \Delta_{fl} - \Delta_{ls} = 15{,}622 \text{ LT}$$

$$\boxed{\begin{array}{l} \Delta_{fl} = 26{,}036 \text{ LT} \\ DWT = 15{,}622 \text{ LT} \end{array}}$$

NOAH'S ARK PROBLEM (CONT)

(c) $KB = 13.50$ FT a℄

$\boxed{KB = 13.50 \text{ FT a℄}}$

$$BM_t = \frac{B^3 L}{12 LBT} = \frac{B^2}{12T} \approx \frac{(75.0)^2}{(12)(27.0)}$$

(d) $BM_t = 17.36$ FT

METACENTRIC RADIUS, $BM_t = 17.36$ FT

$KM_t = 30.86$ FT a.℄

$KG = 27.00$ FT a.℄

(e) $GM_t = 3.86$ FT

METACENTRIC HEIGHT, $GM_t = 3.86$ FT

NEXT, FIND THE EFFECT OF TRANSVERSE WEIGHT SHIFTS. ASSUME ALL ITEMS SHIFTED THROUGH A DISTANCE OF $B/2 = 37.50$ FT.

ITEM	NO.	UNIT WEIGHT LT	WEIGHT LT	TRANSVERSE MOMENT FT-TONS
ELEPHANTS	2	5.0	10.0	375.0
HIPPOPOTAMUSES	2	4.0	8.0	300.0
RHINOCEROSES	2	3.0	6.0	225.0
WALRUSES	2	1.0	2.0	75.0
GIRAFFES	2	1.0	2.0	75.0
YAKS	2	0.5	1.0	37.5
HORSES	2	0.5	1.0	37.5
LIONS	2	0.25	0.5	18.8
TIGERS	2	0.25	0.5	18.8
MISCELLANEOUS			6.4	240.0
			$\Sigma = 37.4$	$\Sigma = 1402.6$

(f) FIND ANGLE OF LIST.

$GM_t = 3.86'$

$wt = 1402.6$ FT-TONS

$\Delta = 26{,}036$ LT

$$GM_t \tan\theta = \frac{wt}{\Delta}$$

$$\tan\theta = \frac{(1402.6 \text{ FT-TONS})}{(3.86 \text{ FT})(26036 \text{ LT})}; \quad \tan\theta = .0140$$

$$\theta = 0.80^\circ$$

ANGLE OF LIST, $\theta = 0.8^\circ$

(1) FIND THE DISPLACEMENT

$$T_f = 12'-6''$$
$$T_a = 11'-6''$$
$$T_M = 12'-0''$$

AT $T_M = 12'-0''$, $\Delta_{L.T} = 2680$ LT (WATER)

$CH\Delta I'TA$ = 965 TONS × $\frac{2 \text{ TONS}}{100 \text{ TONS}}$ = 19.3 LT/FT TRIM

$\Delta_{LT.SW} =$ = 2680 LT

CORRECTION FOR 1.0 FT TRIM BY BOW = -19.3 LT = -19 LT

$\Delta_{SW} =$ = 2661 LT

IN FRESH WATER, $\Delta_{FW} = 2661 \text{ LT} \times \frac{35 \text{ FT}^3/\text{TON}}{35.9 \text{ FT}^3/\text{TON}}$

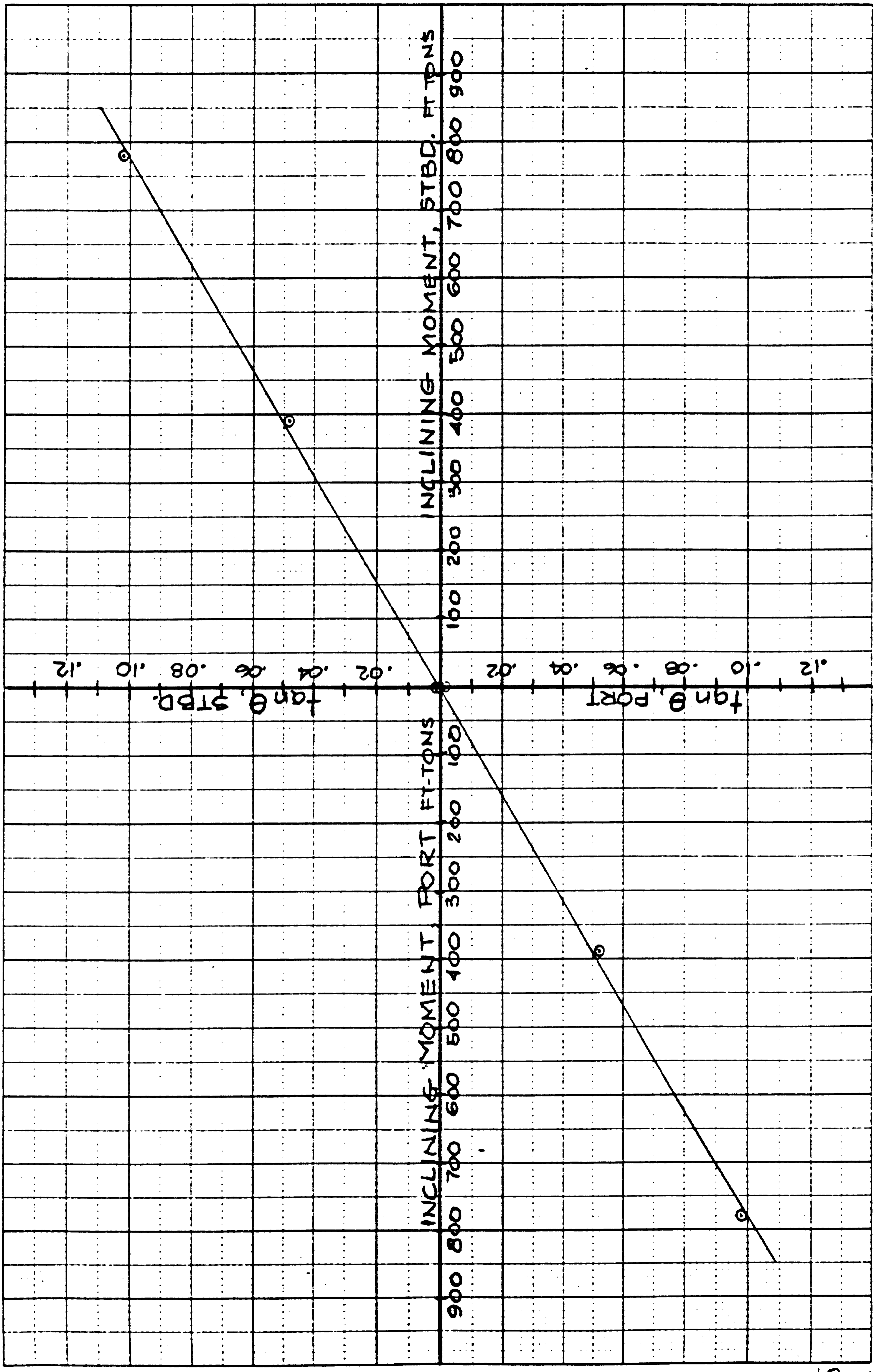
$\Delta_{FW} = 2594$ LT

(a)

POSITION OF WEIGHT	MOM'T FT-TONS	DEFL. OF PEND, IN	tan θ
℄	0	0.00"	0.00
10.00' STBD	390 STBD	4.80" STBD	0.048 S
20.00' STBD	780 STBD	10.20" STBD	0.102 S
℄	0	0.20" STBD	0.002 S
10.00' PORT	390 PORT	5.20" PORT	0.052 P
20.00' PORT	780 PORT	9.80" PORT	0.098 P
℄	0	0.20" PORT	0.002 P

(b) SEE PAGE 2 FOR PLOT OF INCLINING DATA.

PROBLEM 34 TDK/PRVMJR 14 FEB 87 2 of 6



(CON'T)

(c) TO FIND THE SLOPE, PICK A PAIR OF POINTS ON THE FAIRED LINE, SAY ~

(700 S, .090 S) AND (700 P, .090 P)

THEN, $\text{SLOPE} = \dfrac{\tan\theta \text{ INTERCEPT}}{\text{MOMENT INTERCEPT}}$

$$= \frac{.090 + .090}{700 + 700} \frac{1}{\text{FT-TONS}}$$

$$\text{SLOPE} = 0.0001286 \frac{1}{\text{FT-TONS}}$$

$$GM_t = \frac{w \times t}{\Delta \tan\theta} = \frac{1}{(\Delta)\left(\frac{\tan\theta}{\text{MOM'T}}\right)} = \frac{1}{(\Delta)(\text{SLOPE})}$$

$$= \frac{1}{(2594 \text{ LT})(0.0001286 \frac{1}{\text{FT-TONS}})}$$

$$GM_t = 2.9977 = 3.00 \text{ FT.}$$

(d) FROM CURVE 10, "TRANSVERSE METACENTER ABOVE BOTTOM OF KEEL AMIDSHIPS, SCALE 100 TONS = 2 FT",

AT $T_M = 12'\text{-}0''$, $KM_t = 998 \text{ LT} \cdot \dfrac{2 \text{ FT}}{100 \text{ TONS}} = 19.96$ FT a K.

$$KM_t = 19.96 \text{ FT a. K}$$

$$\underline{GM_t = 3.00 \text{ FT}}$$

$$KG = 16.96 \text{ FT a K}$$

$$\boxed{KG = 16.96 \text{ FT a K}}$$

FROM CURVES OF FORM AT $T_M = 12'\text{-}0''$

$$LCG_{\text{LEVEL TRIM}} = LCB_{\text{LEVEL TRIM}} = 275 \text{ TONS} \times \frac{2 \text{ FT}}{100 \text{ TONS}}$$

$$LCG_{L.T.} = 5.50 \text{ FT AFT } ⊗$$

$$MT1'' = 610 \text{ TONS} \times \frac{100 \text{ FT TONS}}{100 \text{ TONS}}$$

$$MT1'' = 610 \text{ FT-TONS/INCH OF TRIM}$$

(CON'T)

$$\text{TRIMMING MOMENT} = 610 \frac{\text{FT-TONS}}{\text{IN}} \times 12 \text{ IN.}$$

$$\text{T.M.} = 7320 \text{ FT-TONS}$$

$$GG_1 = \frac{\text{TRIMMING MOM'T}}{\Delta} = \frac{7320 \text{ FT-TONS}}{2594 \text{ LT}}$$

$$GG_1 = 2.82 \text{ FT (FWD)}$$

NOTE THAT CG SHIFTS FORWARD SINCE TRIM IS BOW DOWN.

$$LCG_{L.T} = 5.50 \text{ FT a. ⊗}$$

$$\underline{GG_1 = 2.82 \text{ FT (FWD)}}$$

$$LCG_1 = 2.68 \text{ FT a ⊗}$$

$$\boxed{LCG_1 = 2.68 \text{ FT a ⊗}}$$

(e) FIND MEAN DRAFT AND GM READY FOR SEA

ITEM	WT LT	VCG FT a. K	V. MOM'T FT-TONS	LCG FT a. ⊗	L. MOM'T FT-TONS
SHIP AS INCLINED	2594	16.96	43,994	2.68 A	6,952 A
WEIGHT CHANGES	+ 660	15.52	10,243	34.00 A	22,440 A
SHIP READY FOR SEA	3254	16.67	54,237	9.03 A	29,392 A

FROM CURVE 2, $(\Delta_{F.W})$ AT $\Delta_{FW} = 3254 \text{ LT}$, $T_m = 14'\text{-}0''$

AT $T_m = 14'\text{-}0''$, $LCG_{L.T.} = LCB_{L.T} = 445 \text{ TONS} \times \frac{2 \text{ FT}}{100 \text{ TON}}$

$$LCG_{L.T} = 8.90 \text{ FT a. ⊗}$$

$$\text{ACTUAL } \underline{LCG_1 = 9.03 \text{ FT a ⊗}}$$

$$\text{TRIMMING LEVER} = 0.13 \text{ FT (AFT)}$$

$$\text{TRIMMING MOM'T} = \text{TRIM LVR} \times \Delta = 0.13 \text{ FT} \times 3254 \text{ LT}$$

(CON'T)

TRIMMING MOM'T = 423 FT-TONS

FROM CURVE 12 AT $T_m = 14'-0"$, $MT1" = 640 \text{ TONS} \times \frac{100 \text{ FT-TONS}}{100 \text{ TONS}}$

$MT1" = 640$ FT-TONS/INCH OF TRIM

$$\text{TRIM} = \frac{\text{TRIMMING MOM'T}}{MT1"} = \frac{423 \text{ FT-TONS}}{640 \frac{\text{FT-TONS}}{\text{IN}}}$$

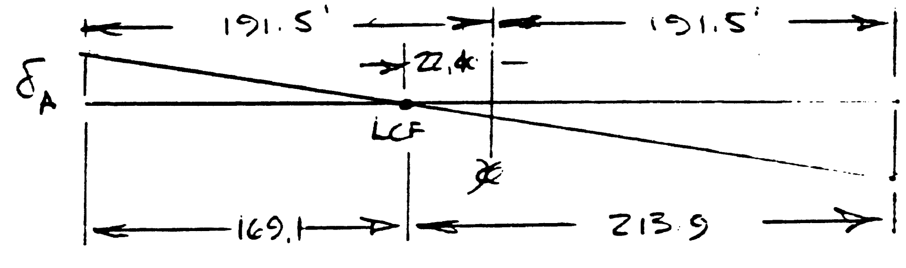
TRIM = 0.66 INCHES (DOWN BY THE STERN)

FOR SMALL TRIMS, SUCH AS THIS, IT IS SUFFICIENTLY ACCURATE TO TAKE HALF THE TOTAL TRIM AND PUT IT AT THE BOW AND HALF AT THE STERN. HOWEVER, FOR THE PURPOSES OF ILLUSTRATION, WE WILL FORMALLY PROPORTION THE TRIM ACCORDING TO THE DISTANCES FROM THE LCF.

THE LCF CURVE IS CURVE 6 AND, UNFORTUNATELY, IS MARKED "CENTER OF GRAVITY OF WATERPLANE AFT OF STATION 10 (M.P.), SCALE 100 TONS = 2 FT"

AT $T_m = 14'-0"$, $LCF = 1120 \text{ TONS} \times \frac{2 \text{ FT}}{100 \text{ TONS}}$ a ⊗

LCF = 22.40 FT a. ⊗.



(1) $$\frac{\delta_A}{169.1} = \frac{\delta_F}{213.9}$$

$$\delta_A = \frac{169.1}{213.9}\delta_F = 0.79\,\delta_F$$

(2) $$\delta_A + \delta_F = 0.66"$$

$$0.79\,\delta_F + \delta_F = 0.66"$$

$$\delta_F = 0.37" \approx 3/8"$$

$$\delta_A = 0.29" \approx 1/4"$$

(CON'T)

$$\begin{array}{lcr} T_{M_1} & = & 14'\text{-}0'' \\ \delta_A & = & +\tfrac{1}{4}'' \\ \hline T_{A_1} & = & 14'\text{-}0\tfrac{1}{4}'' \end{array} \qquad \begin{array}{lcr} T_{M_1} & = & 14'\text{-}0'' \\ \delta_F & = & -\tfrac{3}{8}'' \\ \hline T_{F_1} & = & 13'\text{-}11\tfrac{5}{8}'' \end{array}$$

(NOTE THAT T_M IS WITHIN $\tfrac{1}{8}''$ OF $14'\text{-}0''$)

TO FIND GM_t IN THE READY FOR SEA CONDITION WE NEED KM_t FROM CURVE 10,

AT $T_M = 14'\text{-}0''$, $KM_t = 960 \text{ TONS} \times \dfrac{2 \text{ TONS}}{100 \text{ TONS}}$

$$\begin{array}{lcl} KM_t & = & 19.20 \text{ FT a K.} \\ KG_1 & = & 16.67 \text{ FT a K.} \\ \hline G_1M_t & = & 2.53 \text{ FT} \end{array}$$

(e) RECAP:

$$\boxed{\begin{array}{l} LCG_1 = 9.03 \text{ FT a } \otimes \\ KG_1 = 16.67 \text{ FT a K} \\ T_{A_1} = 14'\text{-}0\tfrac{1}{4}'' \\ T_{F_1} = 13'\text{-}11\tfrac{5}{8}'' \\ G_1M_t = 2.53 \text{ FT} \end{array}}$$

BASIC NAVAL ARCHITECTURE

Unit Number: 13

Title: The ship at rest - static stability - 3

Tape Running Time: 27^M 13^S

Reading Assignment: MSD, pp 68-70

Additional References: PNA, pp 95-96, 99-103

Scope:

The study of static stability is continued. The implications of negative GM and "lolling" are discussed.

Key Points to Emphasize:

1. Discuss the meaning of negative GM in terms of its effect on the Static Stability Curve. Explain Figures 3-17, 3-18 and 3-19, MSD, pp 67.
2. Go over the longitudinal weight shift example and explain the method of similar triangles to distribute the changes in draft fore and aft.
3. Review method for calculating effect of small weight additions on trim and list.

Suggested Problem Assignment: one of 27, 28, 32, one of 35, 36, 37, 38

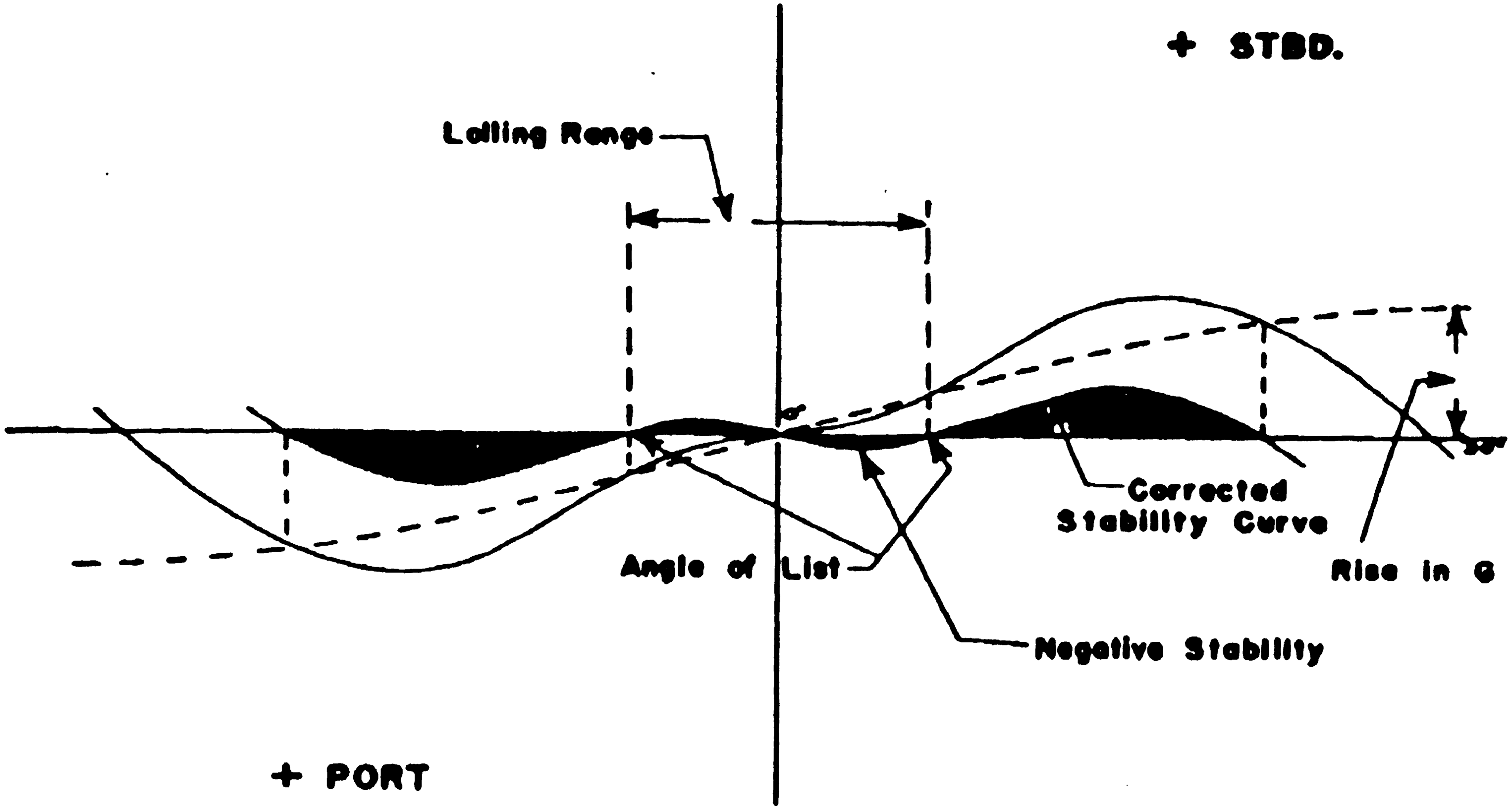
STATIC STABILITY (CON'T)

NEGATIVE GM

- A RISE IN G MAY CAUSE NEGATIVE GM.
- SINCE GZ = GM sin ϕ AT SMALL ANGLES, GZ IS ALSO NEGATIVE.
- MAY NOT BE FATAL IF GZ BECOMES POSITIVE AGAIN AS ANGLE, ϕ , INCREASES.
- THE EFFECT IS KNOWN AS LOLLING. SHIP FLOPS BACK AND FORTH IN RESPONSE TO SMALL WIND OR WAVE EXITATIONS.

STATIC STABILITY (CON'T)

NEGATIVE GM



STATIC STABILITY (CON'T)

LONGITUDINAL WEIGHT SHIFT EXAMPLE

A DD 692 DESTROYER IS IN SALT WATER AT THE FOLLOWING DRAFTS:

$T_f = 13' - 9"$

$T_a = 13' - 9"$

100 TONS OF FUEL OIL ARE SHIFTED FORWARD THROUGH A DISTANCE OF 38.10 FEET. FIND THE NEW DRAFTS.

STATIC STABILITY (CON'T)

LONGITUDINAL WEIGHT SHIFT EXAMPLE

SOLUTION: AT A MEAN DRAFT OF

$$T_m = 13' - 9''$$

FIND MOMENT TO CHANGE TRIM ONE INCH (CURVE 12)

$$MTI = 635 \text{ TONS} \times \frac{100 \text{ FT-TONS}}{100 \text{ TONS}}$$

$$MTI = 635 \text{ FT-TONS PER INCH OF TRIM}$$

THE TRIMMING MOMENT IS

$$w\ell = 100 \text{TONS} \times 38.10 \text{FT} = 3{,}810 \text{ FT-TONS}$$

STATIC STABILITY (CON'T)

LONGITUDINAL WEIGHT SHIFT EXAMPLE

SOLUTION (CON'T)

THE CHANGE IN TRIM WILL BE:

$$\delta \text{TRIM} = \frac{\omega \ell}{\text{MT1}}$$

$$\delta \text{TRIM} = \frac{3{,}810 \text{ FT-TONS}}{635 \text{ FT-TONS/IN}}$$

δ TRIM = 6.0 IN DOWN BY THE BOW.

STATIC STABILITY (CON'T)

LONGITUDINAL WEIGHT SHIFT EXAMPLE

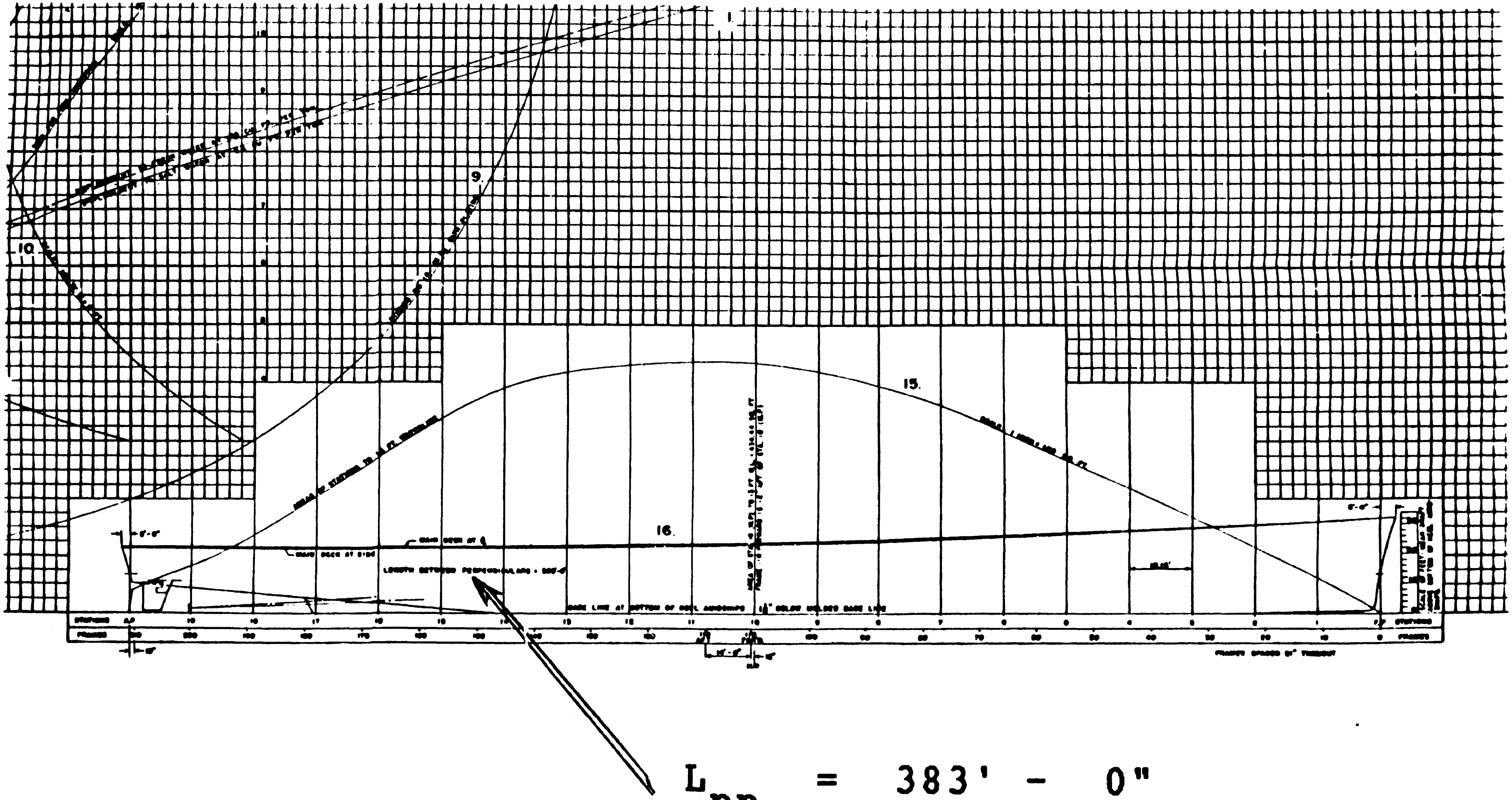
SOLUTION (CON'T)

THE SHIP TRIMS ABOUT THE LCF. TO FIND THE LCF LOOK AT CURVE 6, "CENTER OF GRAVITY OF WATERPLANE AFT OF STA 10 (M.P.)"

AT $T_m = 13'-9''$,

$$LCF = 1{,}122\,TONS \times \frac{2\,FT}{100\,TONS}$$

$$LCF = 22.44\ FT\ AFT\ OF\ STA\ 10$$


9.
10.
15.
16.
MAIN DECK AT ℄
MAIN DECK AT SIDE
LENGTH BETWEEN PERPENDICULARS
BASE LINE AT BOTTOM OF KEEL AMIDSHIPS
STATIONS
FRAMES
A.P
F.P
FRAMES SPACED
THROUGHOUT

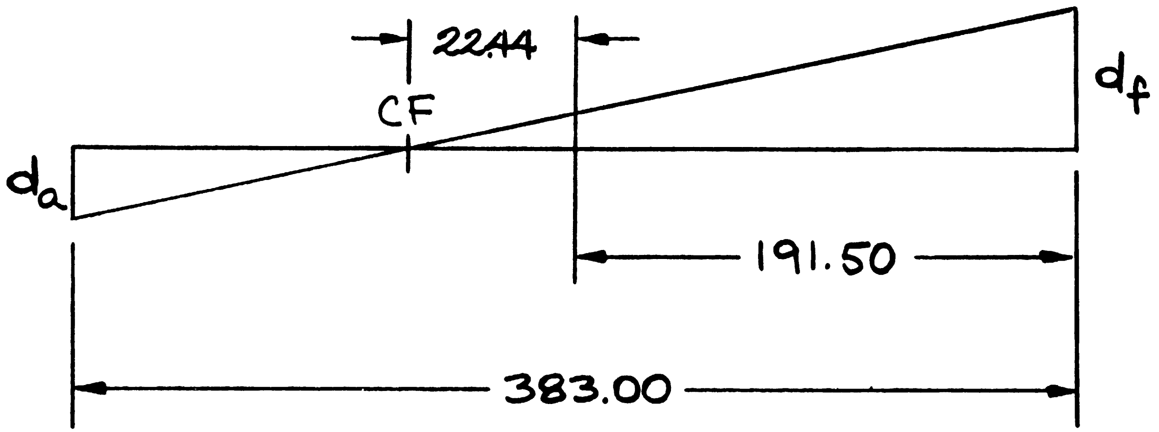
$L_{pp} = 383' - 0"$

STATIC STABILITY (CON'T)

LONGITUDINAL WEIGHT SHIFT EXAMPLE

SOLUTION (CON'T)

THE CHANGE OF TRIM DIAGRAM IS -



BY SIMILAR TRIANGLES

$$d_f = \frac{(\delta \text{ TRIM})(\text{DISTANCE FROM STA 0})}{L}$$

STATIC STABILITY (CON'T)

LONGITUDINAL WEIGHT SHIFT EXAMPLE

SOLUTION (CON'T)

$$d_f = \frac{(6.0\text{ IN})(191.5\text{ FT} + 22.44\text{ FT})}{383.0\text{ FT}}$$

$$d_f = 3.35\text{ IN}$$

$$d_a = 6.0\text{ IN} - 3.35\text{ IN} = 2.65\text{ IN}$$

$$\begin{array}{rl} T_a = & 13'-9'' \\ d_a = & (-)2.65'' \\ \hline T_{a_1} = & 13'-6.35'' \end{array} \qquad \begin{array}{rl} T_f = & 13'-9'' \\ d_f = & (+)3.35'' \\ \hline T_{f_1} = & 14'-0.35'' \end{array}$$

ROUND DRAFTS TO NEAREST 1/4" (WHICH TAKES SOME VERY CLOSE READING!!)

$$\boxed{T_{f_1} = 14'-0\tfrac{1}{4}'' \qquad T_{a_1} = 13'-6\tfrac{1}{4}''}$$

STATIC STABILITY (CON'T)

WEIGHT ADDITIONS

SO FAR WE HAVE TREATED SHIFTS OF WEIGHTS ALREADY ON BOARD.

NOW WE CONSIDER WEIGHT ADDED TO THE SHIP.

WEIGHT ADDITIONS CAUSE:

- INCREASED DISPLACEMENT
- VERTICAL SHIFT IN G AND M
- LIST, IF OFF CENTER
- CHANGE IN TRIM, AND,
- CHANGE IN DRAFTS

STATIC STABILITY (CON'T)

WEIGHT ADDITIONS

IF ONLY ONE RELATIVELY SMALL WEIGHT IS ADDED THINK OF THE PROBLEM IN SEVERAL STEPS:

- ADD THE WEIGHT AT ITS VERTICAL LOCATION AND LONGITUDINALLY AT THE LCF
- FIND THE NEW DISPLACEMENT AND THE NEW KG USING

$$KG_1 = \frac{\Delta_o \; KG_o + wKg}{\Delta_1}$$

WHERE $\Delta_1 = \Delta_o + w$

- FIND <u>PARALLEL SINKAGE</u> USING

$$\delta T_m = \frac{w}{TPI}$$

STATIC STABILITY (CON'T)

WEIGHT ADDITIONS

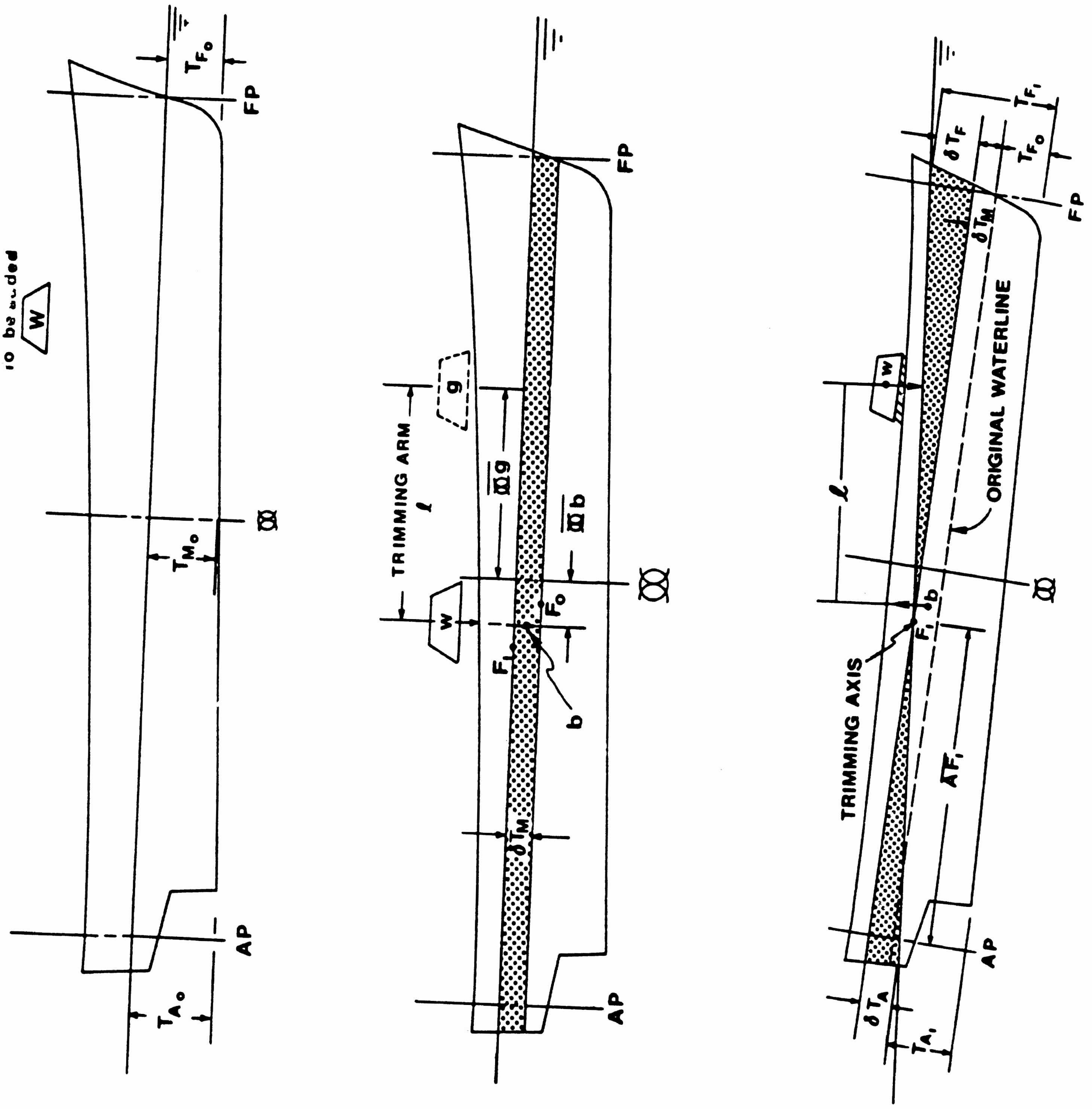
SMALL WEIGHT ADDITIONS (CON'T)

- NOTE: USE AVERAGE TPI BETWEEN OLD T_{m_o} AND NEW T_{m_1}
- SHIFT WEIGHT LONGITUDINALLY TO ITS LOCATION. FIND δTRIM USING

$$\delta \text{TRIM} = \frac{\text{TRIMMING MOMENT}}{\text{MTI}}$$

FIND MTI AT NEW DRAFT

- DISTRIBUTE δTRIM FORE AND AFT AS IN PREVIOUS EXAMPLE


To be added
W
T_{F_o}
FP
T_{M_o}
AP
T_{A_o}
TRIMMING ARM
ℓ
g
$\overline{\text{⊗}g}$
$\overline{\text{⊗}b}$
W
F_o
F_1
b
δT_M
FP
AP
w
ℓ
ORIGINAL WATERLINE
T_{F_1}
δT_F
T_{F_o}
δT_M
FP
b
F_1
TRIMMING AXIS
$\overline{AF_1}$
AP
δT_A
T_{A_1}

STATIC STABILITY (CON'T)

WEIGHT ADDITIONS

- SHIFT WEIGHT TRANSVERSELY TO ITS LOCATION. FIND ANGLE OF LIST, ϕ USING

$$G_1M_1 \tan\phi = \frac{wt}{\Delta_1}$$

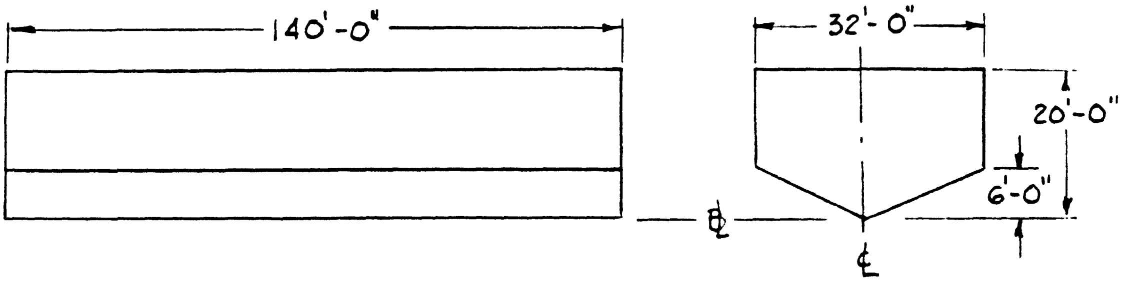
- NOTE: USE NEW GM, G_1M_1 AND NEW DISPLACEMENT, Δ_1

BASIC NAVAL ARCHITECTURE

Problem 27

Problem Level: Basic

A hopper barge has the shape shown below:



a) Calculate the displacement in salt water at four or five drafts from zero up to 20'-0". Plot the Displacement Curve with draft as the ordinate and displacement as the abscissa on a sheet of graph paper. Use a scale of 1" = 4'-0" for draft and 1" = 400 tons for displacement.

b) In the Light Ship condition with no cargo (sand) on board the barge floats at a draft of 8'-0" fore and aft. From your Displacement Curve find the Light Ship Displacement at this draft.

c) 1200 tons of Deadweight (sand) are now loaded uniformly on the barge. From your Displacement Curve find the new mean draft.

d) Find the freeboard and the reserve buoyancy in long tons (s.w.) with the load of sand on board.

Problem 28

Problem Level: Intermediate

A rectangular hopper barge has the following dimensions:

L_{pp} = 142'-0"

B = 35'-0"

D = 20'-0"

The barge is loaded with sand and mud dredgings in brackish water whose specific volume is 35.5 ft^3/ton. The draft in this condition is 16'-0", fore and aft. The barge is now towed to sea (35 ft^3/ton) and the cargo dumped. The draft at sea after dumping cargo is now 5'-0", fore and aft.

Find:
- (a) Displacement of barge and cargo in brackish water
- (b) Displacement of the barge and cargo at sea
- (c) Displacement of the barge after the cargo is dumped
- (d) Deadweight

BASIC NAVAL ARCHITECTURE

Problem 32

Problem Level: Advanced

A shipyard's floating crane mounted on a rectangular barge is to be used to recover a heavy object resting on the bottom in 30 feet of salt water. Gooseneck of the crane boom is at deck level of the barge and 28 feet aft of amidships. It is estimated that the object weighs 48 tons in air and displaces 840 ft^3 of water when fully submerged. The dimensions and KG of the barge before hoisting commences are:

L_{pp} = 105'-0"

B = 36'-0"

$T_f = T_a = T_m$ = 12'-0"

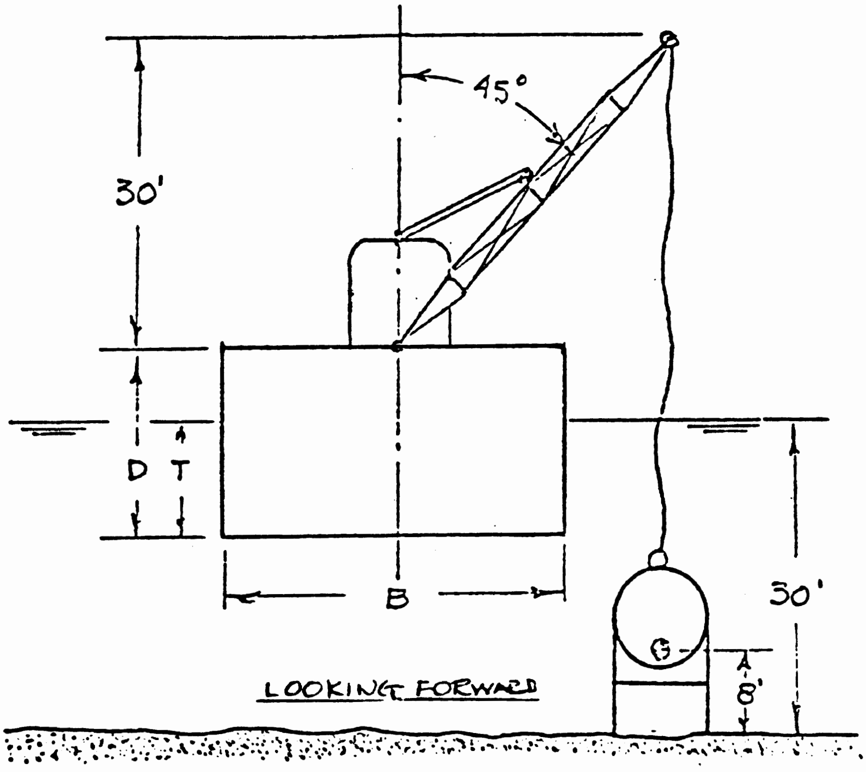
D = 19'-0"

KG = 7.00' above K

Hoisting of the object now commences. Find:

(a) Drafts at each corner of the barge when the object has been hoisted just clear of the bottom.

(b) Drafts at each corner of the barge when the object just clears the water surface. Will the deck edge of the barge submerge at any point?



Problem 35

Problem Level: Basic

An FFG-7-type frigate is in a shipyard in salt water preparing to leave for sea. The drafts and KG are:

T_f = 14'-0"

T_a = 14'-0"

KG = 18.00' above bottom of keel

(1) Find the displacement of the ship.

(2) From the Cross Curves of Stability find the Righting Arms at the above displacement up to an Angle of Inclination of 60°.

Correct the values read from the curves for the actual value of KG. Remember that since the actual KG is below the value assumed in the curves of 19.00 ft., the correction is positive, i.e.

$$GZ = AP + AG \sin \Theta$$

(3) Plot the corrected curve on graph paper to the following scales:

Angle of Inclination: 1" = 10°

Righting Arm: 1" = 0.50'

BASIC NAVAL ARCHITECTURE

Problem 36

Problem Level: Intermediate

A DD692 (long hull) class destroyer is floating in salt water at the following drafts:

T_f = 14'=1-1/2"

T_a = 13'=1-1/2"

KG = 16.50' above

Calculate and plot the Curve of Statical Stability and the Curve of Dynamical Stability for this condition. Find the maximum Righting Arm and the Angle of Inclination at which it occurs. Find the Range of Stability. Estimate GM_t from the curve.

Procedure

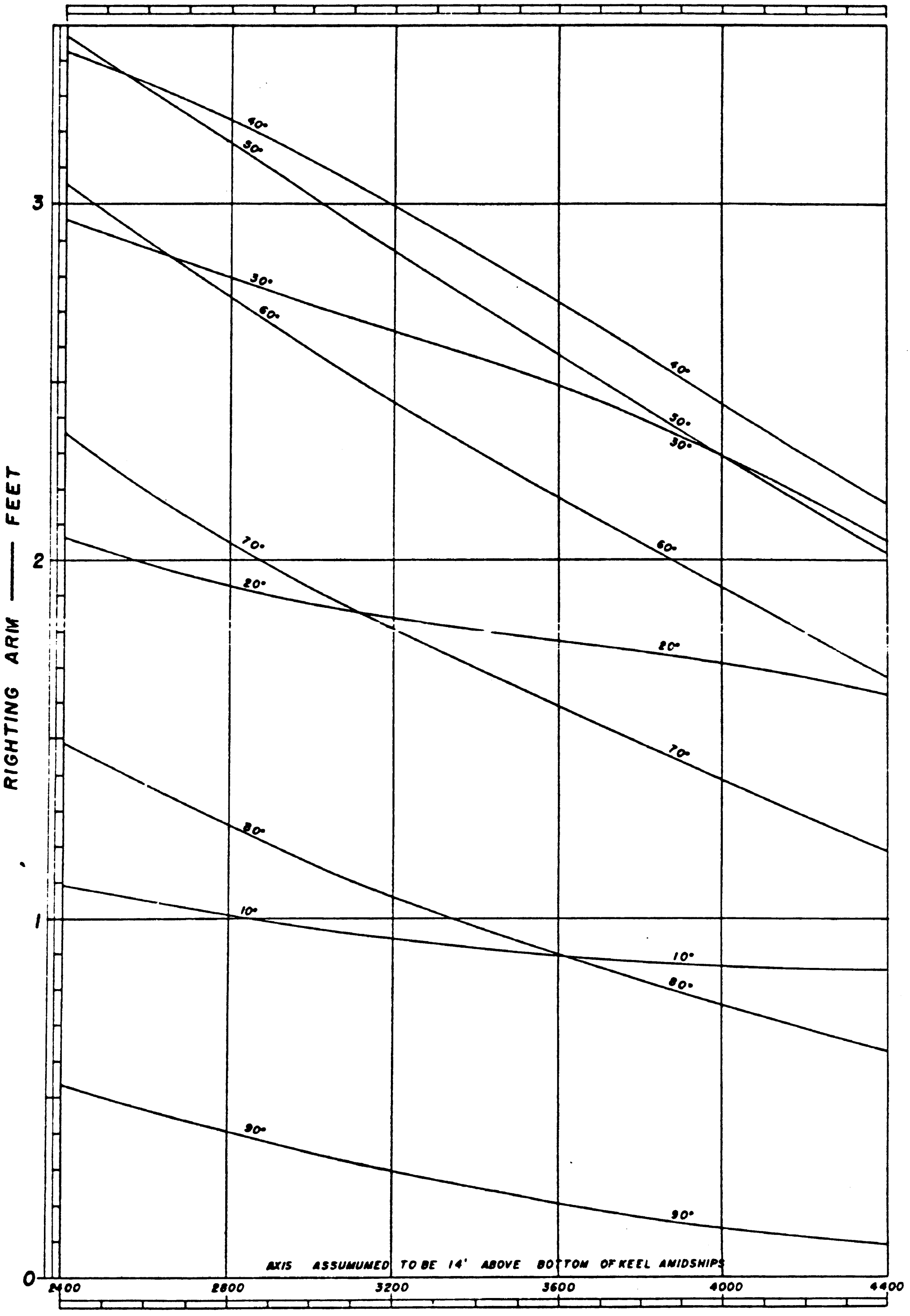
Find the displacement corresponding to the drafts given. Enter the Cross Curves of Stability (attached) with this displacement and find Righting Arms as a function of Angle of Inclination. The Cross Curves are based on an Assumed Center of Gravity, KA, of 14.00' above the base line. The Righting Arms, AP_1 obtained from the Cross Curves must be corrected to the actual KG using the formula:

$$GZ = AP - AG \sin \theta$$

Plot this corrected curve of GZ versus Angle of Inclination on graph paper. Divide the range of stability into a number of equal intervals and record the value of the Righting Arm (corrected) at each of these stations. The Curve of Dynamical Stability is a curve whose ordinate represents work done on ship in inclining up to that angle. In other words it is the integral of the Statical Stability Curve when that curve is plotted as Righting Moment versus Angle of Inclination in radians*. To compute the curve use the trapezoidal rule to integrate successively from the origin over to the stations assigned above. Or, you may simply accumulate areas of individual trapezoids. Be sure to apply a correction factor to convert Righting Arms to Righting Moments and angles to radian measure. Plot this curve on the same graph using an appropriate scale for the ordinate.

* One radian = $\frac{180^\circ}{\pi} = 57.3^\circ$

CROSS CURVES OF STABILITY
DD 692 (LONG HULL)



Problem 37

Problem Level: Basic

For the FFG-7-type frigate of Problem 35, initially upright and floating at the following drafts and KG,

T_f = 14'-0"

T_a = 14'-0"

KG = 18.00' above bottom of keel

find the weight which when shifted 20.00' off centerline to starboard would cause a list of 15° to starboard.

On graph paper, plot the Curve of Static Stability for this condition, both to port and to starboard. Use the following scales:

Angle of Inclination: 1" = 10°

Righting Arm: 1" = 1.00' (some overflow)

Problem 38

Problem Level: Basic

An FFG7-Class frigate is underway at sea with the following estimated drafts:

T_f = 14'-0"

T_a = 14'-0"

(a) Find the displacement and LCG in this condition.

A helicopter carrying stores has a gross weight of 31,600 lbs. and lands on the helodeck 165.0' aft of amidships.

(b) Find the displacements, LCG, and drafts in this condition.

(c) In which direction and how much weight would have to be shifted through a distance of 60.0 ft. to restore the ship to level trim?

PROBLEM 27 | TDK/PRVMJR | 19 JAN 87 | 1 OF 2

REF: GILLMER, pp 39-40

(a) CALCULATE AND PLOT THE DISPLACEMENT CURVE.

WL	CALC'N.	∇ FT^3	Δ LT
0		0	0
3	$\frac{1}{2}(16)(3)(140)$	3,360	96
6	$\frac{1}{2}(32)(6)(140)$	13,440	384
8	⑥ + (32)(2)(140)	22,400	640
14	⑥ + (32)(8)(140)	49,280	1,408
20	⑥ + (32)(14)(140)	76,160	2,176

SEE pp 2 FOR PLOT OF DISPLACEMENT CURVE

(b) FROM DISPLACEMENT CURVE (AND FROM ABOVE) ~

@ $T_m = 8.00'$, $\Delta_{LS} = 640$ LT

$\boxed{\Delta_{L.S} = 640\ \text{LT}}$

$\Delta_{LS} = 640$ LT

DWT $= 1200$ LT

$\Delta_{FL} = 1840$ LT

(c) FROM DISPLACEMENT CURVE @ $\Delta_{FL} = 1840$ LT ~

$T_m = 17.40'$

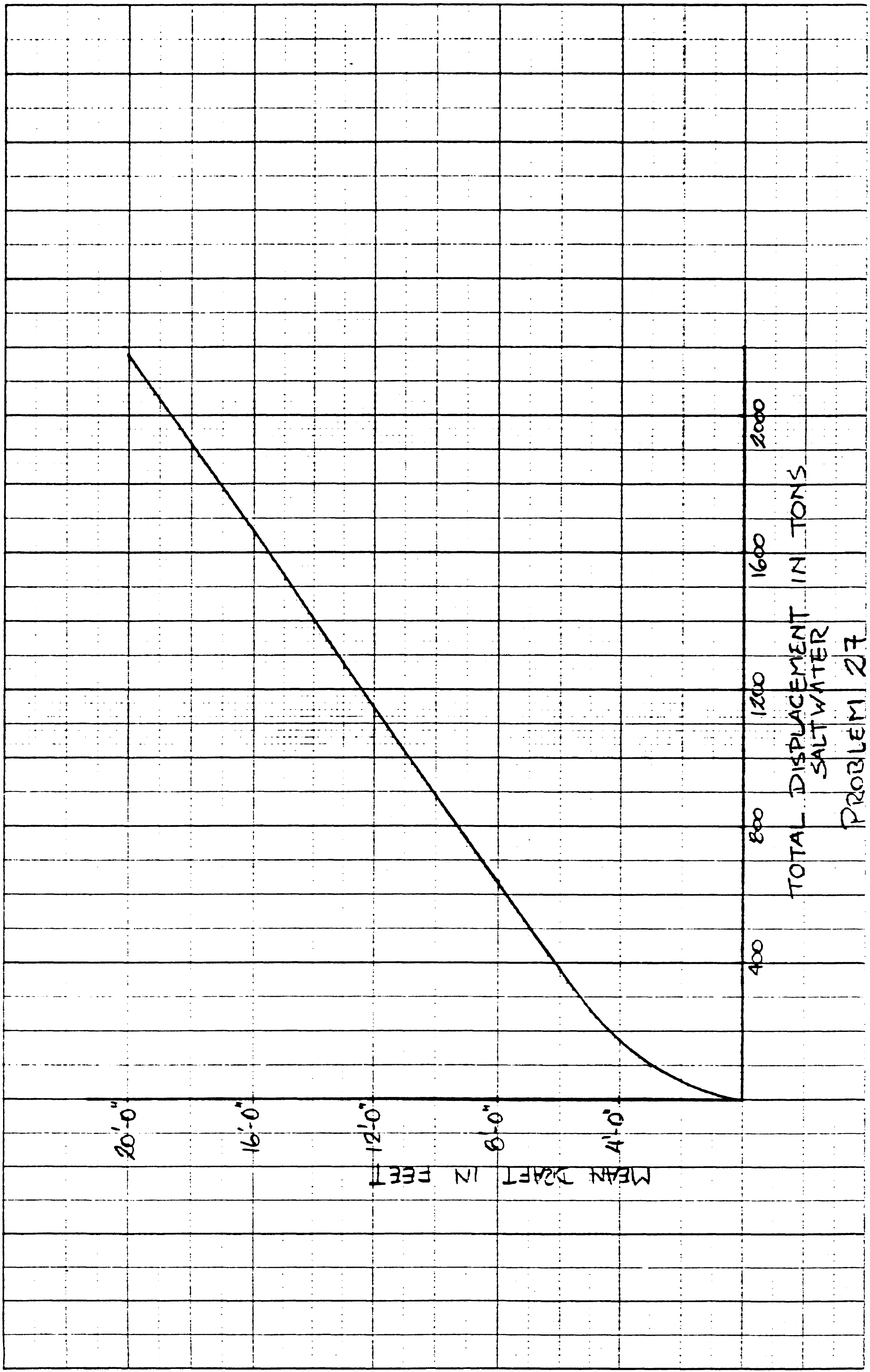
$\boxed{T_m = 17.40\ \text{FT}}$

(d) RESERVE BUOYANCY = WATERTIGHT VOLUME ABOVE W.L / 35

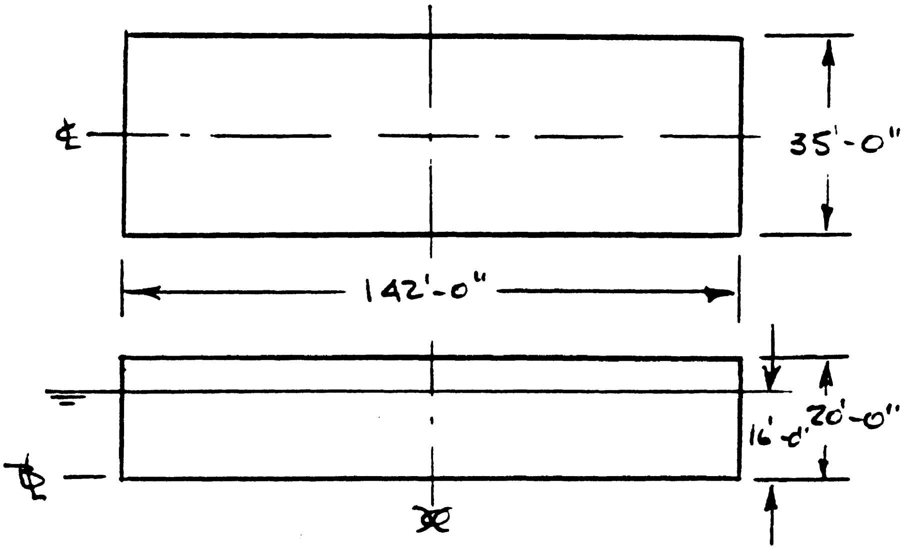
$$\text{RESERVE BUOYANCY} = \frac{(20-17.4)(32)(140)\ \text{FT}^3}{(35)\ \text{FT}^3/\text{TON}}$$

$\boxed{\text{RESERVE BUOYANCY} = 333\ \text{LT}}$

PROBLEM 27 TDK 19 JAN 87 2 OF 2



PROBLEM 28 TDK/PRYMJR 20 JAN 87 1 of 1



(a) FIND DISPLACEMENT OF BARGE AND CARGO IN BRACKISH WATER

$$\Delta_0 = \frac{L \cdot B \times T \ \text{FT}^3}{35.5 \ \text{FT}^3/\text{TON}} = \frac{(142.0)(35.0)(16.0)}{(35.5)} \ ; \ \boxed{\Delta_0 = 2{,}240 \ \text{LT}}$$

(b) THE DISPLACEMENT OF THE BARGE WILL NOT HAVE CHANGED IN PASSING FROM BRACKISH WATER TO SALT WATER; HOWEVER, THE DRAFTS WILL CHANGE

$$\boxed{\Delta_1 = 2{,}240 \ \text{LT}}$$

(c) $$\Delta_2 = \frac{L \cdot B \cdot T \ \text{FT}^3}{35.0 \ \text{FT}^3/\text{TON}} = \frac{(142.0)(35.0)(5.0)}{(35.0)} \ ; \ \boxed{\Delta_2 = 710 \ \text{LT}}$$

(d) $\Delta_{FL} = \Delta_0 = \Delta_1 = 2{,}240 \ \text{LT}$

$\Delta_{EMPTY} = \Delta_2 = \underline{710 \ \text{LT}}$

DEADWEIGHT $= 1{,}530 \ \text{LT}$; $\boxed{\text{DWT} = 1{,}530 \ \text{LT}}$

DISCUSSION OF PROBLEM

(1) IN THE SUBMERGED CONDITION THE OBJECT DISPLACES 840 FT^3 OF SALT WATER. THE BUOYANT FORCE ON THE OBJECT WILL BE $\frac{840 \text{ FT}^3}{35 \text{ FT}^3/\text{TON}} = 24$ LT. THE GRAVITATIONAL FORCE ON THE OBJECT WILL BE ITS WEIGHT OF 48 LT. THUS, NEGLECTING BOTTOM SUCTION FORCES (WHICH IN THE CASE OF AN OBJECT EMBEDDED IN A MUD BOTTOM COULD BE VERY LARGE) THE NET LIFTING FORCE REQUIRED TO LIFT THE OBJECT CLEAR OF THE BOTTOM WILL BE THE DIFFERENCE BETWEEN WEIGHT AND BUOYANCY OR 24 LT. WHEN THE OBJECT IS CLEAR OF THE WATER THE BUOYANT FORCE WILL NO LONGER BE PRESENT (NEGLECTING THAT DUE TO DISPLACEMENT OF AIR) AND THE TENSION IN THE LIFTING LINE WILL BE THE FULL WEIGHT OF THE OBJECT, 48 LT.

(2) WHILE THE CRANE IS LIFTING THE OBJECT THE CRANE AND THE BARGE MAY BE CONSIDERED AS ONE RIGID BODY AND THE TENSION IN THE LIFTING LINE WILL ACT AT THE AXIS OF THE SHEAVE AT THE OUTBOARD END OF THE CRANE BOOM AND MAY BE TREATED AS A WEIGHT ADDED AT THIS POINT.

SOLUTION:

(1) FIND INITIAL DISPLACEMENT.

$$\nabla_o = L \times B \times T_{m_o} = (105 \text{ FT})(36 \text{ FT})(12 \text{ FT}) = 45{,}360 \text{ FT}^3$$

$$\Delta_o = \frac{\nabla_o \text{ FT}^3}{35 \text{ FT}^3/\text{TON}} = \frac{45{,}360 \text{ FT}^3}{35 \text{ FT}^3/\text{TON}} = 1{,}296 \text{ LT}$$

(2) APPLY LIFTING FORCE OF 24 LT AT 30' + 19' = 49' above K AND 30' OFF ℄ TO STBD,

ITEM	WT LT	VCG FT a. K	V. MOM'T FT-TONS
ORIGINAL BARGE	1,296	7.00	9,072
LINE TENSION	24	49.00	1,176
BARGE WITH OBJECT CLEAR OF BOTTOM	1,320	7.76	10,248

$\underline{\underline{\Delta_i = 1{,}320, \; KG_i = 7.76 \text{ FT a K}}}$

(CON'T)

(3) FIND NEW MEAN DRAFT.

$$\Delta_1 = \frac{L \times B \times T_{m_1}\ \text{FT}^3}{35\ \text{FT}^3/\text{TON}}$$

$$T_{m_1} = \frac{35\frac{\text{FT}^3}{\text{TON}}\Delta_1\ \text{LT}}{L \times B} = \frac{35\ \text{FT}^3/\text{TON} \times 1320\ \text{LT}}{105\ \text{FT} \times 36\ \text{FT}} = 12.22\ \text{FT}$$

(NOTE: THIS ALSO COULD HAVE BEEN DONE BY COMPUTING AND APPLYING TPI, TONS PER INCH IMMERSION)

(4) FIND ANGLE OF LIST AND ANGLE OF TRIM.

ANGLE OF LIST: $GM_{t_1}\tan\phi = \dfrac{w \times t}{\Delta_1}$

$$BM_{t_1} = \frac{I_{t_1}}{\nabla_1} = \frac{B^3L/12\ \text{FT}^4}{35\frac{\text{FT}^3}{\text{TON}}\Delta_1\ \text{LT}} = \frac{(36)^3(105)}{(12)(35)(1320)}$$

$BM_{t_1} =$ $= 8.84$ FT

$KB_1 = \dfrac{T_{m_1}}{2} = \dfrac{12.22}{2}$ $= 6.11$ FT a.K.

$KM_{t_1} =$ $= 14.95$ FT a K.

$KG_1 =$ $= 7.76$ FT a K

$GM_{t_1} =$ $= 7.19$ FT

w = LINE TENSION = 24 LT

t = SHEAVE AXIS OFF ℄ = 30.0 FT.

$$\tan\phi_1 = \frac{(24\ \text{LT})(30.0\ \text{FT})}{(7.19\ \text{FT})(1320\ \text{LT})}$$

$$\tan\phi_1 = .07586$$

$$\phi_1 = 4.34^\circ$$

ANGLE OF TRIM:

$$GM_L \tan\alpha = \frac{w \times l}{\Delta_1}$$

(CON'T)

$$BM_{L_1} = \frac{I_{L_1}}{\nabla_1} = \frac{L^3 B/12 \ \mathrm{FT}^4}{35 \frac{\mathrm{FT}^3}{\mathrm{TON}} \Delta_1 \mathrm{LT}} = \frac{(105 \ \mathrm{FT})^3 (36 \ \mathrm{FT})}{(12)(35 \frac{\mathrm{FT}^3}{\mathrm{TON}})(1320 \ \mathrm{LT})}$$

BM_{L_1} = = 75.17 FT

KB_1 = = 6.11 FT a K

KM_{L_1} = = 81.28 FT a K

KG_1 = = 7.76 FT a K

GM_{L_1} = = 73.52 FT

w = LINE TENSION = 24 LT

l = SHEAVE AXIS AFT ⊗ = 28.0 FT

$$\tan \alpha_1 = \frac{(24 \ \mathrm{LT})(28 \ \mathrm{FT})}{(73.52 \ \mathrm{FT})(1320 \ \mathrm{LT})}$$

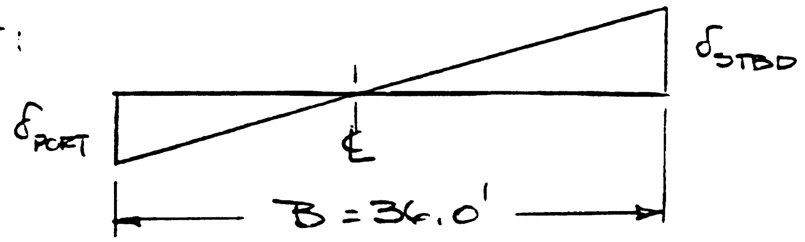
$$\tan \alpha_1 = .006925$$

$$\alpha_1 = 0.40°$$

(5) FIND DRAFTS AT EACH CORNER

APPROACH: FIND CHANGE IN DRAFTS DUE TO LIST, THEN DUE TO TRIM, THEN COMBINE RESULTS ALGEBRAICLLY.

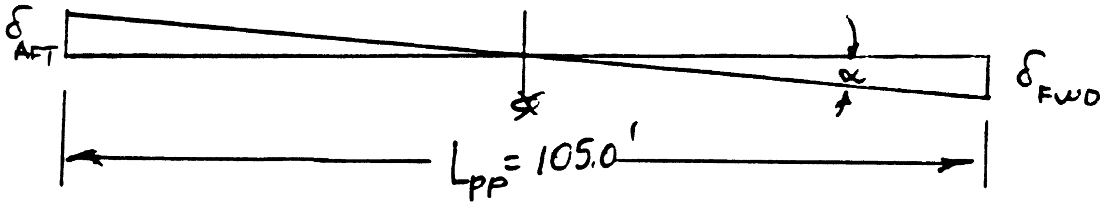
LIST:



$$\delta_{STBD_1} = \delta_{S_1} = +(18.0)(\tan \phi)$$
$$= +(18.0)(.07586)$$
$$\delta_{S_1} = +1.37 \ \mathrm{FT}$$
$$\delta_{PORT_1} = \delta_{P_1} = -1.37 \ \mathrm{FT}.$$

(CON'T)

TRIM: (NOTE THAT LCF IS AMIDSIPS)

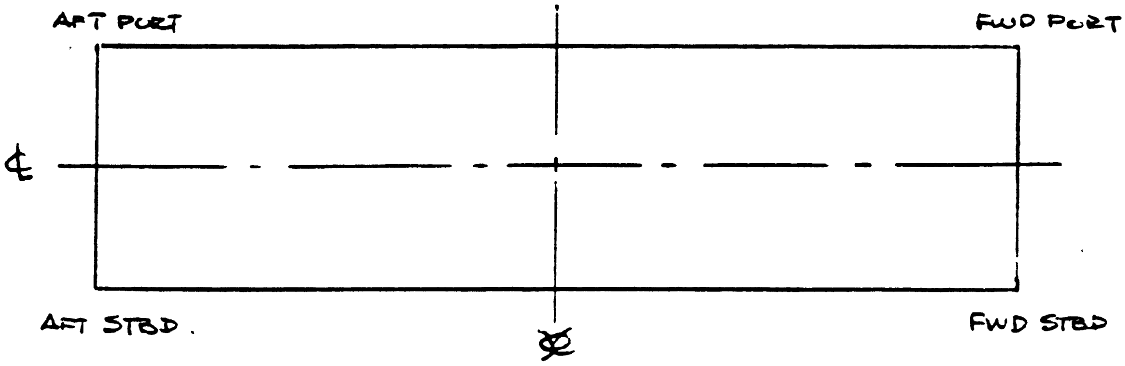


$$\delta_{FWD} = \delta_F = -\left(\frac{105.0}{2}\right)(\tan\alpha)$$

$$= -(52.5)(.006925)$$

$$\delta_F = -0.36 \text{ FT}$$

$$\delta_A = +0.36 \text{ FT}$$



(a)

AFT PORT	AFT STBD	FWD PORT	FWD STBD
$T_{m_1} = 12.22'$	$T_{M_1} = 12.22'$	$T_{M_1} = 12.22'$	$T_{M_1} = 12.22'$
$\delta_P = -1.37'$	$\delta_S = +1.37'$	$\delta_P = -1.37'$	$\delta_S = +1.37'$
$\delta_A = +0.36'$	$\delta_A = +0.36'$	$\delta_F = -0.36'$	$\delta_F = -0.36'$
$T_{A_{P_1}} = 11.21'$	$T_{A_{S_1}} = 13.95'$	$T_{F_{P_1}} = 10.49'$	$T_{F_{S_1}} = 13.23'$

$$\boxed{\begin{aligned} T_{F_{S_1}} &= 13.23 \text{ FT} \\ T_{F_{P_1}} &= 10.49 \text{ FT} \\ T_{A_{S_1}} &= 13.95 \text{ FT} \\ T_{A_{P_1}} &= 11.21 \text{ FT} \end{aligned}}$$

(CON'T)

(b) WHEN THE OBJECT CLEARS THE WATER SURFACE THE BUOYANT SUPPORT WILL BE LOST AND THE LINE TENSION WILL INCREASE TO 48 LT. THIS WILL CAUSE AN INCREASE IN THE SINKAGE OF THE BARGE AND A CHANGE IN THE DRAFTS AT EACH CORNER. THE PROCEDURE IS EXACTLY THE SAME AS IN PART (a) EXCEPT THAT WHEREVER 24 LT WAS USED, 48 LT WILL NOW BE USED.

(1) FIND NEW DISPLACEMENT AND KG.

ITEM	WT LT	VCG FT a.K	V. MOM'T FT-TONS
ORIGINAL BARGE	1,296	7.00	9,072
LINE TENSION	48	49.00	2,352
BARGE WITH OBJECT CLEAR OF WATER	1,344	8.50	11,424

Δ_2 = 1,344 LT KG_2 = 8.50 FT a.K.

$$T_{m_2} = \frac{35 \frac{FT^3}{TON} \times 1344 \text{ LT}}{105 \text{ FT} \times 36 \text{ FT}} = 12.44 \text{ FT}$$

$$BM_{t_2} = \frac{(36)^3(105)}{(12)(35 \frac{FT^3}{TON})(1344 \text{ LT})} = 8.68 \text{ FT}$$

$$KB_2 = \frac{12.44 \text{ FT}}{2} = 6.22 \text{ FT a.K}$$

$$KM_t = 14.90 \text{ FT a.K}$$

$$KG_2 = 8.50 \text{ FT a K}$$

$$GM_{t_2} = 6.40 \text{ FT.}$$

$$\tan\phi_2 = \frac{w \times t}{GM_{t_2}\Delta_2} = \frac{(48_{LT})(30.0 \text{ FT})}{(6.40 \text{ FT})(1344 \text{ LT})} = 0.1674$$

$$\phi_2 = 9.50^\circ$$

(CON'T)

$$BM_{L_2} = \frac{(105\text{ FT})^3(36\text{ FT})}{(12)(35\ \frac{\text{FT}^3}{\text{TON}})(1344\text{ LT})} = \quad = 73.83\text{ FT}$$

$$KB_2 = \quad = \underline{6.22\text{ FT @ K}}$$

$$KM_2 : \quad = 80.05\text{ FT @ K}$$

$$KG_2 : \quad = \underline{8.50\text{ FT @ K}}$$

$$GM_{L_2} = \quad = 71.55\text{ FT}$$

$$\tan \alpha_2 = \frac{(48\text{ LT})(28\text{ FT})}{(71.55)(1344\text{ LT})} = \quad = .01398$$

$$= 0.80^\circ$$

$$\delta_{PORT} = \delta_{P_2} = +(18.0\text{ FT})(\tan \phi_2)$$

$$\delta_{P_2} = +(18.0)(0.1674) \quad = +3.01\text{ FT}$$

$$\delta_{STBD} = \delta_{S_2} = -(18.0)(0.1674) \quad = -3.01\text{ FT}$$

$$\delta_{FWD} = \delta_F = -\left(\frac{105}{2}\text{ FT}\right)(\tan \alpha_2)$$

$$\delta_F = -(52.5)(.01398) \quad = -0.73\text{ FT}$$

$$\delta_{AFT} = \delta_A = +(52.5)(.01398) \quad = +0.73\text{ FT}$$

AFT PORT	AFT STBD	FWD PORT	FWD STBD
$T_{M_2} = 12.44$	$T_{M_2} = 12.44$	$T_{M_2} = 12.44$	$T_{M_2} = 12.44$
$\delta_P = +3.01$	$\delta_S = -3.01$	$\delta_P = +3.01$	$\delta_S = -3.01$
$\underline{\delta_A = +0.73}$	$\underline{\delta_A = +0.73}$	$\underline{\delta_F = -0.73}$	$\underline{\delta_F = -0.73}$
$T_{AP_2} = 16.18$ FT,	$T_{AS_2} = 10.16$ FT	$T_{FP_2} = 14.72$	$T_{FS_2} = 8.70$ FT.

SINCE NONE OF THE DRAFTS EXCEED 19.00 FT, THE DECK EDGE WILL NOT SUBMERGE

$T_{FS_2} = 8.70$ FT
$T_{FP_2} = 14.72$ FT
$T_{AS_2} = 10.16$ FT
$T_{AP_2} = 16.18$ FT

PROBLEM 35 TDK/PRVMUZ 26 FEB 87 1 of 2

GIVEN: FFG 7 FRIGATE AT:

$T_f = 14'-0"$

$T_a = 14'-0"$

KG = 18.00 FT a K

FIND: PLOT OF GZ VS θ

AT $T_m = 14'-0"$, $\Delta = 3270$ LT (SW)

THE ASSUMED POSITION OF THE CENTER OF GRAVITY, AP, FOR THE CROSS CURVES IS ~

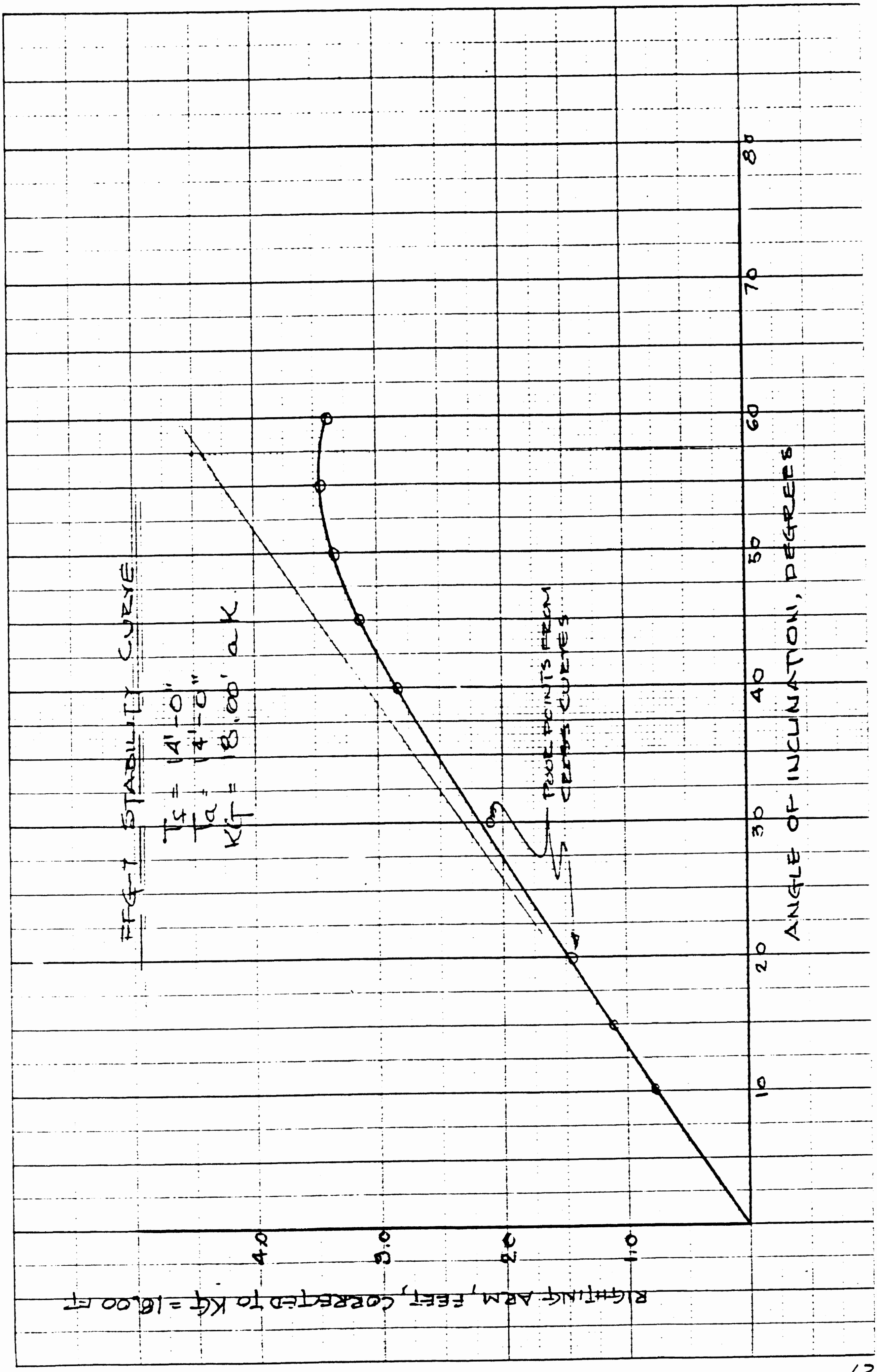
$$
\begin{array}{l}
AP = 19.00 \text{ FT a K} \\
\underline{KG = 18.00 \text{ FT a K}} \\
AG = +1.00 \text{ FT}
\end{array}
$$

SINCE G IS BELOW A, AG IS POSITIVE.

ANGLE OF INCLIN. θ, DEG	AP FT	AG sin θ FT	GZ FT
0°	0.000	0.000	0.000
10°	0.582	0.1736	0.757
15°	0.854	0.2588	1.113
20°	1.106	0.3420	1.448
30°	1.602	0.5000	2.102
40°	2.202	0.6428	2.845
45°	2.440	0.7071	3.147
50°	2.580	0.7660	3.346
55°	2.610	0.8192	3.429
60°	2.536	0.8660	3.402

SEE PP2 FOR PLOT OF GZ VS θ.

PROBLEM 35 TDK/FRVMJR 26 FEB 87 2 of 2



GIVEN: DD 692 (LONG HULL) DESTROYER

$T_f = 14' - 1\frac{1}{2}'' = 14.125'$

$T_a = 13' - 1\frac{1}{2}'' = 13.125'$

$KG = 16.50$ FT a. K.

AT $T_m = 13.625$ FT, $\Delta_0 = 3220$ LT (SW)

CORRECTION FOR 12" TRIM FWD $= 993 \left(\frac{2 \text{ LT}}{100 \text{ LT}}\right) = -19.86$ LT

$\Delta_1 = 3200$ LT (SW)

ASSUMED KG = KA = 14.00 FT a. K

ACTUAL KG = 16.50 FT a. K

AG = 2.50 FT

SINCE THE ACTUAL KG IS ABOVE THE ACTUAL KG THE CORRECTION WILL BE SUBTRACTED.

(1) CALCULATE CURVE OF STATICAL STABILITY

ANGLE OF INCLINATION, θ, DEG.	RIGHTING ARM, AP FT	AG sin θ FT	GZ FT.
10	0.94	0.43	0.51
20	1.84	0.86	0.98
30	2.65	1.25	1.40
40	2.99	1.61	1.38
50	2.87	1.92	0.95
60	2.44	2.17	0.27
70	1.81	1.81	−0.54
80	1.07	1.07	−1.39
90	0.31	0.31	−2.19

A PLOT OF STATICAL STABILITY VS θ IS ON PAGE 3

(CON'T)

(2) CALCULATE CURVE OF DYNAMICAL STABILITY

RIGHTING MOMENT = RIGHTING ARM × DISPLACEMENT

$$1 \text{ RADIAN} = \frac{180°}{\pi} = 57.3°$$

CALCULATE AREAS IN 10° INCREMENTS, THEN ACCUMULATE AREAS

FOR EXAMPLE, THE AREA BETWEEN $\theta = 30°$ AND 40° WILL BE ~

$$\text{AREA} = \frac{1}{2}(GZ_{30°} + GZ_{40°}) \times \frac{10°}{57.3°} \times \Delta$$

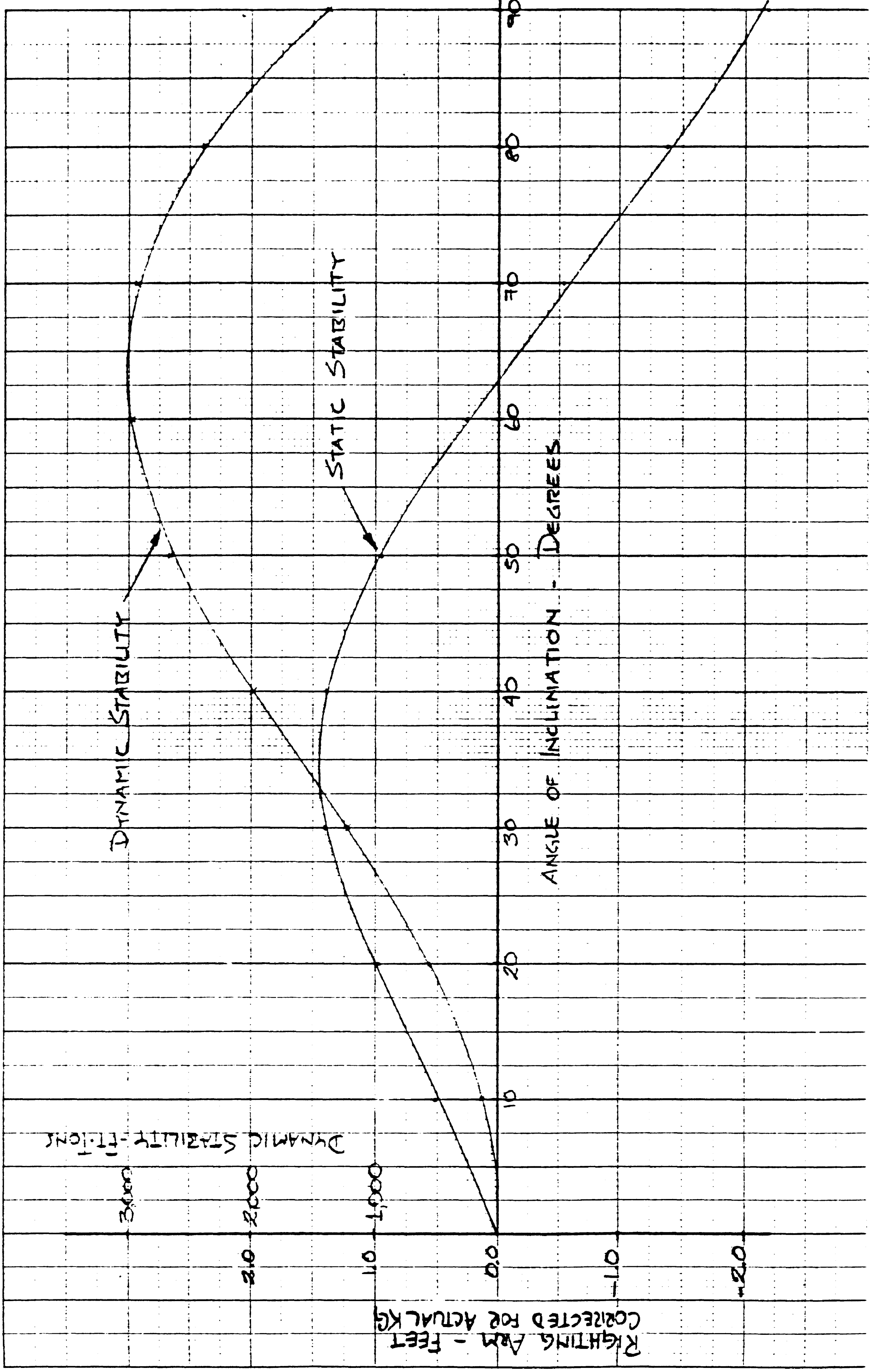
$$= \frac{1}{2}(1.40 + 1.38) \times .1745 \times 3200$$

AREA = 776 FT-TONS BET. 30° AND 40°

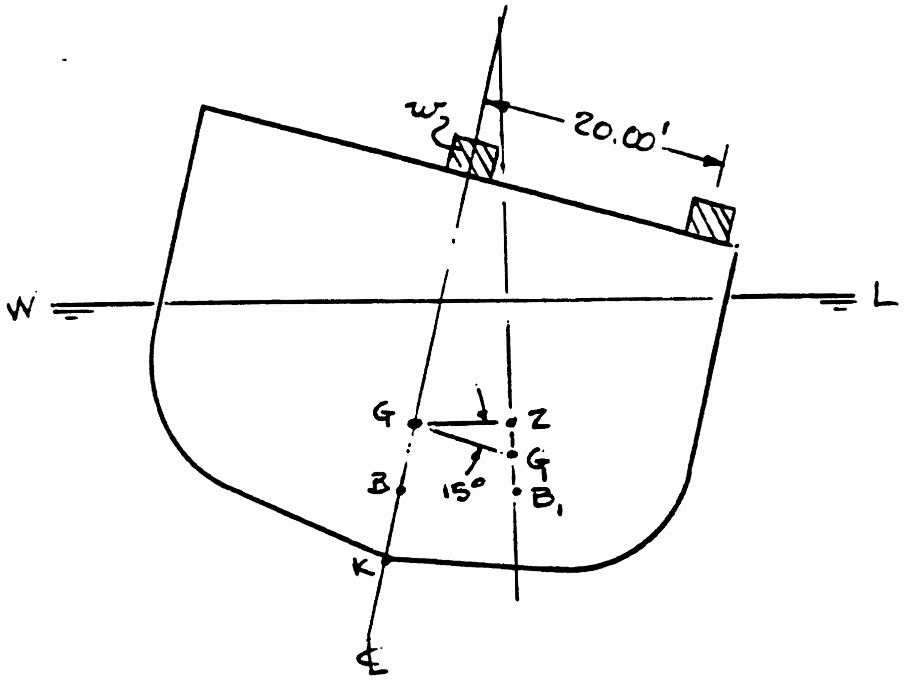
θ DEG.	GZ FT	INCREMENT FROM ~	AREA OF INCREMENT FT-TON	DYNAMICAL STABILITY = ACCUM. AREA FT-TONS
0	0.0			
10	0.51	0° - 10°	142	142
20	0.98	10° - 20°	416	559
30	1.40	20° - 30°	665	1223
40	1.38	30° - 40°	776	1999
50	0.95	40° - 50°	651	2650
60	0.27	50° - 60°	341	2991
70	-0.54	60° - 70°	- 75	2915
80	-1.39	70° - 80°	-539	2376
90	-2.19	80° - 90°	-1000	1377

A PLOT OF DYNAMICAL STABILITY VS. θ IS ON PAGE 3

PROBLEM 36   TDK/FRYMJR   27 FEB 87   3 OF 3



PROBLEM 37 | TDK/PRVMVR | 27 FEB 87 | 1 OF 4



GIVEN:

$T_f = 14'-0"$

$T_a = 14'-0'$

$KG = 18.00$ FT a.K.

FIND: w

FROM PROBLEM 35.

$$\Delta = 3270 \text{ LT.}$$

$$GZ_{15°} = 1.113 \text{ FT.}$$

FROM THE SKETCH ABOVE,

$$GZ_{15} = GG_1 \cos 15°$$

THEN,

$$GG_1 = \frac{GZ_{15}}{\cos 15°} = \frac{1.113}{0.9659} = 1.152 \text{ FT.}$$

ALSO,

$$GG_1 = \frac{w \times t}{\Delta} = \frac{w \times 20.00 \text{ FT}}{3270 \text{ LT}}$$

$$w = \frac{3270 \text{ LT} \times 1.152 \text{ FT}}{20.00 \text{ FT}}$$

$$\underline{w = 188.4 \text{ LT}}$$

SEE COMMENT NEXT PAGE.

COMMENT ON PROBLEM 37

THE ABOVE APPROACH USING RIGHTING ARMS OBTAINED FROM CROSS CURVES WAS INDICATED BECAUSE THE ANGLE OF INCLINATION EXCEEDED THE NORMAL LIMITS FOR THE SMALL ANGLE METACENTRIC-TYPE ANALYSIS.

SUPPOSE METACENTRIC ANALYSIS WERE APPLIED. How LARGE WOULD BE THE ERROR THAT IS INTRODUCED?

$$GM \tan\theta = \frac{w \times t}{\Delta}$$

FROM CURVES OF FORM, $KM = 22.48$ FT a. K

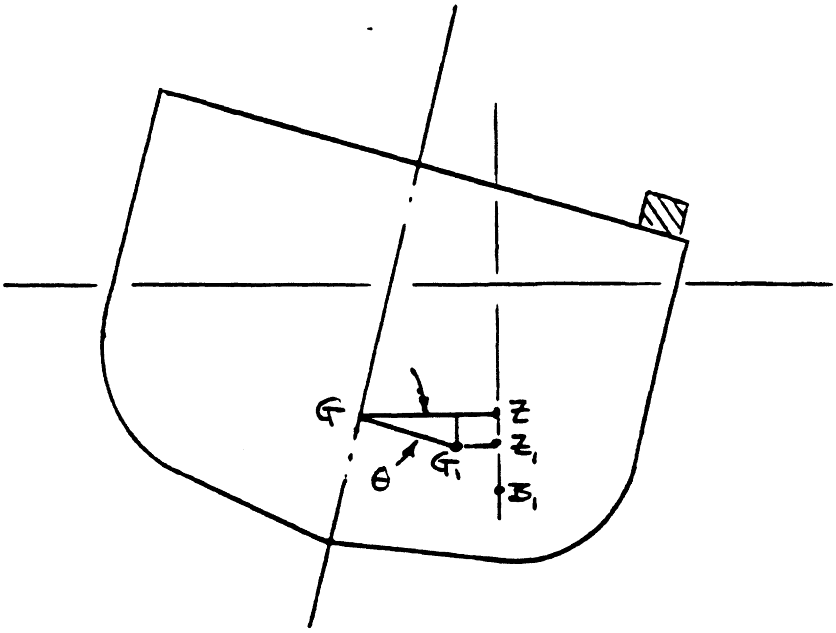
$\underline{KG = 18.00 \text{ FT}}$ a K

$GM = 4.48$ FT

THEN, $(4.48 \text{ FT})(\tan 15°) = \dfrac{w \times 20.00 \text{ FT}}{3270 \text{ LT}}$

$w = 196.3$ LT

ERROR = 7.9 LT = 4.2%



THE SKETCH ON PAGE 1 SHOWED THE SHIP IN EQUILIBRIUM WITH G SHIFTED TO G_1 AND B_1 BELOW G_1. WE NOW CONSIDER THE CASE WHEN THE SHIP IS NOT IN EQUILIBRIUM – THAT IS THE RIGHTING MOMENT WHICH IS GENERATED BY SEPARATING THE WEIGHT AND BUOYANCY FORCES, AS SHOWN ABOVE. NOW THE NEW RIGHTING ARM WILL BE G_1Z_1. IN THIS CASE ~

$$G_1Z_1 = GZ - GG_1 \cos\theta$$

VALUES OF GZ FOR THIS DISPLACEMENT WERE CALCULATED IN PROBLEM 35. GG_1 WAS CALCULATED IN THE FIRST PART OF THIS PROBLEM

$$GG_1 = 1.152 \text{ FT.}$$

NOTE THAT THE SIGN OF THE $GG_1 \cos\theta$ TERM IS + TO PORT

	ANG OF INCL θ, DEG.	GZ	$GG_1 \cos\theta$	STBD G_1Z_1	PORT G_1Z_1
	0	0.000	1.152	−1.152	+1.152
	10	0.757	1.134	−0.377	+1.891
BAD POINT	15	1.113	1.113	0.000	+2.226
	20	1.448	1.083	+0.365	+2.531
FROM CROSS CURVES →	30	2.102	0.998	+1.104	+3.100
	40	2.845	0.882	+1.963	+3.727
	45	3.147	0.815	+2.332	+3.962
	50	3.346	0.740	+2.606	+4.086
	55	3.429	0.661	+2.768	+4.090
	60	3.402	0.576	+2.826	+3.978

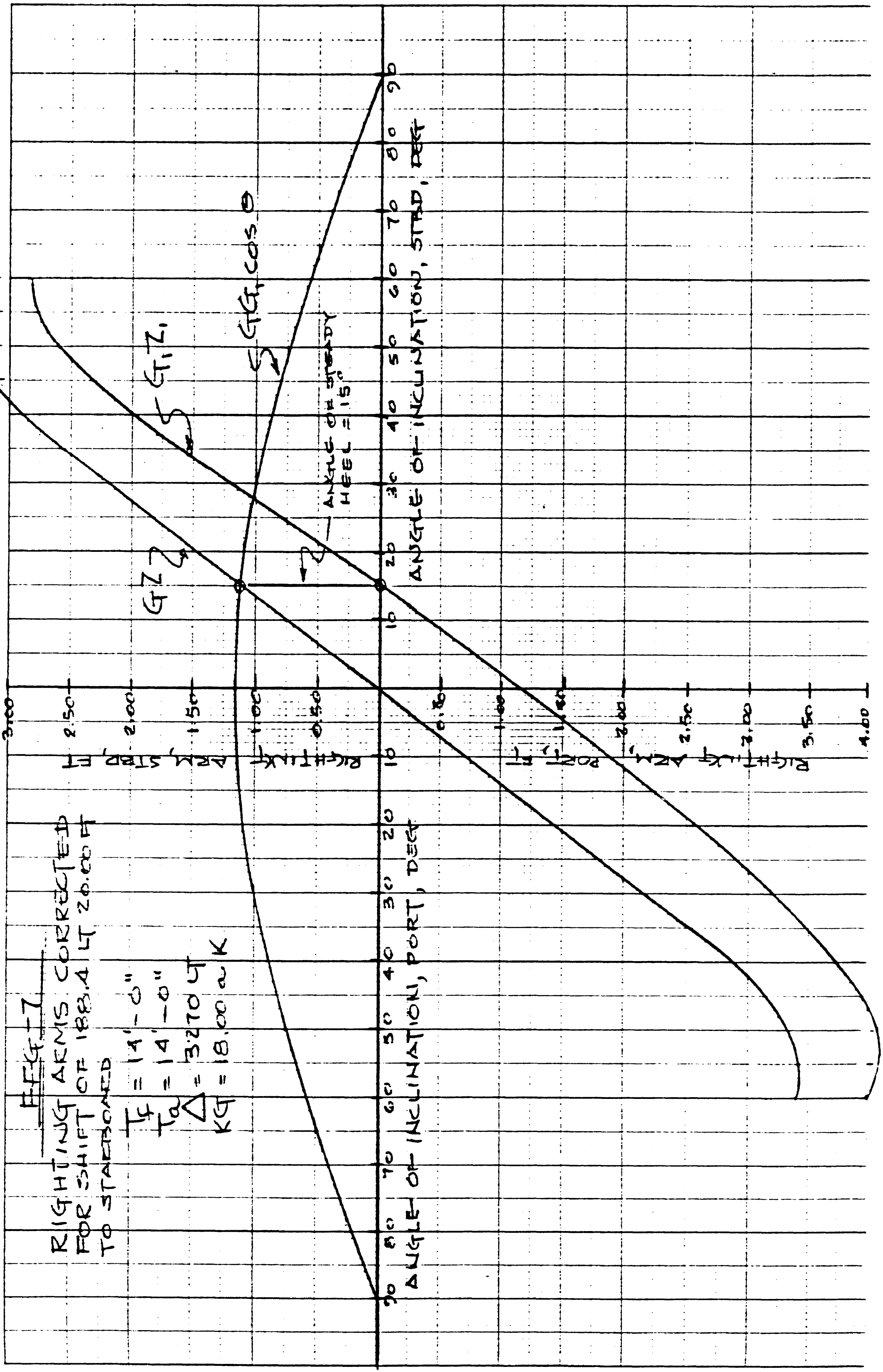


FIG-7

RIGHTING ARMS CORRECTED FOR SHIFT OF 183.4 LT 20.00 FT TO STARBOARD

T_f = 14'-0"
T_a = 14'-0"
Δ = 3270 LT
KG = 18.00 ~ K

GIVEN: $T_f = 14'-0''$

$T_a = 14'-0''$

(a) FIND: Δ, LCG.

FROM CURVES OF FORM AT $T_m = 14.00$ FT.

$$\Delta = 3270 \text{ LT (SW)}$$

SINCE THE SHIP IS AT LEVEL TRIM THE LCG WILL BE AT THE LOCATION OF THE LCB SHOWN ON THE CURVES OF FORM FOR LEVEL TRIM

$$LCG = LCB = 0.00 \text{ FT AFT } Ø$$

(b) FIND: Δ, LCG, DRAFTS AFTER HELO HAS LANDED.

HELO = 31,600 LB = 14.11 LT AT 165.0 FT AFT Ø

ITEM	WT, LT	l.c.g., FT	MOM'T
ORIGINAL SHIP	3270	0.0 A	0
HELO	14.11	165.0 A	2328 A
Σ	3284.11	0.709 A	2328 A

AT $\Delta_1 = 3284$ LT THE MOM'T TO TRIM ONE INCH IS:

MT1" = 718 FT-TONS/INCH OF TRIM.

THE TRIMING MOM'T FROM TABLE ABOVE

$T.M._1 = 2328$ FT-TONS

AND THE TRIM WILL BE:

$$\text{TRIM} = \frac{2328 \text{ FT-TONS/IN}}{718 \text{ FT-TONS}} = 3.24 \text{ IN.}$$

THE SHIP WILL TRIM ABOUT THE LCF, WHICH FOR THIS CASE IS 22.3 FT AFT OF Ø. FOR LARGE TRIMS THE TRIM SHOULD BE DISTRIBUTED PROPORTIONATELY (NEXT PG)

ABOUT THE LCF, BUT FOR SMALL TRIMS SUCH AS THIS IT IS SUFFICIENTLY ACCURATE TO DISTRIBUTE HALF FORWARD AND HALF AFT.

THE SINKAGE WILL BE: $\dfrac{\text{ADDED WEIGHT}}{\text{MOM'T TRIM ONE INCH}}$

$$\text{SINKAGE} = \frac{14.11 \text{ LT}}{31.4 \text{ LT/IN}} = 0.45 \text{ IN}$$

$$\begin{aligned} T_{m_1} &= 14' - 0.45 \text{ IN} \\ \delta_A &= \underline{(+)\,1.62 \text{ IN}} \\ T_{a_1} &= 14' - 2.07 \text{ IN} \end{aligned} \qquad \begin{aligned} T_{m_1} &= 14' - 0.45 \text{ IN} \\ \delta_f &= \underline{(-)\,1.62 \text{ IN}} \\ T_{f_1} &= 13' - 10.83'' \end{aligned}$$

NOTES: SINCE THE WEIGHT IS ADDED AFT THE DRAFT AFT WILL INCREASE AND THE DRAFT FWD WILL DECREASE.

READING DRAFTS TO A HALF INCH TAKES SOME IMAGINATION, SO DECIMALS OF AN INCH DON'T HAVE MUCH SIGNIFICANCE, BUT IN CASES OF MULTIPLE CHANGES SOMETIMES THE DECIMALS ACCUMULATE. CARRY THE NEAREST TENTH OF AN INCH TO THE END OF THE PROBLEM, THEN ROUND.

(b)

$$\boxed{\begin{aligned} \Delta_1 &= 3284 \text{ LT.} \\ LCG &= 0.709 \text{ FT AFT } \otimes \\ T_f &= 13'-10.8'' \\ T_{a_1} &= 14'-2.1'' \end{aligned}}$$

(c) FIND: WEIGHT, w, TO BE SHIFTED THRU A DISTANCE OF 60.0 FT TO RESTORE THE SHIP TO LEVEL TRIM

THE TRIMING MOM'T WAS FOUND TO BE 2328 FT-TONS A. TO REMOVE THE TRIMING MOM'T SHIFT w FORWARD

$$w \times 60.0' = 2328 \text{ FT-TONS}$$

$$\underline{\underline{w = 38.8 \text{ LT}}}$$

BASIC NAVAL ARCHITECTURE

Unit Number:	14
Title:	The ship at rest - static stability - 4
Tape Running Time:	27^M 20^S
Reading Assignment:	MSD, pp 329-331
Additional References:	PNA, pp 99-103 (repeated)

Scope:

The treatment of static stability is concluded by examples of determination of drafts and list following multiple weight additions and/or removals.

Key Points to Emphasize:

1. Review example given.
2. Emphasize that same tabular procedure is followed for weight removals, except that sign is changed in weight and moment columns.

Suggested Problem Assignment: one of 19, 20, 33, one of 39, 40, 41

STATIC STABILITY (CON'T)

WEIGHT ADDITIONS

LARGER WEIGHTS OR MULTIPLE WEIGHTS

- USE TABULAR FORMAT. (NOTE: CAN ALSO USE THIS METHOD FOR SMALL WEIGHT CASE)

ITEM	WEIGHT	CG	MOMENT

- ILLUSTRATE BY EXAMPLE.

STATIC STABILITY (CON'T)

WEIGHT ADDITION EXAMPLE

A FFG-7 FRIGATE IS IN A SHIPYARD (SALT WATER) FITTING OUT FOR SEA. THE SHIP IS UPRIGHT. THE DRAFTS AND KG ARE:

$T_f = 12' - 3"$

$T_a = 13' - 9"$

$KG = 20.10$ FT A.K.

THE FOLLOWING WEIGHTS ARE ADDED:

	wt	lcg	vcg	tcg
AMMO	80	130.0F	29.0	0.0
STORES	60	150.0A	15.0	5.0 PORT
FUEL OIL	40	52.0F	3.0	0.0

FIND DRAFTS AND LIST AFTER WEIGHT ADDITION.

STATIC STABILITY (CON'T)

WEIGHT ADDITION EXAMPLE (CON'T)

1. FIND DISPLACEMENT AND HYDROSTATICS IN ORIGINAL CONDITION

T_f = 12'-3" = 12.25'

T_a = 13'-9" = $\underline{13.75'}$

T_m = 13.00'

AT T_m = 13.00' Δ = 2,910 LT

LCB = 2.65 FT F

LCF = 18.9 FT A

TPI = 30.2 TONS/IN

MTI = 652 FT-TONS/IN

NOTE: BE CAREFUL OF SCALES WHEN READING CURVES.

STATIC STABILITY (CON'T)

WEIGHT ADDITION EXAMPLE (CON'T)

THE DISPLACEMENT MUST BE CORRECTED FOR 1.50 FT TRIM AFT, BUT - CDITA CURVE IS NOT GIVEN FOR FFG-7. USE FORMULA,

$$\text{CDITA} = 12\,\frac{\text{TPI}\cdot\text{LCF}}{\text{L}}$$

$$\text{CDITA} = \frac{(12\ \text{IN/FT})(30.2\ \text{TONS/IN})(18.9\ \text{FT})}{(408\ \text{FT})}$$

$$\text{CDITA} = +16.8\ \text{TONS/FT}$$

LCF IS AFT AND TRIM IS AFT SO SIGN IS +

$$\Delta = 2{,}910\ \text{LT}$$

$$\text{CORR} = \underline{+\ 25\ \text{LT}}$$

$$\Delta_0 = 2{,}935\ \text{LT}$$

STATIC STABILITY (CON'T)

WEIGHT ADDITION EXAMPLE

2. FIND LCG IN ORIGINAL CONDITION. LCG IS NOT GIVEN IN CURVES, BUT LCB IN LEVEL TRIM CONDITION IS. TO FIND THE LCG SHIFT WHICH CAUSED THE TRIM, USE:

$$\text{TRIMMING MOMENT} = \text{TRIM} \times \text{MTI}$$

THEN LONGITUDINAL SHIFT,

$$CG_o = \frac{\text{TRIM MOM'T}}{\triangle}$$

STATIC STABILITY (CON'T)

WEIGHT ADDITION EXAMPLE (CON'T)

TRIMMING MOMENT = (18 IN)(652 FT-TONS/IN)

T.M. = 11,736 FT-TONS

$GG_O = \frac{11,736 \text{ FT-TONS}}{2,935 \text{ TONS}}$

GG_O = 4.00 FT A

LEVEL TRIM LCG = LCB = 2.65 FT F

LCG_O = 1.35 FT A

STATIC STABILITY (CON'T)

WEIGHT ADDITION EXAMPLE (CON'T)

3. WE ARE NOW READY TO DO THE CALCULATION <u>IN TABULAR FORMAT</u>.

ITEM	WT	LCG	LM	VCG	VM	TCG	TM
ORIG SHIP	2,935	1.35 A	3,962A	20.10	58,994	0.0	0
AMMO	80	130.0 F	10,400 F	29.00	2,320	0.0	0
STORES	60	150.0 A	9,000 A	15.00	900	5.0 P	300 P
FUELOIL	40	52.0 F	2,080F	3.00	120	0.0	0
NEW SHIP	3,115	0.15A	482A	20.01	62,334	0.096P	300P

STATIC STABILITY (CON'T)

WEIGHT ADDITION EXAMPLE (CON'T)

4. FIND NEW DRAFTS.

FROM CURVES OF FORM AT NEW DISPLACEMENT:

AT $\Delta_1 = 3115$, T_{LCF} = 13.60 FT = 13'-7¼"

LCB = 1.00 FT F

LCF = 21.10 FT A

TPI = 30.92 TONS/IN

MTI = 693 FT-TONS/IN

STATIC STABILITY (CON'T)

WEIGHT ADDITION EXAMPLE (CON'T)

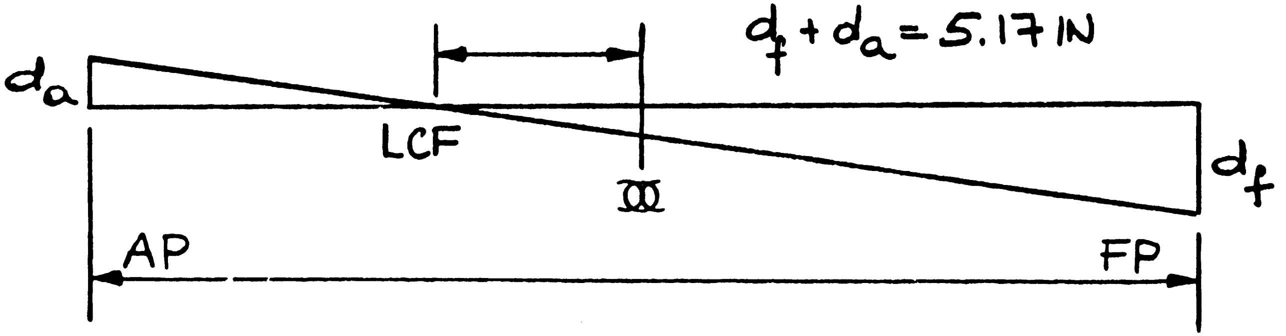
LEVEL TRIM LCB = LEVEL TRIM LCG = 1.00 FT F

NEW SHIP LCG_1 = 0.15 FT A

TRIMMING LEVER = 1.15 FT (AFT)

$$\text{TRIM. MOM'T.} = \Delta \cdot \text{TRIM. LVR.} = 1.15 \cdot 3115 = 3582 \text{ FT-TONS}$$

$$\delta \text{Trim} = \frac{\text{TRIM. MOM'T}}{\text{MTI}} = \frac{3582 \text{ FT-TONS}}{693 \text{ FT-TONS/IN}} = 5.17 \text{ IN}$$



STATIC STABILITY (CON'T)

WEIGHT ADDITION EXAMPLE (CON'T)

$$d_f = 5.17 \times \frac{204.0 + 21.10}{408.0}$$

$$d_f = 2.85 \text{ IN}$$

$$d_a = 2.32 \text{ IN}$$

$$T_{LCF} = 13'\text{-}7\tfrac{1}{4}''$$

$$d_a = \underline{(+)2\tfrac{1}{4}''}$$

$$T_a = 13'\text{-}9\tfrac{1}{2}''$$

$$= 13'\text{-}7\tfrac{1}{4}''$$

$$d_f = \underline{(-)2\tfrac{3}{4}''}$$

$$T_f = 13'\text{-}4\tfrac{1}{2}''$$

STATIC STABILITY (CON'T)

WEIGHT ADDITION EXAMPLE (CON'T)

5. WE MUST STILL FIND THE ANGLE OF LIST.

USE: $GM \tan \phi = \frac{wt}{\Delta}$

FROM CURVES OF FORM AT Δ_1 = 3115 LT:

KM_T = 22.55 A. ℄

KG_1 = 20.01 A. ℄

G_1M_T = 2.54 FT

FROM TABULAR CALC. wt = 300 FT-TONS

$$\tan \phi = \frac{(300 \text{ FT-TONS})}{(2.54 \text{ FT})(3115 \text{ TONS})} = .0379$$

$$\phi = 2.2^\circ \text{ (PORT)}$$

STATIC STABILITY (CON'T)

WEIGHT ADDITION EXAMPLE (CONCLUDED)

RECAP: AFTER WEIGHT ADDITIONS THE DRAFTS AND ANGLE OF LIST WILL BE

$$T_f = 13' - 9\tfrac{1}{2}''$$

$$T_a = 13' - 4\tfrac{1}{2}''$$

$$\text{LIST} = \phi = 2.2^\circ \text{ (PORT)}$$

STATIC STABILITY (CON'T)

WEIGHT REMOVALS

SAME PROCEDURE AS WEIGHT ADDITIONS, EXCEPT -

1. MINUS SIGN IN WEIGHT COLUMN

2. MINUS SIGN IN WEIGHT COLUMN CHANGES THE SIGN IN MOMENT COLUMNS.

Problem 19

Problem Level: Basic

Refer to the Curves of Form for the FFG7-type frigate. Note that there is no curve provided for Correction to Displacement due to One Foot Change of Trim by the Stern (CD1TA)

The formula for this parameter is:

$$\text{CD1TA} = \frac{A_{wp} \times \text{LCF}}{35\ L_{pp}}$$

where the LCF is measured from midships and is taken as positive aft

The waterplane area, A_{wp}, may be found from the relationship for Tons per Inch Immersion, (TPI)

$$\text{TPI} = \frac{A_{wp}}{420}$$

(1) Derive a formula for CD1TA in terms of TPI, LCF, and L_{pp}

The location of the LCG in the level trim condition may be found from the Curves of Form by finding the LCB at the level trim draft, since the LCB and the LCG are always in a vertical line. To find the shift in the LCG that has caused the ship to assume a trimmed attitude use the following relationships:

$$\text{Trim} = \quad = T_a - T_f$$

$$\text{Shift in G} = GG_1 = \frac{\text{MTI} \times \text{Trim}}{\Delta}$$

where MTI = Moment to Trim One Inch

(2) An FFG7-type frigate is floating at the following drafts:

T_f = 12'-6"

T_a = 15'-0"

Find: LCG, LCB, LCF, KB, KM_T, MTI, TPI, A_{wp}, A_m, CD1TA, Δ .

BASIC NAVAL ARCHITECTURE

Problem 20

Problem Level: Basic

A PD-214-type container ship is alongside a dock in a shipyard in fresh water (36.0 ft^3/ton) at the following drafts:

$$T_f = 29'-0''$$

$$T_a = 29'-0''$$

Find the displacement and LCG in this condition.

The ship now steams out to sea. Find the drafts at sea with the following fuel oil burn-off:

Item	Wt lt	LCG Ft from Midships
Fuel Burned	230.00	38.00 F

BASIC NAVAL ARCHITECTURE

Problem 33

Problem Level: Basic

Using "Displacement and Other Curves" for a DD692 Class destroyer furnished in Modern Ship Design, find the displacement (s.w.) and LCG of the ship at the following drafts.

$$T_f = 13'\text{-}0''$$

$$T_a = 14'\text{-}6''$$

BASIC NAVAL ARCHITECTURE

Problem 39

Problem Level: Basic

A PD-214-type container ship has the following weight breakdown in the full load condition:

Item	Weight lt	VCG Ft above B_L	LCG Ft from Midships
Lightship	12270	38.00	30.60 A
Crew and Effects	20	89.00	170.00 A
Stores	30	52.50	124.50 A
Potable Water	200	14.50	137.00 A
Boiler Feed Water	200	2.80	151.30 A
Lube Oil	50	8.00	190.20 A
Diesel Oil	1	1.80	190.20 A
Fuel Oil	2300	14.00	38.10 F
Containers @ 19.45 lt			
Hold: 411		37.50	8.00 F
On deck-2 high: 142		75.20	8.00 F
On deck-3rd tier: 61		88.00	21.50 A
S.W. Ballast	1860	2.60	58.40 F

Find:

Deadweight
Drafts, forward and aft, with all weights on board except containers and s.w. ballast
Drafts, forward and aft, LCG and KG in the Full Load condition
GM_t in the Full Load condition without free surface correction

Note: Use tabular format for CG calculations.

Problem 40

Problem Level: Intermediate

A PD-214-type containership is in salt water alongside a loading pier. The drafts and estimated KG are:

T_f = 24'-6"

T_a = 28'-0"

KG = 29.80 FT a. K

(1) Find the displacement and LCG in this condition.

(2) Twenty containers with an average weight of 20 tons each are shifted forward from Hold #5 to Hold #2, distance of 260.0 ft. KG after the shift remains the same. Find the LCG and drafts in this condition.

(3) After the container shift the ship has a list of 5° to starboard. How many more containers at 20 tons each can be loaded to bring the ship to level trim at her full load draft of 30'-0"? The added containers will be placed on deck and in holds with an average VCG for the added load of 78.60 feet above the keel. What will be the required longitudinal and transverse center of gravity of the added container cargo to achieve level trim with no list?

Problem 41

Problem Level: Intermediate

The FFG-7-type frigate of Problem 35 is at sea with the following drafts and KG:

T_f = 14'-0"

T_a = 14'-0"

KG = 18.00' above bottom of keel

(a) Convert the Righting Arms found in Problem 35 to Righting Moments by means of the relationship:

Righting Moment = G2·Δ

Plot the curve of Righting Moments versus Angle of Inclination, Θ .

Righting Moments: 1" = 2000 ft-tons

Angle of Inclination: 1" = 10°

(b) Calculate the Dynamical Stability in increments of 10° up to 60°. Plot on the same scale as for Righting Moments.

Recall that Dynamical Stability is the area under the Static Stability Curve when that curve is plotted as Righting Moment versus Angle of Inclination in radians. 1 radian = $180/\pi$ = 57.3 degrees. Use the Trapezoidal Rule to calculate areas. Ref: Gillmer, pp 333.

(c) A heeling arm due to beam wind has been calculated and is represented by the equation:

Wind heeling arm = $1.50 (\cos \Theta)^2$

where Θ is the Angle of Inclination. Calculate the Wind heeling moments and plot on the same plot. Determine the angle of steady heel due to a beam wind.

(1) $$\text{CD1'TA} = \frac{A_{WP} \times LCF}{35 \times L_{PP}}$$

AND, $A_{WP} = 420 \times TPI$

$$\therefore \text{CD1'TA} = \frac{\overset{12}{\cancel{420}} \times TPI \times LCF}{\cancel{35} \times L_{PP}}$$

$$\boxed{\text{CD1'TA} = \frac{12 \times TPI \times LCF}{L_{PP}}}$$

(2) FFG7 FLOATING AT

$T_f = 12'-6''$

$T_a = 15'-0''$

$T_m = 13'-9'' = 13.75'$

TRIM = 2.50' AFT

AT $T_M = 13.76'$,

$\Delta_0 = 3170$ LT

TPI = 31.10 LT/IN

LCF = 21.60 FT AFT ℄

$L_{PP} = 408.00$ FT

$$\therefore \text{CD1'TA} = \frac{(12\ \text{IN/FT})(31.10\ \text{LT/IN})(21.60\ \text{FT})}{408.00\ \text{FT}}$$

CD1'TA = 19.76 LT / FOOT OF TRIM

FOR 2.50' TRIM AFT, CORR = (+ 2.50)(19.76)

CORR = +49 LT.

$\Delta_0 = 3170$ LT

CORR = + 49 LT

$$\boxed{\Delta_1 = 3219\ \text{LT.}}$$

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(2) (CON'T)

AT A LEVEL TRIM AND $T_M = 13.75'$, LCB = 0.60 FT FWD

MTI = 705 FT-TON/IN

$$G_0G_1 = \frac{\text{TRIMMING MOM'T}}{\Delta} = \frac{(705 \frac{\text{FT-TON}}{\text{IN}})(30 \text{ IN})}{3219 \text{ TON}}$$

SHIFT DISTANCE = G_0G_1 = 6.57 FT AFT

$LCB_0 = \underleftarrow{LCG_0 = 0.60 \text{ FT FWD}} ⊗$

$$\boxed{LCB_1 = LCG_1 = 5.97 \text{ FT AFT } ⊗}$$

FROM CURVES OF FORM ~

KB = 8.50 FT A. $\underline{B}$

KM_T = 22.52 FT A. $\underline{B}$

TPI = 31.10 LT/IN.

$A_{WP} = 420 \times 31.10 = 13{,}062 \text{ FT}^2$

FROM BONJEAN'S CURVES ~

$A_m = 450 \text{ FT}^2$

RECAP:

LCG = 5.97 FT AFT ⊗
LCB = 5.97 FT AFT ⊗
LCF = 21.60 FT AFT ⊗
KB = 8.50 FT A. $\underline{B}$.
KM_T = 22.52 FT A. $\underline{B}$.
MTI = 705 FT-TON/INCH
TPI = 31.10 LT/IN
A_{WP} = 13,062 FT^2
A_m = 450 FT^2
CDI'TA = 19.76 LT/FT TRIM
Δ = 3219 LT (SW)

A PD-214 TYPE CONTAINER SHIP IS IN FRESH WATER AT DRAFTS:

$$T_f = 29'-0''$$
$$T_a = 29'-0''$$

FROM THE CURVES OF FORM WE FIND -

IN SALT WATER $\Delta = 27.7(1000) = 27,700$ LT

AND LCB = 4.30 FT AFT ⊗

IN FRESH WATER, $\Delta_{fw} = \frac{35.0 \text{ FT}^3/\text{LT}}{36.0 \text{ FT}^3/\text{LT}} \times 27,700$

$$\Delta_{fw} = 26,931 \text{ LT}$$

SINCE THE LCB IS THE CENTROID OF THE UNDERWATER VOLUME, IT IS RELATED ONLY TO DRAFTS, AND NOT TO WATER DENSITY. ALSO SINCE THE LCG AND THE LCB MUST ALWAYS BE AT THE SAME LONGITUDINAL LOCATION. THUS THE CONDITION OF THE SHIP ALONGSIDE THE DOCK IS -

$$\Delta_{fw} = 26,931 \text{ LT}$$

LCB = LCG = 4.30 FT AFT ⊗

NEXT, TO FIND THE EFFECT OF FUEL OIL BURN-OFF, USE TABULAR FORMAT.

ITEM	WEIGHT LT	CG FM ⊗	MOM'T FT TONS
ORIGINAL SHIP	26,931	4.30 A	115,803 A
F.O. BURN OFF	− 230	38.50 F	8,855 A
SHIP AT SEA	26,701	4.67 A	124,658 A

NOTES:

(1) SINCE THE F.O. BURN OFF HAS A MINUS SIGN THIS CHANGES THE SIGN ON THE MOM'T FROM F TO A.

(2) THE CG IS OBTAINED SIMPLY BY DIVIDING THE MOMENT BY THE WEIGHT, $\frac{124,658 \text{ A}}{26,701} = 4.67 \text{A}$

(CON'T)

NOW, TO FIND THE MEAN DRAFT AT SEA, GO BACK INTO THE CURVES OF FORM WITH THE NEW DISPLACEMENT ~

@ 26,701 LT SALT WATER, T_m = 28.15 FT A.B.L.

AND, AT LEVEL TRIM, LCB = 3.80 FT AFT ⊈

SINCE THE LCG AT SEA IS AFT OF THE LEVEL TRIM LCB THE SHIP WILL TRIM DOWN BY THE STERN UNTIL THE TWO ARE ALIGNED.

LEVEL TRIM LCB = 3.80 FT A

LCG = 4.67 FT A

TRIM LEVER = 0.87 FT A

TRIM MOMENT = 0.87 × 26,701 FT TONS

T.M. = 23,230 FT-TONS

FROM THE CURVES OF FORM AT THE NEW DRAFT THE MOMENT TO TRIM ONE INCH IS,

MTI = 2658 FT-TONS / INCH TRIM

AND THE TRIM WILL BE

$$\text{TRIM} = \frac{\text{TRIMMING MOMENT}}{\text{MTI}} = \frac{23{,}230 \text{ FT-TONS}}{2658 \ \frac{\text{FT-TONS}}{\text{IN}}}$$

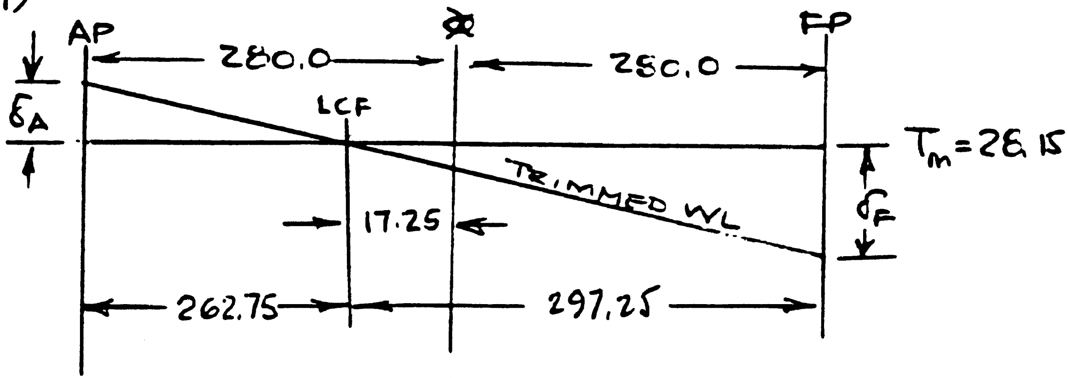
TRIM = 8.73"

THE SHIP WILL TRIM ABOUT THE LCF WHICH, IN GENERAL, NOT AMIDSHIPS. THUS THE TOTAL TRIM IS NOT EVENLY DIVIDED BETWEEN THE DRAFTS FORE AND AFT, BUT MUST BE PROPORTIONED.

FROM THE CURVES OF FORM AT THE NEW DRAFT

LCF = 17.25 FT AFT ⊈

(CON'T)



$$(1) \quad \delta_A + \delta_F = 8.73''$$

$$\delta_A = 8.73'' - \delta_F$$

ALSO, BY SIMILAR TRIANGLES ~

$$\frac{\delta_A}{262.75} = \frac{\delta_F}{297.25}$$

$$\delta_F = \frac{297.25}{262.75} \delta_A$$

$$\delta_F = 1.13 \, \delta_A$$

$$\delta_F = 1.13(8.73'' - \delta_F)$$

$$2.13 \delta_F = 9.90$$

$$\delta_F = 4.64''$$

$$\delta_A = 4.09''$$

FINALLY, SINCE $T_m = 28.15' = 28' - 1.8''$

$$\begin{array}{lcl} T_m & = & 28' - 1.8'' \\ \delta_A & = & (+) \quad 4.1'' \\ \hline T_a & = & 28' - 5.9'' \end{array} \qquad \begin{array}{lcl} T_m & = & 28' - 1.8'' \\ \delta_F & = & (-) \quad 4.6'' \\ \hline T_f & = & 27' - 9.2'' \end{array}$$

SHAVING THE DRAFTS TO 1/10 INCH REALLY IS A BIT MUCH! FOR PRACTICAL PURPOSES ~

$$\boxed{\begin{array}{l} T_f = 27' - 9'' \\ T_a = 28' - 6'' \end{array}}$$

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GIVEN: DD692

$T_f = 13'-0"$

$T_a = 14'-6"$

$T_m = 13'-9"$

FIND: Δ, LCG

SOLUTION: AT $T_m = 13'-9"$, $\Delta = 3262$ LT

THE DISPLACEMENT MUST BE CORRECTED FOR 18" TRIM.

READ CURVE "ADDITION TO DISPLACEMENT DUE TO 1 FT CHANGE OF TRIM BY STERN. SCALE 100T = 2T."

AT $T_m = 13'-9"$ READ $CH\Delta 1' TA = 992 \times \frac{2T}{100T} = 19.84$ LT

$\Delta_{LEVEL\ TRIM} =$ $= 3262$ LT

CORR FOR 1.5 FT TRIM AFT $= 1.5 \times 19.84 = 29.76 =$ $+30$ LT

$\Delta =$ $= 3292$ LT

TO FIND THE LCG IN THE TRIMMED CONDITION FIRST FIND THE LCB IN THE LEVEL TRIM CONDITION,

THEN, $LCG_{LEVEL\ TRIM} = LCB_{LEVEL\ TRIM}$

THE SHIFT IN THE CG THAT CAUSED THE TRIM CONDITION WILL BE -

$$GG_1 = \frac{\text{TRIMMING MOMENT}}{\Delta}$$

AND, TRIMMING MOMENT $= MT1' \times$ TRIM.

FROM CURVE 12, AT $T_M = 13'-9"$,

$MT1" = 635$ FT-TONS/INCH OF TRIM

(CON'T)

THEN, TRIMMING MOMENT = $635 \frac{\text{FT-TONS}}{\text{IN}} \times 18 \text{ IN}$

TRIMMING MOMENT = 11,430 FT-TONS

$$GG_1 = \frac{11{,}430 \text{ FT-TONS}}{3292 \text{ LT}} = 3.47 \text{ FT. (AFT)}$$

THE SHIFT WILL BE IN THE AFT DIRECTION SINCE THE TRIM IS BY THE STERN.

AT LEVEL TRIM, FROM CURVE 4 AT $T_M = 13'\text{-}9''$

$$LCB = 430 \text{ TONS} \times \frac{2 \text{ FT}}{100 \text{ TONS}}$$

LCB = LCG = 8.60 FT AFT STA 10

$\underline{GG_1 = 3.47 \text{ FT (AFT)}}$

LCG_1 = 12.07 FT AFT STA 10 (¢)

Δ = 3292 LT

LCG = 12.07 FT AFT ¢

GIVEN: WEIGHTS AND CTRS FOR PD-214

FIND: DEADWEIGHT; DRAFTS IN LIGHTSHIP AND FULL LOAD CONDITION; LCG, KG, GM_t IN FULL LOAD CONDITION

NOTE: USE TABULAR FORMAT FOR CALCULATIONS

ITEM	WEIGHT, LT	VCG FT a. BL	V. MOM'T FT-TONS	LCG FT FM ⊗	L. MOM'T FT-TONS
LIGHTSHIP	12 270.00	38.00	466 260.0	30.60 A	375462.0 A
CREW AND EFFECTS	20.00	89.00	1780.0	170.00 A	3400.0 A
STORES	30.00	52.50	1575.0	124.50 A	3735.0 A
POTABLE WATER	200.00	14.50	2900.0	137.00 A	27400.0 A
BOILER FEED	200.00	2.80	560.0	151.30 A	30260.0 A
LUBE OIL	50.00	8.00	400.0	190.20 A	9510.0 A
DIESEL OIL	1.00	1.80	1.8	190.20 A	190.2 A
FUEL OIL	2300.00	14.00	32 200.0	38.10 F	87630.0 F
SUBTOTAL	15 071.00	33.55	505 676.8	24.04 A	362 327.2 A
CONTAINERS: HOLD	7993.95	37.50	299 773.13	8.00 F	63 951.6 F
ON-DK, 2 HIGH	2761.90	75.20	207 694.88	8.00 F	22095.2 F
ON DK, 3RD TIER	1186.45	88.00	104 407.6	21.50 A	25508.7 A
SW BALLAST	1860.00	2.60	4836.0	58.40 F	108624.0 F
TOTAL	28 873.30	38.87	1 122388.4	6.69 A	193 165.1 A

NOTE: CONTAINER WEIGHTS OBTAINED BY MULTIPLYING AVERAGE WEIGHT PER CONTAINER, 19.454, BY THE NUMBER OF CONTAINERS.

a) DEADWEIGHT = FULL LOAD Δ − LIGHT SHIP Δ

$$\Delta_{FULL\ LOAD} = 28,873.30 \quad LT$$

$$\Delta_{LIGHT\ SHIP} = \underline{12,270.00} \quad LT$$

DEADWEIGHT = 16,603.3 LT

b) NOTE: WEIGHTS AND CENTERS FOR THE CASE "ALL WEIGHTS ON BOARD EXCEPT CONTAINERS AND S.W. BALLAST" IS SHOWN IN TABULATION ON LINE MARKED 'SUBTOTAL'

Δ = 15071.0 LT ; LCG = 24.04 FT AFT ⊄

THE TRIMING ARM WILL BE THE DIFFERENCE BETWEEN THE ACTUAL LCG AND THE LEVEL TRIM LCB GIVEN IN THE CURVES OF FORM

FROM THE CURVES OF FORM AT Δ = 15071 LT

T_m = 17.12 FT

MT1" = 2174 FT-TONS/IN

LCB = 1.00 FT FWD ⊄

THE TRIMINGARM WILL BE

LCB = 1.00 FT F
LCG = 24.04 FT A

T.A. = 25.04 FT A

AND THE TRIMING MOMENT WILL BE,

T.M. = (25.04 FT A)(15071 LT)

T.M. = 377,378 FT-TONS

AND THE TRIM WILL BE :

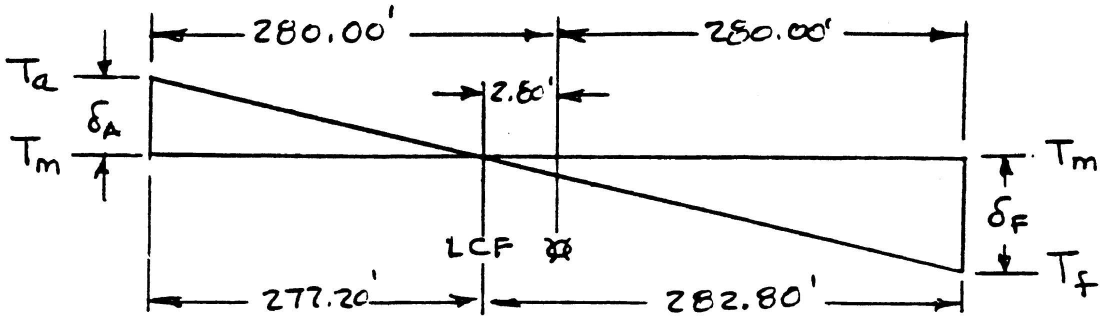
$$TRIM = \frac{TM}{MT1"} = \frac{377,378 \text{ FT-TONS}}{2174 \text{ FT-TONS/IN}}$$

TRIM = 173.6 IN

THIS TRIM IS SUFFICIENTLY LARGE TO BE DISTRIBUTED IN PROPORTION TO THE LOCATION OF THE LCF

AT T_m = 17.12 FT, LCF = 2.80 FT AFT ⊗

(NOTE THAT READING THE CURVES TO TWO DECIMAL PLACES IS MOSTLY FICTION)



$$(1) \quad \delta_A + \delta_F = 173.6 \text{ IN}$$

$$(2) \quad \frac{\delta_A}{277.2} = \frac{\delta_F}{282.8}$$

$$\delta_A = \frac{277.2}{282.8}\delta_F = 0.980\,\delta_F$$

$$(1) \text{ AND } (2) \quad .980\,\delta_F + \delta_F = 173.6 \text{ IN}$$

$$1.98\,\delta_F = 173.6 \text{ IN}$$

$$\delta_F = 87.7 \text{ IN}$$

$$\delta_A = 85.9 \text{ IN}$$

(NOTE THAT USING THE LCF METHOD MAKES A DIFFERCE OF ABOUT AN INCH OF DRAFT F & A, IN THIS CASE. IN CASES IN WHICH THE LCF IS FURTHER AFT THE DIFFERENCE COULD BE LARGER.

T_m = 17.12' = 17'-1.4"
δ_A = (+) 7'-1.9"
T_a = 24'-3.3"

T_m = 17'-1.4"
δ_F = (-) 7'-3.7"
T_f = 9'-9.7"

WITH ALL WEIGHTS ON BOARD EXCEPT CONTAINERS AND SW BALLAST

T_f = 9'-9.7"
T_a = 24'-3.3"

(c) IN THE FULL LOAD CONDITION ~

$$\Delta = 28{,}873 \text{ LT}$$

LCG = 6.69 FT AFT ⊗

VCG = KG = 38.87 FT a.K.

FIND: DRAFTS AND GM_t (w/o F.S. CORRECTION)

FROM CURVES OF FORM AT $\Delta = 28{,}873$ LT

T_m = 30.08 FT.

LCB = 4.95 FT AFT ⊗

LCF = 20.18 FT AFT ⊗

MT1" = 2838 FT-TONS/IN

THE TRIMMING ARM WILL BE:

LCB = 4.95 FT AFT ⊗

LCG = 6.69 FT AFT ⊗

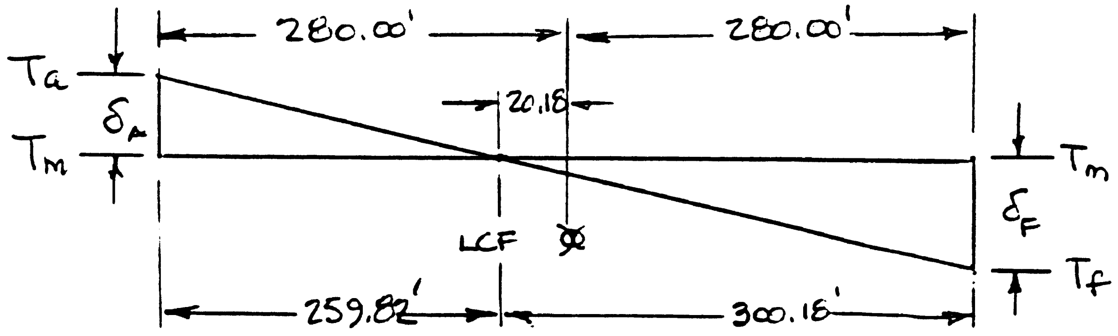
T.A. = 1.74 FT (AFT)

T.M. = 1.74 FT × 28873 LT

T.M. = 50239 FT-TONS (AFT)

$$\text{TRIM} = \frac{\text{T.M.}}{\text{MT1"}} = \frac{50239 \text{ FT-TONS}}{2838 \text{ FT-TONS/IN}}$$

TRIM = 17.7" (AFT)



$$(1) \quad \delta_A + \delta_F = 17.7''$$

$$(2) \quad \frac{\delta_A}{259.82} = \frac{\delta_F}{300.18}$$

$$\delta_A = .866\,\delta_F$$

$$(1)\text{ AND }(2) \quad .866\,\delta_F + \delta_F = 17.7''$$

$$1.866\,\delta_F = 17.7''$$

$$\delta_F = 9.5''$$

$$\delta_A = 8.2''$$

$$T_m = 30.08\text{ FT} = 30' - 1'' \qquad T_m = 30' - 1''$$

$$\delta_A = (+) \quad 8.2'' \qquad \delta_F = (-) \quad 9.5''$$

$$T_a = 30' - 9.2'' \qquad T_f = 29' - 3.5''$$

FIND GM_t: FROM CURVES OF FORM AT $T_m = 30.08$

$$KM_t = 40.80\text{ FT a. K.}$$

$$\underline{KG = 38.87\text{ FT a. K}}$$

$$GM_t = 1.93\text{ FT}$$

(c) IN THE FULL LOAD CONDITION:

$$T_f = 29' - 3.5''$$

$$T_a = 30' - 9.2''$$

$$LCG = 6.69\text{ FT AFT } \otimes$$

$$KG = 38.87\text{ FT a. K.}$$

$$GM_t = 1.93\text{ FT}$$

GIVEN: PD-214 IN SW WITH

$T_f = 24'-6''$

$T_a = 28'-0''$

$KG = 38.50$ FT a. K

(a) FIND Δ, LCG.

$T_f = 24'-6''$
$T_a = 28'-0''$

$T_M = 26'-3'' = 26.25'$

TRIM $= 3'-6'' = 3.50$ FT BY STERN

Δ AT $T_m = 26.25' = 24{,}550$ LT (SW)

THE DISPLACEMENT FOUND FROM THE CURVES OF FORM IS FOR LEVEL TRIM. THE ABOVE VALUE MUST BE CORRECTED FOR THE 3.50 FT TRIM BY THE STERN. USE THE CURVE "CORRECTION TO DISPL. FOR 1'-0" TRIM BY THE STERN".

AT $T_M = 26.25'$, CDI'TA $= +28.5$ LT

FOR 3.50' TRIM BY STERN $= 3.5 \times 28.5 = 99.75$ LT ≈ 100 LT

LEVEL TRIM Δ = 24,550 LT
TRIM CORRECTION = (+) 100 LT

CORRECTED Δ = 24,650 LT.

NOTE: AN ALTERNATE METHOD OF FINDING THE DISPLACEMENT IN A TRIMMED CONDITION IS TO FIND THE DRAFT AT THE LCF, THEN USE THIS DRAFT TO FIND THE DISPLACEMENT. TO FIND THE DRAFT AT THE LCF A SIMILAR TRIANGLE METHOD MAY BE EMPLOYED SIMILAR TO THE METHOD SHOWN IN PROBLEM 39.

CDI'TA IS GENERALLY EASIER, BUT THE SIGN CONVENTION IS TREACHEROUS. IF THE LCF AND THE TRIM ARE BOTH THE SAME (AFT, AFT) OR (FWD, FWD) THE CORRECTION IS ADDITIVE; OTHERWISE SUBTRACTIVE.

AT $T_m = 26.25$ FT FROM CURVES OF FORM THE LEVEL TRIM LCB = LEVEL TRIM LCG IS ~

$$LCG_{LT} = LCB_{LT} = 2.75 \text{ FT AFT ℄}$$

ALSO,

$$MT1'' = 2508 \text{ FT-TONS/IN.}$$

THE MOMENT CAUSING THE TRIM WILL BE ~

$$\begin{aligned} T.M. &= MT1'' \times \text{TRIM} \\ &= 2508 \text{ FT-TONS/IN} \times 3.50 \text{ FT} \times 12 \tfrac{\text{IN}}{\text{FT}} \\ T.M. &= 105,336 \text{ FT-TONS} \end{aligned}$$

AND THE SHIFT IN THE LCG REQUIRED TO GENERATE THIS TRIMING MOMENT WILL BE:

$$T.M. = GG_1 \times \Delta$$

$$GG_1 = \frac{105,336 \text{ FT-TONS}}{24,650 \text{ LT}}$$

$$\begin{aligned} GG_1 &= 4.27 \text{ FT (AFT)} \\ LCG_{LT} &= \underline{2.75 \text{ FT AFT ℄}} \end{aligned}$$

$$\underline{\underline{LCG_1 = 7.02 \text{ FT AFT ℄}}}$$

(b) FIND: LCG, DRAFTS AFTER SHIFT OF 20 CONTAINERS AT 20 LT EA. THRU 260.00 FT. FWD.

$$\text{SHIFT MOMENT} = 20 \text{ CONT} \times 20 \tfrac{\text{LT}}{\text{CONT}} \times 260.00 \text{ FT}$$

$$= 104,000 \text{ FT-TONS}$$

$$\text{LCG SHIFT} = G_1G_2 = \frac{104,000 \text{ FT-TONS}}{24,650 \text{ LT}} = 4.22' \text{ FWD.}$$

$$\begin{aligned} LCG_1 &= 7.02 \text{ FT AFT ℄} \\ G_1G_2 &= \underline{4.22 \text{ FT (FWD}} \end{aligned}$$

$$\underline{\underline{LCG_2 = 2.80 \text{ FT AFT ℄}}}$$

THE SHIP IS NOW NEARLY AT LEVEL TRIM. THE TRIMING MOMENT WILL BE ~

$$\begin{aligned} LCG_{LT} &= 2.75 \text{ FT AFT ℄} \\ LCG_2 &= \underline{2.80 \text{ FT AFT ℄}} \end{aligned}$$

$$\text{TRIMING ARM} = .05 \text{ FT (AFT)}$$

$$T.M. = .05' \times 24{,}650\ LT = 1232.5\ \text{FT-TONS}$$

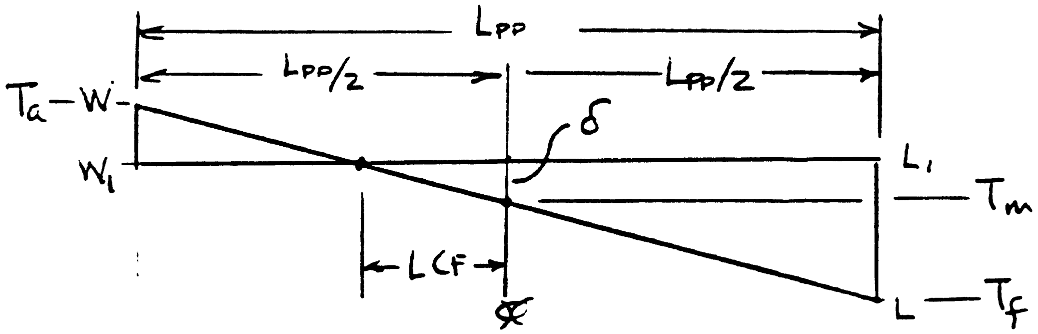
AND THE TRIM IS: $$TRIM = \frac{T.M.}{MT1''} = \frac{1232.5\ \text{FT-TONS}}{2508\ \text{FT-TONS/IN}}$$

$$TRIM = 0.5\ \text{IN. (AFT)}$$

THE NATURAL THING TO DO NOW WOULD BE TO PLACE HALF OF THIS TRIM FWD AND HALF AFT BASED ON THE ORIGINAL MEAN DRAFT - 26.25' - WRONG !!

FOR THIS PROBLEM THE DIFFERENCES ARE SMALL BUT FOR OTHER PROBLEMS THEY MAY NOT BE.

THE SHIP TRIMS ABOUT THE LCF. AFTER REMOVING THE TRIM THE SHIP WILL NOT FLOAT AT THE ORIGINAL MEAN DRAFT .



THE SHIP ORIGINALLY FLOATS AT WL WITH DRAFTS T_f AND T_a. IN THIS CONDITION THE MEAN DRAFT T_m IS THE DRAFT AMIDSHIPS.

AFTER SHIFTING WEIGHTS ON BOARD TO REMOVE THE TRIM THE SHIP WILL TRIM ABOUT THE LCF AND THE NEW WATERLINE WILL BE W_1L_1. FOR LCF AFT AND TRIM AFT THE DIFFERENCE, δ, WILL HAVE TO BE ADDED TO THE ORIGINAL T_m.

BY SIMILAR TRIANGLES,

$$\frac{\delta}{LCF} = \frac{TRIM}{L_{PP}}$$

$$\delta = \frac{TRIM \times LCF}{L_{PP}}$$

IT'S CDI"TA IN REVERSE, FROM THE CURVES OF FORM THE LCF AT $T_m = 26.25'$ = 14.60 FT AFT ⊗ {CLOSE ENOUGH}

FOR THIS PROBLEM, $\delta = \dfrac{3.50\ \text{FT} \times 14.60\ \text{FT}}{5600.00\ \text{FT}} = .091\ \text{FT}$

$$\delta = .091\ \text{FT} \times 12\ \text{IN/FT} = 0.5\ \text{IN}$$

THUS THE DRAFTS WITH TRIM REMOVED WILL BE.

$$\begin{aligned} T_m &= 26'-3'' \\ \delta &= (+)\quad 1.1'' \\ \hline T_{f_1} = T_{a_1} = T_{m_1} &= 26'-4.1'' \end{aligned}$$

NOW WE APPLY THE SMALL TRIM, 0.5 IN, HALF FWD AND HALF AFT. FOR LARGER TRIMS WE WOULD USE THE PROPORTIONAL TRIANGLE METHOD.

$$\begin{aligned} T_{m_1} &= 26'-4.1'' \\ \text{AFT } \tfrac{\delta}{2} &= (+)\quad .25 \\ \hline T_{a_2} &= 26'-4.35'' \end{aligned} \qquad \begin{aligned} T_{M_1} &= 26'-4 \\ \text{FWD } \tfrac{\delta}{2} &= (-)\quad .25 \\ \hline T_{f_2} &= 26'-3.85'' \end{aligned}$$

THE CORRECTIONS ARE HARDLY WORTH BOTHERING WITH IN THIS PROBLEM, BUT IN OTHER PROBLEMS THEY COULD BE WORTH THE TROUBLE.

NOTE: COMPARE THE RESULT OBTAINED USING THE δ METHOD ABOVE WITH THAT OBTAINED BY ENTERING THE CURVES OF FORM WITH $\Delta = 24{,}650$ LT. AS CLOSE AS CAN BE READ FROM THE CURVES $T_{M_1} = 26.3$ FT $= 26'-3.6''$ COMPARED TO $T_{M_1} = 26'-4.1$ IN ABOVE.

(b)

AFTER SHIFTING 20 CONTAINERS FORWARD THRU 260.00 FT;

$$LCG_2 = 2.80\ \text{FT AFT} ⊈$$

$$T_f = 26'-3.9''$$

$$T_a = 26'-4.4''$$

(C) FIND: NUMBER OF CONTAINERS TO BRING THE SHIP DOWN TO $T_f = T_a = 30'\text{-}0''$.

LCG OF ADDED CONTAINERS FOR LEVEL TRIM.

TCG OF ADDED CONTAINERS TO REMOVE 5° LIST TO STARBOARD

AT $T_M = T_f = T_a = 30'\text{-}0''$ FROM CURVES OF FORM

$\Delta_3 = 28{,}800$ LT (SW)

ORIGINAL DISPL. $\Delta = 24{,}650$ LT (SW)

REQ'D TO ADD: $= 4150$ LT

NUMBER OF CONTAINERS $= \dfrac{4150 \text{ LT}}{20 \text{ LT/CONT.}} = 207.5$ CONTAINERS

ROUN'D TO: 207 CONTAINERS TO BE ADDED

THEN, $\Delta_3 = 28{,}790$ LT.

AT $T_M = 30'\text{-}0''$ $LCG_3 = LCB_{L.T} = 4.90$ FT AFT Ø

ITEM	WT LT	LCG FT FM Ø	L. MOM'T FT-TONS
REQ'D SHIP	28,790	4.90 A	141,071 A
ORIG. SHIP	24,650	2.80 A	69,020 A
WT TO ADD	4140	17.40 A	72,051 A

THE LCG OF THE 207 ADDED CONTAINERS MUST BE

$LCG_{CONT} = 17.40$ FT AFT Ø

NEXT, FIND KG AFTER ADDING THE 207 CONTAINERS

ITEM	WT LT	VCG FT a K	V. MOMT FT-TONS
ORIG SHIP	24,650	29.80	734570
ADDED CONT'R	4,140	78.60	325404
REQ'D SHIP	28,790	36.82	1059974

THE NEW KG = KG_3 = 36.82 FT a. K.

FROM THE CURVES OF FORM AT $T_M = 30.00'$

$$KM_t = 40.80 \text{ FT a K.}$$

$$KG_3 = 36.82 \text{ FT a K}$$

$$G_3M_t = 3.98 \text{ FT.}$$

APPLY:

$$GM \tan\theta = \frac{w \times t}{\Delta}$$

$$(3.98 \text{ FT})(\tan 5^\circ) = \frac{4140 \text{ LT} \times t \text{ FT.}}{28,790 \text{ LT}}$$

$$t = 2,42 \text{ FT} \quad (\text{PORT})$$

(c)

ADD 207 CONTAINERS WITH AN AVERAGE LONG'L AND TRANSVERSE LOCATION OF

$$LCG_{CONT} = 17.40 \text{ FT AFT } \text{⊗}$$

$$TCG = 2.42 \text{ FT PORT}$$

(a) FROM PROBLEM 35, $\Delta = 3270$ LT. GZ AS GIVEN BELOW.

$$\text{RIGHTING MOMENT} = GZ \cdot \Delta$$

ANGLE OF INCLIN., DEG	GZ FT	RIGHTING MOMENT FT-TONS
0	0.000	0
10	0.757	2475
20	1.448	4735
30	2.102	6874
40	2.845	9303
50	3.346	10941
60	3.402	11125

(b) WE MAY CONVERT FROM DEGREES TO RADIANS BY MULTIPLYING ONCE BY $10°/57.3 \frac{\text{DEG}}{\text{RAD}}$ AT THE END.

θ	RM	0°–10°		0°–20°		0°–30°		0°–40°		0°–50°		0°–60°	
DEG	FT-TONS	TM	f(A)	TM	f(A)	TM	f(A)	TM	f(A)	TM	f(A)	TM	f(A)
0	0	½	0	½	0	½	0	½	0	½	0	½	0
10	2475	½	1238	1	2475	1	2475	1	2475	1	2475	1	2475
20	4735			½	2368	1	4735	1	4735	1	4735	1	4735
30	6874					½	3437	1	6874	1	6874	1	6874
40	9303							½	4652	1	9303	1	9303
50	10941									½	5471	1	10941
60	11125											½	5563
Σ			1238		4843		10647		18736		28858		39891
Area $= \Sigma \cdot \frac{10°}{57.3}$ (FT-TONS)			216		845		1858		3270		5037		6962

(c) WIND HEELING MOMENT = WIND HEEL. ARM × Δ

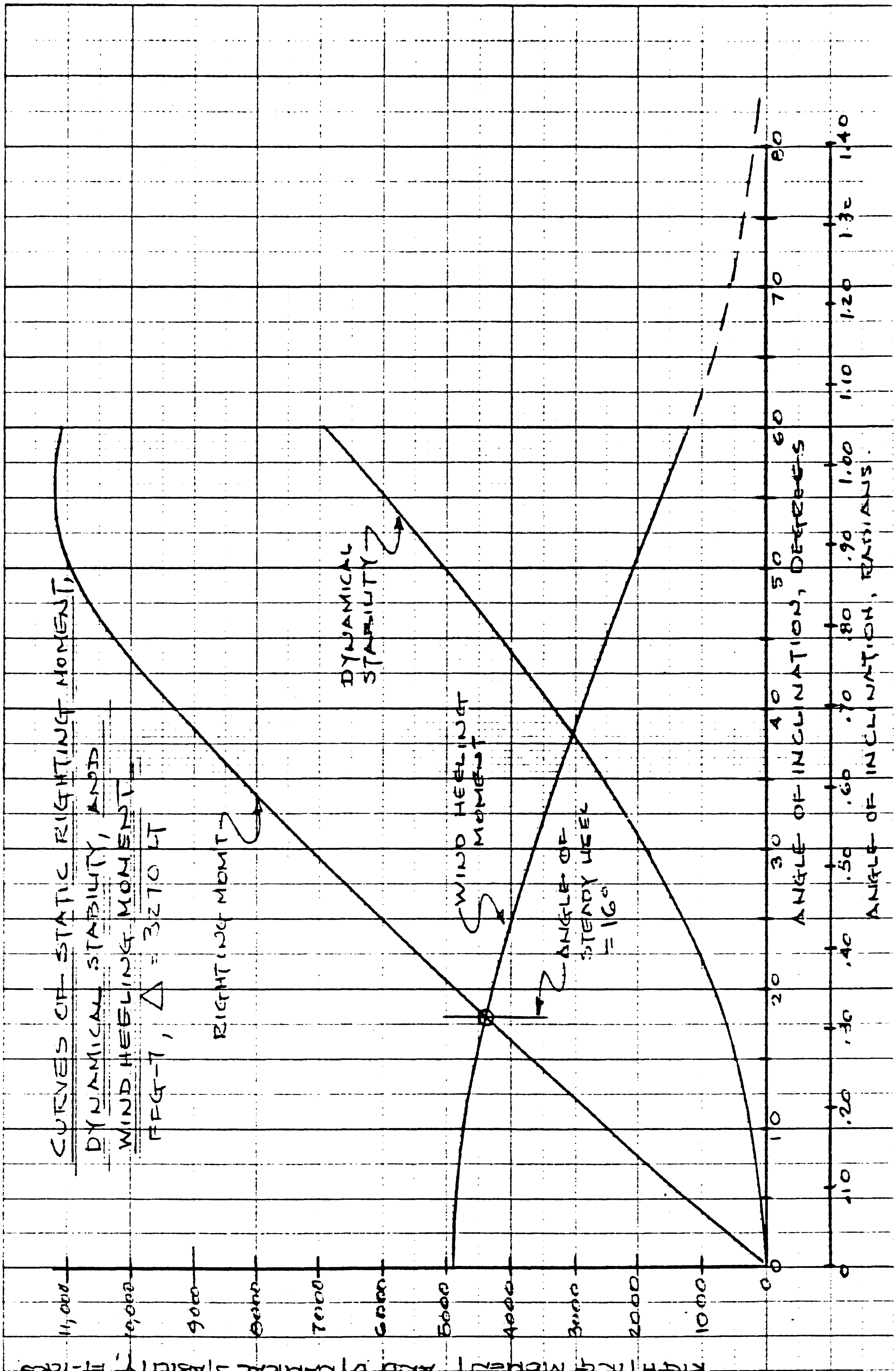
WIND HEELING ARM = $1.50(\cos\theta)^2$

ANGLE OF INCLINATION, θ, DEG.	W. H. A. = $1.50(\cos\theta)^2$ FT	W. H. M = W.H.A × 3270 FT-TONS
0	1.500	4905
10	1.455	4757
20	1.325	4331
30	1.125	3679
40	0.880	2878
50	0.620	2027
60	0.375	1226

FROM THE PLOT THE ANGLE OF STEADY HEEL WILL BE AT THE INTERSECTION OF THE WIND HEELING MOMENT AND THE RIGHTING MOMENT CURVES

ANGLE OF STEADY HEEL = 16°

PROBLEM 41 TDK/FRVMJR 2 MAR 87 3 of 3



BASIC NAVAL ARCHITECTURE

Unit Number: 15

Title: Ship hazards and vulnerability - 1

Tape Running Time: $30^M 25^S$

Reading Assignment: MSD, pp 71-76

Additional References: PNA, pp 78-88, 121-133, 141-149

Scope:

Floodable length definitions are introduced and the meaning of floodable length curves is explained. Free surface effects on the virtual rise in G are introduced.

Key Points to Emphasize:

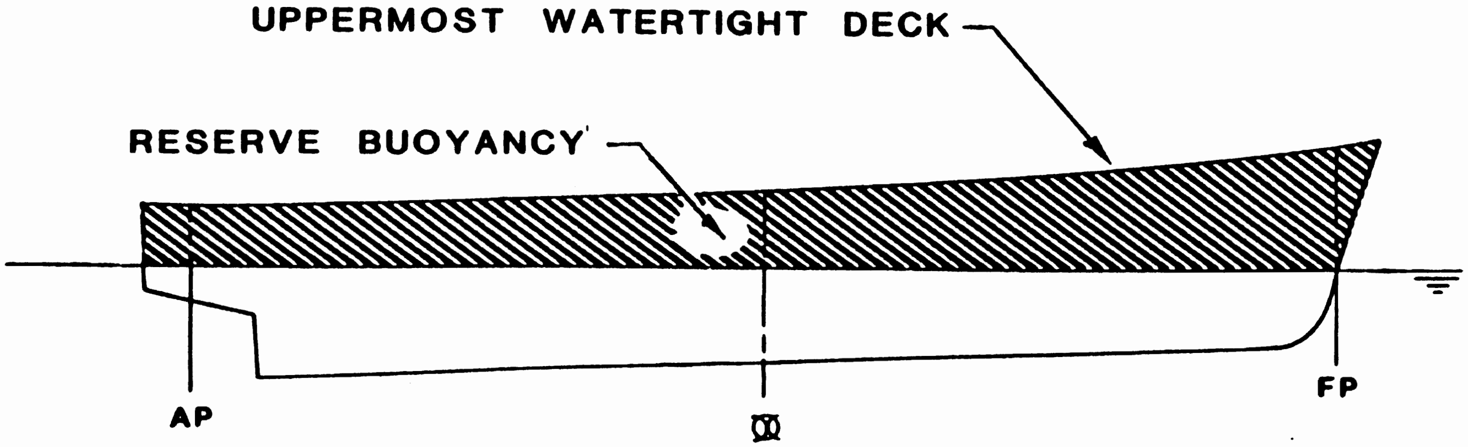
1. Review definitions of floodable length terms.
2. Emphasize typical shape of floodable length curves with minimum and maximum points.
3. Discuss influence of freeboard, sheer, form.
4. Discuss importance in setting bulkheads in early stage design.
5. Emphasize graphical interpretation using arc tan 2 triangles.
6. Explain Figure 4-3, MSD, pp 73. Discuss flooded stability.
7. Discuss free surface effect. Explain that the free surface creates a transverse weight shift that can be treated as a virtual rise in G.
8. Go over calculation of moment of inertia of free surface, density correction, effect on Static Stability Curve (Fig. 4-5, MSD, pp 75).
9. If time permits comment on paragraphs 5.9 and 5.10, PNA, pp 88.

Suggested Problem Assignment: 26, 42 or 43

SHIP HAZARDS AND VULNERABILITY

RESERVE BUOYANCY

RESERVE BUOYANCY IS THE TOTAL WATERTIGHT VOLUME CONTAINED BETWEEN THE WATERLINE AND THE UPPERMOST WATERTIGHT DECK



15.2

SHIP HAZARDS AND VULNERABILITY (CON'T)

RESERVE BUOYANCY IS ONE MEASURE OF A SHIP'S ABILITY TO SURVIVE DAMAGE.

WATERTIGHT SUBDIVISION, THAT IS THE LOCATION OF WATERTIGHT BULKHEADS, IS ALSO A VERY IMPORTANT FACTOR IN SHIP SURVIVABILITY.

THE LOCATION OF TRANSVERSE W.T. BULKHEADS IS LIMITED BY THE FLOODABLE LENGTH CURVE.

<u>SHIP HAZARDS AND VULNERABILITY (CON'T)</u>

<u>FLOODABLE LENGTH DEFINITIONS</u>

<u>BULKHEAD DECK.</u> THE BULKHEAD DECK IS THE UPPERMOST DECK TO WHICH THE TRANSVERSE WATERTIGHT BULKHEADS EXTEND.

<u>MARGIN LINE.</u> THE MARGIN LINE IS A LINE DRAWN PARALLEL TO AND THREE INCHES BELOW THE BULKHEAD DECK AT SIDE.

SHIP HAZARDS AND VULNERABILITY (CON'T)

FLOODABLE LENGTH DEFINITIONS

PERMEABILITY. PERMEABILITY IS THE PERCENTAGE OF VOLUME IN A SPACE WHICH CAN BE FLOODED

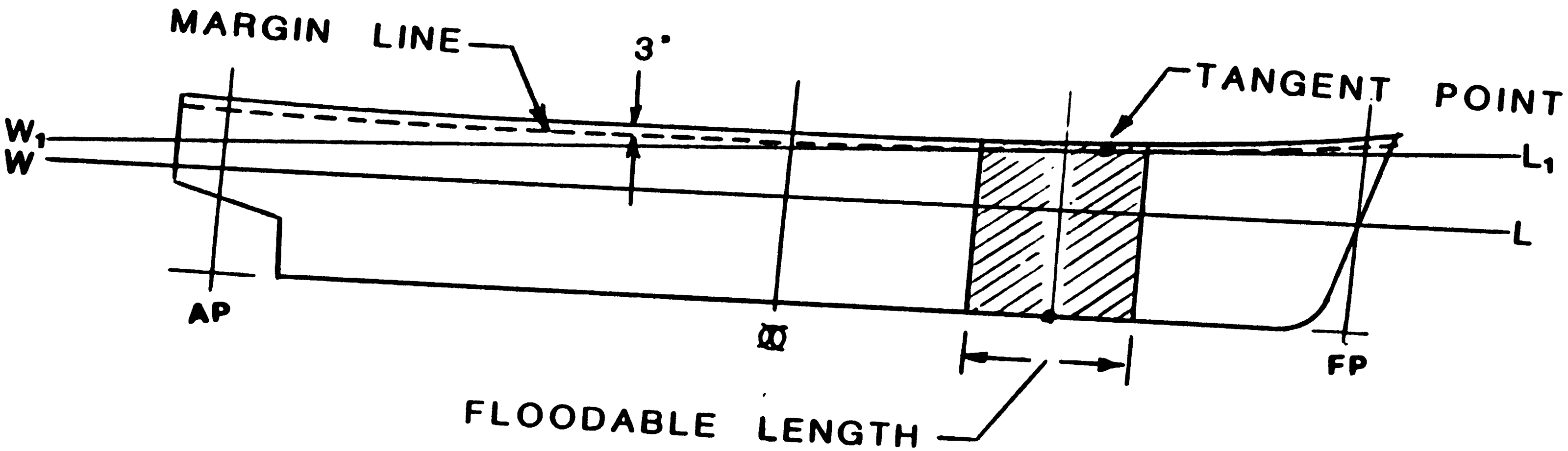
$$\mu = \frac{\text{AVAILABLE VOLUME}}{\text{TOTAL VOLUME}}$$

SHIP HAZARDS AND VULNERABILITY (CON'T)

FLOODABLE LENGTH DEFINITIONS

IMPORTANT !!

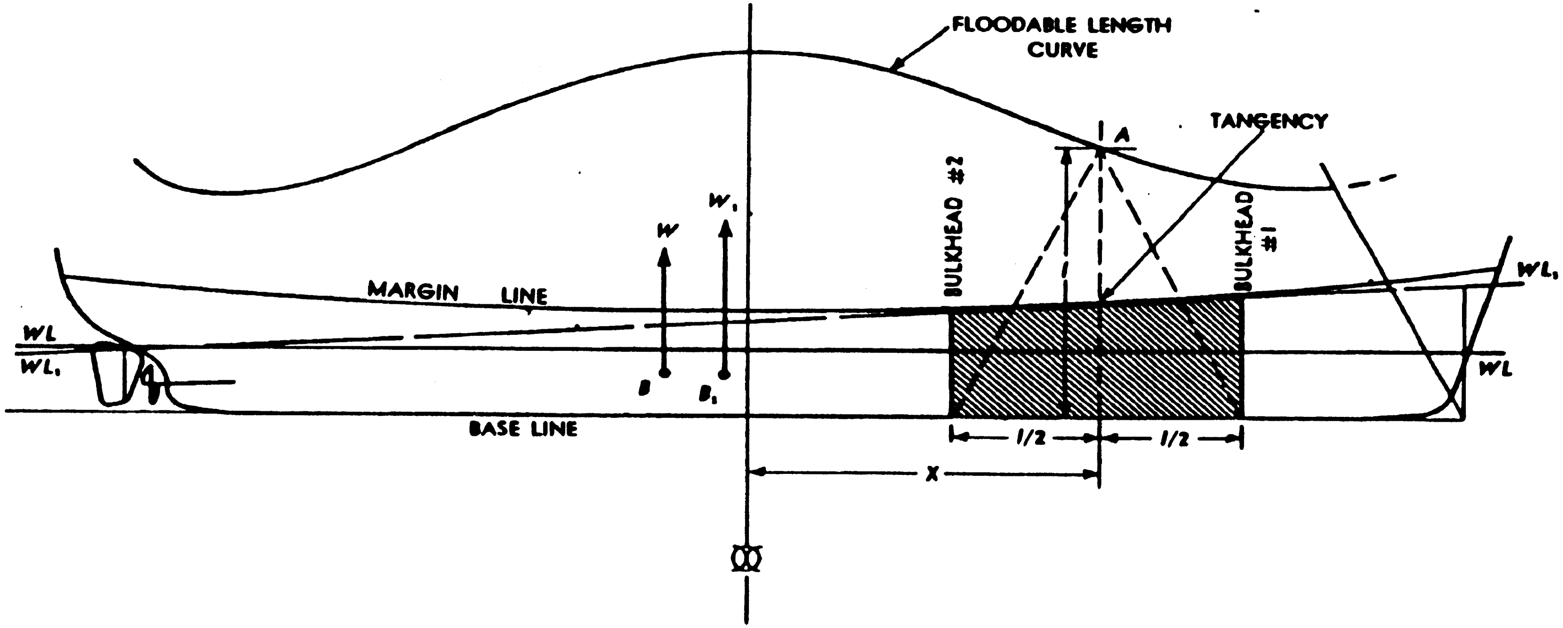
FLOODABLE LENGTH: FLOODABLE LENGTH IS THE MAXIMUM LENGTH OF A COMPARTMENT WHICH CAN BE FLOODED TO CAUSE A DAMAGED SHIP TO FLOAT AT A WATERLINE TANGENT TO THE MARGIN LINE

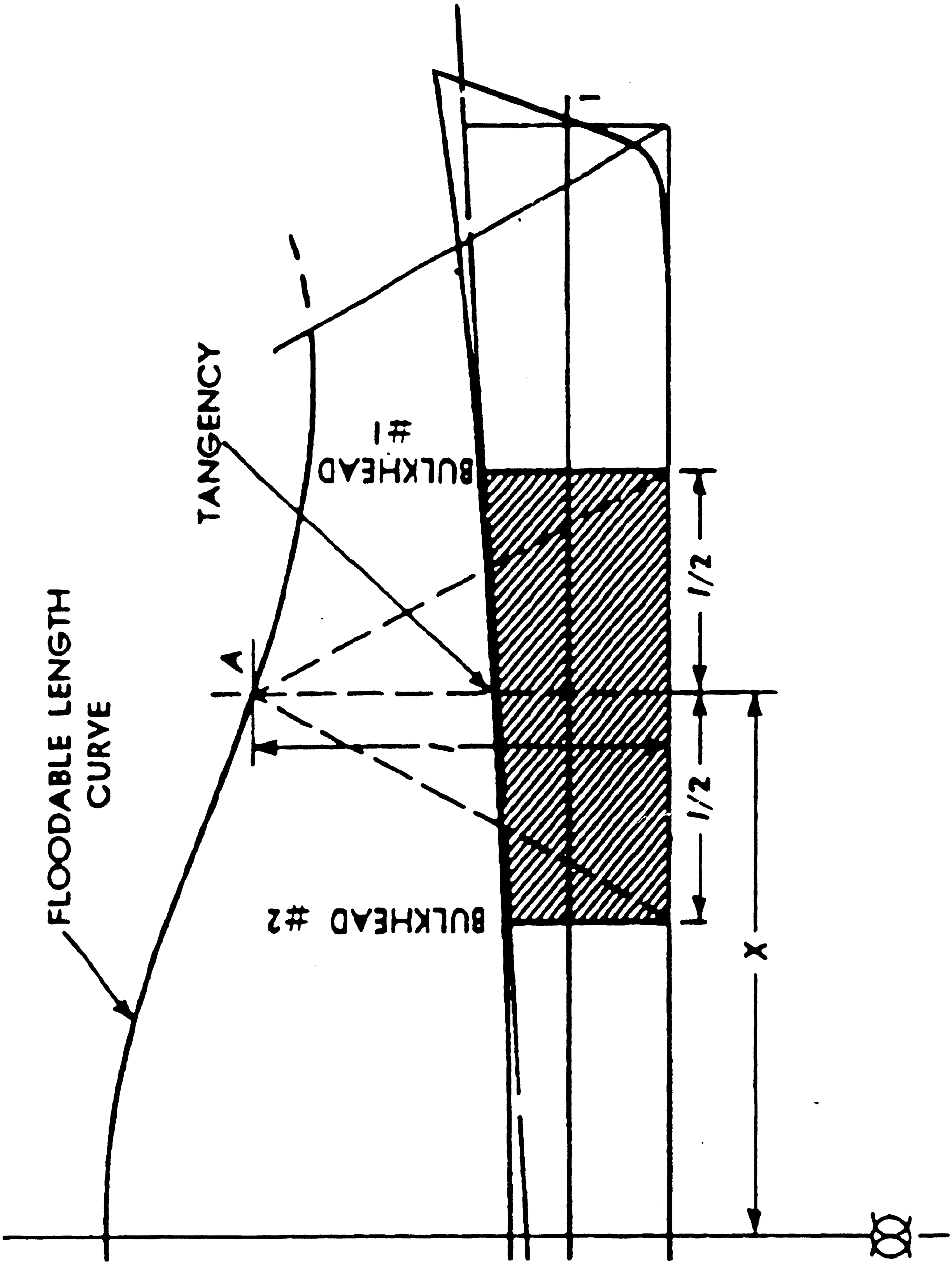


SHIP HAZARDS AND VULNERABILITY (CON'T)

CURVE OF FLOODABLE LENGTH

THE CURVE OF FLOODABLE LENGTH IS A CURVE THAT AT EVERY POINT IN ITS LENGTH HAS AN ORDINATE REPRESENTING THE LENGTH OF SHIP WHICH MAY BE FLOODED WITH THE CENTER OF LENGTH AT THAT POINT AND WITHOUT THE MARGIN LINE BEING SUBMERGED

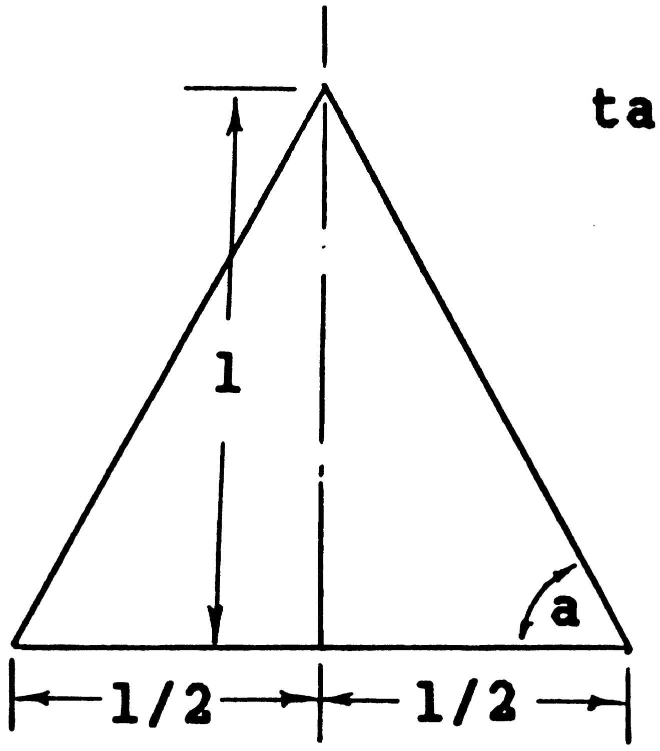



FLOODABLE LENGTH CURVE
TANGENCY
BULKHEAD #1
BULKHEAD #2
A
l/2
l/2
X

SHIP HAZARDS AND VULNERABILITY (CON'T)

FLOODABLE LENGTH

ARC TAN 2 TRIANGLES



$$\tan a = \frac{1}{1/2} = 2$$

$$a = \tan^{-1} 2$$

$$a = 63.43^{\circ}$$

SHIP HAZARDS AND VULNERABILITY (CON'T)

FLOODING STANDARDS

ONE COMPARTMENT STANDARD OF FLOODING

ANY ONE COMPARTMENT MAY BE FLOODED WITHOUT IMMERSING THE SHIP BELOW THE MARGIN LINE. NO W.T. BULKHEADS MAY BE RUPTURED.

TWO COMPARTMENT STANDARD OF FLOODING

ANY TWO ADJACENT COMPARTMENTS MAY BE FLOODED WITHOUT IMMERSING THE SHIP BELOW THE MARGIN LINE. THE COMMON W.T. BULKHEAD MAY BE RUPTURED.

ETC....FOR THREE COMPARTMENT STANDARD

SHIP HAZARDS AND VULNERABILITY (CON'T)

FLOODABLE LENGTH DEFINITIONS

FACTOR OF SUBDIVISION AND PERMISSABLE LENGTH

(PASSENGER VESSELS ONLY)

- CFR 46 INCORPORATES REQUIREMENTS OF INTERNATIONAL TREATIES, e.g., SOLAS - SAFETY OF LIFE AT SEA CONVENTIONS

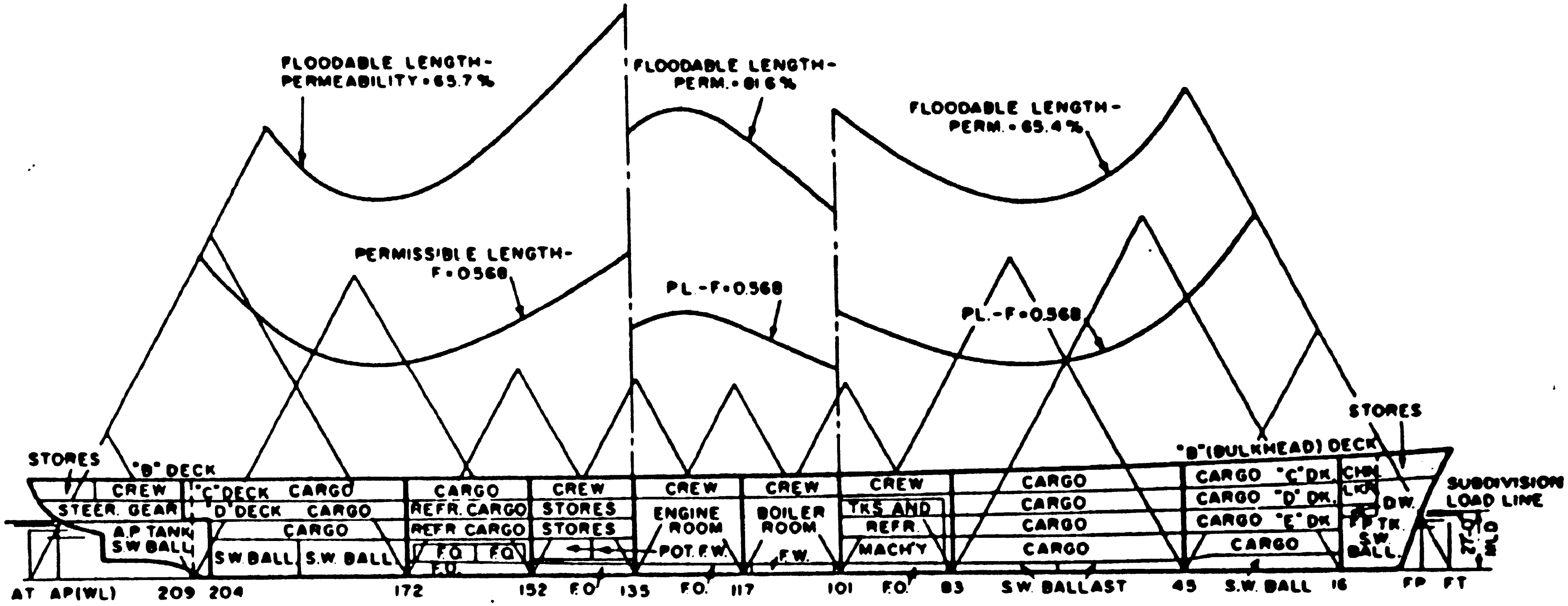
- FOR PASSENGER VESSELS ONLY (MORE THAN 12 PASSENGERS) -

  PERMISSABLE LENGTH (OF W.T. COMPARTMENT)
  = FLOODABLE LENGTH X FACTOR OF SUBDIVISION

- F.S. = .5 MEANS TWO COMPARTMENT STANDARD

SHIP HAZARDS AND VULNERABILITY (CON'T)

FLOODABLE LENGTH CURVE EXAMPLE



SHIP HAZARDS AND VULNERABILITY (CON'T)

IMPORTANT REFERENCE

- LEGAL REQUIREMENTS FOR SHIP CONSTRUCTION, SHIP FITTINGS AND SAFETY EQUIPMENT, LOAD LINES, INTACT STABILITY AND SUBDIVISION ARE CONTAINED IN -

  CODE OF FEDERAL REGULATIONS, TITLE 46, "SHIPPING" (CFR 46)
- COMES IN NINE VOLUMES
- U.S. COAST GUARD IS RESPONSIBLE FOR ADMINISTRATION.

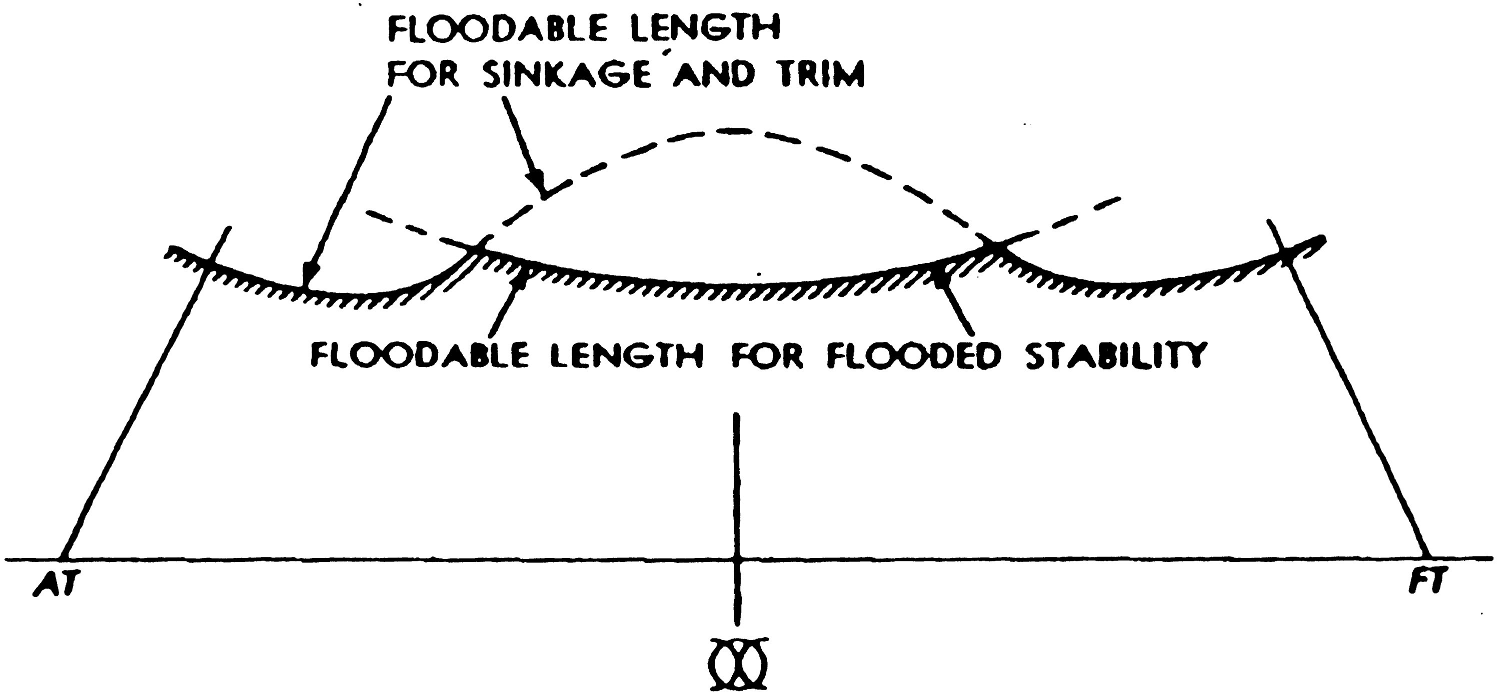
SHIP HAZARDS AND VULNERABILITY (CON'T)

FLOODABLE LENGTH LIMITED BY TRANSVERSE STABILITY

- TREATMENT SO FAR HAS BEEN BASED ON THE LIMITS OF SINKAGE AND TRIM CAUSED BY SHELL-TO-SHELL FLOODING OF A DAMAGED COMPARTMENT
- FLOODING ALSO AFFECTS TRANSVERSE STABILITY
  - LOSS OF WATERPLANE INERTIA LOWERS M
  - ADDED WATER CAUSES RISE IN G
- FLOODABLE LENGTH LIMITED BY TRANSVERSE STABILITY IS MOST AFFECTED IN MIDSHIPS REGION

SHIP HAZARDS AND VULNERABILITY (CON'T)

SINKAGE AND TRIM AND FLOODED STABILITY LIMITS



SHIP HAZARDS AND VULNERABILITY (CON'T)

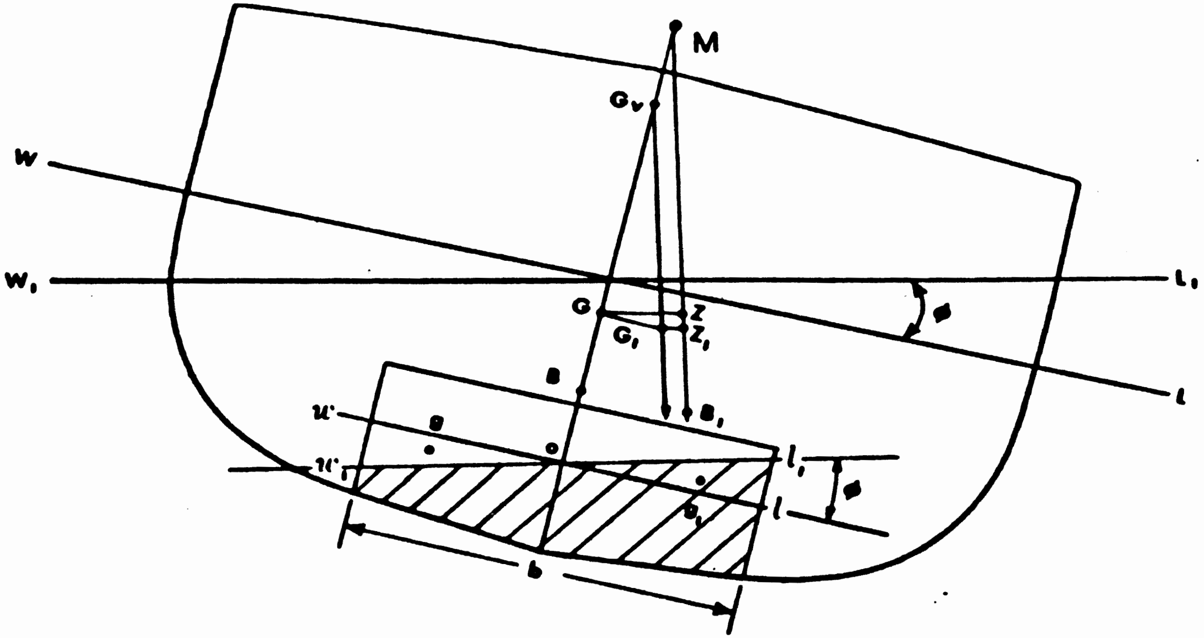
FREE SURFACE EFFECT

TANKS OR COMPARTMENTS PARTIALLY FILLED WITH A LIQUID HAVE A SURFACE WHICH IS FREE TO REMAIN HORIZONTAL AS THE SHIP INCLINES.

IF THE TANK IS PRESSED UP (COMPLETELY FILLED), THERE IS NO FREE SURFACE EFFECT

SHIP HAZARDS AND VULNERABILITY (CON'T)

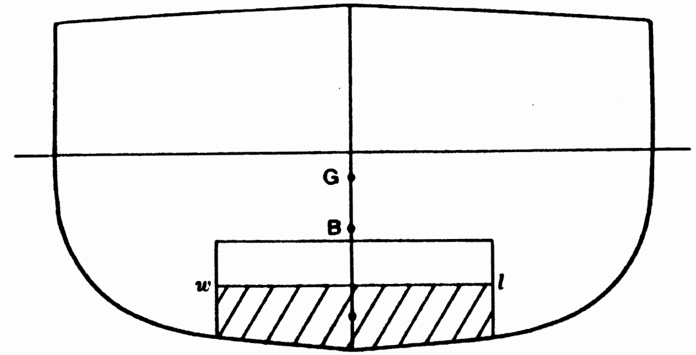
FREE SURFACE EFFECT

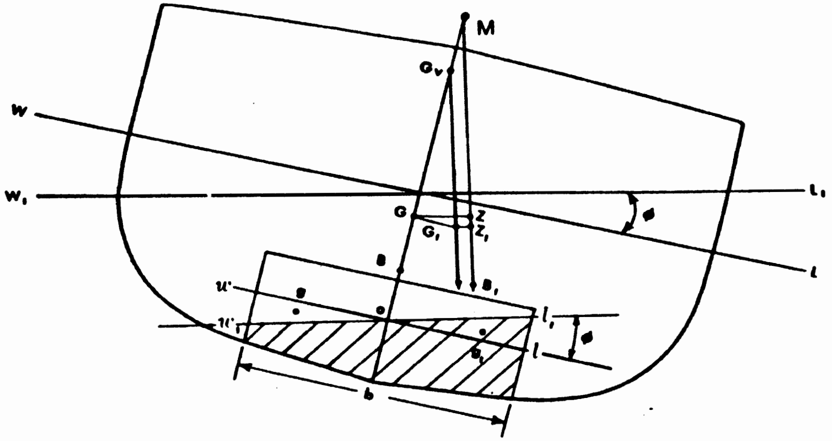


NOTE THAT THE SHIFT OF THE WEDGE OF LIQUID CAUSES A LARGE TRANSVERSE SHIFT COMPARED TO A SLIGHT RISE IN THE CG OF THE WEDGE.

SHIP HAZARDS AND VULNERABILITY (CON'T)

FREE SURFACE EFFECT





SHIP HAZARDS AND VULNERABILITY (CON'T)

FREE SURFACE EFFECT

- STUDENT SHOULD FOLLOW DERIVATION ON PAGE 74, MODERN SHIP DESIGN
- THE RESULT IS -

$$G_1Z_1 = \left[GM - \frac{\gamma_t}{\gamma_w} \frac{i}{\nabla} \right] \sin \delta\phi$$

γ_t = SPECIFIC GRAVITY OF FLUID IN TANK

γ_w = SPECIFIC GRAVITY OF WATER (FRESH WATER = 1.000, SEA WATER = 1.026)

i = TRANSVERSE MOMENT OF INERTIA OF TANK SURFACE (ABOUT LONG'L AXIS)

∇ = VOLUME OF DISPLACEMENT OF SHIP

SHIP HAZARDS AND VULNERABILITY (CON'T)

FREE SURFACE EFFECT

THE TERM $\frac{\gamma_t}{\gamma_\omega} \frac{i}{\nabla}$ ACTS TO REDUCE GM.

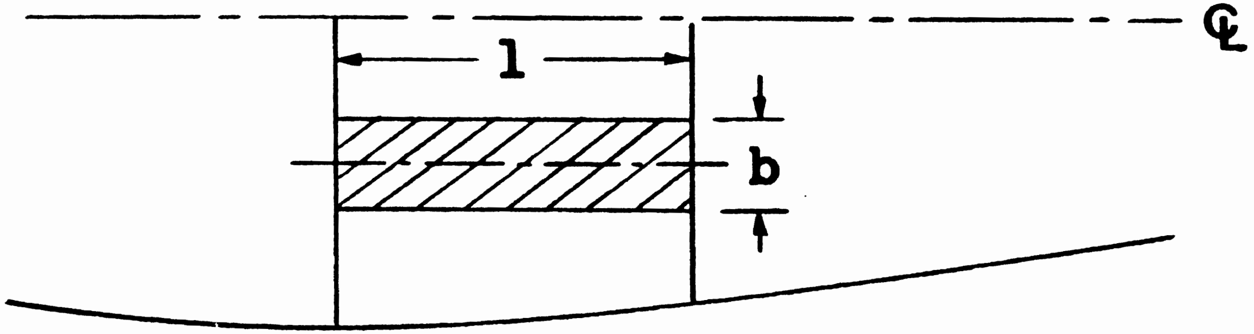
SINCE M IS CONSTANT FOR SMALL ANGLES THE EFFECT IS THE SAME AS A RISE IN G.

THUS, ALTHOUGH FREE SURFACE EFFECT IS CAUSED PREDOMINANTLY BY A TRANSVERSE WEIGHT SHIFT, IT ACTS LIKE A VERTICAL RISE IN G.

FOR THIS REASON THE TERM $\frac{\gamma_t}{\gamma_\omega} \frac{i}{\nabla}$ IS CALLED THE VIRTUAL RISE IN THE CENTER OF GRAVITY.

SHIP HAZARDS AND VULNERABILITY (CON'T)

FREE SURFACE EFFECT



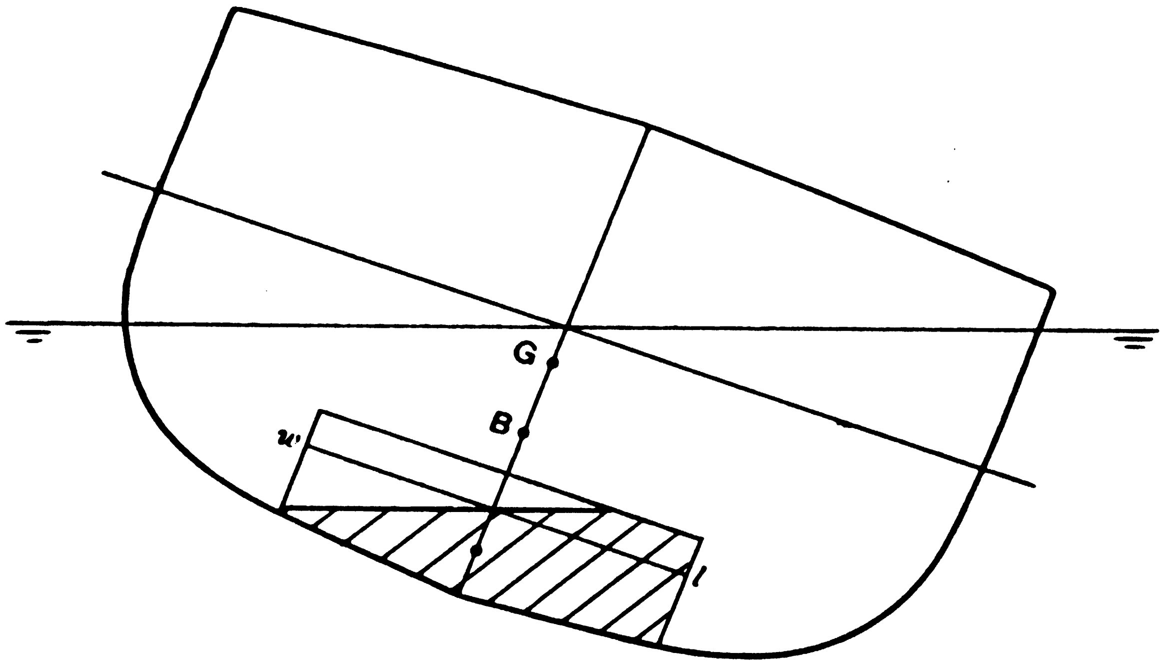
THE MOMENT OF INERTIA OF A RECTANGULAR FREE SURFACE IS -

$$i = \frac{b^3 l}{12}$$

MESSAGE: THE FREE SURFACE EFFECT IS PROPORTIONAL TO THE CUBE OF THE BREADTH OF THE TANK. LONG, NARROW TANKS WILL HAVE SMALLER FREE SURFACE LOSSES.

SHIP HAZARDS AND VULNERABILITY (CON'T)

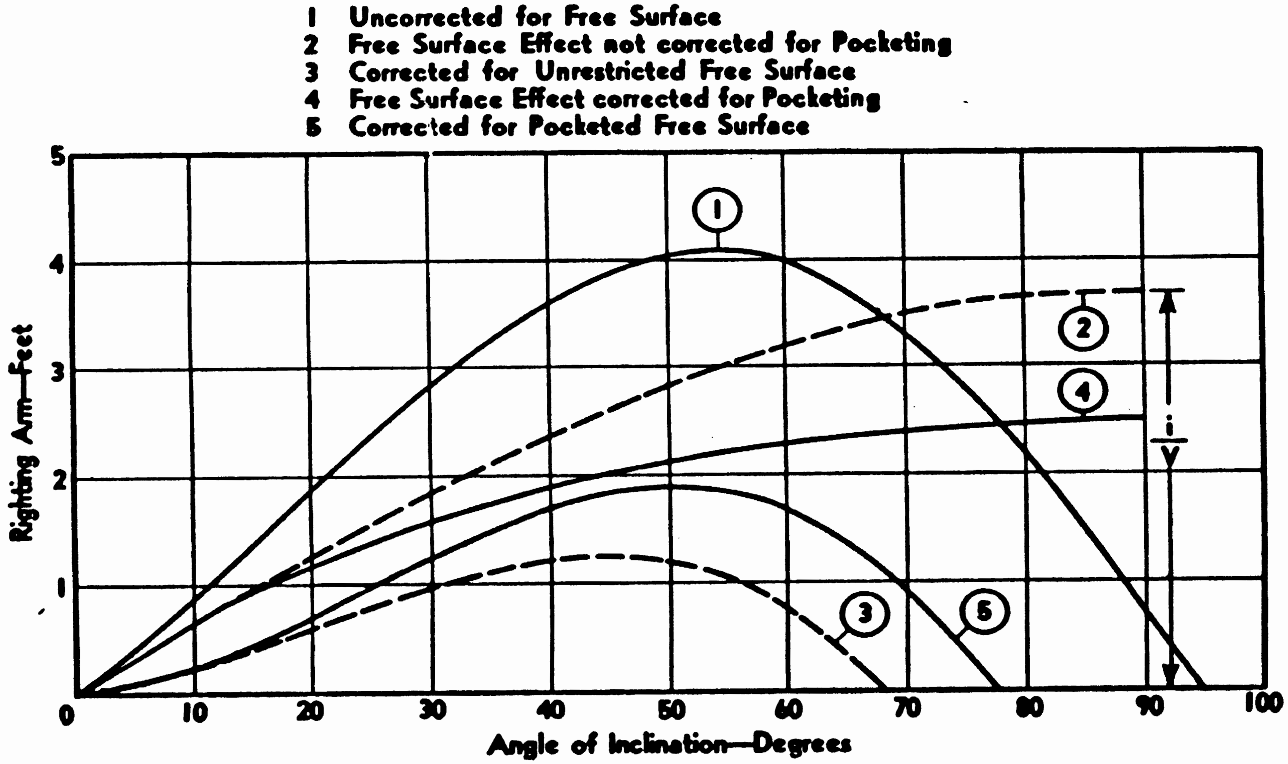
FREE SURFACE - POCKETING



WHEN THE FREE SURFACE COMES IN CONTACT WITH THE TOP OF THE TANK THE EFFECT IS CALLED POCKETING.

SHIP HAZARDS AND VULNERABILITY (CON'T)

FREE SURFACE - POCKETING



BASIC NAVAL ARCHITECTURE

Problem 26

Problem Level: Basic

A rectangular barge 120' x 35' x 10' has a draft of 4.0 ft. in salt water. KG = 5 ft. The barge then floods an off center tank, dimensions 35 ft. fore and aft by 15 ft. athwartships to a depth of 4 feet in salt water. The center of gravity of the flooding water is located 20 feet to starboard of the ℄, 40 feet aft of the c.f. and 5 feet above the keel. Find: (a) new displacement in tons, (b) new mean draft, (c) GM corrected for free surface, (d) Angle of List.

Problem 42

Problem Level: Basic

A rectangular barge has the following dimension, drafts and KG in salt water:

L_{pp} = 120'-0"

B = 35'-0"

D = 10'-0"

$T_f = T_a$ = 4'-0"

KG = 5.00' above B_L

Initially, the barge has no list.

An off-center tank, dimensions 35.0 ft fore and aft by 15.0 ft athwartships, is flooded to a mean depth of 4.0 ft with salt water. The center of gravity of the water in the tank is 10.0 ft to starboard of the centerline.

Find:

(a) original displacement, KB, BM_t, and GM_t

(b) displacement and volume of displacement after flooding

(c) KB, and KM_t after flooding

(d) GG_1 due to added weight of flooding water

(e) moment of inertia of the surface of the flooding water

(f) free surface correction, G_1G_v, due to flooding water

(g) G_vM_t, metacentric height corrected for center of gravity shift and free surface

(h) Angle of List

BASIC NAVAL ARCHITECTURE

Problem 43

Problem Level: Basic

A FFG-7-Class frigate is floating in salt water at the following drafts and KG:

T_f = 14'-9"

T_a = 13'-3"

KG = 20.00' above B_L

(a) Find the displacement, LCG and GM_t in this condition.

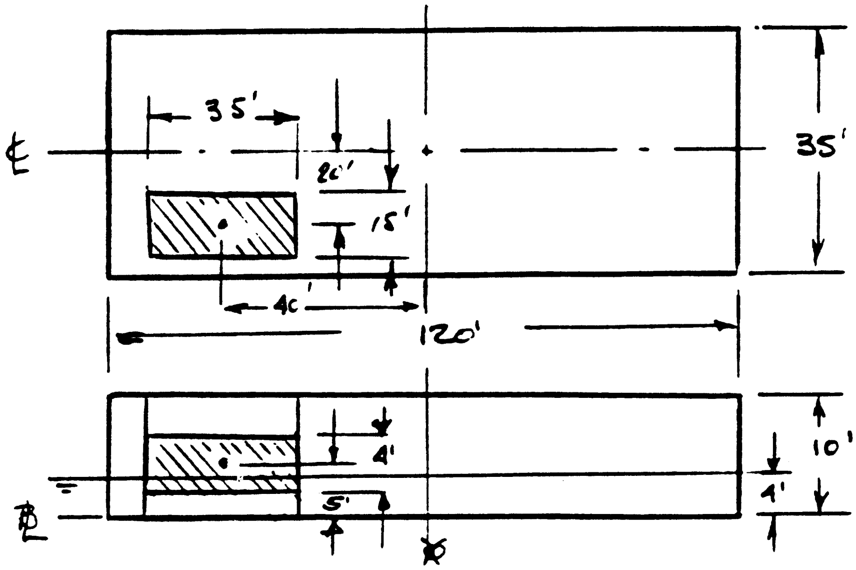
(b) From the Cross Curves of Stability construct the Static Stability Curve for this condition.

(c) Damage to the ship results in 500 tons of flooding water being admitted to the ship. The c.g. of the flooding water is on the centerline and 12.50 ft above the baseline. The free surface loss due to the flooding water is 2.0 ft. There is no free communication effect. Find the metacentric height. Plot the Righting Moment curve.

(d) The wind heeling moment for the ship at 0° inclination is 1600 ft-tons. Plot the Wind Heeling Moment curve on the same plot as (c) above and find the angle of steady heel that would result. (Recall that the wind heeling moment is a function of $\cos^2 \Theta$).

PROBLEM 26 | TDK/PEVMJr. | 16 JAN 87 | 1 OF 2

REF: GILLMER, PP 68-69



NOTE: THE LCF IS AT THE CENTROID OF THE RECTANGULAR WATERPLANE WHICH WILL BE AMIDSHIPS.

INITIAL CONDITIONS;

$KG_0 = 5.00'$ a. ℔

$T_{f_0} = T_{a_0} = 4.00'$

$$\Delta_0 = \frac{(120)(35)(4)\ \text{FT}^3}{35\ \ \text{FT}^3/\text{TON}} \ ; \qquad \Delta_0 = 480\ \text{LT}$$

WEIGHT EFFECTS OF FLOODING WATER:

$$\text{WEIGHT OF FLOODING WATER, } \omega = \frac{(35)(15)(4)\ \text{FT}^3}{(35)\ \text{FT}^3/\text{TON}} \ ; \quad w = 60\ \text{LT}.$$

ITEM	WT	VCG	V. MOM'T	LCG	L. MOM'T
ORIG BARGE	480	5.00	2400.0	0.0	0.0
FLOODING WATER	60	5.00	300.0	40.0 A	2400.0A
BARGE W/ WATER	540	5.00	2700.0	4.44 A	2400.0

(a) NEW DISPLACEMENT = 540 LT ; $\boxed{\Delta_1 = 540\ \text{LT}}$

(b) NEW MEAN DRAFT:

$$\Delta_1 = \frac{L \times B \times T_{m_1}}{35}$$

$$T_{m_1} = \frac{(35\ \text{FT}^3/\text{TON})(540\ \text{LT})}{(120\ \text{FT})(35\ \text{FT})} = 4.50\ \text{FT} \ ; \qquad \boxed{T_{m_1} = 4.50\ \text{FT}}$$

15-27

(c) FIND GM CORRECTED FOR FREE SURFACE.

ORIGINAL KB: $KB_0 = \frac{T_0}{2} = \frac{4.00}{2}$; $KB_0 = 2.00$ FT a ℄

NEW KB: $KB_1 = \frac{T_{m_1}}{2} = \frac{4.50}{2} = 2.25$ $KB_1 = 2.25'$ FT a ℄

$$5M_t = \frac{I_t}{\nabla} = \frac{I_t}{35\Delta} = \frac{(35)^{\overset{2}{\cancel{3}}}(\overset{10}{\cancel{120}})}{(\cancel{12})(\cancel{35})(540)} \;; \qquad BM_t = 22.69'$$

$KB_1 = 2.25$ FT a ℄

$BM_t = 22.69$ FT

$KM_t = 24.94$ FT a ℄

$KG_1 = 5.00$ FT a ℄

$GM_{t_1} = 19.69$ FT

$\boxed{GM_{t_1} = 19.69 \text{ FT}}$

(d) FIND ANGLE OF LIST.

$$GM \tan\theta = \frac{w + d}{\Delta}$$

$$\tan\theta = \frac{w \times d}{GM\,\Delta}$$

$w = 60$ LT

$d = 20$ FT

$GM = GM_{t_1} = 19.69$ FT

$\Delta = 540$ LT

$$\tan\theta = \frac{(60 \text{ LT})(20 \text{ FT})}{(19.69 \text{ FT})(540 \text{ LT})}$$

$$\tan\theta = .1129$$

$$\theta = 6.44^\circ$$

$\boxed{\text{ANGLE OF LIST, } \theta = 6.44^\circ}$

GIVEN: RECTANGULAR BARGE IN SALT WATER

$$L_{PP} = 120'\text{-}0''$$

$$B = 35'\text{-}0''$$

$$D = 10'\text{-}0''$$

$$T_f = T_a = 4'\text{-}0''$$

$$KG = 5.00 \text{ FT a. } \mathrm{\mathcal{B}}$$

(a) FIND: ORIGINAL Δ, KB, BM_t, GM_t

SINCE THE BARGE IS RECTANGULAR, $\nabla = L_{PP} \times B \times T$

AND $\Delta = \dfrac{L_{PP} \times B \times T}{35}$

$$\nabla = 120.00 \text{ FT} \times 35.00 \text{ FT} \times 4.00 \text{ FT}$$

$$\nabla = 16{,}800 \text{ FT}^3$$

$$\Delta = \frac{120.00 \text{ FT} \times \cancel{35}.00 \text{ FT} \times 4.00 \text{ FT}}{\cancel{35} \text{ FT}^3/\text{TON}}$$

$$\underline{\underline{\Delta = 480 \text{ LT}}}$$

FOR THIS RECTANGULAR FORM THE CENTER OF BUOYANCY, WHICH IS THE CENTROID OF THE UNDERWATER VOLUME WILL BE AT EXACTLY HALF THE DRAFT. NOTE THAT THIS IS <u>NOT</u> TRUE FOR NON-RECTANGULAR SHIP-SHAPE FORMS

$$KB = \frac{T_m}{2} = \frac{4.00 \text{ FT}}{2}$$

$$\underline{\underline{KB = 2.00 \text{ FT a } \mathrm{\mathcal{B}}}}$$

NEXT, $BM_t = \dfrac{I_t}{\nabla}$ WHERE I_t = TRANS MOM'T OF INERTIA OF WATERPLANE

SINCE THE WATERPLANE IS RECTANGULAR, WE MAY COMPUTE I_t DIRECTLY FROM ~

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

NOTE THAT FOR THE TRANSVERSE MOMENT OF INERTIA IT IS THE TRANSVERSE DIMENSION, THE BEAM, WHICH IS CUBED. FOR THE LONGITUDINAL MOMENT OF INERTIA IT IS THE LONGITUDINAL DIMENSION, THE LENGTH, WHICH IS CUBED.

$$BM_t = \frac{\cancel{120.00\,FT} \times (\cancel{35\,FT} \times 35\,FT \times 35\,FT)}{\cancel{120.00\,FT} \times \cancel{35\,FT} \times 4.00\,FT \times 12}$$

$$BM_t = 25.52\ FT$$

$KB = 2.00$ FT a. BL

$BM_t = 25.52$ FT

$KM_t = 27.52$ FT a. BL

$KG = 5.00$ FT a. BL

$GM_t = 22.52$ FT

(b) FIND: Δ_1, ∇_1 AFTER FLOODING 35' × 15' × 4' COMP'T.

THE VOLUME OF FLOODING WATER WILL BE:

$$\nabla_{FL.W.} = 35.00\,FT \times 15.00\,FT \times 4.00\,FT$$

$$\nabla_{FL.W} = 2100\ FT^3$$

$$\Delta_{FL.W.} = \frac{\cancel{35.00\,FT} \times 15.00\,FT \times 4.00\,FT}{\cancel{35}\,FT^3/TON}$$

$$\Delta_{FL.W} = 60\ LT.$$

NOTE TO INSTRUCTOR: TO REDUCE COMPUTATIONAL THESE RECTANGULAR BARGE PROBLEMS ARE USUALLY SET UP SO THAT SOME CANCELATION IS POSSIBLE.

$\nabla = 16{,}800\ FT^3$

$\nabla_{FLW.} = 2{,}100\ FT^3$

$\nabla_1 = 18{,}900\ FT^3$

$\Delta = 480\ LT$

$\Delta_{FLW} = 60\ LT$

$\Delta_1 = 540\ LT$

(c) FIND: KB, KM_t AFTER FLOODING.

THE BARGE NOW HAS LIST AND, IN FACT, MAY HAVE TRIM (BUT THIS IS NOT KNOWN BECAUSE THE LONGITUDINAL LOCATION OF THE FLOODED COMPARTMENT IS NOT GIVEN). HOWEVER, BECAUSE OF THE RECTANGULAR UNDERWATER FORM THE CENTER OF BUOYANCY IS STILL AT HALF THE DRAFT — BUT THE NEW DRAFT

$$\nabla_1 = L_{pp} \times B \times T_{m_1}$$

$$T_{m_1} = \frac{\nabla_1}{L_{pp} \times B}$$

$$T_{m_1} = \frac{18{,}900 \text{ FT}^3}{120.00 \text{ FT} \times 35 \text{ FT}}$$

$$T_{m_1} = 4.50 \text{ FT}$$

$$KB_1 = \frac{T_{m_1}}{2} = \frac{4.50 \text{ FT}}{2}$$

$$\underline{\underline{KB_1 = 2.25 \text{ FT a. Ƀ}}}$$

$$BM_{t_1} = \frac{I_t}{\nabla_1} \quad \left\{ I_t \text{ HAS NOT CHANGED} \right.$$

$$BM_{t_1} = \frac{120.00 \text{ FT} \times (35.00 \text{ FT})^3}{18{,}900 \text{ FT}^3 \times 12}$$

$$BM_{t_1} = 22.69 \text{ FT}$$

$$\underline{KB_1 = 2.25 \text{ FT a. Ƀ}}$$

$$\underline{\underline{KM_{t_1} = 24.94 \text{ FT a. Ƀ}}}$$

(d) FIND: GG_1 DUE TO ADDED WEIGHT OF FLOODING WATER.

NOTE: WE COULD USE THE FORMULA — OR WE COULD USE THE TABULAR FORM FOR THE CALCULATION. THE TABULAR FORMAT IS OFTEN LESS CONFUSING TO THE STUDENT. HERE THE REQUIREMENT CALLS FOR THE SHIFT DISTANCE, GG_1, NOT THE NEW KG.

ITEM	WT LT	VCG FT a. BL	V. MOM'T FT-TONS
ORIG BARGE	480	5.00	2400
FLOOD WTR.	60	2.00	120
BARGE AFTER FLOODING	540	4.67	2520

ORIG KG = 5.00 FT a BL

KG₁ = 4.67 FT a. BL

$GG_1 = 0.33$ FT

(e) FIND: MOMENT OF INERTIA (TRANSVERSE) OF FREE SURFACE

$$i_t = \frac{l b^3}{12}$$

$$i_t = \frac{35.00 \text{ FT} \times (15.00 \text{ FT})^3}{12}$$

$$i_t = 9844 \text{ FT}^4$$

(f) FIND: FREE SURFACE CORRECTION DUE TO FLOODING WATER.

$$G_1 G_V = \frac{i_t}{\nabla_1}$$

NO DENSITY CORR. IS REQ'D BECAUSE BOTH FLUIDS ARE THE SAME. OTHERWISE CORR. IS REQ'D

$$G_1 G_V = \frac{9844 \text{ FT}}{18,900 \text{ FT}^3}$$

$$G_1 G_V = 0.52 \text{ FT}$$

(g) FIND: $G_V M_t$

$GM_t = 22.52$ FT.
$GG_1 = (+)\ 0.33$ FT

$G_1M_t = 22.85$ FT
$G_1G_V = (-)\ 0.52$ FT

$$\underline{\underline{G_V M_t = 22.33 \text{ FT}}}$$

(h) FIND: ANGLE OF LIST.

APPLY $GM \tan\theta = \dfrac{w \times t}{\Delta}$

$GM = G_V M_t = 22.33$ FT
$w = 60$ LT
$t = 10.00$ FT (STBD)

$$\tan\theta = \frac{60 \text{ LT} \times 10.00 \text{ FT}}{22.33 \text{ FT} \times 540 \text{ LT}}$$

$$\tan\theta = .04976$$

$$\underline{\theta = 2.85^{\circ} \text{ (STBD)}}$$

GIVEN

$T_f = 14'-9"$

$T_a = 13'-3"$

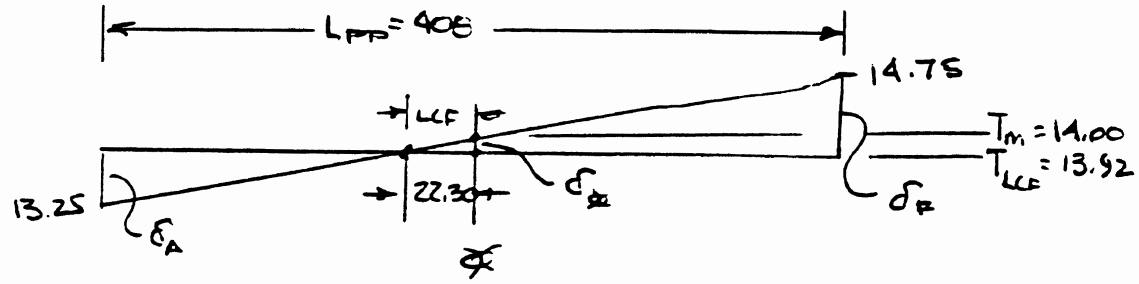
$KG = 20.00$ FT. a ℄

(a) **FIND:** Δ, LCG, GM_t

$$\begin{aligned} T_f &= 14.75' \\ T_a &= 13.25' \\ \hline \text{TRIM} &= 1.50' \end{aligned}$$

$$T_m = 14.00 \text{ FT}$$

CORRECTION FOR TRIM. LCF METHOD



$$\frac{\delta_{\not\subset}}{LCF} = \frac{\delta_F + \delta_A}{L_{PP}}$$

$$\delta_{\not\subset} = 22.30 \times \frac{1.50}{408.00}$$

$$\delta_{\not\subset} = .082$$

THE DRAFT AT THE LCF WILL BE:

$$\begin{aligned} T_m &= 14.00 \text{ FT} \\ \delta_{\not\subset} &= (-)\,.08 \text{ FT} \\ \hline T_{m_1} &= 13.92 \text{ FT} \end{aligned}$$

NOW, FROM THE CURVES OF FORM AT $T_{m_1} = 13.92$ FT

$$\underline{\Delta = 3340 \text{ LT (SW)}}$$

CORRECTION FOR TRIM. CD12"TA METHOD. USE THE CORRECTION, $CD12''TA = \frac{12 \times LCF \times TPI}{L_{PP}}$

$$LCF = 22.30 \text{ AFT } ⊄$$

$$TPI = 33.98 \text{ TONS/IN}$$

$$CD12''TA = \frac{12 \times 22.30 \times 33.98}{408}$$

$$CD12''TA = 22.29 \text{ TONS}/12''TA$$

$$CORR = (1.50 \text{ FT TRIM})(22.29 \text{ TONS}/12''TA)$$

$$= (-)\ 33.4 \text{ TONS}$$

AT $T_M = 14.00$ FT $\Delta_0 = 3370$ LT

CORR $= (-)\ 33.4$ LT

$\Delta = 3336.6$ LT

(NOTE THE SIMILARITY BETWEEN THE TWO METHODS)

AT $T_M = 14'\text{-}0''$, (USING $T_M = 13.92$ WOULD BE SLIGHTLY MORE ACCURATE),

$$LCG_{L.T.} = LCB_{LT} = 0.00 \text{ FT AFT } ⊄$$

$$MT1'' = 717 \text{ FT-TONS/INCH.}$$

MOMENT REQ'D TO CAUSE 18" TRIM BY THE BOW = 717×18 FT-TONS

$$GG_1 = \frac{717 \text{ FT-TONS/IN} \times 18 \text{ IN}}{3336.6 \text{ LT}}$$

$$GG_1 = 3.87 \text{ FT (FWD)}$$

$$LCG_{LT} = 0.00 \text{ FT FWD } ⊄$$

IN THE TRIMMED CONDITION = 3.87 FT FWD ⊄

AT $T_m = 14'-0''$, $KM_t = 22.48$ FT a ℄

$KG_1 = 20.00$ FT a ℄.

$G_1M_t = 2.48$ FT

(b) PLOT: STATIC STABILITY CURVE

$$G_1Z = AP + AG_1 \sin\theta$$

FROM THE CROSS CURVES, VALUES OF AP AT $\Delta = 3340$ LT ARE SHOWN BELOW:

$KA = 19.00$ FT a ℄

$KG_1 = 20.00$ FT a ℄.

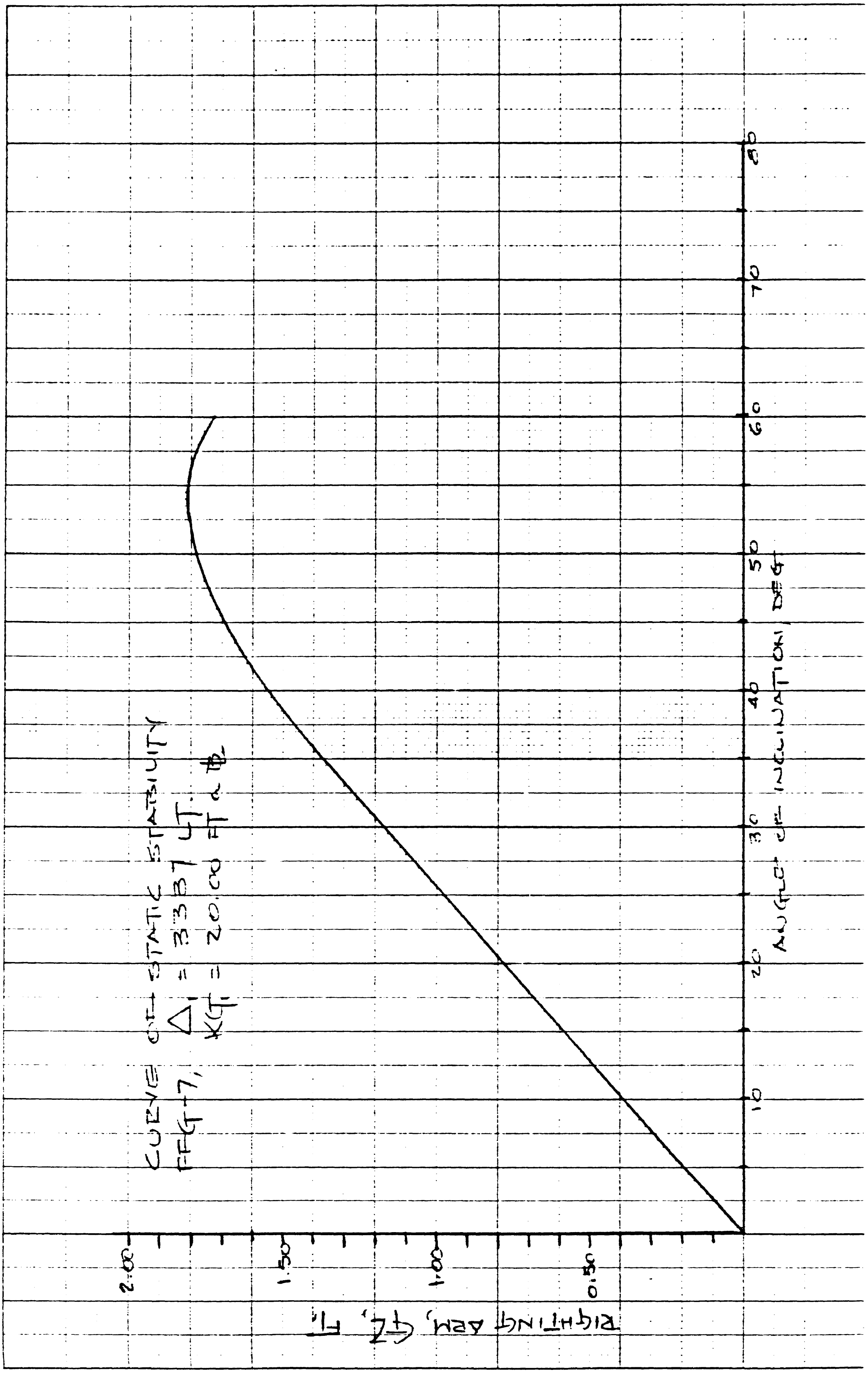
$AG_1 = 1.00$ FT

SINCE G IS ABOVE A, THE CORRECTION WILL BE (−)

ANGLE OF INCLINATION, θ, DEG.	AP FT	$AG_1 \sin\theta$ FT	G_1Z. FT
0	0.00	0.00	0.00
10	0.585	0.174	0.411
15	0.853	0.259	0.594
20	1.102	0.342	0.760
30 *	1.595	0.500	1.095
40	2.190	0.643	1.547
45	2.430	0.707	1.723
50	2.550	0.766	1.784
55	2.625	0.819	1.806
60	2.592	0.866	1.726

* (ON THE CROSS CURVES THE 30° CURVE IS OFF SLIGHTLY)

PROBLEM 43 (CON'T)   TDK/PRVMJR   4 MAR 87   4 OF 7



THERE WILL BE THREE EFFECTS FROM THE FLOODING WATER.

(1) THE ADDED WEIGHT OF THE FLOODING WATER AT 12.50 FT a ℄ WILL LOWER THE CENTER OF GRAVITY (FROM G_1 TO G_2),

(2) THE FREE SURFACE EFFECT WILL CAUSE A VIRTUAL RISE IN THE CENTER OF GRAVITY (FROM G_2 TO G_V) AND CONSEQUENTLY A LOSS IN GM,

(3) THE NEW WATERPLANE WILL CAUSE A CHANGE IN KM_t.

(1) EFFECT OF ADDED WEIGHT.

ITEM	WEIGHT LT	VCG FT a. ℄	V. MOM'T FT-TONS
ORIG. SHIP	3337	20.00	66740
FLOOD WATER	500	12.50	6250
SHIP AFTER FLOODING	3837	19.02	72990

(2) THE FREE SURFACE EFFECT IS GIVEN AS 2.0 FT

$$KG_2 = 19.02 \text{ FT a. ℄}$$

$$G_2G_V = (+)\,2.00 \text{ FT}$$

$$KG_V = 21.02 \text{ FT a. ℄}$$

(3) AT $\Delta = 3837_{LT}$, $KM_t = 22.27$ FT a ℄

$$G_VM_t = 1.25 \text{ FT}$$

WE MAY FIND THE RIGHTING MOMENT CURVE AFTER DAMAGE BY APPLYING A CORRECTION DIRECTLY TO THE ORIGINAL DATA FROM THE CROSS CURVES ($AG_v = 2.02$ FT) AND MULTIPLYING BY Δ_2, OR BY APPLYING A VERTICAL RISE CORRECTION ($G_1G_v = 1.02$ FT) AND MULTIPLYING BY Δ_2 AS SHOWN BELOW

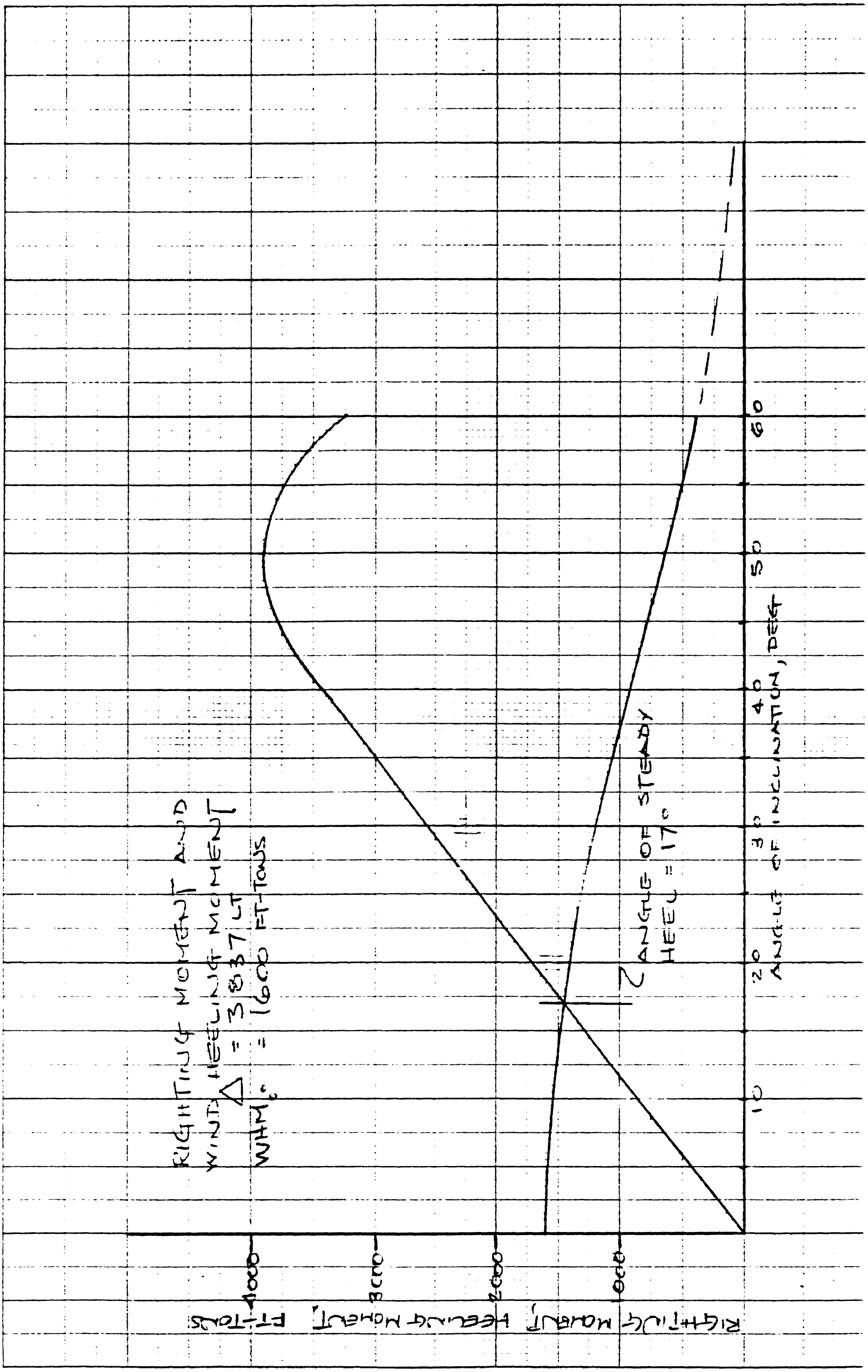
$G_1G_v = 1.02'$ $\Delta_2 = 3837$ LT.

ANGLE OF INCLINATION, θ, DEG	G_1Z FT	$G_1G_v \sin\theta$ FT	G_vZ FT	RIGHTING MOM'T= $G_vZ \cdot \Delta_2$, FT-TONS
0	0.000	0.000	0.000	0
10	0.411	0.177	0.234	898
15	0.594	0.264	0.330	1266
20	0.760	0.349	0.411	1577
30	1.095	0.510	0.585	2245
40	1.547	0.656	0.891	3419
45	1.723	0.721	1.002	3845
50	1.784	0.781	1.003	3849
55	1.806	0.836	0.970	3722
60	1.726	0.883	0.843	3235

(d) WIND HEELING MOM'T = $\Delta_2(\cos^2\theta)$;

ANGLE OF INCLINATION θ, DEG	WIND H.M $= 1600 \cos^2\theta$ FT-TONS
0	1600
10	1552
15	1493
20	1413
30	1200
40	939
45	800
50	661
55	526
60	400

FROM THE PLOT, ANGLE OF STEADY HEEL = 17°


RIGHTING MOMENT AND
WIND HEELING MOMENT
Δ = 3837 LT
WHM₀ = 1600 FT-TONS
ANGLE OF STEADY
HEEL = 17°
ANGLE OF INCLINATION, DEG
10
20
30
40
50
60
RIGHTING MOMENT, HEELING MOMENT, FT-TONS
1000
2000
3000
4000

BASIC NAVAL ARCHITECTURE

Unit Number:	16
Title:	Ship hazards and vulnerability - 2
Tape Running Time:	35^M 35^S
Reading Assignment:	MSD, pp 79-85, 91-93, 253-255, 333-339
Additional References:	USN Design Data Sheet 079-1 CFR 46, Subchapter 5

Scope:

The effect of a ship holed so that flooding water is in free communication with the sea is discussed. USN and CFR 46 stability criteria are outlined.

Key Points to Emphasize:

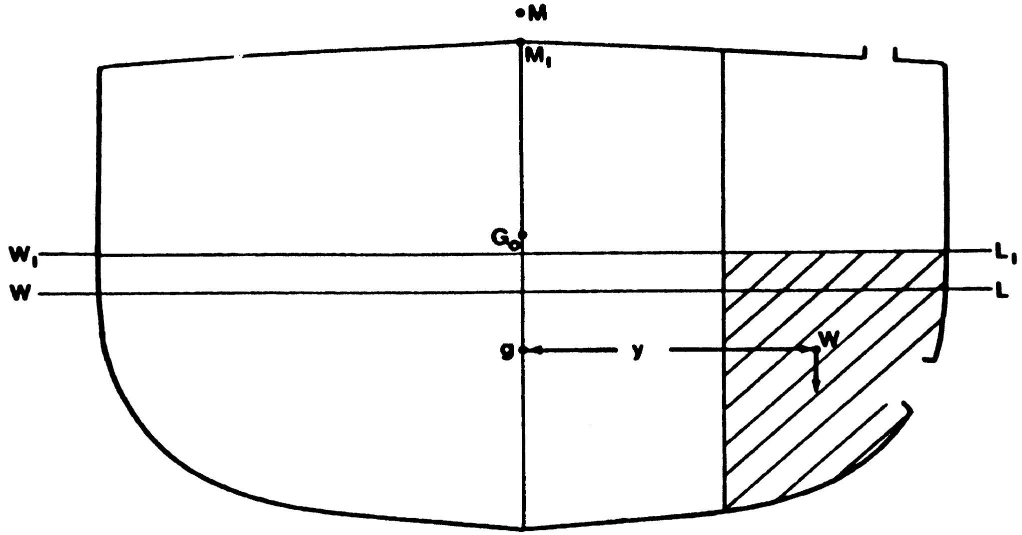
1. Instructor should obtain and review USN DDS 079-1 and CFR 46 Subchapter 5 before this class session.
2. Go over steps in free communication solution, MSD, pp 80-81.
3. Emphasize that free communication effect applies only to unsymmetrical flooding. Discuss design implications on location of longitudinal bulkheads, cross connection arrangements.
4. USN Stability Criteria. Emphasize energy concepts. Emphasize artificial yet practical nature of criteria. Student should understand this criteria thoroughly.
5. Review CFR 46 stability criteria and applicability.

Suggested Problem Assignment: 44 or 45

SHIP HAZARDS AND VULNERABILITY (CON'T)

FREE COMMUNICATION EFFECT

IF A SHIP'S HULL IS HOLED BELOW THE WATERLINE SO THAT THE SEA MAY FLOW FREELY INTO AND OUT OF THE DAMAGED COMPARTMENT THE CONDITION IS DESCRIBED AS PARTIAL FLOODING WITH FREE COMMUNICATION WITH THE SEA.



SHIP HAZARDS AND VULNERABILITY (CON'T)

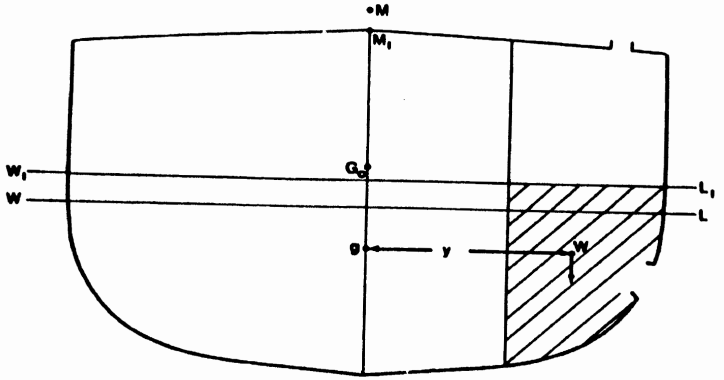
FREE COMMUNICATION EFFECT

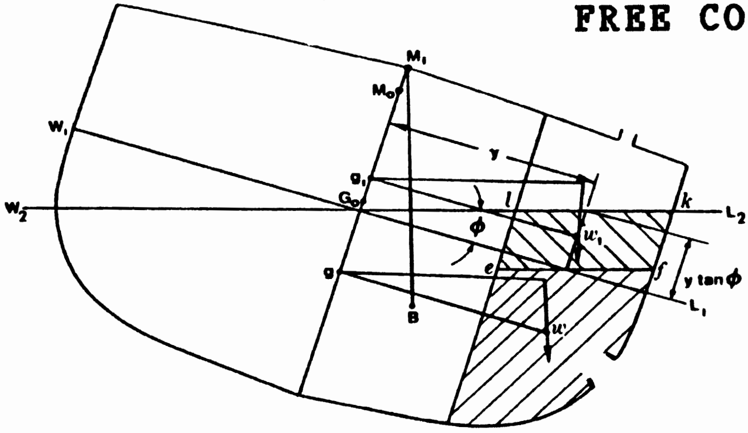
THERE ARE SEVERAL EFFECTS:

1. THE WEIGHT OF THE FLOODING WATER CAUSES THE SHIP TO SINK DEEPER IN THE WATER TO A NEW WATERLINE.
2. THE ADDED WEIGHT OF WATER CAUSES A SHIFT IN THE CENTER OF GRAVITY (USUALLY DOWNWARD).
3. THERE IS A RISE IN THE CENTER OF GRAVITY DUE TO THE FREE SURFACE EFFECT.
4. BECAUSE OF THE OFF-CENTER WEIGHT THE SHIP LISTS AND MORE WATER FLOWS IN (FREE COMMUNICATION EFFECT)

SHIP HAZARDS AND VULNERABILITY (CON'T)

FREE COMMUNICATION EFFECT





FREE COMM. EFFECT =

$$\frac{ay^2}{\nabla_1} \cdot \sin\phi$$

SHIP HAZARDS AND VULNERABILITY (CON'T)

FREE COMMUNICATION EFFECT

- STUDENT SHOULD FOLLOW DERIVATION OF ADDED WEIGHT METHOD, PP80-81, MSD.
- SUMMARY OF CORRECTIONS

1. ADDED WEIGHT OF FLOODING WATER CAUSES VERTICAL CG SHIFT, GG_1
   CORRECTION = $GG_1 \sin\phi$ (RISE -, DOWN +)
2. FREE SURFACE = $\frac{i}{\nabla_1} \sin\phi$ (VIRT RISE -)
3. FREE COMMUNICATION = $\frac{ay^2}{\nabla_1} \sin\phi$
4. TRANSVERSE SHIFT = $\frac{wy}{\Delta_1} \cos\phi$

$$G_4Z = GZ - \left(\pm\ GG_1 + \frac{i}{\nabla_1} + \frac{ay^2}{\nabla_1}\right)\sin\phi - \left(\frac{wy}{\Delta_1}\right) \cos\phi$$

SHIP HAZARDS AND VULNERABILITY

ADDED WEIGHT VERSUS LOST BUOYANCY

- PROBLEMS INVOLVING FLOODING, E.G.,
    - FLOODABLE LENGTH
    - FREE COMMUNICATION

  MAY BE TREATED BY CONSIDERING THE FLOODING WATER AN ADDED WEIGHT,

  OR,

  BY CONSIDERING THE FLOODED SPACE A LOST BUOYANT VOLUME

SHIP HAZARDS AND VULNERABILITY (CON'T)

ADDED WEIGHT VERSUS LOST BUOYANCY

- ADDED WEIGHT METHOD AND LOST BUOYANCY METHOD GIVE SIMILAR RESULTS
- ADDED WEIGHT IS USUALLY MORE CONVENIENT
- LOST BUOYANCY IS A BETTER REPRESENTATION OF THE PHYSICAL CONDITIONS

SHIP HAZARDS AND VULNERABILITY (CON'T)

STABILITY CHARACTERISTICS

INDICATORS OF A SHIP'S STABILITY CHARACTERISTICS ARE:

- GM
- RANGE OF STABILITY
- AREA UNDER GZ CURVE

BUT THE MOST IMPORTANT IS

- MAXIMUM RIGHTING ARM AND THE ANGLE AT WHICH IT OCCURS

SHIP HAZARDS AND VULNERABILITY (CON'T)

STABILITY CRITERIA

- U.S. NAVAL SHIPS MUST MEET STABILITY CRITERIA SET FORTH IN:

  U.S.N. DESIGN DATA SHEET DDS 079-1

- COMMERCIAL VESSELS MUST MEET STABILITY CRITERIA SET FORTH IN:

  CFR 46 SUBCHAPTER S

SHIP HAZARDS AND VULNERABILITY (CON'T)

U.S. NAVY INTACT STABILITY CRITERIA

1. CRITERIA UNDER ADVERSE WIND AND SEA CONDITIONS
   - ASSUME BEAM WINDS FROM 50-100 KNOTS
     - 100 KNOTS FOR NEW OCEAN GOING SHIPS LIKELY TO ENCOUNTER HURRICANE
     - 50 KNOTS FOR EXISTING SHIPS UNDER PROTECTED CONDITIONS
     - OTHER INTERMEDIATE REQUIREMENTS
2. ASSUME SHIP ROLLS 25° INTO WIND.

SHIP HAZARDS AND VULNERABILITY (CON'T)

U.S. NAVY INTACT STABILITY CRITERIA

THE HEELING MOMENT IN FOOT-LBS IS -

$$\text{H.M.} = (\text{PRESSURE})(\text{AREA})(\text{LVR})$$

$$= \underset{\text{PRESSURE COEFF.}}{(.0035)} \cdot \underset{\text{WIND VELOCITY}}{(V_W^2)} \cdot \underset{\text{AREA}}{(A \cos\phi)} \cdot \underset{\text{LVR}}{(h \cos\phi)}$$

THE $\cos\phi$ TERM ACCOUNTS FOR THE CHANGE IN PROJECTED AREA AND LEVER ARM

$$\text{THE HEELING ARM} = \frac{\text{HEELING MOMENT}}{2240\ \Delta}$$

SHIP HAZARDS AND VULNERABILITY (CON'T)

U.S. NAVY INTACT STABILITY CRITERIA

$$\text{HEELING ARM} = \frac{.0035\ V_W^2\ Ah}{2240} \cos^2\phi$$

V_W = WIND VELOCITY, KNOTS

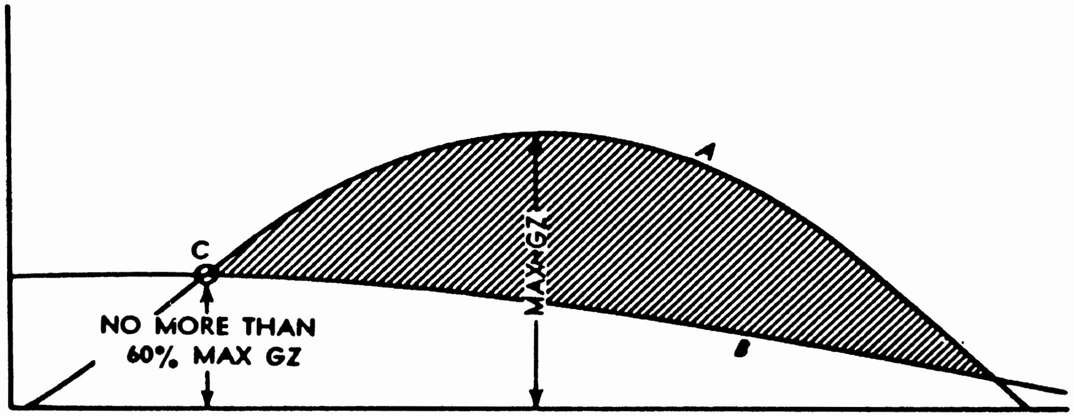
A = LATERAL AREA OF SHIP ABOVE THE WATERLINE, FT^2

h = LEVER ARM FROM HALF-DRAFT TO CENTROID OF SAIL AREA, FT

ϕ = ANGLE OF INCLINATION

SHIP HAZARDS AND VULNERABILITY (CON'T)

U.S. NAVY INTACT STABILITY CRITERIA



CURVE A IS THE RIGHTING ARM CURVE

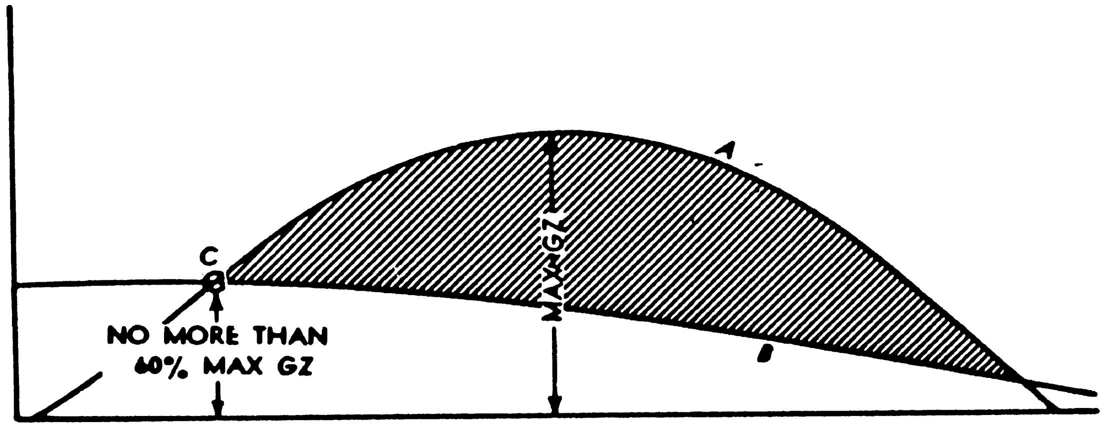
CURVE B IS THE HEELING ARM CURVE

POINT C IS THE ANGLE OF STEADY HEEL DUE TO WIND

SHIP HAZARDS AND VULNERABILITY (CON'T)

U.S. NAVY INTACT STABILITY CRITERIA

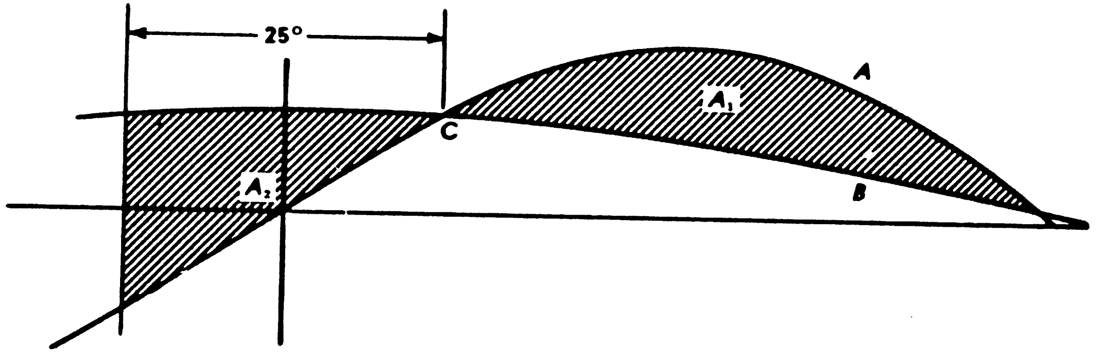
CRITERIA



- HEELING ARM AT POINT C NO MORE THAN 60% OF MAXIMUM GZ
- ANGLE OF STEADY HEEL CANNOT EXCEED 10° (15° FOR SHIPS IN SERVICE)

SHIP HAZARDS AND VULNERABILITY (CON'T)

U.S. NAVY INTACT STABILITY CRITERIA

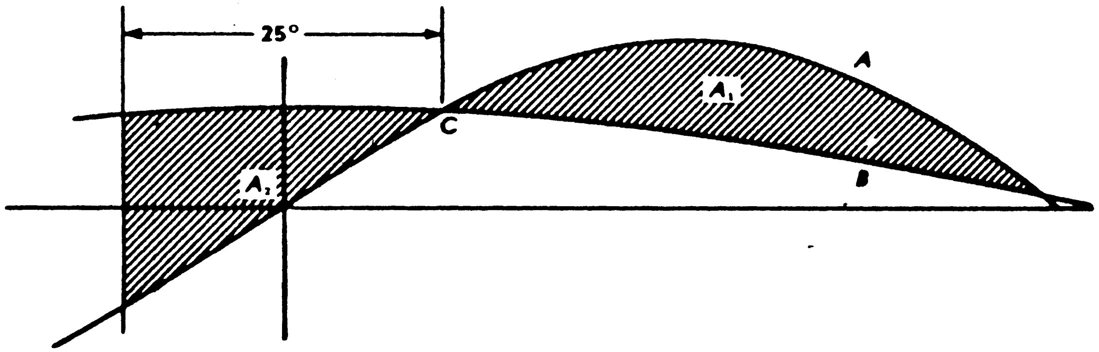


AS SHIP ROLLS 25° INTO WIND IT WILL STORE ENERGY EQUAL TO AREA A_2

AS SHIP ROLLS BACK AWAY FROM WIND IT WILL TAKE AWAY AN EQUAL AREA FROM AREA A_1

SHIP HAZARDS AND VULNERABILITY (CON'T)

U.S. NAVY INTACT STABILITY CRITERIA



THERE MUST BE AT LEAST A 40% RESERVE, THAT IS -

$\underline{A_1 \text{ AT LEAST 1.4 TIMES } A_2}$

SHIP HAZARDS AND VULNERABILITY (CON'T)

U.S. NAVY INTACT STABILITY CRITERIA

OTHER USN INTACT STABILITY CRITERIA EXIST FOR:

- LIFTING HEAVY WEIGHTS OVER THE SIDE
- TOW LINE PULL FOR TUGS
- CROWDING OF PERSONNEL TO ONE SIDE
- HIGH SPEED TURNING

TOPSIDE ICING MUST BE CONSIDERED FOR SHIPS WHICH WILL OPERATE IN ARCTIC

SHIP HAZARDS AND VULNERABILITY (CON'T)

CFR 46 STABILITY REQUIREMENTS

- SUBCHAPTER S, CFR 46
- ADMINISTERED BY USCG
- REQUIREMENTS VARY WITH VESSEL TYPE, LENGTH AND GROSS TONNAGE
- STABILITY TEST (INCLINING EXPERIMENT) REQUIRED TO FIND LIGHTSHIP, VCG, LCG, AND $\triangle$
- REQUIREMENTS ARE SPECIFIED FOR THE LOCATION OF W.T. DOORS
- CORRECTIONS FOR FREE SURFACES ARE REQUIRED

SHIP HAZARDS AND VULNERABILITY (CON'T)

CFR 46 STABILITY REQUIREMENTS

- REQUIRED GM FOR EACH LOADING CONDITION FOR ALL INSPECTED VESSELS:

$$GM \geq \frac{PAH}{W \tan (T)}$$

P = .005 + $(L/14,200)^2$ TONS/FT^2 (OCEAN SERVICE)(OTHER FORMULAE FOR OTHER SERVICES)

L = L_{pp}, FT

A = LATERAL AREA ABOVE WL, FT^2

H = DISTANCE FROM HALF DRAFT TO CENTROID OF LATERAL AREA, FT

W = DISPLACEMENT, LT

T = 14° OR ANGLE AT WHICH ONE HALF OF FREEBOARD IS IMMERSED

SHIP HAZARDS AND VULNERABILITY (CON'T)

CFR 46 STABILITY REQUIREMENTS

- THERE ARE ADDITIONAL REQUIREMENTS FOR MINIMUM GM AND MAXIMUM GZ FOR VESSELS UNDER 328 FEET AND VESSELS OF UNUSUAL FORM

- THERE ARE ADDITIONAL REQUIREMENTS FOR BOTH SMALL AND LARGE PASSENGER VESSELS

Problem 44

Problem Level: Intermediate

An FFG-7 Class frigate is underway at sea with the following estimated drafts and GM:

T_f = 14'-0"

T_a = 14'-6"

GM_t = 3.00 ft.

While in this condition the ship is damaged below the waterline and floods a compartment 25.0 ft. fore and aft by 14.0 ft. athwartships with 90 tons of seawater in free communication with the sea. The c.g. of the flooding water is 10.0 ft. above the keel and 7.0' to starboard of the centerline. Find: (a) KM_1, and KG_1 due to the added weight of the flooding water, (b) free surface effect, (c) free communication effect, (d) final metacentric height after flooding, and (e) list due to the flooding.

Problem 45

Problem Level: Intermediate

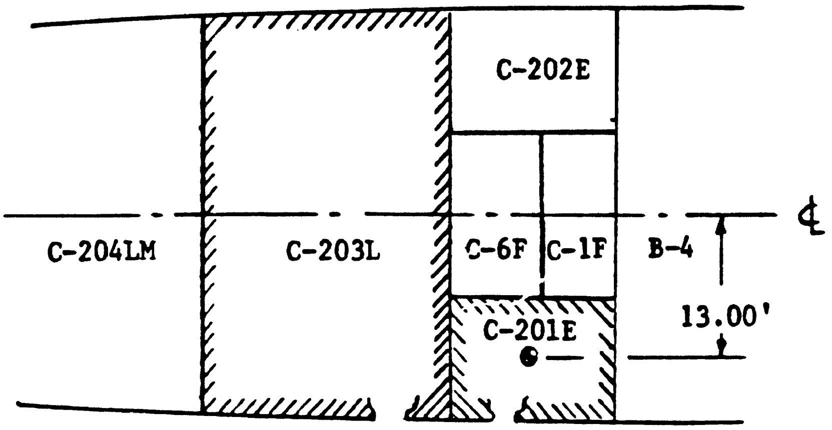
A DD 692 (long hull) class destroyer initially upright and at level trim is engaged in battle action at the following displacement and GM:

Δ = 3500 LTSW

GM = 3.50'

The ship is damaged at the waterline. The following compartments are flooded with a mean depth of 4.0 ft of flooding water in the compartment:

Compartment	Location	Length	Breadth
C-201E	Frs. 145-157	15.75'	13.00'
C-203L	Frs. 157-170	22.75'	39.00'



(a) Find the added weight of flooding water in each compartment.

(b) Find the free surface loss in GM due to the damage in each compartment.

(c) Find the loss in GM due to free communication effort.

(d) Find the resulting GM and angle of list.

GIVEN:

$T_f = 14'\text{-}0''$

$T_a = 14'\text{-}6''$

$GM_t = 3.00$ FT.

DAMAGED COMP'T $l = 25.00$ FT

$b = 14.00$ FT

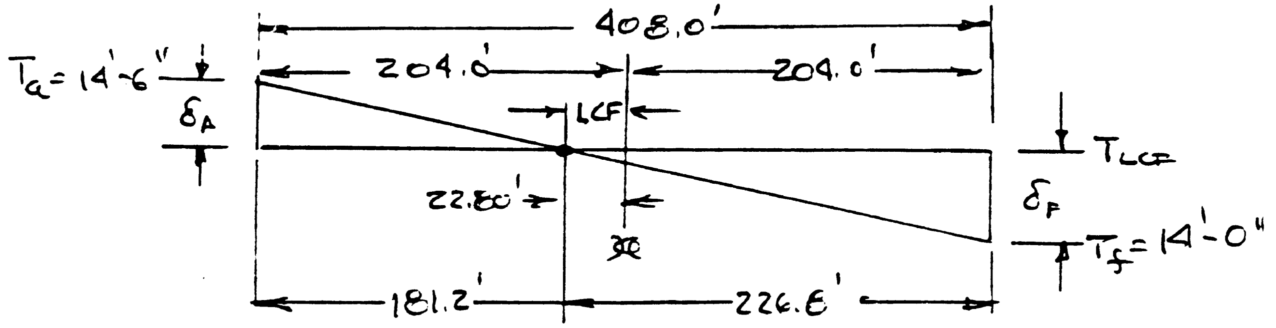
FLOODING WATER: $w = 90$ LT

$vcg = 10.00$ FT a. K

$tcg = 7.00$ FT STBD.

(a) FIND: KM_1, KG_1 AFTER FLOODING.

FIRST, THE SHIP HAS 0.50 FT TRIM BY THE STERN. TO FIND Δ WE MAY EITHER USE THE METHOD OF COMPUTING CD12'TA, OR WE MAY COMPUTE THE DRAFT AT THE LCF AND ENTER THE CURVES OF FORM WITH THAT DRAFT. THIS TIME WE WILL USE THE LATTER METHOD.



$$\frac{\delta_F}{226.8} = \frac{\delta_A}{181.2}$$

$$\delta_F = \frac{226.8}{181.2}\,\delta_A = 1.252\,\delta_A$$

$$\delta_F + \delta_A = 0.50 \text{ FT}$$

$$1.252\,\delta_A + \delta_A = 0.50 \text{ FT}$$

$$\delta_A = \frac{0.50 \text{ FT}}{1.252} = 0.22 \text{ FT}$$

$$\delta_F = 0.28 \text{ FT}.$$

$$T_{LCF} = 14.28 \text{ FT}$$

AT T_{LCF} = 14.28 FT, Δ = 3370 LT

KM_t = 22.45 FT a K.

SINCE GM_t = 3.00 FT

THEN KG = 19.45 FT a. K.

THE DISPLACEMENT AFTER DAMAGE WILL BE~

ORIGINAL Δ = 3370 LT

FLOODING WATER = 90 LT

AFTER DAMAGE, Δ_1 = 3460 LT.

TO FIND THE NEW DRAFT WE WILL USE TPI". FOR LARGER CHANGES OF DRAFT TPI" SHOULD BE FOUND USING THE AVERAGE OF THE NEW DRAFT AND THE OLD DRAFT, BUT FOR THIS CASE IT WILL BE SUFFICIENTLY ACCURATE TO USE THE OLD DRAFT.

AT T_{LCF} = 14.28 FT, TPI" = 31.65 TONS/IN

THE SINKAGE WILL BE $\frac{90 \text{ LT}}{31.65 \text{ TONS/IN}}$ = 2.84 IN

SINKAGE = 0.24 FT

T = 14.28 FT

T_1 = 14.52 FT.

AT T_1 = 14.52 FT KM_{t_1} = 22.42 FT a K.

ITEM	WT LT	VCG FT a. K.	VM FT-TONS
ORIG SHIP	3370	19.45	65547
FLOOD WTR	90	10.00	900
SHIP AFTER DAMAGE	3460	19.20	66447

(a) KM_{t_1} = 22.42 FT a K

KG_1 = 19.20 FT a K

(b) FIND THE ~~FREE SURFACE~~ EFFECT, $G_1 G_2$.

$$G_1 G_2 = \frac{i}{\nabla}$$

NOTES. - BOTH FREE SURFACE AND FREE COMMUNICATION ARE VIRTUAL EFFECTS, BUT LABEL THEM G_2 AND G_3.

- SINCE FLOODING WATER AND SEA WATER ARE OF THE SAME DENSITY NO DENSITY CORRECTION IS NECESSARY
- $i = \frac{lb^3}{12}$

$$G_1 G_2 = \frac{\frac{(25\text{ FT})(14\text{ FT})^3}{12}}{(3460\text{ LT})(35\text{ FT}^3/\text{LT})}$$

$$G_1 G_2 = 0.047\text{ FT.}$$

$$\boxed{\begin{array}{l}\text{(b) FREE SURFACE EFFECT:}\\ G_1 G_2 = +0.047\text{ FT}\end{array}}$$

(c) FIND THE ~~FREE~~ COMMUNICATION EFFECT, $G_2 G_3$

$$G_2 G_3 = \frac{a y^2}{\nabla}$$

$$G_2 G_3 = \frac{(25\text{ FT})(14\text{ FT})(7\text{ FT})^2}{(3460\text{ LT})(35\text{ FT}^3/\text{TON})}$$

$$G_2 G_3 = 0.142\text{ FT}$$

$$\boxed{\begin{array}{l}\text{(c) FREE COMMUNICATION EFFECT:}\\ G_2 G_3 = +0.142\text{ FT}\end{array}}$$

(d) FIND FINAL METACENTRIC HEIGHT AFTER FLOODING.

$$\begin{array}{lcl} KG_1 & = & 19.20\text{ FT} \\ G_1 G_2 & = & +0.047\text{ FT} \\ G_2 G_3 & = & \underline{+0.142\text{ FT}} \\ KG_3 & = & 19.389\text{ FT} \end{array} = 19.39\text{ FT. a K}$$

(d) CON'T.

$$KM_3 = KM_1 = 22.42 \text{ FT a K}$$

$$\underline{KG_3 = 19.39 \text{ FT a K}}$$

(d) $\underline{G_3M_3 = 3.03 \text{ FT.}}$

(e) FIND THE ANGLE OF LIST.

$$GM \tan\theta = \frac{w \times t}{\Delta}$$

$$\tan\theta = \frac{(50 \text{ LT})(7.0 \text{ FT})}{(3.03 \text{ FT})(3460 \text{ T})}$$

$$\tan\theta = .0601$$

$$\theta = 3.44^\circ$$

(e) FINAL ANGLE OF LIST:

$$\theta = 3.44^\circ$$

COMMENT ON PROBLEM:

IN DAMAGE PROBLEMS THERE ARE FIVE EFFECTS THAT SHOULD BE CONSIDERED:

1. FREE-SURFACE EFFECT
2. FREE COMMUNICATION EFFECT
3. EFFECT OF ADDED WEIGHT OF FLOODING WATER ON TRIM
4. EFFECT OF ADDED WEIGHT OF FLOODING WATER ON KG.
5. EFFECT OF UNSYMMETRICAL FLOODING ON LIST.

SUFFICIENT INFORMATION IS PROVIDED IN THE PROBLEM TO EVALUATE ALL OF THESE EFFECTS, AND THE SOLUTION WILL BE DEVELOPED ON THIS BASIS. HOWEVER, IN THIS PROBLEM EFFECTS NUMBER (3) AND (4) ARE SMALL. IN OTHER DAMAGE PROBLEMS THESE EFFECTS MAY BE QUITE IMPORTANT. THE INSTRUCTOR SHOULD REVIEW THE SOLUTION AND DECIDE WHETHER TO INCLUDE OR TO OMIT THESE EFFECTS.

SOLUTION:

GIVEN:

$\Delta_0 = 3500$ LTSW

$G_0M_0 = 3.50$ FT

DIMENSIONS, LOCATION, AND DEPTH OF FLOODING WATER IN COMPTS C-201E AND C-203L

FIRST, FIND INTACT DRAFT AND KG.

AT $\Delta = 3500$ LTSW, $T_{m_0} = 14.84$ FT

$$KM_0 = (953 \text{ TONS})\left(\frac{2 \text{ FT}}{100 \text{ TONS}}\right)$$

$KM_0 = 19.06$ FT a. K.

$\underline{G_0M_0 = 3.50 \text{ FT}}$

$G_0M_0 = 15.56$ FT a. K.

16-27

NEXT, FIND THE WEIGHT AND CENTERS OF THE FLOODING WATER IN THE TWO COMPARTMENTS

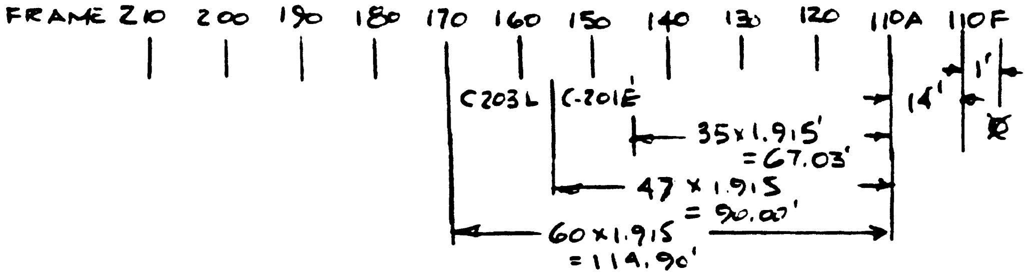
	C-201 E	C-203L
DIMENSIONS	15.75' × 13.00' × 4.0'	22.75' × 39.00' × 4.0'
VOL., FLOOD. WATER	819.0 FT^3	3549.0 FT^3
WEIGHT, FLOOD WTR.	23.4 LT	101.4 LT
TOTAL WT., FLOOD WTR	124.8 LT	

THE TRANSVERSE CENTERS ARE SHOWN ON THE DIAGRAM. THE LONGITUDINAL CENTERS MAY BE COMPUTED FROM THE FRAME NUMBERS GIVEN AND THE INFORMATION SHOWN ON THE PROFILE SKETCH ON THE CURVES OF FORM ("DISPLACEMENT AND OTHER CURVES")

THE SHIP HAS BEEN HOLED AT THE WATERLINE AND THE FLOODING WATER WILL RISE TO THE LEVEL OF THE EXTERNAL SEA WATER. THE ADDED WEIGHT OF THE FLOODING WATER (USING THE ADDED WEIGHT METHOD) WILL CAUSE SINKAGE AND TRIM AFT, SO THAT IN ORDER TO FIND THE V.C.G. OF THE FLOODING WATER THE WATERLINE MUST BE FOUND. SINCE THE DEPTH OF WATER IN THE COMPARTMENT IS GIVEN AS 4.0 FT, THE V.C.G. OF THE FLOODING WATER WILL BE HALF THIS DISTANCE BELOW THE DRAFT AT THE LONGITUDINAL LOCATION OF THE COMPARTMENT.

IN TRUTH, SINKAGE, TRIM AND LIST ARE COUPLED EFFECTS AND A TRUE SOLUTION CAN ONLY BE FOUND ITERATIVELY, AS IS DONE IN COMPUTER PROGRAMS SUCH AS SHCP, THE APPROXIMATE NATURE OF THESE HAND SOLUTIONS SHOULD BE POINTED OUT TO THE STUDENTS.

LOCATION OF COMPARTMENTS:



FRAME 145 = 82.03 FT AFT ⊗
FRAME 157 = 105.00 FT AFT ⊗

MIDPOINT C-201E = 93.52 FT AFT ⊗

FRAME 157 = 105.00 FT AFT ⊗
FRAME 170 = 129.90 FT AFT ⊗

MIDPOINT C-203L = 117.45 FT AFT ⊗

TO ESTIMATE THE CHANGE OF TRIM THINK OF ADDING THE WEIGHT AT THE LCF, WHICH WOULD PRODUCE NO CHANGE IN TRIM, THEN SHIFTING THE WEIGHTS TO THE REQUIRED LOCATION. ACTUALLY, FOR LARGE SINKAGES A BETTER ESTIMATE WILL BE OBTAINED THE AVERAGE LCF AND MT1" BETWEEN NEW AND OLD WATERLINES BUT FOR THIS PROBLEM THAT WOULD BE SPLITTING HAIRS.

$$LCF_1 = (1117\ LT)\left(\frac{2\ FT}{100\ LT}\right) = 22.34'\ AFT ⊗$$

$$MT1''_1 = (647\ LT)\left(\frac{100\ FT\text{-}TONS/IN}{100\ LT}\right)$$

$$MT1''_1 = 647\ FT\text{-}TONS/IN$$

TRIMMING ARM, C-201E = 93.52 FT AFT ⊗
− 22.34 FT AFT ⊗ (LCF)
= 71.18 FT

TRIMMING MOM'T, C-201E = 71.18 FT × 23.4 LT = 1666 FT-TONS

TRIMMING ARM, C-203L = 117.45 FT AFT ⊗
− 22.34 FT AFT ⊗ (LCF)
= 95.11 FT

TRIMMING MOM'T, C-203L = 95.11 FT × 101.4 LT = 9644 FT-TONS

TOTAL TRIMMING MOM'T = 11,310 FT-TONS (AFT)

$$\text{CHANGE OF TRIM} = \frac{\text{TRIMMING MOM'T}}{\text{MTI}'}$$

$$= \frac{11,310 \text{ FT-TONS}}{647 \text{ FT-TONS/IN}}$$

$$= 17.5''$$

$$= 1.46 \text{ FT.}$$

FOLLOW THE USUAL SIMILAR TRIANGLE PROCEDURE TO APPORTION THIS INTO δ_F AND δ_A

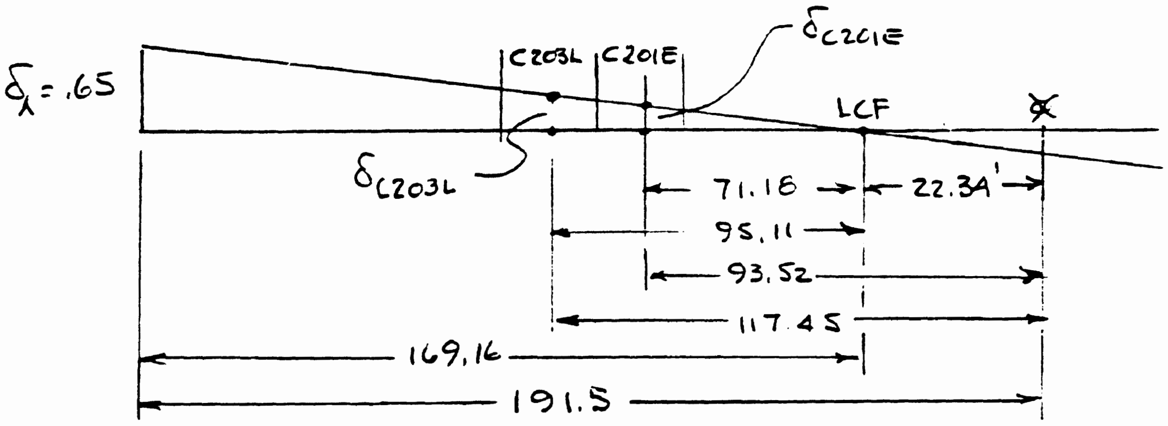
$$\delta_F + \delta_A = 1.46$$

$$\frac{\delta_F}{191.5 + 22.34} = \frac{\delta_A}{191.5 - 22.34}$$

$$\delta_F = 1.26\,\delta_A$$

$$2.26\,\delta_A = 1.46$$

$$\delta_A = .65 \text{ FT}$$



BY SIMILAR TRIANGLES:

$$\frac{.65}{169.16} = \frac{\delta_{C203L}}{95.11} = \frac{\delta_{C201E}}{71.18}$$

$$\delta_{C203L} = 0.37 \text{ FT}$$

$$\delta_{C201E} = 0.27 \text{ FT}$$

THE DRAFT AND V.C.G. AT THE MIDPOINT OF THESE COMPARTMENTS WILL BE:

C-201E

$$T_M = 14.84 \text{ FT a K}$$

$$\delta_{201E} = \underline{+0.27}$$

$$T_{C201E} = 15.11 \text{ FT a K}$$

$$\underline{-2.00 \text{ FT}}$$

$$V.C.G._{201E} = 13.11 \text{ FT a K.}$$

C-203L

$$T_M = 14.84 \text{ FT a K.}$$

$$\delta_{C203L} = \underline{0.37 \text{ FT}}$$

$$T_{C203L} = 15.21 \text{ FT a K}$$

$$\underline{-2.00 \text{ FT}}$$

$$V.C.G._{C203L} = 13.21 \text{ FT a K.}$$

WE MAY NOW FIND KG_1 OF THE FLOODED SHIP (WITHOUT FREE SURFACE OR FREE COMMUNICATION CORRECTIONS).

ITEM	WT LT	VCG FT a K	V.M. FT-TONS
ORIG. SHIP	3500	15.56	54460
FLOODING WTR C-201E	23.4	13.11	307
FLOODING WTR C-203L	101.4	13.21	1339
DAMAGED SHIP	3624.8	15.48	56106

(NOTE HOW SMALL THE EFFECT OF INCLUDING THE TRIM CORRECTION IS IN THIS PROBLEM, BUT IN CASES IN WHICH LARGE SINKAGE AND TRIM IS INVOLVED THESE CORRECTIONS MUST BE CONSIDERED.)

WE ARE NOW READY TO CALCULATE THE FREE SURFACE AND FREE COMMUNICATION CORRECTIONS.

	C-201E	C-203L
DAMAGED Δ_1	3624.8 LT	
DAMAGED ∇_1	126,868 FT³	
DIMENSIONS	15.75' × 13.00' × 4.0'	22.75' × 39.00' × 4.0'
t.c.g FLOOD. WTR.	13.00' (STBD)	0.0
i/∇_1	$\frac{(15.75)(13)^3/12 \text{ FT}^4}{126,868 \text{ FT}^3}$	$\frac{(22.75)(39.00)^3/12 \text{ FT}^4}{126,868 \text{ FT}^3}$
$i/\nabla_1 =$	0.023 FT	0.886 FT
ay^2/∇_1	$\frac{(15.75)(13.00)(13.00)^2 \text{ FT}^4}{126,868 \text{ FT}^3}$	$\frac{(22.75)(39.00)(0.0)^2 \text{ FT}^4}{126,868 \text{ FT}^3}$
$ay^2/\nabla_1 =$	0.273 FT	0.0 SINCE $y=0$

NOTE THAT THE FREE COMMUNICATION EFFECT APPLIES ONLY IN THE CASE OF UNSYMMETRICAL FLOODING.

BOTH FREE SURFACE AND FREE COMMUNICATION ARE VIRTUAL EFFECTS, BUT DESIGNATE THESE BY SUBSCRIPTS 2 AND 3 RESP'Y.

TOTAL FREE SURFACE: C-201E = 0.023 FT
C-203L = 0.886 FT

$G_1G_2 = 0.909$ FT $= 0.91$ FT

TOTAL FREE COMMUNICATION: C-201E = 0.273 FT
C-203L = 0.0 FT

$G_2G_3 = 0.273$ FT $= 0.27$ FT.

THEN,

$KG_1 = 15.48$ FT a.K.
$G_1G_2 = +0.91$ FT
$G_2G_3 = +0.27$ FT

$KG_3 = 16.66$ FT a.K.

AT $T_m = 14.84$ FT a K $KM_1 = KM_3 = (949 \text{ LT})\left(\frac{2 \text{ FT}}{100 \text{ LT}}\right)$

$$KM_3 = 18.98 \text{ FT a K.}$$

$$KG_v = \underline{KG_3 = 16.66 \text{ FT a.K}}$$

$$G_vM_3 = G_3M_3 = 2.32 \text{ FT.}$$

FINALLY,

$$G_3M_3 \tan\theta = \frac{w \times t}{\Delta_3}$$

$$\tan\theta = \frac{(23.4 \text{ LT})(13.00 \text{ FT})}{(2.32 \text{ FT})(3624.8)}$$

$$\tan\theta = .03617$$

$$\theta = 2.07^\circ \text{ (STBD)}$$

RECAP

(a) ADDED WEIGHT OF FLOODING WATER; C-201E = 23.4 LT

C-203L = 101.4 LT

(b) FREE SURFACE LOSS: C-201E = 0.023 FT

C-203L = 0.886 FT

(c) FREE COMMUNICATION EFFECT: C-201E = 0.273 FT

C-203L = 0.0 FT

(d) FINAL GM: $G_3M_3 = 2.32$ FT

ANGLE OF LIST: $\theta = 2.07^\circ$ (STBD)

BASIC NAVAL ARCHITECTURE

Unit Number: 17

Title: Ship hazards and vulnerability - 3

Tape Running Time: $35^M\ 45^S$

Reading Assignment: MSD, pp 85-93

Additional References: PNA, pp 118-120, 149-165

Introduction to Naval Architecture (INA), Gillmer, pp 180-200

Scope:

Factors affecting the survivability of naval ships are discussed, including ability to survive underwater attack, protection of vital systems against flooding, protection against collision and stranding. The approach to damaged stability analysis is outlined but details are not developed. Assumed damage conditions and criteria for survival are outlined.

Key Points to Emphasize:

1. Supplement video graphics with photographs of damaged ships as available.
2. Stress damaged conditions which are assumed and criteria for survival.
3. Go over the effect of stranding on G and method of analysis. Drydocking analysis example will be given in next unit.
4. Discuss "vee-lines" and design implications.

Suggested Problem Assignment: 47, one of 48, 49, 50

SHIP HAZARDS AND VULNERABILITY (CON'T)

SUBDIVISION OF NAVAL SHIPS

CONSIDERATIONS:

- ABILITY TO SURVIVE UNDERWATER ATTACK
- PROTECTION OF VITAL SPACES AGAINST FLOODING
- INTERFERENCE OF SUBDIVISION WITH ARRANGEMENTS
- INTERFERENCE OF SUBDIVISION WITH ACCESS AND SYSTEMS
- PROVISION FOR CARRYING LIQUIDS
- POSSIBILITY OF COLLISION DAMAGE
- POSSIBILITY OF STRANDING

SHIP HAZARDS AND VULNERABILITY (CON'T)

ABILITY TO SURVIVE UNDERWATER ATTACK

- TRANSVERSE W.T. BULKHEADS ARE THE MOST EFFECTIVE FORM OF SUBDIVISION.
- LONGITUDINAL W.T. BULKHEADS INTRODUCE THE DANGER OF UNSYMMETRICAL FLOODING.
    - MAY CREATE DANGEROUS LIST AND LOSS OF FREEBOARD.
    - MUST DEWATER PROMPTLY OR COUNTERFLOOD ON OPPOSITE SIDE.
    - CROSS CONNECTION SYSTEMS ARE REQUIRED TO INSURE COUNTERFLOODING CAN BE DONE QUICKLY.

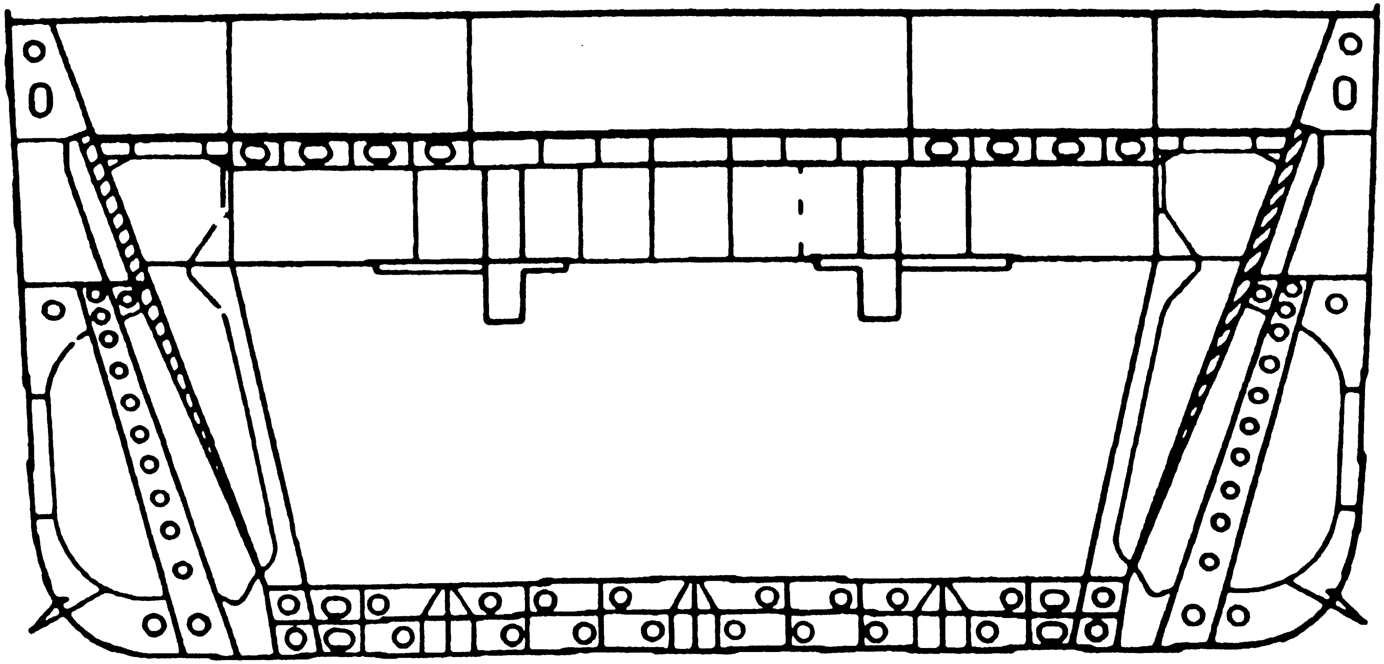
SHIP HAZARDS AND VULNERABILITY (CON'T)

PROTECTION OF VITAL SPACES - NAVAL SHIPS

- VITAL SPACES ARE THOSE THAT ARE MANNED AT BATTLE STATIONS (GENERAL QUARTERS) AND SPACES THAT CONTAIN ESSENTIAL EQUIPMENT.
- BEST PROTECTION WOULD BE TO ENCLOSE VITAL SPACES WITH W.T. BULKHEADS.
- ABILITY TO DO THIS IS LIMITED BY SHIP SIZE, ACCESS AND ARRANGEMENT CONSIDERATIONS, AND UNSYMMETRICAL FLOODING CONSIDERATIONS.

SHIP HAZARDS AND VULNERABILITY (CON'T)

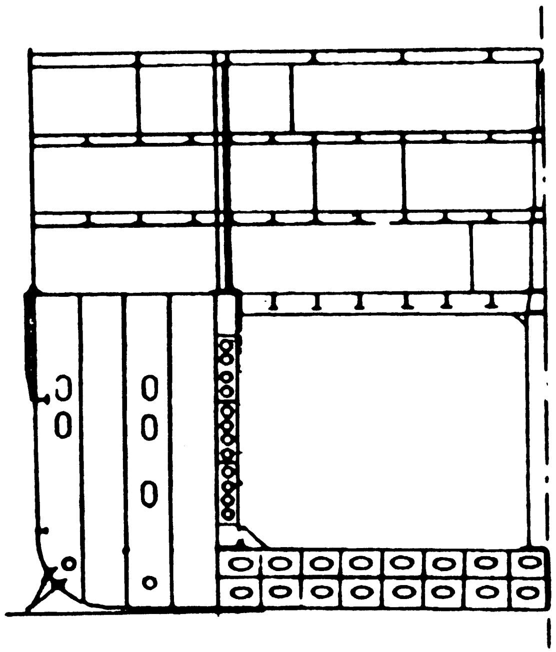
SIDE PROTECTION SYSTEMS - NAVAL SHIPS



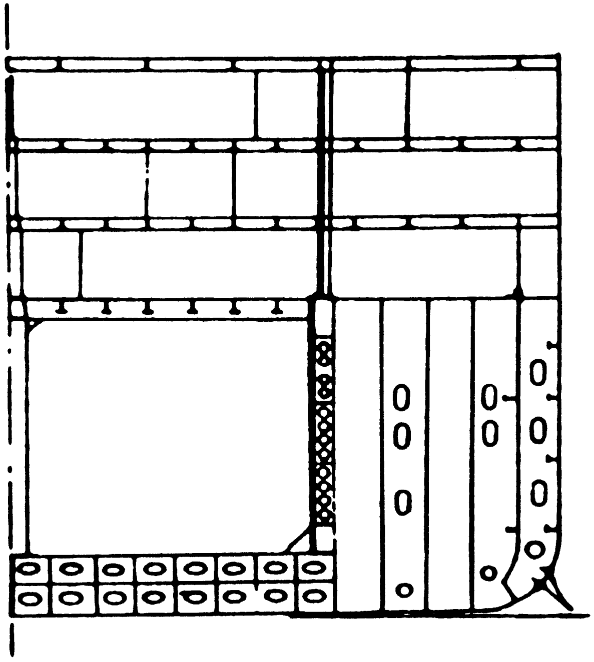
IOWA Class Battleships **MIDSHIP SECTION**

SHIP HAZARDS AND VULNERABILITY (CON'T)

SIDE PROTECTION SYSTEMS - NAVAL SHIPS



MIDSHIP SECTION 1943

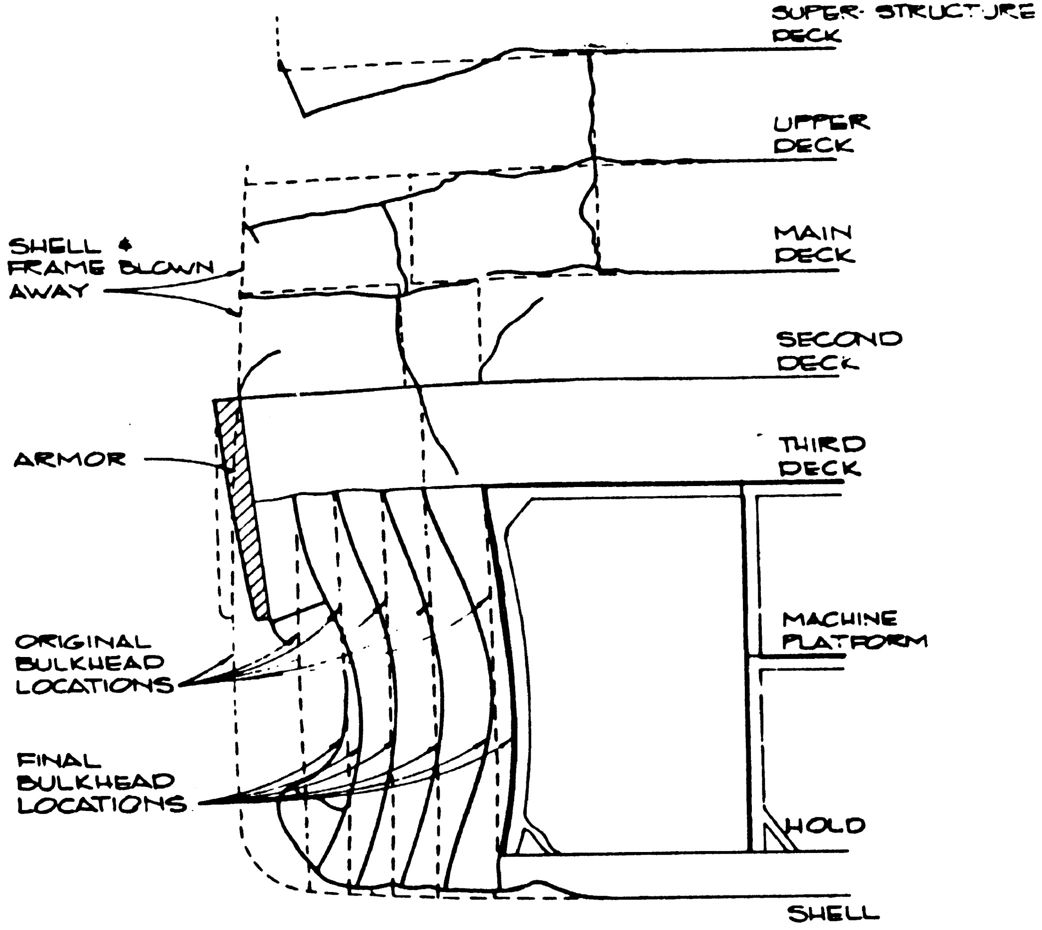


MIDSHIP SECTION 1952

**ESSEX Class
Aircraft Carriers**

SHIP HAZARDS AND VULNERABILITY (CON'T)

SIDE PROTECTION SYSTEMS - NAVAL SHIPS



U.S.S. WEST VIRGINIA AFTER TORPEDO HIT AT PEARL HARBOR

SHIP HAZARDS AND VULNERABILITY (CON'T)

DAMAGED STABILITY REQUIREMENTS FOR NAVAL SHIPS

- BASED ON ASSUMED EXTENT OF DAMAGE WHICH DEPENDS ON:
  - SIZE AND FUNCTION OF SHIP
  - WHETHER SIDE PROTECTION SYSTEMS ARE PRESENT
- A NUMBER OF DAMAGE CASES ARE ANALYZED
- LIMITING CRITERIA ARE:
  - ANGLE OF HEEL AFTER DAMAGE
  - ANGLE OF HEEL AFTER COUNTERFLOODING (SHIPS w/o SIDE PROTECTION)
  - RESERVE DYNAMIC STABILITY (SHIPS w/ SIDE PROTECTION)

SHIP HAZARDS AND VULNERABILITY (CON'T)

ASSUMED DAMAGE CONDITIONS - NAVAL SHIPS

1. SHIPS WITH SIDE PROTECTION SYSTEMS.

   - UNSYMMETRICAL FLOODING IS THE PRIMARY CONCERN.
   - CONSIDER VARIOUS DAMAGE SCENARIOS INCLUDING MULTIPLE HITS ON THE SAME SIDE:
     - FOR DESIGN, THE ANGLE OF LIST FROM FLOODING IN ANY OF THESE SCENARIOS SHOULD NOT EXCEED 20°.
     - ARRANGEMENTS MUST EXIST FOR RAPIDLY CORRECTING LIST TO LESS THAN 5°.

SHIP HAZARDS AND VULNERABILITY (CON'T)

ASSUMED DAMAGE CONDITIONS - NAVAL SHIPS

2. SHIPS WITHOUT SIDE PROTECTION SYSTEMS.

- UNDER 100 FEET IN LENGTH
  - MUST BE ABLE TO WITHSTAND FLOODING OF ANY ONE MAIN COMPARTMENT.
- 100 FEET TO 300 FEET IN LENGTH.
  - MUST BE ABLE TO WITHSTAND FLOODING OF ANY TWO ADJACENT COMPARTMENTS.

SHIP HAZARDS AND VULNERABILITY (CON'T)

ASSUMED DAMAGE CONDITIONS - NAVAL SHIPS

- OVER 300 FEET IN LENGTH.
  - COMBATANTS AND PERSONNEL CARRIERS MUST WITHSTAND A LENGTH OF DAMAGE EQUAL TO 15% OF LENGTH.
  - DAMAGE LENGTH EQUALS 12.5% OF LENGTH FOR OTHER TYPES.

SHIP HAZARDS AND VULNERABILITY (CON'T)

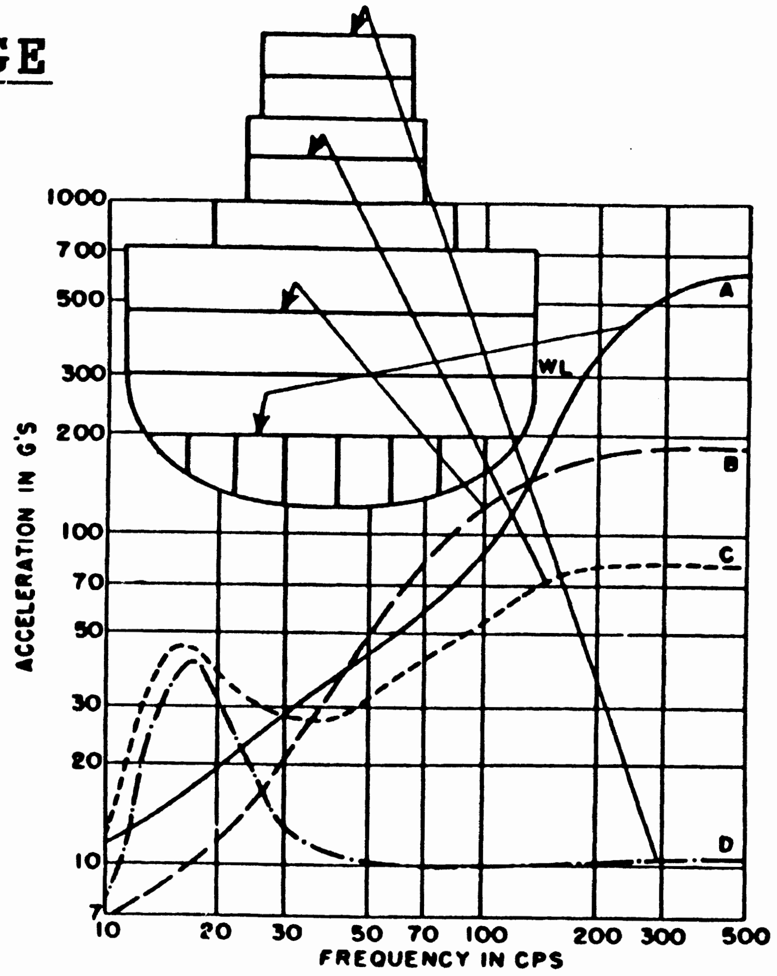
COLLISION PROTECTION

- ALL SHIPS, NAVAL AND MERCHANT, ARE REQUIRED TO HAVE A WATERTIGHT COLLISION BULKHEAD UP TO THE BULKHEAD DECK LOCATED NOT LESS THAN 5% OF THE LENGTH AFT THE F.P.
- FOR PASSENGER VESSELS IN COMPUTING THE MAXIMUM SEPARATION BETWEEN MAIN TRANSVERSE WATERTIGHT BULKHEADS THE ASSUMED DAMAGE IS:

  LENGTH - MINIMUM SPACING OF BHDS.
  DEPTH - 20% OF THE BEAM.
  HEIGHT - BASELINE TO MARGIN LINE.

SHIP HAZARDS AND VULNERABILITY (CON'T)

SHOCK DAMAGE



GROUNDING AND STRANDING

A SHIP WHICH HAS BEEN STOPPED BECAUSE OF CONTACT WITH THE BOTTOM IS SAID TO BE GROUNDED.

IF THE SHIP IS UNABLE TO FREE ITSELF IT IS SAID TO BE STRANDED.

GROUNDING AND STRANDING

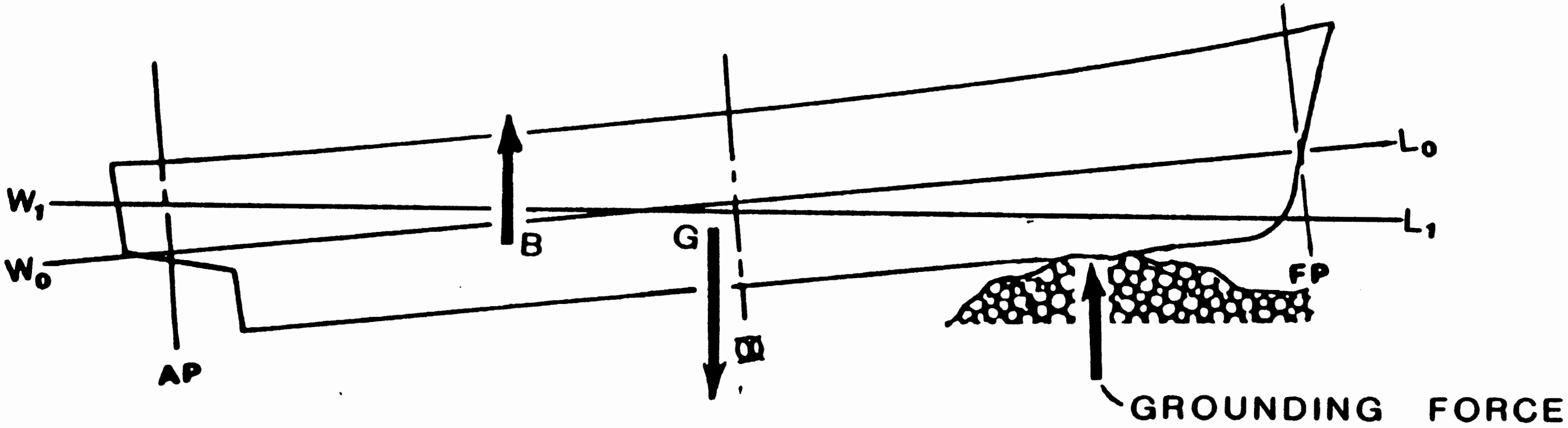
- MOST EFFECTIVE PROTECTION IS A COMPLETE INNER BOTTOM.
- GROUNDING ON A FLAT SAND OR MUD BOTTOM:
    - STABILITY NOT USUALLY A PROBLEM.
    - POUNDING IN A SURF ZONE MAY BE A PROBLEM.
    - CLOGGING OF SEA CHESTS MAY BE A PROBLEM.
    - SHIP MAY BE ABLE TO FREE ITSELF AT HIGH TIDE, OR IT MAY HAVE TO BE PULLED OFF.

GROUNDING AND STRANDING

- IF A SHIP GROUNDS ON A CORAL REEF OR ON ROCKS AND IS SUPPORTED OVER A SMALL AREA:
  - — NOW, STABILITY MAY BE A PROBLEM.
  - — IF THE GROUNDING HAS PRODUCED A LONG TEAR IN THE BOTTOM, PROGRESSIVE FLOODING MAY BECOME A PROBLEM.
  - — JETTISONING OF ON BOARD WEIGHTS MAY BE REQUIRED TO RE-FLOAT THE SHIP.

GROUNDING AND STRANDING

- WHEN THE SHIP IS AGROUND THE SHIP IS NO LONGER A TWO FORCE SYSTEM. A THIRD FORCE, THE GROUNDING FORCE IS NOW INTRODUCED.



- WEIGHT AND BUOYANCY ARE NO LONGER VERTICALLY ALIGNED.

GROUNDING AND STRANDING

- THE GROUNDING FORCE ACTS LIKE A WEIGHT REMOVAL AT THE KEEL.
- THIS CAUSES A VIRTUAL RISE IN THE CENTER OF GRAVITY.
- A SERIOUS LIST COULD RESULT IF:
  - THE GROUNDING FORCE IS ACTING OVER ONLY A SMALL AREA, AND
  - THE TIDE FALLS.
- GROUNDING PROBLEM IS SIMILAR TO DRYDOCKING PROBLEM, WHICH WILL BE DISCUSSED NEXT.

GROUNDING AND STRANDING

APPROACH WHEN GROUNDED

1. DETERMINE WHERE ALONG THE SHIP CONTACT IS BEING MADE WITH BOTTOM.
2. EVALUATE DAMAGE AND FLOODING, IF ANY.
3. DETERMINE STATE OF TIDE AT TIME OF GROUNDING AND EXPECTED RISE AND FALL.
4. DETERMINE -
    - DISPLACEMENT, FREE FLOATING, AT TIME OF GROUNDING.
    - DISPLACEMENT, AS GROUNDED, JUST AFTER GROUNDING.

GROUNDING AND STRANDING

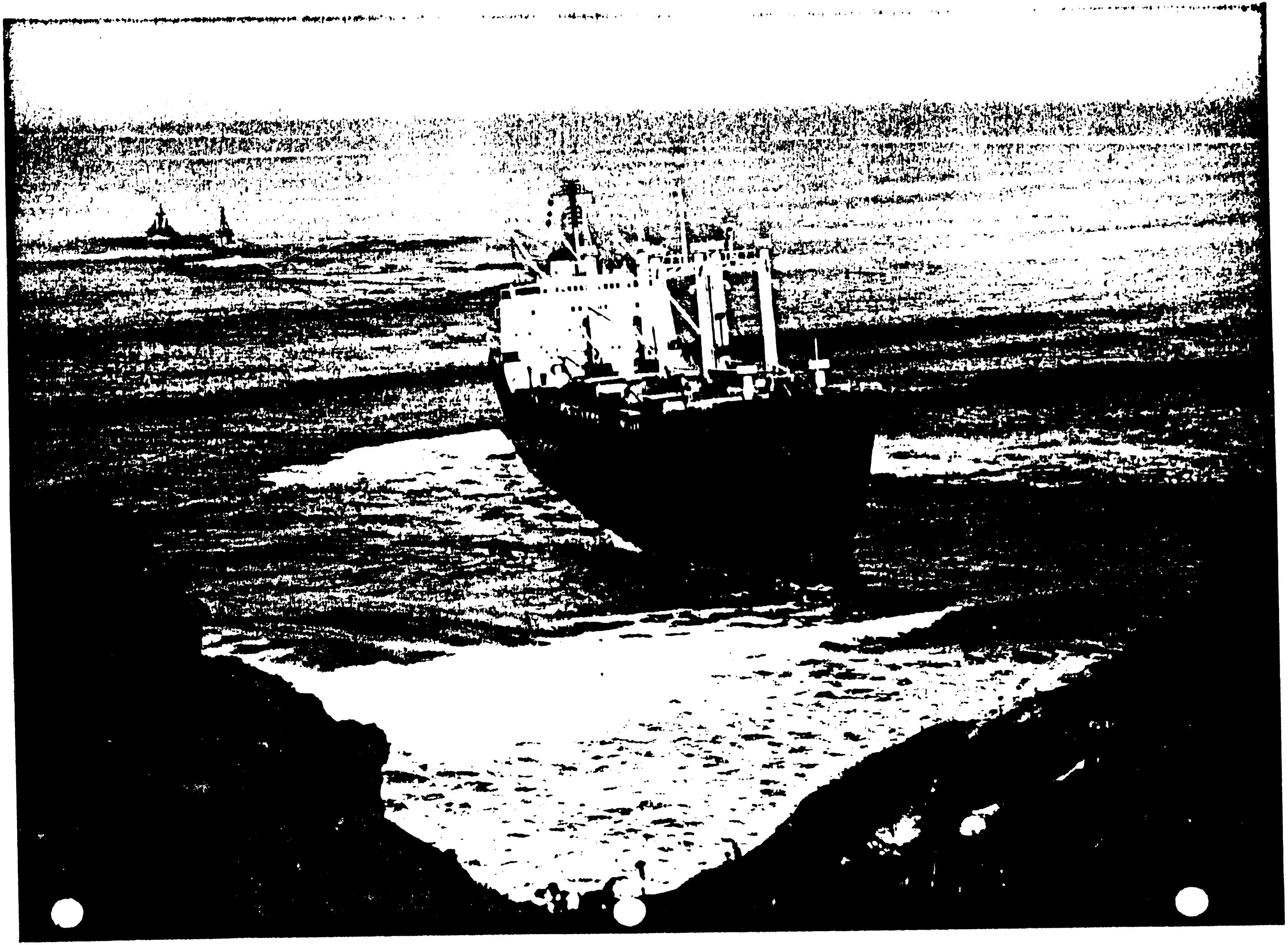
APPROACH WHEN GROUNDED

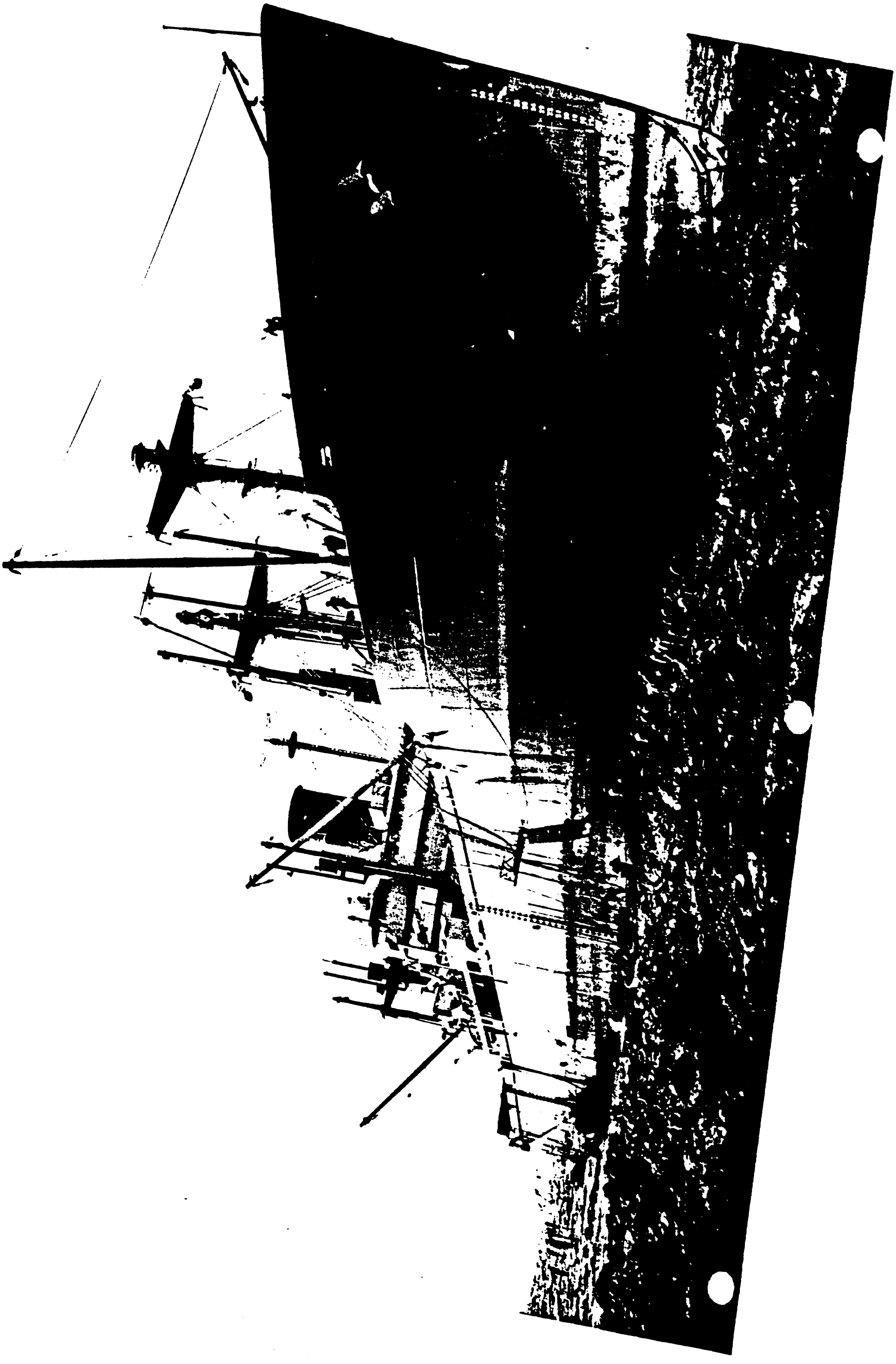
Δ = DISPLACEMENT, FREE FLOATING
Δ_1 = DISPLACEMENT, AS GROUNDED
W = GROUNDING FORCE
THEN, W = $\Delta - \Delta_1$

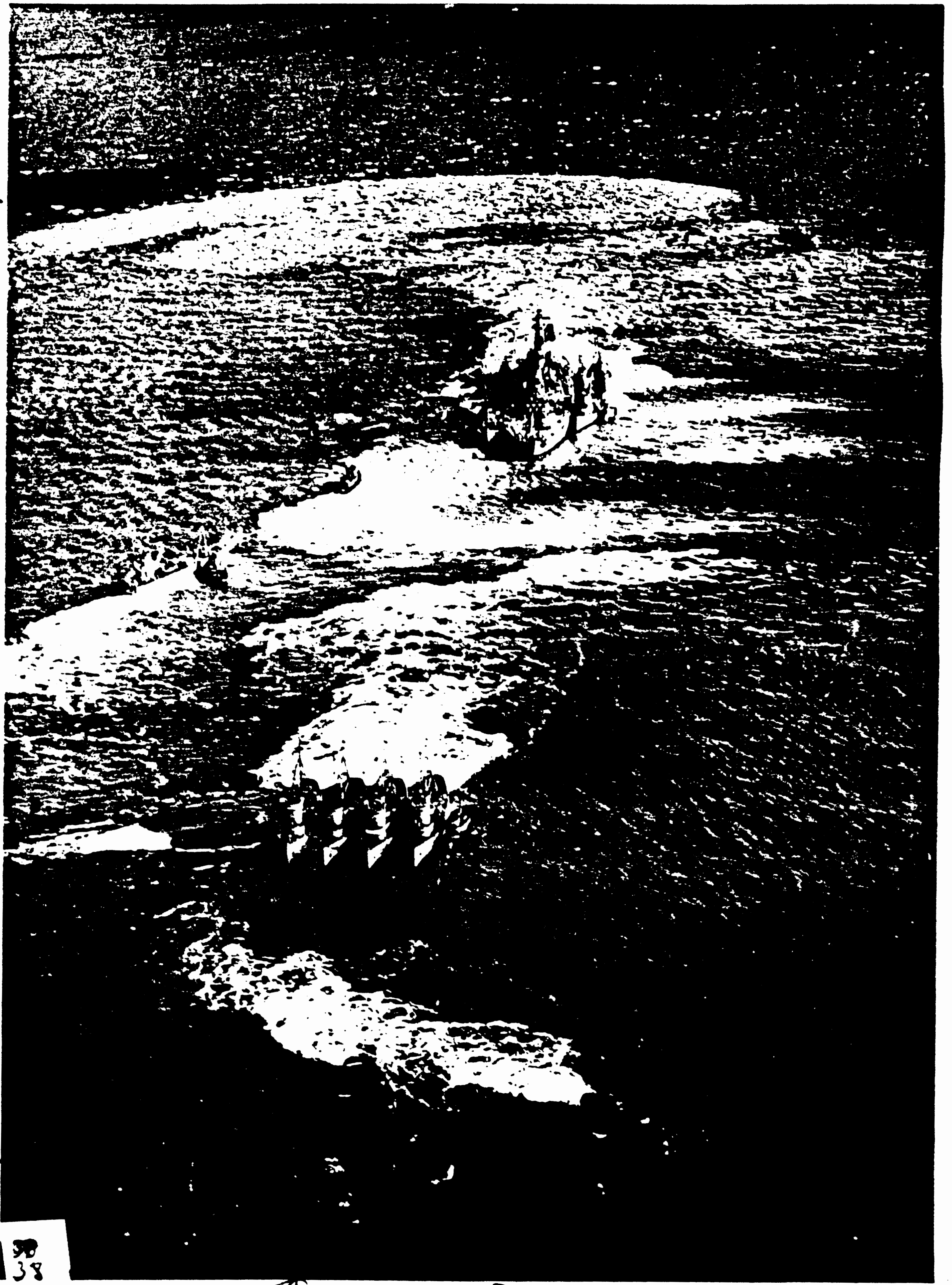
ITEM	WT	VCG	MOMENT
ORIGINAL SHIP	Δ	KG	$KG \cdot \Delta$
GROUNDING FORCE	-W	0	0
SHIP GROUNDED	$\Delta_1 = \Delta - W$	$\frac{KG \cdot \Delta}{\Delta_1}$	$KG \cdot \Delta$

$$\text{NEW } KG_1 = KG \cdot \frac{\Delta}{\Delta_1}$$

THERE WILL BE A VIRTUAL RISE IN G !!!







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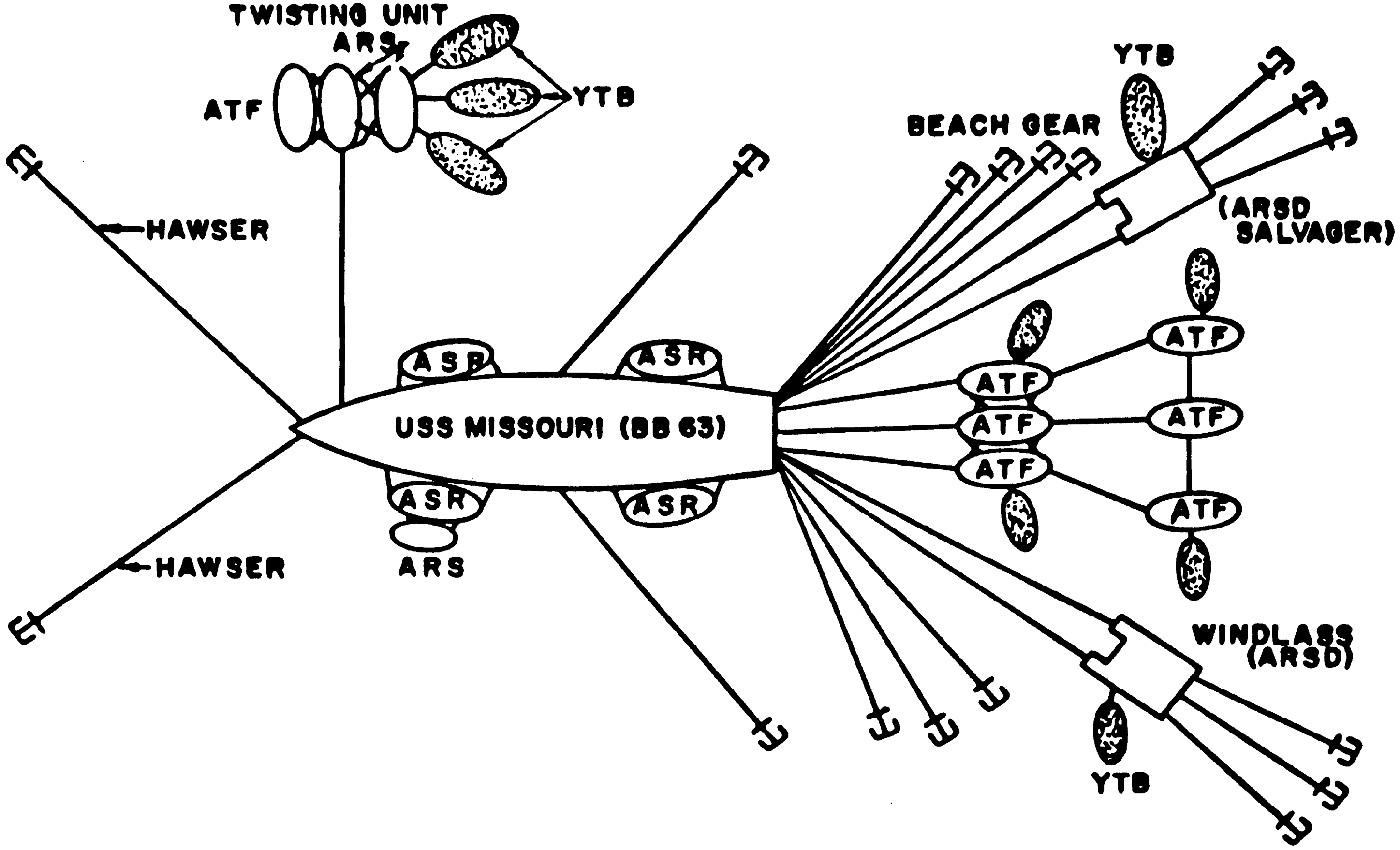
(A), 200x25

17-25

GROUNDING AND STRANDING



BASIC NAVAL ARCHITECTURE

Problem 47

Problem Level: Intermediate

An FFG-7-type frigate with low fuel and no ballast in the fuel tanks is in the following condition in salt water:

T_f = 13'-0"

T_a = 14'-0"

KG = 20.50' above the keel

(a) Plot the Static Stability Curve for the ship in this condition.

Determine the angle of steady wind heel, Point C on Fig 4-11, pp 84, Gillmer, using the wind heeling arm equation given on pp 84. Take:

V_w = 100 knots

h = 25.60 ft

A = 13000 ft^2

Notes:

(1) The FFG-7 30^0 cross curve is plotted slightly lower than it should be.
(2) In the formula on pp 84, M_w is the heeling arm, not the heeling moment (confusing notation).
(3) The units buried in the constant .0035 are lbs/ft^2kt^2

Problem 48

Problem Level: Basic

An FFG7 Class frigate enters a graving dock in fresh water at the following drafts and KG.

T_f = 13'-6"

T_a = 13'-6"

KG = 18.00' above keel

The side blocks in the dock must be fitted after the ship has settled on the keel blocks but before the water level has been lowered to the point where the ship will develop a list. Thus the critical condition occurs when GM becomes negative.

Find the ship's mean draft when GM = 0 and thereafter becomes negative. Find the total load on the keel blocks at this point.

Problem 49

Problem Level: Intermediate

A DD 692 (long hull) class destroyer is underway at sea with the following approximate drafts and KG:

T_f = 13'-7"

T_a = 13'-7"

KG = 16.50' above keel

Find: (a) LCB, LCG, and displacement afloat

The ship grounds on a coral reef. A survey shows that the ship is resting on a coral ledge between frames 80 and 90 and that the hull is intact and not seriously damaged. The drafts are now:

T_f = 10'-0"

T_a = 14'-0"

Find: (b) location and magnitude of the buoyant force in the grounded condition

(c) location and magnitude of the grounding force exerted by the reef on the ship

(d) GM in the grounded condition

A rise of tide of 1.25 ft. is expected in about two hours when the next high tide occurs.

(e) Make an estimte of the grounding force at the high tide

BASIC NAVAL ARCHITECTURE

Problem 50

Problem Level: Basic

Calculate the following parameters and coefficients for the ship data given below:

Ship Speed = V = 20.00 knots

Ship Length = L_{pp} = 400'-0"

Find: Speed-Length Ratio = $\frac{V}{\sqrt{L}}$

Froude Number = $F_n = \frac{v}{\sqrt{gL}}$

Reynolds Number = $R_n = \frac{vL}{\nu}$ at 59° F sea water

ITTC Friction Coefficient = $C_f = \frac{.075}{(\log_{10} R_n - 2)^2}$

Tables of Kinematic Viscosity and Density of fresh water and sea water are given in the Appendix to the Problem Set.

GIVEN: FFG-7 $T_f = 13-0''$

$T_a = 14'-0''$

$KG = 20.50$ FT a. K.

FIND: ANGLE OF STEADY HEEL FOR

$V_w = 100$ KTS

$h = 25.60$ FT

$A = 13,000$ FT²

SOLUTION:

$$\begin{array}{l} T_f = 13'-0'' \\ \underline{T_a = 14'-0''} \\ T_m = 13'-6'' \end{array}$$

AT $T_m = 13'-6''$ $\Delta_m = 3080$ LT SW

LCF = 20.72 FT AFT ⊗

TP1" = 30.80 TONS/IN

TO CORRECT DISPLACEMENT FOR TRIM,

$$CD12''TA = \frac{12 \times TP1'' \times LCF}{L}$$

$$= \frac{12 \text{ IN/FT} \times 30.80 \text{ TONS/IN} \times 20.72 \text{ FT}}{408.0 \text{ FT}}$$

$CD12''TA = 18.77$

THEN, ROUNDING, CORR = +19 LT

$$\begin{array}{l} \Delta_m = 3080 \\ \text{CORR} = \underline{+19} \\ \Delta = 3099 \text{ LT.} \end{array}$$

THE ASSUMED HEIGHT OF THE CENTER OF GRAVITY IS KA = 19.00 FT a K.

$$\begin{aligned} KG &= 20.50 \text{ FT a K} \\ KA &= 19.00 \text{ FT a K} \\ \hline AG &= 1.50 \text{ FT} \end{aligned}$$

NEXT, ENTER CROSS CURVES OF STABILITY WITH Δ = 3099 LT ≃ 3100 LT, OBTAIN VALUES OF AZ, AND CORRECT FOR AG = 1.50 FT.

ANGLE OF INCLINATION, ϕ DEG	(FROM CROSS CURVES) AZ FT	AG sin ϕ (=1.50 sin ϕ) FT	GZ (FOR KG =20.50' a K) FT
10	.59	.26	.33
15	.85	.39	.46
20	1.09	.51	.58
* 30	1.56	.75	.81
40	2.12	.96	1.16
45	2.38	1.06	1.32
50	2.56	1.15	1.41
55	2.62	1.23	1.39
60	2.58	1.30	1.28

* NOTE THAT 30° CROSS CURVE HAS BEEN MISPLOTTED. POINTS ARE LOW.

NEXT, CALCULATE THE WIND HEELING ARM.

$$M_w = \frac{.0035 V_w^2 A h \cos^2 \phi}{2240 \Delta}$$

WHERE M_w = HEELING ARM (NOT MOMENT), FT

V_w = WIND VELOCITY, KNOTS.

= 100 KTS

A = PROJECTED LATERAL AREA ABOVE WL; FT^2

= 13 000 FT^2

h = CENTER OF LATERAL AREA ABOVE HALF DRAFT, FT

= 25.60 FT

NOTE THAT THE UNITS BURIED IN THE CONSTANT ARE $\frac{LBS}{FT^2 KT^2}$

$$M_w = \frac{(.0035 \frac{LBS}{FT^2 KT^2})(100 KT)^2(13000 FT^2)(25.60 FT)}{(2240 \frac{LBS}{LT})(3099 LT)} \cos^2\phi$$

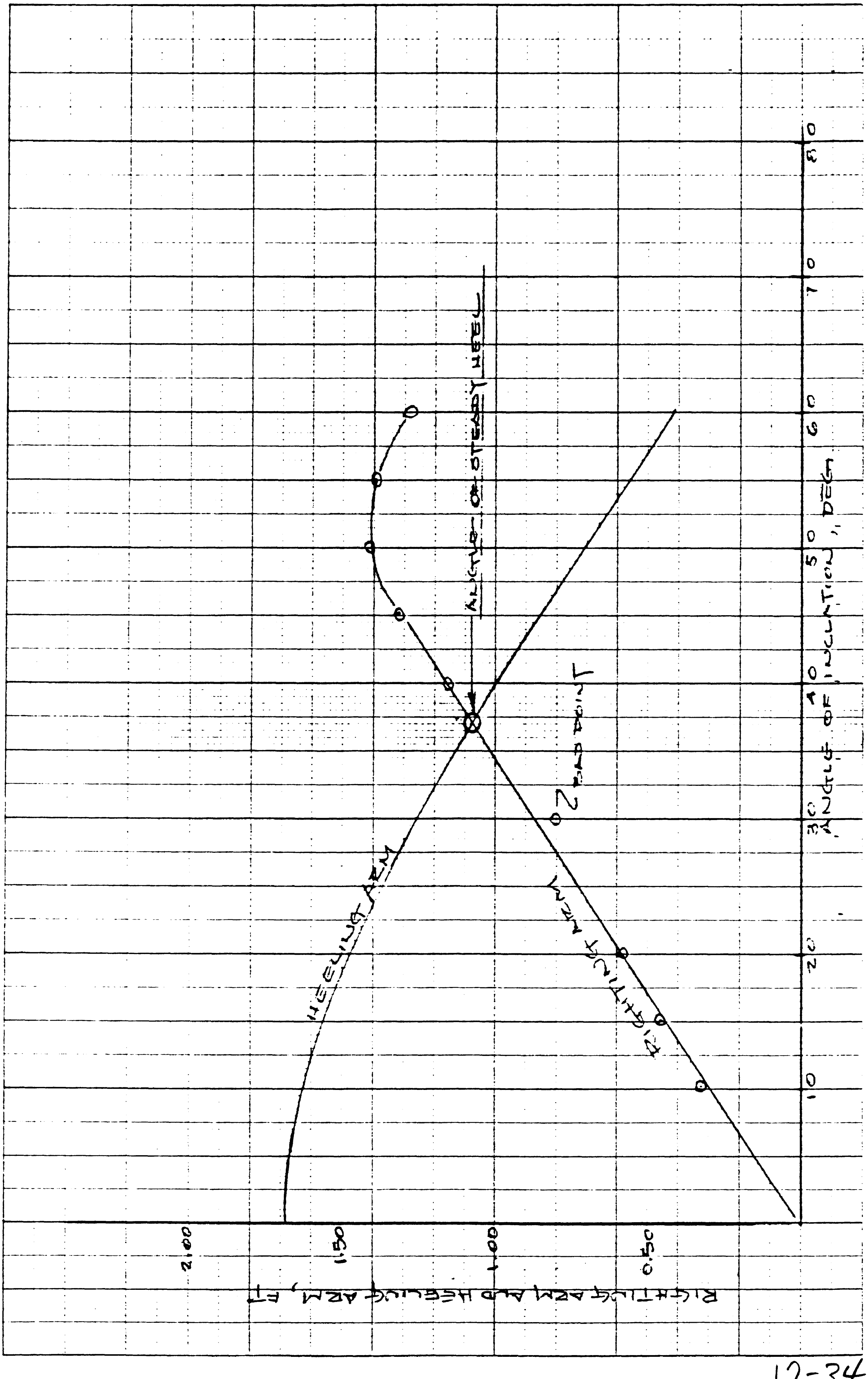
$$M_w = 1.68 \cos^2\phi$$

ϕ	M_w
DEG.	FT
0	1.68
10	1.63
20	1.48
30	1.26
40	0.99
50	0.69
60	0.42
70	0.20
80	0.05
90	0.0

FROM THE PLOT, **ANGLE OF STEADY HEEL = 37°**

COMMENT: 37° IS TOO LARGE AN ANGLE OF HEEL FOR THIS LOADING. THE SHIP IS NOT IN A SATISFACTORY LOADING CONDITION WITH THIS KG. THE PROBLEM ILLUSTRATES THE NECESSITY OF BALLASTING AS FUEL GETS LOW.

PROBLEM 47 PRVMJR 28 OCT 88 4 of 4



GIVEN

$T_f = 13'-6''$

$T_a = 13'-6''$

$KG = 18.00$ a. K.

FIND: DRAFTS AND LOAD ON KEEL BLOCKS WHEN GM = 0

APPROACH: THE KEY RELATIONSHIP IS

$$KG_1 = KG_0 \frac{\Delta_0}{\Delta_1}$$

LOAD ON KEEL BLOCKS = $L = \Delta_0 - \Delta_1$

WHERE KG_0, Δ_0 = ORIGINAL FREE FLOATING KG AND DISPLACEMENT

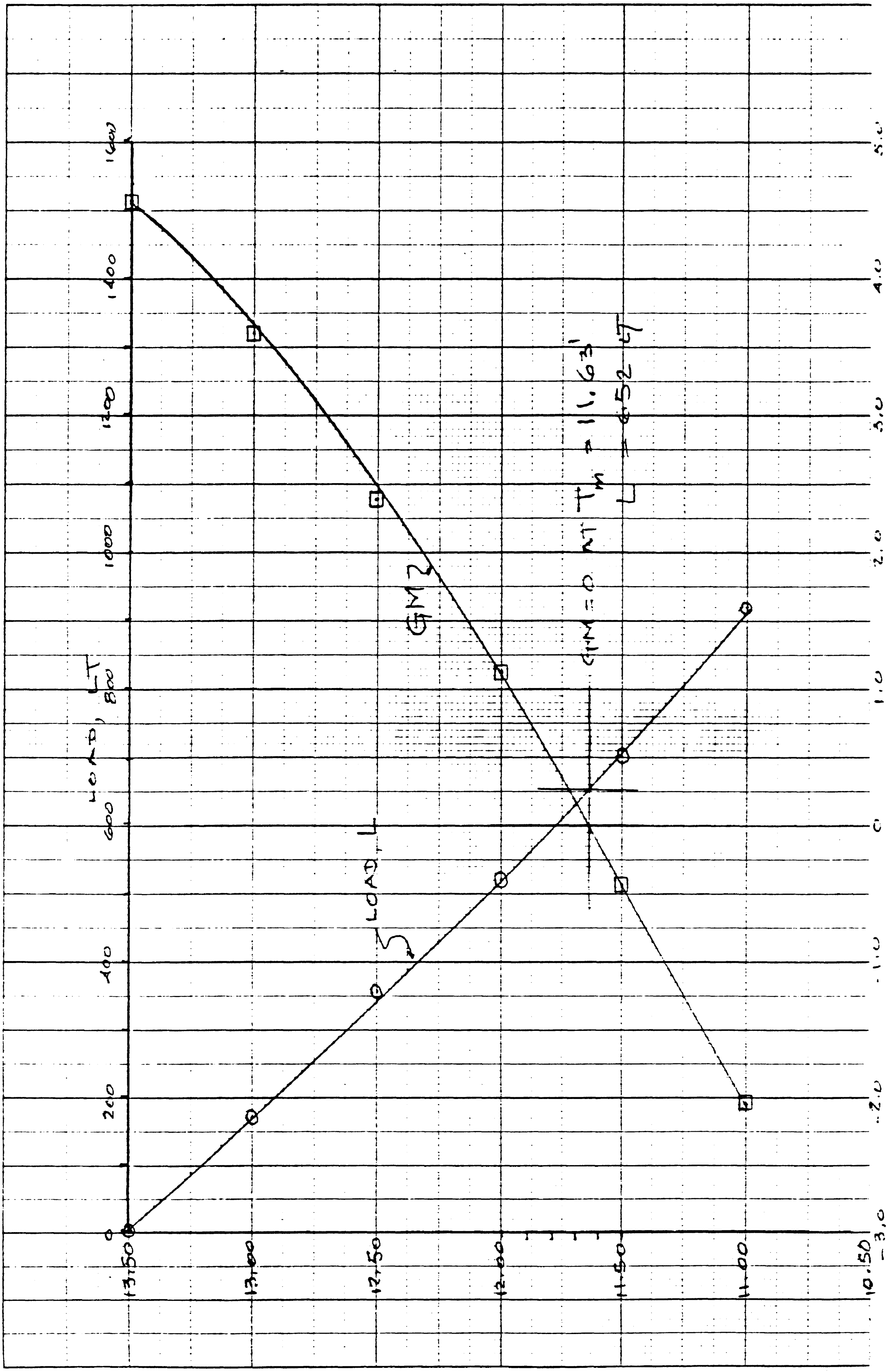
KG_1, Δ_1 = KG AND DISPLACEMENT AT LOWERED WATER LEVEL

DRAFT, T FT.	Δ_1 LT	KG_1 (= 18.00 Δ_0/Δ_1)	KM_t FT	GM (= $KM_t - KG_1$) FT	L (= $\Delta_0 - \Delta_1$) LT
13'-6"	3080	18.00	22.57	4.57	0
13'-0"	2910	19.05	22.65	3.60	170
12'-6"	2725	20.34	22.72	2.38	355
12'-0"	2560	21.66	22.78	1.12	520
11'-6"	2380	23.29	22.85	-0.44	700
11'-0"	2220	24.97	22.92	-2.05	860

FROM PLOT, GM = 0 AT T_m = 11.63 FT = $11'-7\frac{1}{2}''$

LOAD ON KEEL BLOCKS AT GM=0 = 652 LT

PROBLEM 48 PRVMJR/TDK 6 MAR 87 2 OF 2



GIVEN: FREE FLOATING, $T_{f_0} = 13'\text{-}7'' = 13.58'$

$T_{a_0} = 13'\text{-}7'' = 13.58'$

$KG_0 = 16.50$ FT a.K.

(a) FIND: LCB, LCG AND DISPLACEMENT AFLOAT

FROM "DISPLACEMENT AND OTHER CURVES"
AT $T_M = 13.58$ FT,

$$\Delta_0 = 3190 \text{ LTSW}$$

$$\text{LCB (LEVEL TRIM)} = 410 \text{ LT} \times \frac{2 \text{ FT}}{100 \text{ LT}} = 8.20 \text{ FT AFT } ⊄$$

(a) $\Delta_0 = 3190$ LTSW

$LCG_0 = LCB_0 = 8.20$ FT AFT ⊄

(b) FIND: LCB, Δ IN GROUNDED CONDITION.

DRAFTS AGROUND: $T_f = 10'\text{-}0''$

$T_a = 14'\text{-}0''$

SINCE THE HULL IS INTACT THE LOCATION AND MAGNITUDE OF THE BUOYANT FORCE IS STRICTLY A FUNCTION OF THE UNDERWATER HULL SHAPE AND MAY BE FOUND FROM THE CURVES OF FORM.

$T_{f_1} = 10'\text{-}0''$

$T_{a_1} = 14'\text{-}0''$

$T_{M_1} = 12'\text{-}0''$

THE LEVEL TRIM DISPLACEMENT AT $T_{M_1} = 12'\text{-}0''$ IS

$$\Delta_M = 2680 \text{ LT}$$

$$\text{CD } 12'' \text{ TA} = 965 \text{ LT} \times \frac{2 \text{ LT}}{100 \text{ LT}} = 19.3 \text{ LT PER FT OF TRIM AFT}$$

FOR 48" TRIM AFT CORRECTION = $4' \times 19.3$ LT/FT = 77.2 LT

$$\Delta_1 = 2757 \text{ LT}$$

THE MOMENT REQUIRED TO CAUSE 48' TRIM AFT WILL BE TRIM × MTI" AND THE SHIFT IN THE CENTER OF BUOYANCY WILL BE $\dfrac{\text{TRIMMING MOMENT}}{\Delta}$

$$\text{LCB AT } T_m = 12'\text{-}0" = 275 \text{ LT} \times \frac{2 \text{ FT}}{100 \text{ LT}} = 5.50' \text{ AFT } ⊗$$

$$\text{MTI" AT } T_m = 12'\text{-}0" = 610 \text{ LT} \times \frac{100 \text{ FT-TONS}}{100 \text{ LT}} = 610 \frac{\text{FT-TONS}}{\text{IN}}$$

$$\text{MOMENT TO CAUSE 48" TRIM} = 48 \text{ IN} \times 610 \text{ FT-TONS/IN}$$

$$\text{TRIM MOM'T} = 29{,}280 \text{ FT-TONS}$$

$$\text{SHIFT IN LCB DUE TO TRIM} = \frac{29{,}280 \text{ FT-TONS}}{2757 \text{ LT}}$$

$$\text{LCB SHIFT} = 10.62 \text{ FT AFT}$$

$$\text{LCB (LEVEL)} = 5.50 \text{ FT AFT } ⊗$$

$$\text{LCB}_1 = 16.12 \text{ FT AFT } ⊗$$

(b) IN THE GROUNDED CONDITION THE LOCATION AND MAGNITUDE OF THE BUOYANT FORCE WILL BE:

$$\text{(b)} \quad \underline{\underline{\Delta_1 = 2757 \text{ LT}}}$$

$$\underline{\underline{\text{LCB}_1 = 16.12 \text{ FT AFT } ⊗}}$$

(c) FIND! LOCATION AND MAGNITUDE OF THE GROUNDING FORCE.

THE SHIP IS GROUNDED BETWEEN FRAMES 80 AND 90. TAKE FRAME 85 AS A MEAN.

FRAME SPACING = 21" (FROM BOTTOM OF PROFILE VIEW ON "DISPLACEMENT AND OTHER CURVES)

$$\text{FROM FRAME 85 TO FRAME 110} = 25 \text{ FR} \times \frac{21"}{12"/1} = 43.75'$$

$$\text{FROM FRAME 110 TO } ⊗ \qquad = \underline{-1.00'}$$

$$\text{GROUNDING FORCE} = 42.75 \text{ FT FWD } ⊗$$

THE MAGNITUDE OF THE GROUNDING FORCE WILL BE $\Delta_0 - \Delta_1$.

$$\Delta_0 = 3190 \text{ LT}$$
$$\Delta_1 = 2757 \text{ LT}$$

GROUNDING FORCE, F_1 = 433 LT.

(C) THE LOCATION AND MAGNITUDE OF THE GROUNDING FORCE WILL BE:

(c) F_1 = 433 LT AT A MEAN LOCATION 42.75 FT FWD OF $\otimes$

(d) FIND THE MAGNITUDE OF THE GROUNDING FORCE AFTER A 1.25 FT RISE OF TIDE.

ASSUME THE SHIP IS HARD AGROUND AND WILL NOT CHANGE ATTITUDE AS THE TIDE RISES.

THEN, $T_{M_2} = 13.25'$

$\text{CD12"TA} = 990 \text{ LT} \times \frac{2 \text{ LT}}{100 \text{ LT}} = 19.8$ LT/FT TRIM

FOR 48" TRIM CORRECTION = 4' × 19.8 LT/FT

CORR = 79.2 LT.

AT $T_{M_2} = 13.25'$, Δ_M = 3095 LT

CORR = + 79 LT

Δ_2 = 3174 LT

Δ_c = 3190 LT

GROUNDING FORCE, F_2 = 16 LT

(d) FOLLOWING THE RISE IN TIDE THE GROUNDING FORCE WILL BE

(c) F_2 = 16 LT

17:39

(THE SHIP SHOULD BE ABLE TO FREE HERSELF USING ONLY THE BACKING FORCE OF THE PROPS.)

GIVEN: $V = 20.00$ KTS

$L_{pp} = 400'\text{-}0''$

FIND: $\dfrac{V}{\sqrt{L}}$, F_n, R_n, C_f

IN COMPUTING SPEED-LENGTH RATIO V IS IN KNOTS

$$\frac{V}{\sqrt{L_{pp}}} = \frac{20.00 \text{ KTS}}{\sqrt{400.00 \text{ FT}}}$$

$$\underline{\frac{V}{\sqrt{L_{pp}}} = 1.0}$$

NOTE THAT SPEED-LENGTH RATIO, ALTHOUGH CONVENIENT, IS DIMENSIONALLY CORUPT.

FROUDE NUMBER USES VELOCITY IN FT/SEC.
1 KNOT = 1.688 FT/SEC, $g = 32.17$ FT/SEC^2

$$\text{FROUDE NO., } F_n = \frac{V}{\sqrt{g L_{pp}}} = \frac{20.00 \text{ KTS} \times 1.688 \frac{\text{FT/SEC}}{\text{KT}}}{\sqrt{32.17 \text{ FT/SEC}^2 \times 400.00 \text{ FT}}}$$

$$\underline{F_n = .298}$$

NOTE THAT NOW ALL UNITS CANCEL. AN EASY CONVERSION TO REMEMBER IS TO MULTIPLY SPEED-LENGTH RATIO BY .3 TO GET FROUDE NO.

$$\text{REYNOLDS NO., } R_n = \frac{V L}{\nu}$$

TABLES OF ν, THE KINEMATIC VISCOSITY OF WATER ARE GIVEN IN THE APPENDIX TO THE PROBLEM SET. AT 59° F (A STANDARD TEMPERATURE FOR POWERING PREDICTIONS) THE VALUE OF KINEMATIC VISCOSITY IN SEAWATER IS:

$$\nu = 1.2817 \times 10^{-5} \frac{\text{FT}^2}{\text{SEC}}$$

(EXPLAIN TO STUDENTS WHY HEADER OF TABLE SHOWS $\nu_s \times 10^5$)

$$R_n = \frac{20.00\,\text{KTS} \times 1.688\,\frac{\text{FT/SEC}}{\text{KT}} \times 400.00\,\text{FT}}{1.2817 \times 10^{-5}\,\text{FT}^2/\text{SEC}}$$

(NOTE THAT UNITS CANCEL)

$$\underline{\underline{R_n = 10,536 \times 10^5 = 1.0536 \times 10^9}}$$

FINALLY,

$$C_f = \frac{.075}{(\log_{10} R_n - 2)^2}$$

$$\log_{10} R_n = \log_{10}(1.0536 \times 10^9) = 9.02268$$

$$C_f = \frac{.075}{(9.02268 - 2)^2}$$

$$\underline{\underline{C_f = .0015207 = 1.5207 \times 10^{-3}}}$$

(WHEN WORKING WITH RESISTANCE COEFFICIENTS IT IS CONVENIENT TO CARRY 10-3 ALONG FOR EACH COEFFICIENT)

BASIC NAVAL ARCHITECTURE

Unit Number: 18

Title: Ship hazards and vulnerability - 4

Tape Running Time: 27^M 28^S

Reading Assignment: MSD, pp 90-91 (repeat)

Additional References: PNA, pp 118-120, 256-270

Scope:

Types of drydocks and drydock procedures are discussed. An example of stability analysis during drydocking is given.

Key Points to Emphasize:

1. If sponsoring institution is a shipyard instructor, should describe shipyard drydocks and drydocking procedure.

2. Review some history of load line assignment for merchant vessels. Discuss form parameters which are considered in load line calculations. Review load line marks and their meaning.

3. Obtain a copy of DDS 079-2. Discuss factors which are considered in establishing freeboards for naval ships.

Suggested Problem Assignment: 46, one of unassigned problems 48, 49, 50

DRYDOCKING

TYPES OF DRY DOCKS

- GRAVING DOCKS.
- FLOATING DRYDOCKS.
- VERTICAL LIFT PLATFORMS.
- OTHER TYPES (STRADDLE CRANES, MARINE RAILWAYS).

PRE-DOCKING CONFERENCE

- BETWEEN CAPTAIN, CHIEF ENGINEER AND DOCKING OFFICER TO SETTLE ALL DOCKING ARRANGEMENTS.

DRYDOCKING

BEFORE DOCKING -

- SHIP MAKES BEST EFFORTS TO REMOVE ALL TRIM AND LIST.
- DOCKING OFFICER SETS KEEL BLOCKS IN DRY DOCK ACCORDING TO SHIP'S DOCKING PLANS.
- USUAL PROCEDURE IS TO LAND SHIP ON KEEL BLOCKS, THEN HAUL BILGE BLOCKS LATERALLY INTO POSITION.
- SIDE SHORES MAY BE USED IN LIEU OF OR IN ADDITION TO BILGE BLOCKS.

DRYDOCKING

STABILITY DURING DOCKING

- AS WATER LEVEL IS LOWERED SHIP MAKES CONTACT WITH KEEL BLOCKS.
- LOAD ON KEEL BLOCKS ACTS LIKE WEIGHT REMOVAL AT KEEL.
- SIMILAR TO GROUNDING PROBLEM,

$$KG_v = KG_o \cdot \frac{\Delta_o}{\Delta_1}$$

- MUST HAVE SIDE BLOCKS SET BEFORE

$$G_v M_1 = 0$$

DRYDOCKING

EXAMPLE:

A BEAR CLASS CUTTER ENTERS A GRAVING DOCK WITH THE FOLLOWING DRAFTS AND ESTIMATED KG:

T_f = 14' - 0"
T_a = 14' - 0"
KG = 17.00 FT A BL.

THE SHIP IS INITIALLY UPRIGHT. THE KEEL BLOCKS ARE LEVEL AND 4'-0" ABOVE DOCK FLOOR. AS THE WATER LEVEL IS LOWERED AND THE SHIP SETTLES ON THE KEEL BLOCKS, FIND THE WATER LEVEL AT WHICH THE SHIP'S GM = 0.

DRYDOCKING

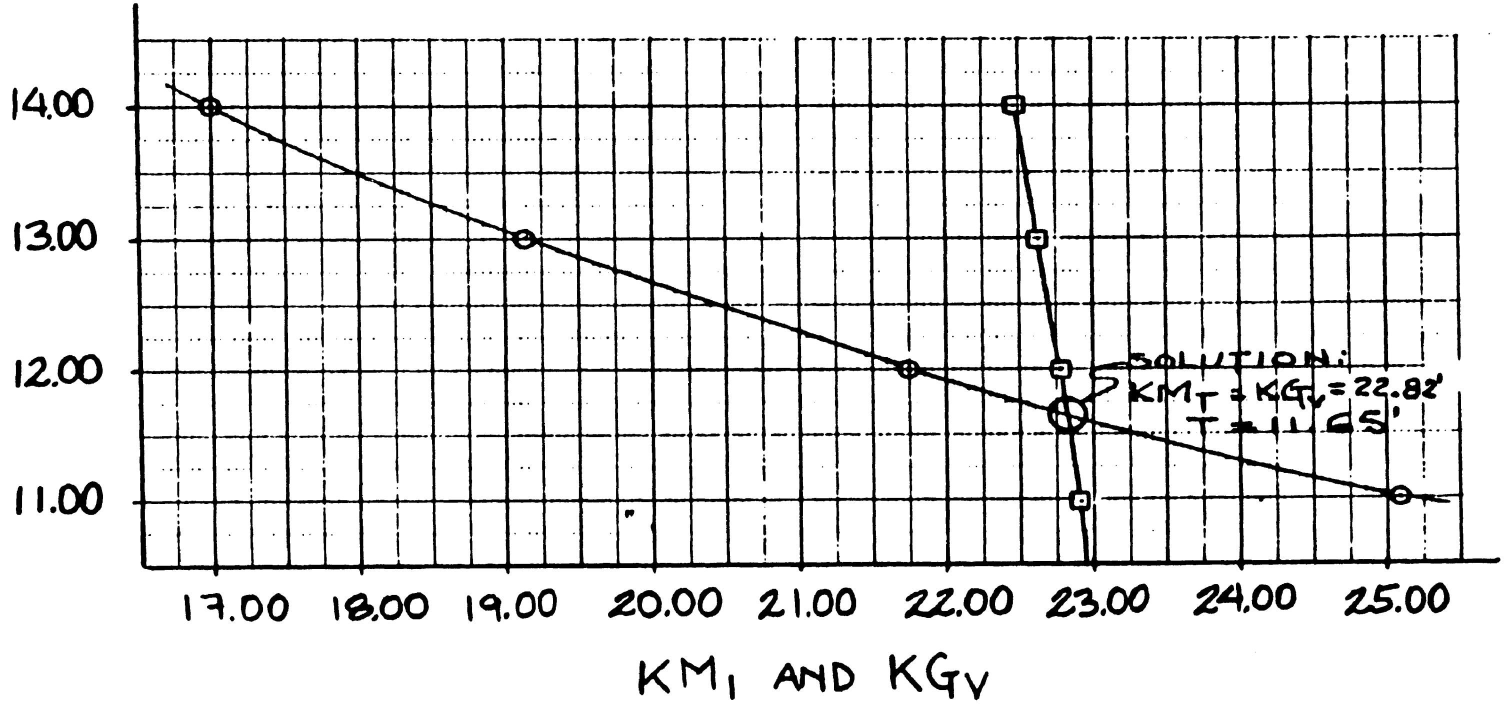
SOLUTION

$$KG_v = KG_o \cdot \frac{\Delta_o}{\Delta_1} = 17.00 \cdot \frac{3,275}{\Delta_1}$$

T	Δ_1 LT	KG_v FT A BL	KM_1 FT A BL
14.00	3,275	17.00	22.48
13.00	2,910	19.13	22.63
12.00	2,560	21.75	22.78
11.00	2,220	22.92	25.08

DRYDOCKING

PLOT TO DETERMINE SOLUTION POINT



DRYDOCKING

RECAP

AT A SHIP DRAFT OF 11.65',

$$KM_T = KG_v = 22.82'$$

AND

$$GM_v = 0$$

AT THIS DRAFT THE DEPTH OF WATER OVER THE FLOOR OF DOCK WILL BE:

$$T = 11.65'$$

$$\text{HEIGHT OF BLOCKS} = \underline{\ 4.00'\ }$$

$$\text{WATER DEPTH} = 15.65' = 15' - 7\ 3/4"$$

BILGE BLOCKS MUST BE IN PLACE BEFORE WATER LEVEL REACHES THIS DEPTH.

FREEBOARD AND LOAD LINES - MERCHANT SHIPS

HISTORICAL

- FIRST ATTEMPTS TO ESTABLISH RULES FOR FREEBOARDS IN GREAT BRITAIN IN EARLY 1800'S.
- MERCHANT SHIPPING ACT OF 1875 (GREAT BRITAIN) PROMOTED BY SAMUEL PLIMSOLL, M.P. REQUIRED A LOAD LINE MARK ON FOREIGN VESSELS, STILL KNOWN AS THE "PLIMSOLL MARK".
- NO RESTRICTIONS IN U.S. UNTIL 1917.
- INTERNATIONAL CONVENTION ON LOAD LINES FIRST IN 1930; MOST RECENT 1966 SETS FORTH RULES FOR LOAD LINE MARKINGS.

FREEBOARD AND LOAD LINES - MERCHANT SHIPS

APPLICABLE U.S. LOAD LINE REGULATIONS ARE CONTAINED IN CFR 46, SUBCHAPTER E.

FREEBOARD RULES ARE PURELY EVOLUTIONARY AND ARE NOT BASED ON SCIENTIFIC DEVELOPMENT.

MINIMUM FREEBOARD IS DESIGNED TO PROVIDE ADEQUATE RESERVE BUOYANCY BASED ON EXPERIENCE.

FREEBOARD AND LOAD LINES - MERCHANT SHIPS

BASIC SUMMER FREEBOARD IS TABULATED IN CFR 46. EXAMPLE: (CARGO SHIPS)

L, FT	FREEBOARD, INCHES
200	22.9
400	68.2
600	116.8
800	154.8

CORRECTIONS ARE APPLIED FOR

- BLOCK COEFFICIENT
- LENGTH OF SUPERSTRUCTURE
- AMOUNT OF SHEER
- AMOUNT OF DECK CAMBER

FREEBOARD AND LOAD LINES - MERCHANT SHIPS

- FREEBOARD MARKS:

BASIC FREEBOARD	-	S	SUMMER FBD
LESS FREEBOARD FOR	-	TF	TROPICAL FRESH WATER
		F	FRESH WATER
		T	TROPICAL
MORE FREEBOARD FOR	-	W	WINTER
	-	WNA	WINTER NORTH ATLANTIC

- SHIPS CARRYING TIMBER DECK CARGO MAY BE ASSIGNED SPECIAL MARKS:

  LS, LTF, LF, LT, LW, LWNA (L FOR LUMBER).

FREEBOARD AND LOAD LINES - MERCHANT SHIPS

CLASSIFICATION SOCIETIES

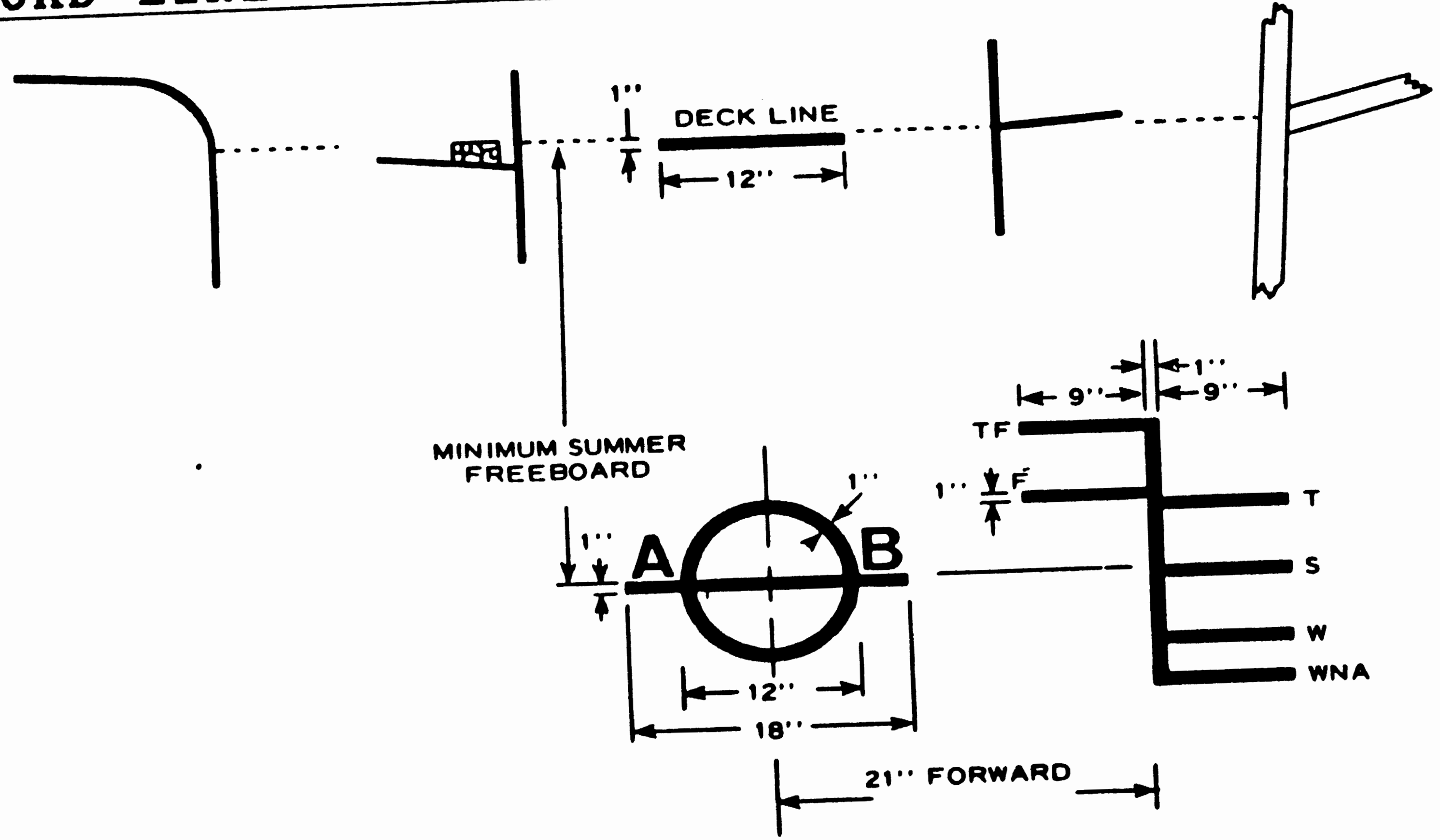
- LOAD LINE CERTIFICATES MAY BE ISSUED BY:
  - COMMANDANT, USCG
  - AMERICAN BUREAU OF SHIPPING
  - OTHER CLASSIFICATION SOCIETIES WHEN APPOINTED FOR SPECIFIC VESSELS

- LETTERS A-B ON SUMMER MARKS MEAN THAT LOAD LINE CERTIFICATE WAS ISSUED BY ABS.

- OTHER CLASSIFICATION SOCIETIES:
  - LR LLOYD'S REGISTER OF SHIPPING (BRITISH)
  - BV BUREAU VERITAS (FRENCH)
  - DNV DET NORSKE VERITAS (NORWEGIAN)

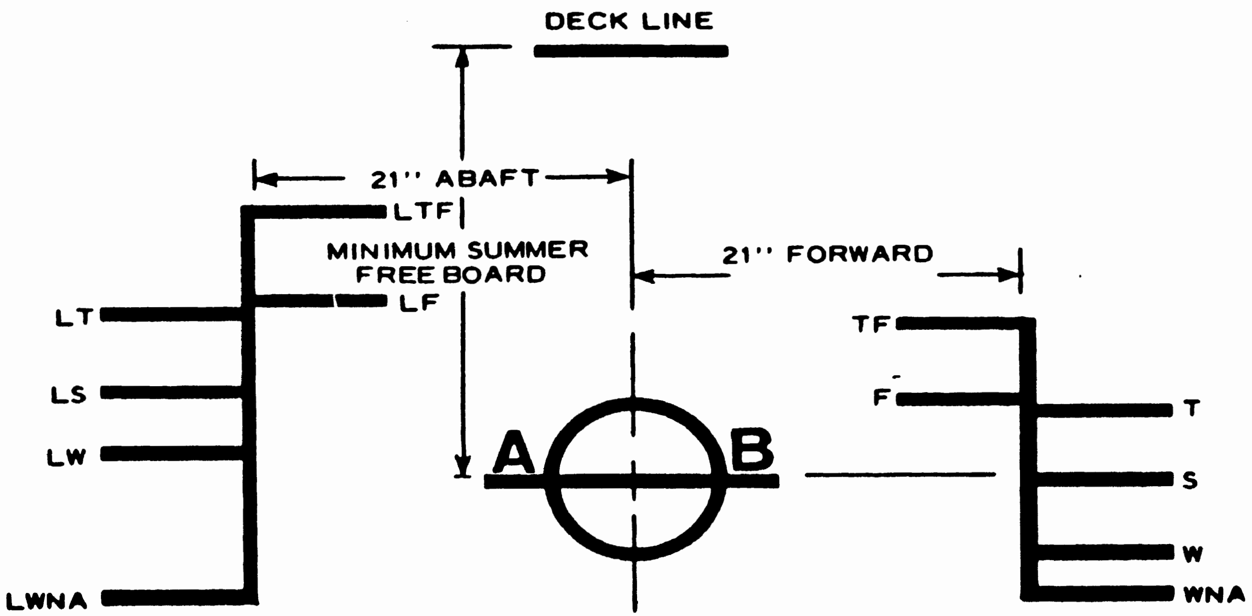
FREEBOARD AND LOAD LINES - MERCHANT SHIPS

LOAD LINE MARKINGS:



FREEBOARD AND LOAD LINES - MERCHANT SHIPS

TIMBER LOAD LINE MARKINGS:



FREEBOARD AND LOAD LINES - NAVAL SHIPS

- MAJOR CONSIDERATION IS DECK WETNESS.
- SUBDIVISION, RESERVE BUOYANCY ARE COVERED BY OTHER REQUIREMENTS.
- METHODS SET FORTH IN DDS 079-2.
- VARIOUS FORMULAE ARE GIVEN
  - BASED ON SHIP MOTION MODEL TESTS AND COMPUTER STUDIES
  - FOR DIFFERENT SHIP TYPES
- BASIC ANALYTICAL TOOL IS SHIP MOTION COMPUTER PROGRAM, SMP.

BASIC NAVAL ARCHITECTURE

Problem 46

Problem Level: Advanced

Part A. A CVE class ship is tied up, starboard side to, alongside the outfitting piers at Boston Naval Shipyard (salt water). You are ship superintendent and are responsible for the safety of the ship while it is undergoing conversion and modernization.

Prior to entering the shipyard, the ship had a displacement of 28,000 tons with an actual location of the CG (uncorrected for free surface effect) 29.5' above the keel. An estimated 1500 tons of stores, water and oil were removed having an aggregate CG of 10.8' above the keel. All tanks were pumped dry and the ship has no list.

Utilizing the general stability diagram, determine for the above condition the ship's:

1) Maximum righting arm
2) Angle of maximum righting arm
3) Range of stability

Part B. The starboard main engine, condenser, reduction gear, propeller, shafting, and associated auxiliary machinery are removed. The weight and location of items removed are as follows:

			CG LOCATION	
ITEM	WEIGHT	HT. ABOVE KEEL	DIST. FROM ℄	PORT/STBD
Turbines	45,920 lbs	15 feet	25 feet	Stbd
Condenser	47,264 lbs	8 feet	28 feet	Stbd
Reduction Gear	43,904 lbs	12 feet	26 feet	Stbd
Shafting	67,200 lbs	6 feet	26 feet	Stbd
Propeller	20,675 lbs	1 foot	26 feet	Stbd
Aux. Machinery	223,037 lbs	4 feet	26 feet	Stbd

After removal of the above machinery:

1) What would be the ship's list?
2) What would be the ship's GM (approx.)? Calculate this value.

Problem 46 (continued)

Problem Level: Advanced

Part C. In order to maintain the ship without list a counterweight is placed on deck, its CG 40' above the keel and 35 feet off the ship's centerline.

1) How much counterweight is necessary?
2) Has the stability of the ship been markedly affected so as to endanger its safety? Give angle and magnitude of the max. righting arm and range of stability.

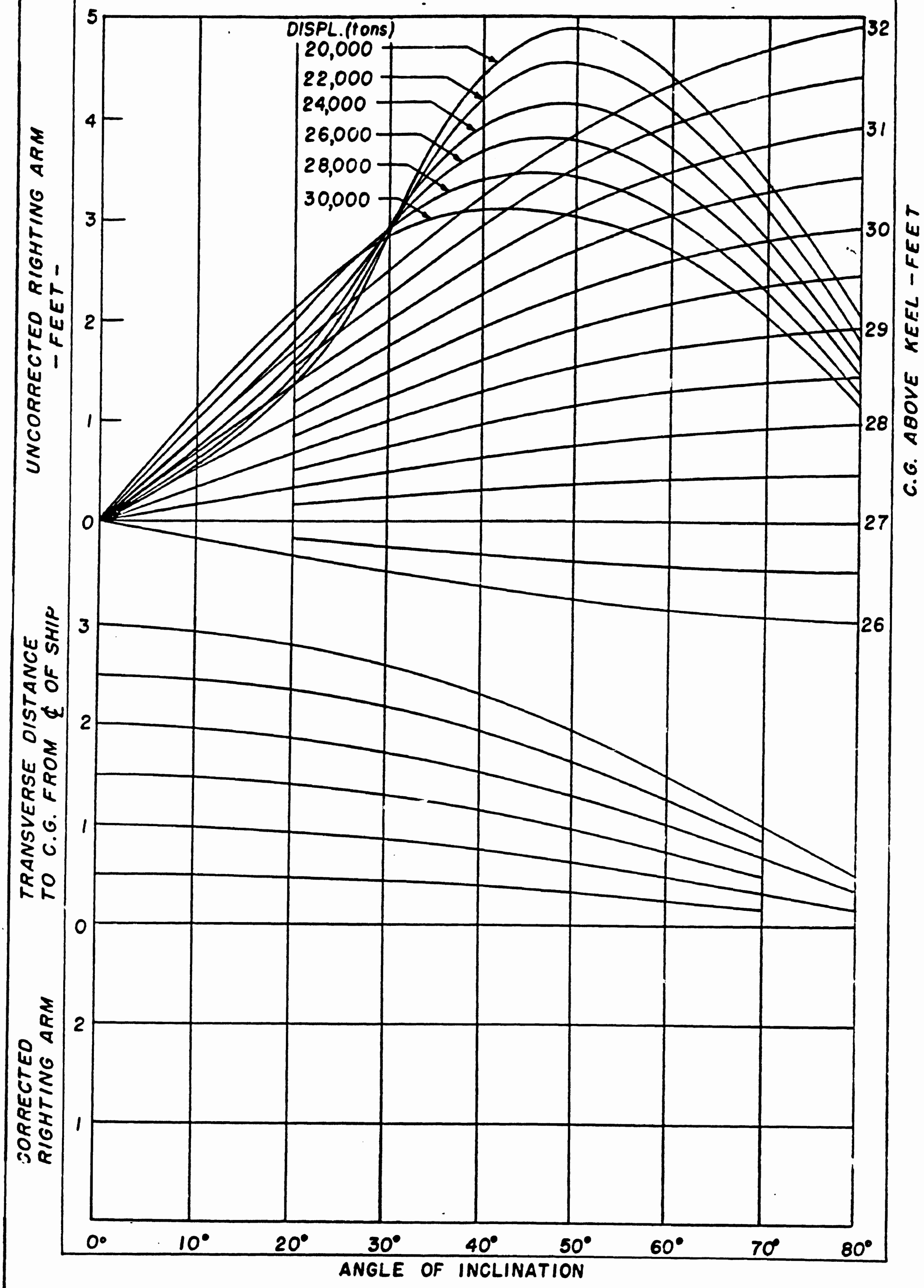
Part D. During the night the covering on the starboard stern tube works loose in rough water. An area 12.5' wide and 140' long floods to a depth of 5 feet with salt water. This area is in free communication with the sea and is 28 feet off the centerline on the starboard side.

1) What is the change in stability of the ship on the affected side?

Part E. There is danger that an additional area 20 feet wide by 50 feet long will flood to a depth of 3.5 feet (not in free communication with the sea).

1) If this area floods will the ship capsize?
2) What would be the effect of removing the counterweight from on deck?
3) What would be the final stability conditions if the additional area did flood and the counterweight were removed?

GENERAL STABILITY DIAGRAM — CVE 105



[illegible]-19

STABILITY DATA SHEET

1	2	3	4	5	6	7a	7b	8	9	10a	10b
Description of wt. change Compt. No., etc.	Location of compt. Port or Stbd.	Dimensions of Free Surf. (bxl) ft. x ft.	Dist. from c.g. of wt. change to ℄ (y) ft.	Added (+) or Removed (−) weight, tons	Height above keel, kg. ft.	Added vertical moments (+wxkg) ft. tons	Removed vertical moments (−wxkg) ft. tons	i $(\frac{b^3 x l}{12})$ feet^4	ay^2 $(b x l x y^2)$ feet^4	Stbd. inclining moments (wxy) ft. tons	Port inclining moments (wxy) ft. tons
TOTALS ⟶					☒						

ORIGINAL CONDITION

DISPLACEMENT (W) ________ TONS

KG (not cor. for F.S.) ________ FT.

FREE SURFACE EFFECT IN SHIPS TANKS = ________ FT.

F.S. = FREE SURF. EFFECT x ∇ = ________ FT.^{4}

FINAL CONDITION

DISPLACEMENT (W$_1$) = W ± $\boxed{5}$ = (   ) (   ) = ________ TONS

NET VERTICAL MOMENT = ± wxKg = $\boxed{7a}$ − $\boxed{7b}$ = ________ FT. TONS

$KG_1 = \frac{(WxKG) \pm wxkg}{W_1} = \frac{(\quad x \quad)(\quad)}{(\quad)} =$ ________ FT

NET VIRTUAL SHIFT $= \frac{F.S. + i + ay^2}{V_1} = \frac{F.S. + 8 + 9}{35 \times W_1} =$

$\frac{(\quad) + (\quad) + (\quad)}{35(\quad)} =$ ________ FT.

NET INCLINING MOMENT

$\boxed{10a} - \boxed{10b}$ = ________ FT. TONS

OFF CENTER DISTANCE OF C.G. (NET INCL. ARM AT 0°) =

$\frac{NET\ INCL.\ MOM.}{W_1} = \frac{(\quad)}{(\quad)} =$ ________ FT.

KG$_1$ = ________ FT.

NET. VIR. SHIFT = ________ FT.

VIRTUAL KG $\boxed{\quad FT.}$

12-20

COMMENT ON PROBLEM

THIS PROBLEM IS AN EXERCISE IN STATIC STABILITY THAT EXAMINES THE EFFECTS OF ADDING AND REMOVING WEIGHT AND THE RESULTING INFLUENCE ON VESSEL STABILITY. PAGES 60-80 OF MODERN SHIP DESIGN ARE APPLICABLE TO THIS PROBLEM.

SOLUTION

PART A

GIVEN:

$\Delta_0 = 28{,}000$ TONS
$KG_0 = 29.5$ FT

$-W = 1500$ TONS
$KG_W = 10.8$ FT

OBJECTIVE: FIND

$\overline{GZ}$ MAX
Φ AT $\overline{GZ}$ MAX
RANGE OF Φ

FIRST WE MUST DETERMINE THE NEW Δ AND KG.

$$\begin{array}{rl} \Delta = 28{,}000 & \text{TONS} \\ -\ \underline{1500} & \text{TONS} \\ 26{,}500 & \text{TONS} \end{array}$$

$$\Delta = 26{,}500 \text{ TONS}$$

$$\overline{KG} = \frac{(\Delta_0)(KG_0) + (W)(KG_W)}{\Delta}$$

$$\overline{KG} = \frac{(28000 \text{ TONS})(29.5 \text{ FT}) + (-1500 \text{ TONS})(10.8 \text{ FT})}{26500 \text{ TONS}}$$

$$\overline{KG} = 30.56 \text{ FT}$$

THE STABILITY CURVES SHOWN ARE FOR A KG OF 27'. IN ORDER TO DETERMINE THE DESIRED VALUES, A CORRECTED GZ CURVE MUST BE PLOTTED FOLLOWING THE FORMULA $\overline{GZ} = \overline{AP} - \overline{AG} \sin\phi$ GIVEN IN GILLMER PAGE 64. VALUES THEN CAN BE READ OFF THE CORRECTED $\overline{GZ}$ CURVE. IT IS EASIEST TO PLOT THE CORRECTED $\overline{GZ}$ CURVE IN THE SPACE BELOW THE EXISTING $\overline{GZ}$ CURVES. $\overline{AP}$ VALUES MUST BE READ OFF THE $\overline{GZ}$ CURVE FOR A $\Delta = 26500$ TONS. $\overline{AG} = KG - KG_0 = 3.56$

ONCE THE CORRECTED $\overline{GZ}$ CURVE IS PLOTTED, VALUES CAN BE READ DIRECTLY.

1) MAXIMUM $\overline{GZ} = 1.3$ FT

2) MAX $\overline{GZ}$ OCURRS AT 40°

3) RANGE OF STABILITY = 62°

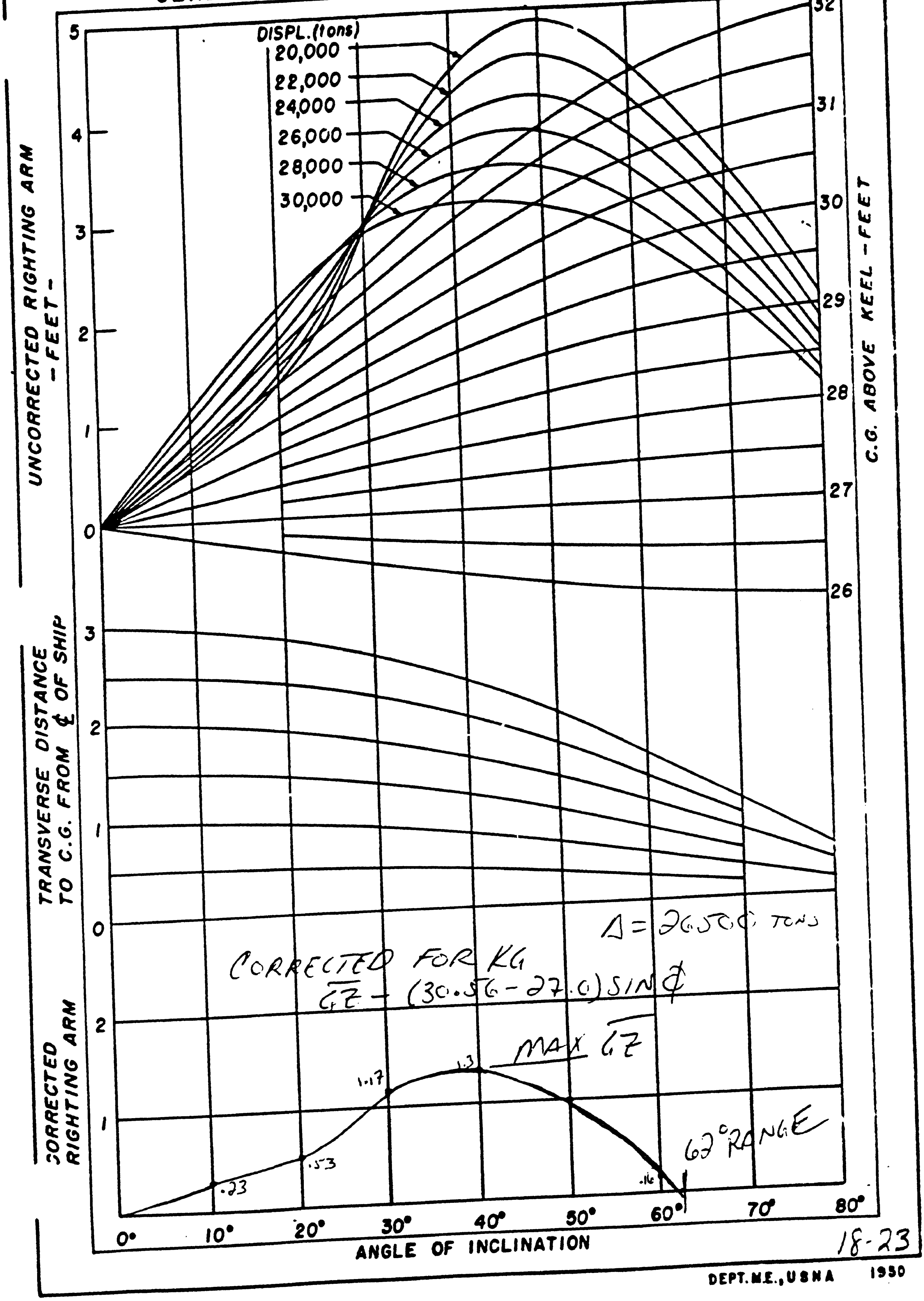
PART B

THE FIRST STEP IS TO DETERMINE TOTAL WEIGHT LOSS, VCG (KG) AND TCG OF THE REMOVED ITEMS. THIS IS BEST ACCOMPLISHED IN TABULAR FORMAT. ONCE THAT IS COMPLETED, THR NEW DISPLACEMENT AND KG FOR THE SHIP MUST BE DETERMINED, ALONG WITH THE NEW TCG FOR THE SHIP. AGAIN A CORRECTED $\overline{GZ}$ CURVE MUST BE PLOTTED, THIS TIME FOR A TRANSVERSE SHIFT IN CG FOLLOWING THE FORMULA $GZ = AP - \overline{AG} \cos\phi$ (GILLMER PG 65) THE INTERSECTION OF THE $\overline{GZ}$ CURVE WITH THE ANGLE OF INCLINATION AXIS REVEALS THE PERMANENT LIST. THE EASIEST WAY TO SOLVE FOR THE LIST IS TO FIRST CONSTRUCT THE CORRECTED $\overline{GZ}$ CURVE FOR KG CHANGE (AS DONE IN PART A). NEXT, CONSTRUCT THE COSINE CORRECTION CURVE FOR A TCG CHANGE. THE INTERSECTION OF THE COSINE CORRECTION CURVE WITH THE CORRECTED $\overline{GZ}$ CURVE OCCURS AT THE ANGLE OF PERMANENT LIST.

JCK

PROBLEM 46 PART A pg 3 of 16

GENERAL STABILITY DIAGRAM — CVE 105



$\Delta = 26500$ TONS

CORRECTED FOR KG

$\overline{GZ} - (30.56 - 27.0) \sin \phi$

MAX $\overline{GZ}$

62° RANGE

18-23

DEPT. M.E., USNA 1950

WEIGHT	VCG	MOMENT	TCG	MOMENT
45,920	15'	688800	25'	1148000
47,264	8'	378112	28'	1323392
43904	12'	526848	26'	1141504
67200	6'	403200	26'	1747200
20675	1'	20675	26'	537550
223,037	4'	892148	26'	5798962

$\Sigma = 448000$ lbs

$\Sigma = 2909783$ FT-lbs

$\Sigma = 11696608$ FT-lbs

$$VCG = \text{VERTICAL MOMENT}/\text{WEIGHT}$$

$$= 2909783/448000$$

$$VCG = 6.50 \text{ FT}$$

$$TCG = \text{TRANSVERSE MOMENT}/\text{WEIGHT}$$

$$= 11696608/448000$$

$$TCG = 26.11 \text{ FT STBD}$$

$$\Delta_{SHIP} = \Delta_0 - \text{WEIGHT OF MACHINERY}$$

$$\Delta_{SHIP} = \underset{\text{(FROM PART A)}}{26{,}500 \text{ TONS}} - \left(\frac{448000 \text{ lbs}}{2240 \text{ lbs/TON}}\right)$$

$$\Delta_{SHIP} = 26300 \text{ TONS}$$

$$\overline{KG}_{SHIP} = \frac{(\Delta_0)(KG) - (\text{WEIGHT})(VCG)}{\Delta_{SHIP}}$$

$$\overline{KG}_{SHIP} = \frac{(26500)(30.56) - (200)(6.50)}{26300}$$

$$\overline{KG}_{SHIP} = 30.77 \text{ FT}$$

ASSUMING THE SHIP IS INITIALLY UPRIGHT (ZERO LIST, OR TCG = 0)

$$TCG_{SHIP} = \frac{(\text{WEIGHT OF MACHY})(\text{TCG OF MACHY})}{\Delta_{SHIP}}$$

$$TCG_{SHIP} = \frac{(200 \text{ TONS})(26.11 \text{ FT})}{26300 \text{ TONS}}$$

$$TCG_{SHIP} = 0.2 \text{ FT}$$

WE NOW KNOW THE NEW Δ, KG AND TCG OF THE SHIP AND CAN CONSTRUCT THE TWO NECESSARY CORRECTION CURVES. SEE STABILITY DIAGRAM FOR PLOTTED CURVES.

1) BASED ON THE CORRECTED CURVES,

LIST = 10°

2) $$\overline{GM} = \frac{(W)(TCG)}{\Delta \tan \phi}$$ (Gillmer pg 70)

$$\overline{GM} = \frac{(200 \text{ TONS})(26.11 \text{ FT})}{(26300 \text{ TONS}) \tan 10^\circ}$$

$$\overline{GM} = 1.13 \text{ FT}$$

PART C

1) THE HEELING MOMENT INDUCED BY THE WEIGHT REMOVAL IN PART B MUST BE NEGATED BY THE ADDITION OF AN EQUAL AND OPPOSITE MOMENT.

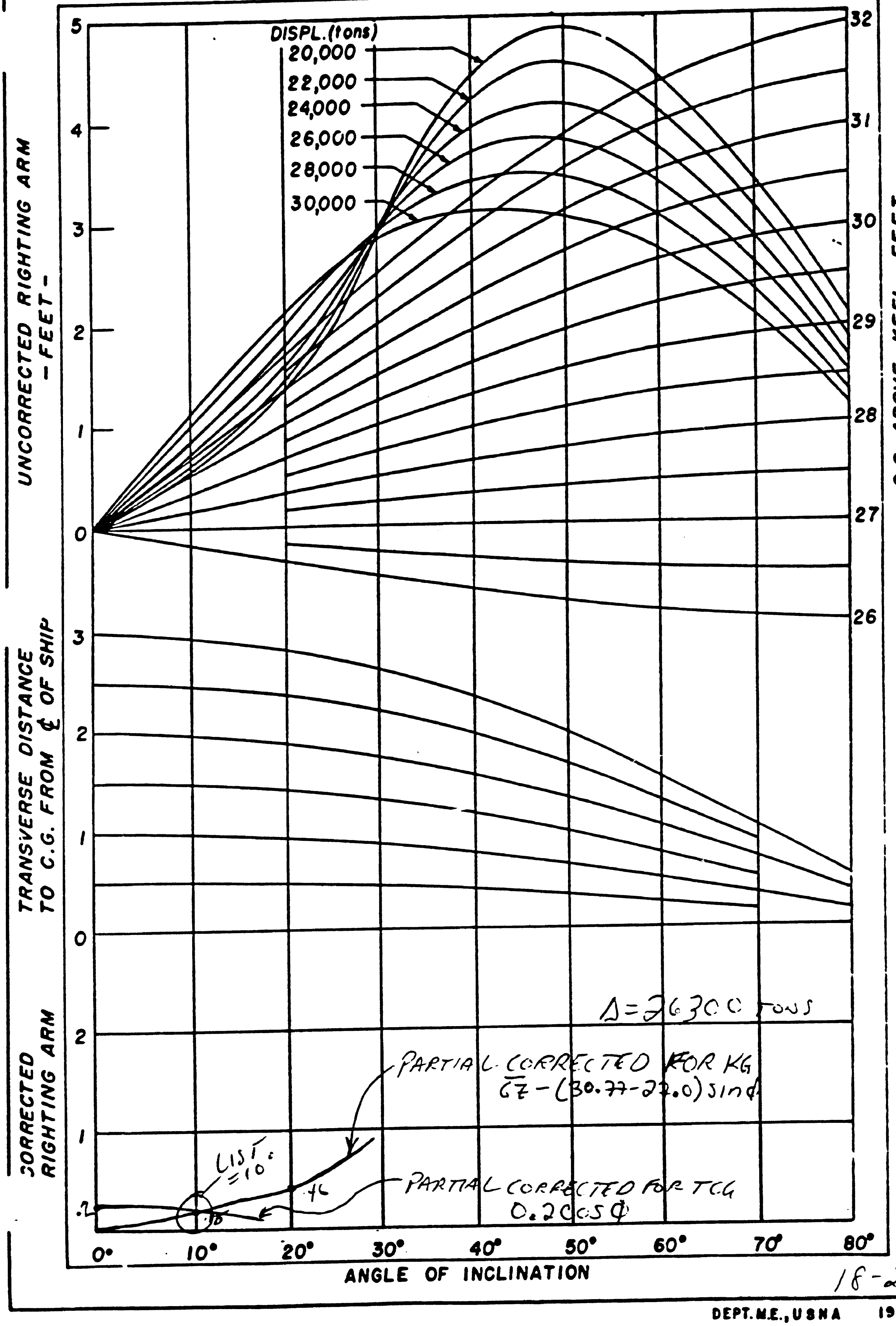
$$(\text{REMOVED WEIGHT})(TCG) = (\text{ADDED WEIGHT})(TCG)$$

$$(200 \text{ TONS})(26.11 \text{ FT}) = (W)(35 \text{ FT})$$

$$W = 149.2 \text{ TONS}$$

PROBLEM 46 JcK PART B PG 6 of 16

GENERAL STABILITY DIAGRAM — CVE 105



18-26

DEPT. M.E., USNA 1950

2) IN ORDER TO DETERMINE THE EFFECTS ON STABILITY, THE NEW Δ AND KG MUST BE DETERMINED.

$$\Delta = \Delta_0 + W$$

$$\Delta = 26300 \text{ TONS} + 149 \text{ TONS}$$

$$\Delta = 26449 \text{ TONS}$$

$$KG = \frac{\Delta_0 KG_0 + W KG}{\Delta}$$

$$KG = \frac{(26300)(30.77) + (149)(40)}{26449}$$

$$KG = 30.82 \text{ FT}$$

AGAIN A CORRECTED $\overline{GZ}$ CURVE MUST BE DRAWN USING THE FORMULA $\overline{GZ} - (30.82-27)\sin\phi$ OR, $\overline{GZ} - 3.82\sin\phi$ SEE STABILITY DIAGRAM FOR NEW CURVE.

$\overline{GZ}$ MAX = 1.20 FT

AT 37°

RANGE = 59°

STABILITY HAS NOT BEEN MARKEDLY AFFECTED.

PART D

1) MUST DETERMINE CORRECTED KG, TCG & Δ AND PLOT CORRECTED $\overline{GZ}$ CURVE AND COSINE CURVE AS IN PART B

WEIGHT OF ADDED WATER DUE TO FLOODING

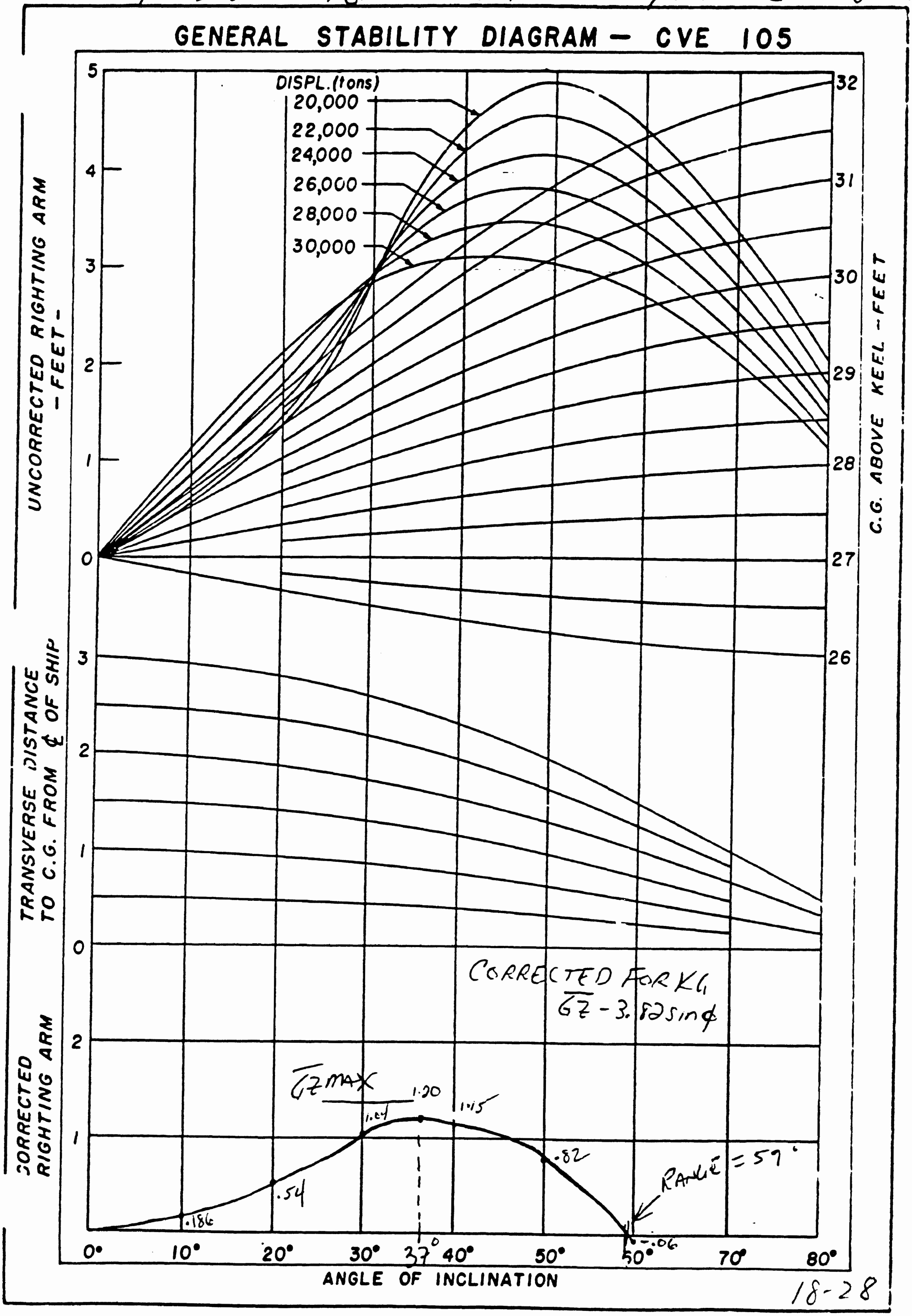
$= \text{VOLUME ft}^3 / 35 \text{ ft}^3/\text{ton}$

$$W = (12.5')(140')(5')/35$$

$$W = 250 \text{ TONS}$$

18-27

PROBLEM 46 JCK PART C. 8:=16



GENERAL STABILITY DIAGRAM — CVE 105

18-28

DEPT. M.E., USNA 1950

$$\Delta = \Delta_0 + W$$

$$\Delta = 26449 \text{ TONS} + 250 \text{ TONS}$$

$$\underline{\Delta = 26699 \text{ TONS}}$$

THREE CORRECTIONS TO KG :

- WEIGHT EFFECT
- FREE SURFACE EFFECT
- FREE COMMUNICATION EFFECT } GILLMER PG 79-81

REDUCTION IN KG DUE TO WEIGHT :

$$= \frac{(W)(KG_{SHIP} - KG_{CMPT})}{\Delta}$$

$$= \frac{(250)(30.22 - 2.5)}{26699}$$

$$KG_W = -0.27'$$

$$F.S.E. = i/\nabla$$ (GILLMER PG 80)

$$i = b^3 L/12$$ ∇ = VOLUME OF DISP.

$$i = (12.5)^3 (140)/12$$

$$i = 22786 \text{ FT}^4$$

$$\nabla = 35\Delta$$

$$\nabla = 35(26699 \text{ TONS})$$

$$\nabla = 934465 \text{ FT}^3$$

$$F.S.E. = 22786 \text{ FT}^4 / 934465 \text{ FT}^3$$

$$F.S.E. = 0.02 \text{ FT}$$

$$F.C.E. = ay^2/\nabla$$ (GILLMER PG 80)

a = AREA OF CMPT (L x B)
y = DISTANCE OFF ℄
∇ = VOLUME OF DISPLACEMENT

$$F.C.E. = (12.5)(140')(28')^2 / 934465 \text{ FT}^3$$

$$F.C.E. = 1.47 \text{ FT}$$

$$\text{CORRECTED } KG = KG_o - KG_w + F.S.E. + F.C.E.$$

$$KG = 30.82' - .27' + .02' + 1.47'$$

$$\underline{KG = 32.04 \text{ FT}}$$

$$\text{CORRECTED } TCG = \frac{(W)(TCG)}{\Delta}$$

$$TCG = \frac{(250 \text{ TONS})(28')}{26699 \text{ TONS}}$$

$$\underline{TCG = 0.26 \text{ FT}}$$

FOR: Δ = 26699 TONS
KG = 32.04 FT
TCG = 0.26 FT

MUST PLOT CORRECTED $\overline{GZ}$ CURVE

$$\overline{GZ} - 5.04 \sin \phi$$

AND SUBTRACT FROM THAT THE COSINE CORRECTION CURVE

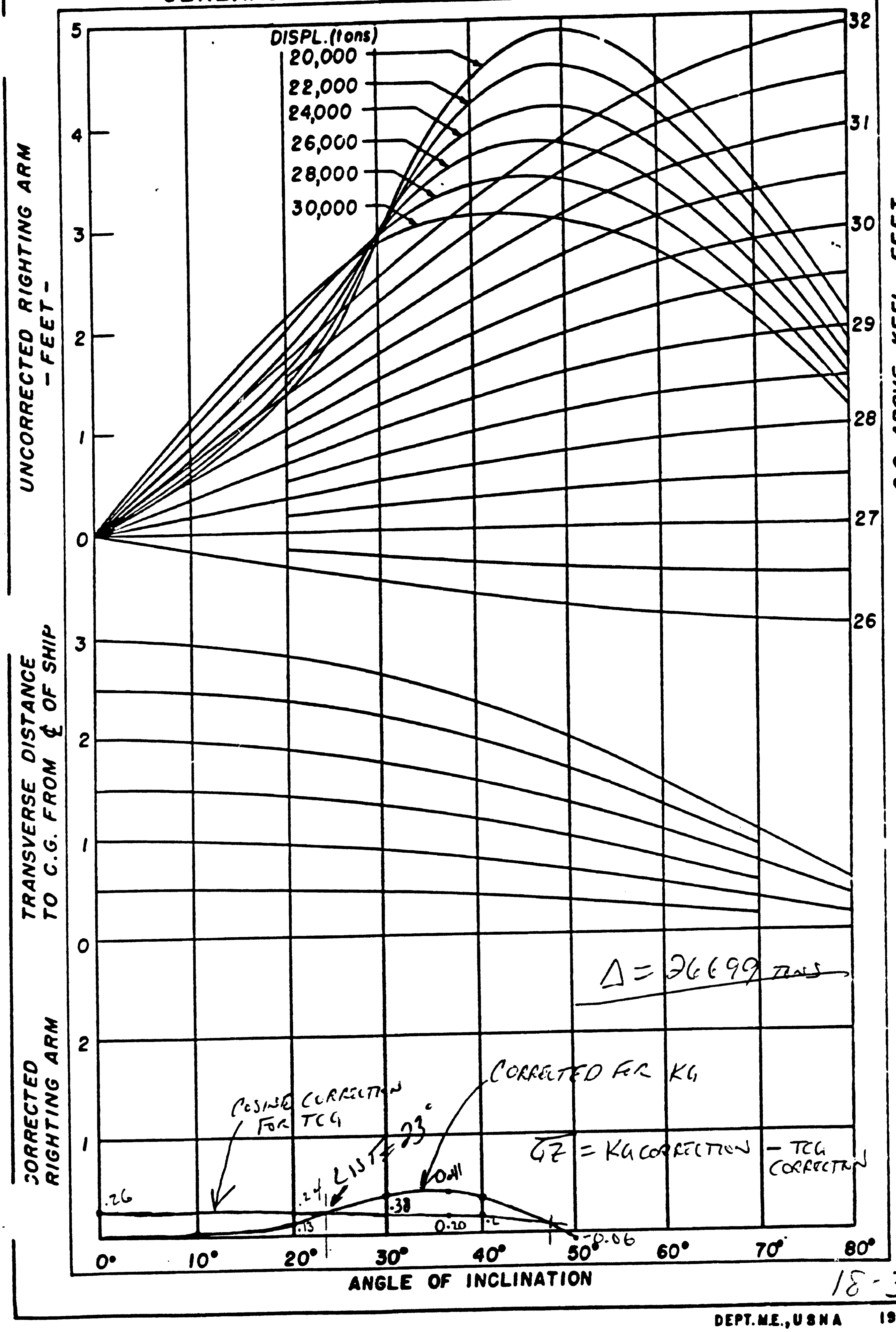
$$0.26 \cos \phi$$

SEE STABILITY DIAGRAM, PART D

LIST = 23°
$\overline{GZ}$ MAX = 0.21 FT AT 37°
RANGE = 47°

PROBLEM 46 JCK PART D PG 11 OF 16

GENERAL STABILITY DIAGRAM — CVE 105



18-31

DEPT. M.E., USNA 1950

PART E

MUST DETERMINE NEW Δ, TCG & KG DUE TO FLOODING. THERE IS NO MENTION THAT THE FLOODED AREA IS OFF ℄ SO ASSUME TCG = 0 FOR THE AREA.

ADDED WEIGHT = $(20')(50')(3.5')/35\ \text{ft}^3/\text{TON}$

$W = 100$ TONS

TWO CORRECTIONS TO KG:
- WEIGHT EFFECT
- FREE SURFACE EFFECT

REDUCTION IN KG DUE TO WEIGHT:

$$= \frac{W(KG_{SHIP} - KG_{CMPT})}{\Delta}$$

$$= \frac{(100\text{ TONS})(32.04 - \frac{3.5}{2})}{26799\text{ TONS}}$$

$KG_W = 0.11$ FT

$F.S.E. = i/\nabla$

$$= \frac{(50)(20)^3/12}{26799(35)}$$

$F.S.E. = 0.04$ FT

ADJUSTED $KG = KG_{SHIP} - KG_W + F.S.E.$

$KG = 32.04 - 0.11 + 0.04$

$\underline{KG = 31.97\ \text{FT}}$

THE ADDITION OF 100 TONS ON THE ℄ HAS NO SIGNIFICANT EFFECT ON TCG, SO TCG STILL = 0.26 FT (FROM PART D)

1) THE SHIP WILL CAPSIZE IF THE $\overline{GM}$ BECOMES LESS THAN ZERO. $\overline{GM}$ CAN BE DETERMINED FROM THE $\overline{GZ}$ CURVE BY DRAWING A STRAIGHT LINE TANGENT TO THE SLOPE OF THE $\overline{GZ}$ CURVE AT 0° AND INTERSECTING A VERTICAL LINE AT 57.3°. (THIS IS SHOWN IN GILLMER PAGE 67)

THE CORRECTED $\overline{GZ}$ CURVE FOR A CHANGE IN KG IS SHOWN ON THE STABILITY DIAGRAM FOR PART E

$\overline{GM} = 0.17$ FT SO THE SHIP WILL <u>NOT</u> CAPSIZE

2) PARTICULARS FOR THE COUNTERWEIGHT ARE:

W = 149 TONS
KG = 40'
TCG = 35' PORT

REMOVING THE COUNTERWEIGHT FROM THE PORT SIDE WOULD RESULT IN AN INCREASE IN THE STBD LIST OF THE SHIP. THE SHIP IS CURRENTLY HEELING TO 23°.

3) DETERMINE NEW Δ, KG AND TCG FOR THE SHIP AND PLOT CORRECTED $\overline{GZ}$ CURVE AND COSINE CURVE.

$$\Delta = 26799 \text{ TONS} - 149 \text{ TONS}$$

$$\Delta = 26650 \text{ TONS}$$

$$KG = \frac{(26799 \text{ TONS})(31.97) - (149 \text{ TONS})(40')}{26650 \text{ TONS}}$$

$$\underline{KG = 31.93 \text{ FT}}$$

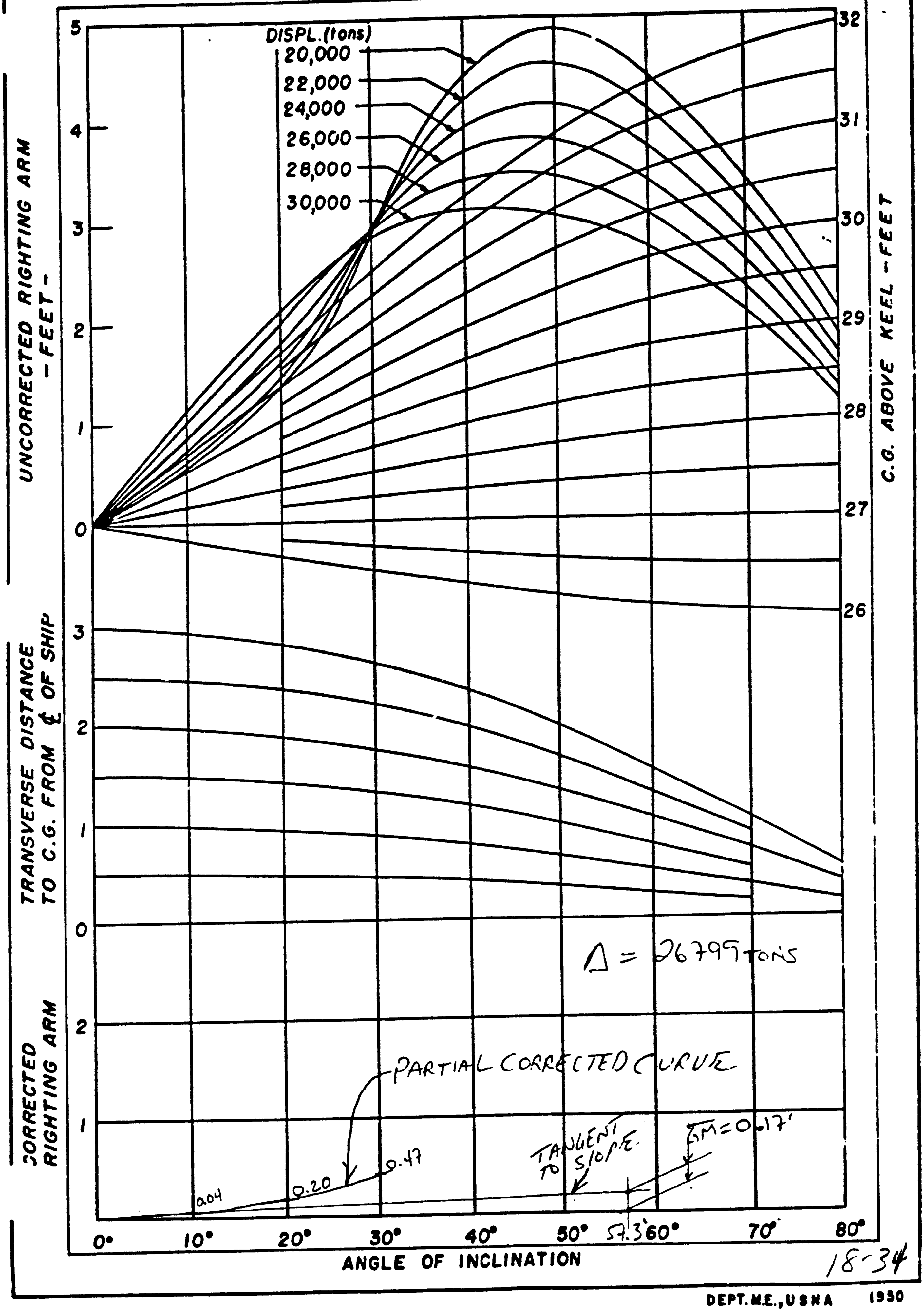
$$TCG = \frac{(26799 \text{ TONS})(0.26') + (149 \text{ TONS})(35')}{26650 \text{ TONS}}$$

$$\underline{TCG = 0.46 \text{ FT}}$$

18.33

PROBLEM 46 JCK PART E (1) 14 of 16

GENERAL STABILITY DIAGRAM — CVE 105



18-34

DEPT. M.E., USNA 1950

SEE STABILITY DIAGRAM PART E (3)
FOR CORRECTED CURVES.

LIST = 30°

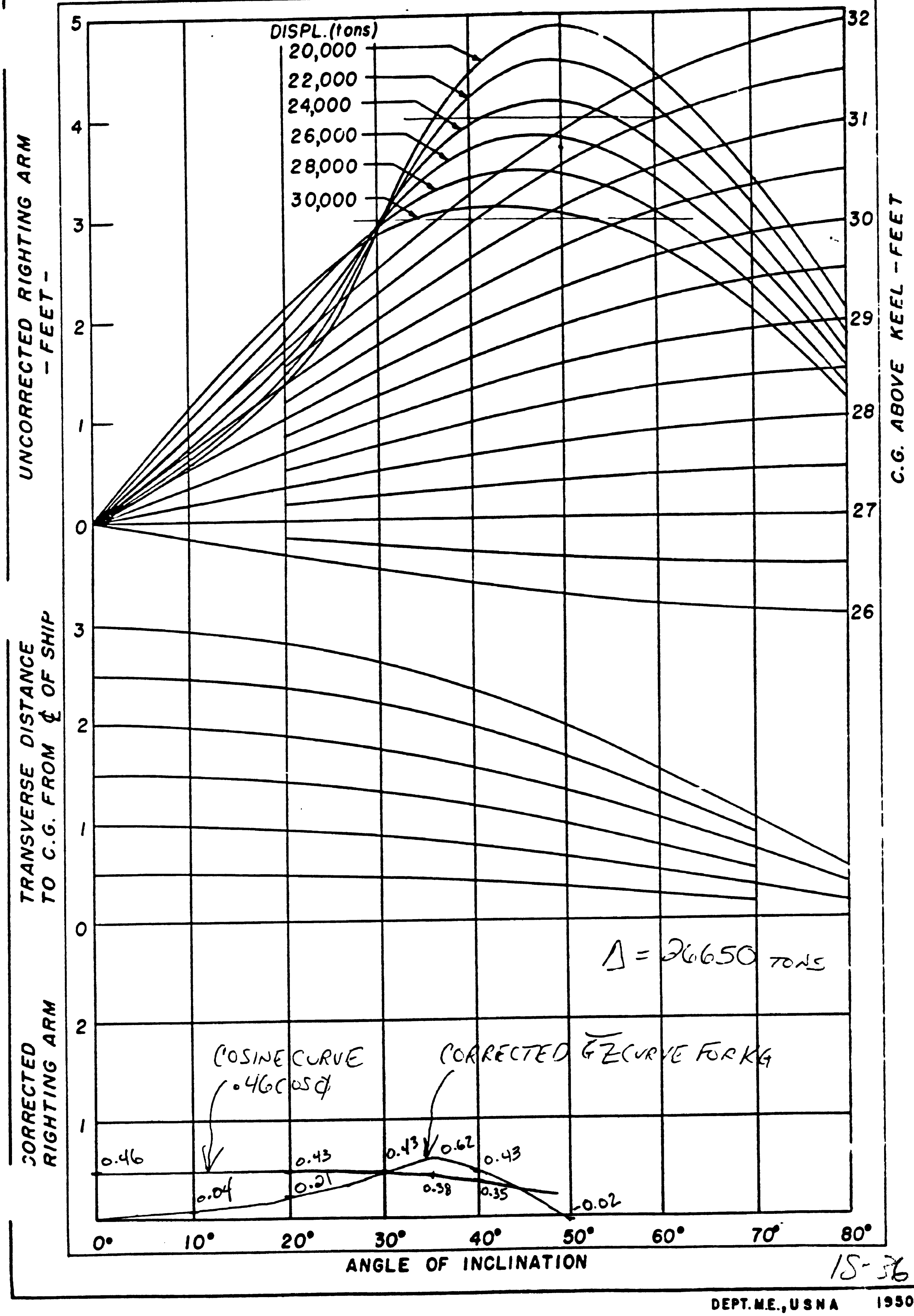
$\overline{GZ}$ MAX = 0.62 - 0.38

= 0.24 FT AT 35°

RANGE OF STABILITY = 44°

PROBLEM 46 JCK PART E (3) 16 of 16

GENERAL STABILITY DIAGRAM — CVE 105



15-36

DEPT. M.E., U S N A 1950

BASIC NAVAL ARCHITECTURE

Unit Number:	19
Title:	Submarine hydrostatics and stability
Tape Running Time:	29^M 27^S
Reading Assignment:	MSD, pp 41-49, 76-79
Additional References:	PNA, pp 98-99, 106-112, 116-117

Scope:

Basic features of submarines and their ballasting systems are described. Sequence of ballasting operations to submerge and to surface is outlined. Relationship of B, G, and M for submarines is defined. Static stability curve for typical submarine is presented.

Key Points to Emphasize:

1. Review names, locations, and purposes of submarine ballast tanks.
2. Review basic sequence of ballasting operations, Fig. 2-18, MSD, pp 42.
3. At instructor's option go over the equilibrium polygon, Fig. 2-26, MSD, pp 48-49.
4. Review and explain Fig. 4-7, MSD, pp 76-79. Note that Fig. 4-7 is for WWII fleet boats.

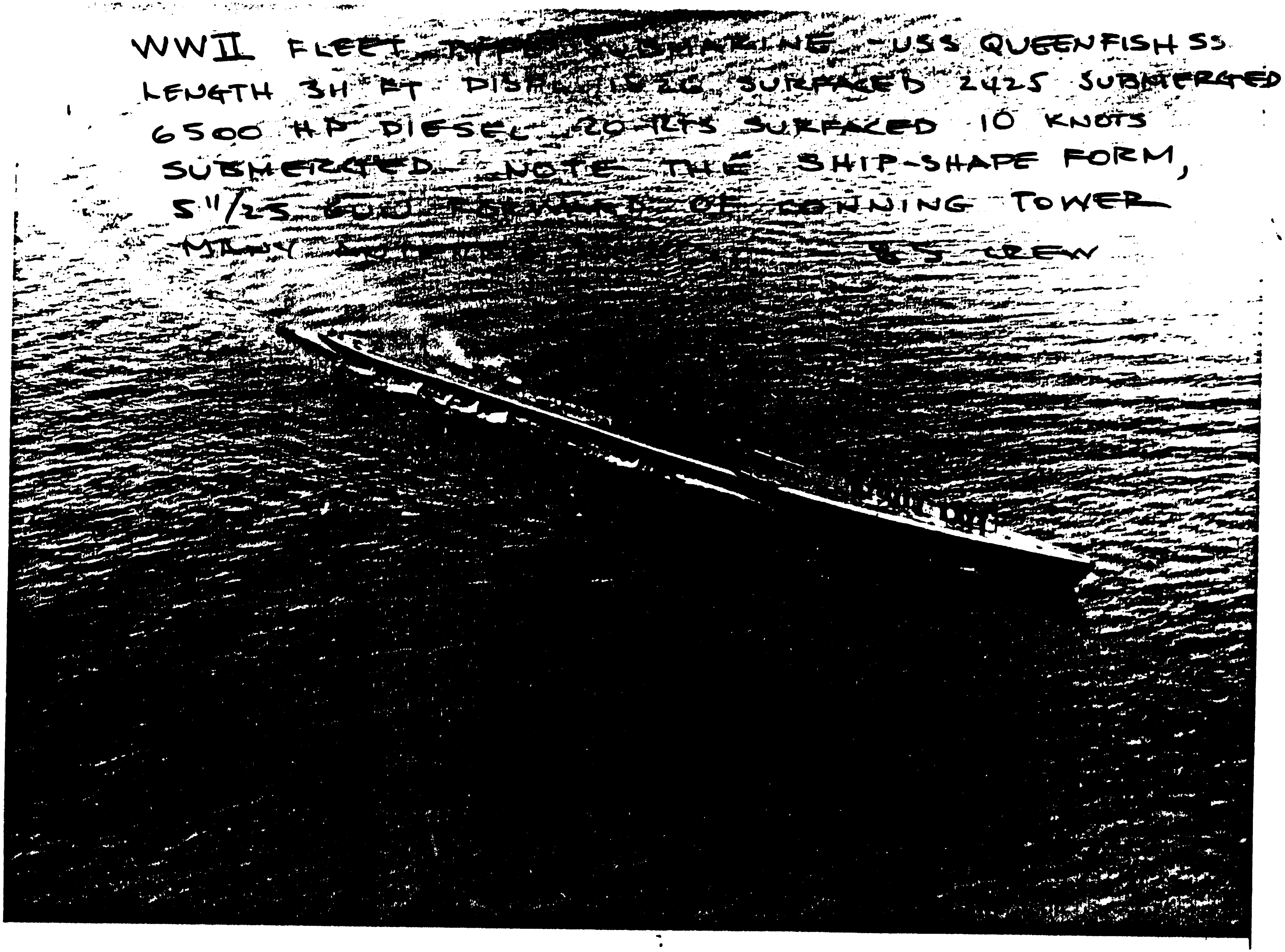
Suggested Problem Assignment: 21, 22

SUBMARINE HYDROSTATICS AND STABILITY

SUBMARINES - THEN AND NOW

- BEFORE THE ADVENT OF NUCLEAR POWER SUBMARINES SPENT MOST OF THEIR TIME ON THE SURFACE AND WERE DESIGNED AS SURFACE SHIPS WHICH COULD SUBMERGE.

- WITH THE ADVENT OF NUCLEAR POWER SUBMARINES COULD BE DESIGNED AS TRUE SUBMERSIBLES WHICH COULD SPEND LONG PERIODS OF TIME SUBMERGED.



WWII FLEET TYPE SUBMARINE - USS QUEENFISH SS
LENGTH 311 FT DISPL 1526 SURFACED 2425 SUBMERGED
6500 HP DIESEL 20 KTS SURFACED 10 KNOTS
SUBMERGED NOTE THE SHIP-SHAPE FORM,
5"/25 GUN FORWARD OF CONNING TOWER
MANY [illegible] 85 CREW

NUCLEAR POWERED BALLISTIC MISSLE SUBMARINE
-OHIO CLASS - SSBN 726 - LENGTH 560 FT
DISPLACEMENT 16,764/18,750 24 TRIDENT MISSLES
4 TORPEDO TUBES 16 OFFICERS 148 MEN - BLUE
AND GOLD CREWS - 70 DAY MISSIONS.
NOTE CYLINDRICAL HULL FORM

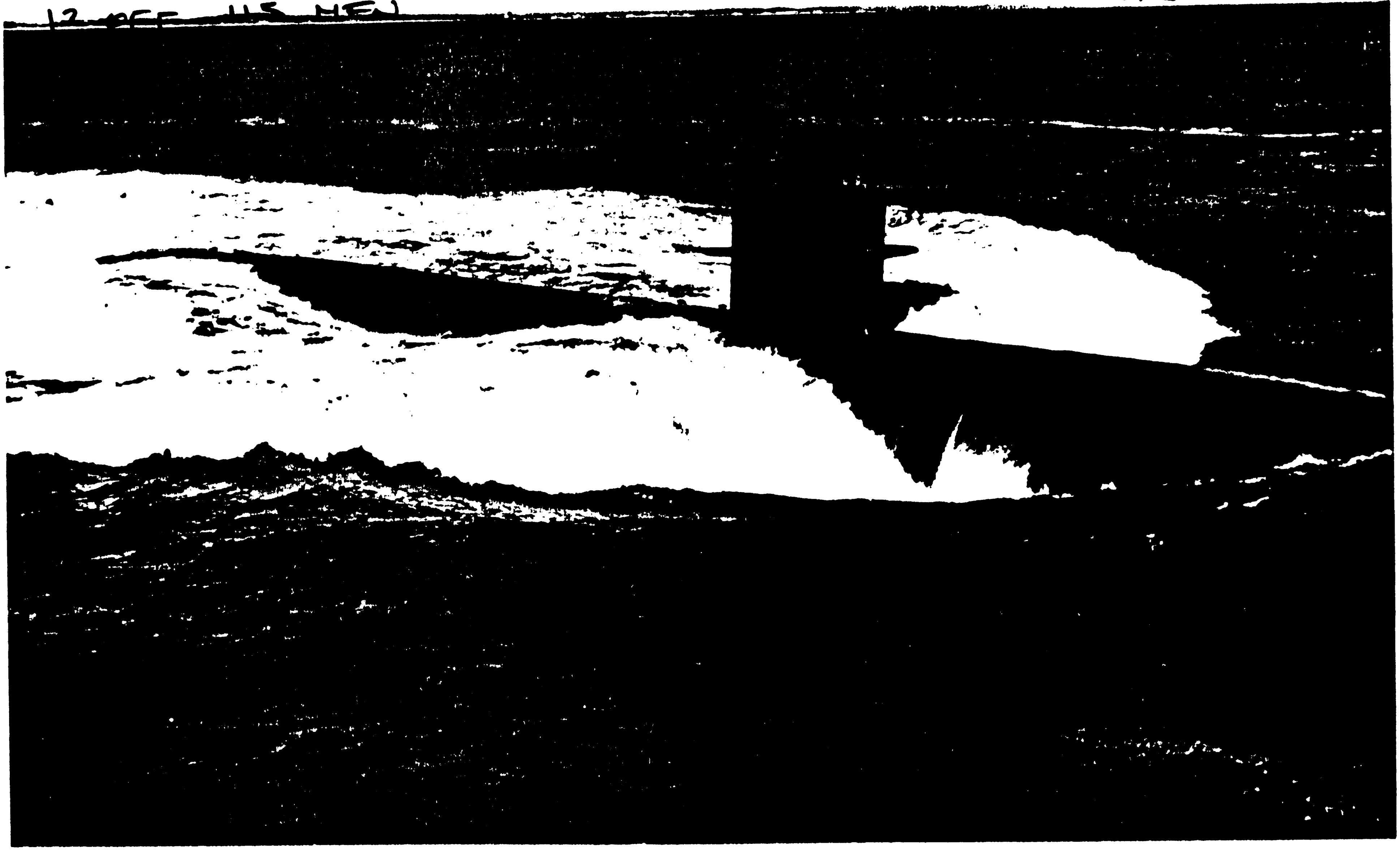
OHIO CLASS SSBN

SSN 690 - PHILADELPHIA SSN 688 LOS ANGELES CL.

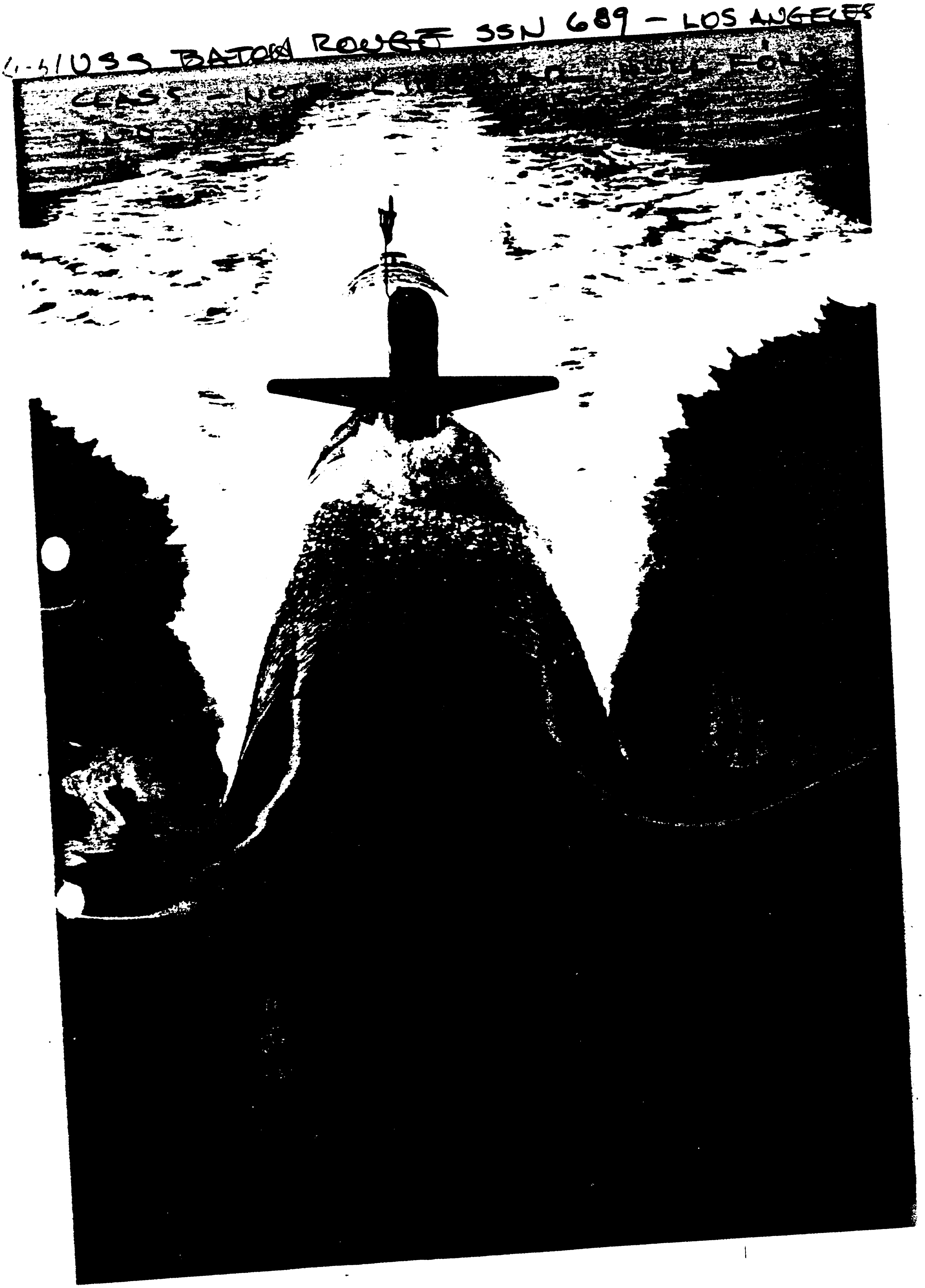
DISPL. 6080/6927 360 FT Speed 30+ SUBMERGED.

35,000 HP 7 BLADED PROP 12 TOMAHAWK 4 TT 22 reloads

12 OFF 115 MEN



4-4/USS BATON ROUGE SSN 689 - LOS ANGELES CLASS - NO



SUBMARINE HYDROSTATICS AND STABILITY

SUBMARINE FEATURES

- LIGHT SHIP WEIGHT - WEIGHT AS BUILT WITH NO BALLAST, FUEL, STORES, CREW AND PAYLOAD ON BOARD.

- LEAD BALLAST IS ADDED TO LOWER G AND TO ADJUST SUBMERGED WEIGHT = SUBMERGED BUOYANCY.

- THE PRESSURE HULL IS THAT PORTION OF THE HULL THAT IS DESIGNED TO WITHSTAND THE HYDROSTATIC PRESSURE OF THE WATER DOWN TO THE CRUSH DEPTH.

SUBMARINE HYDROSTATICS AND STABILITY

SUBMARINE FEATURES (CON'T)

- **MAIN BALLAST TANKS** (MBT'S) ARE BALLASTED WITH SEA WATER TO INCREASE THE DISPLACEMENT OF THE SUBMARINE AND CAUSE IT TO SUBMERGE. MBT'S ARE "SOFT STRUCTURE" EXTERNAL TO THE PRESSURE HULL AND ARE DESIGNED TO SUPPORT THE HYDROSTATIC PRESSURE IN THE SURFACED CONDITION.

- **VARIABLE BALLAST TANKS** ARE USED TO MAKE ADJUSTMENTS IN THE WEIGHT AND TRIM OF THE SUBMERGED SUBMARINE AND INCLUDE:

FORWARD TRIM TANK	(FTT)
AFTER TRIM TANK	(ATT)
AUXILIARY TANKS	(AUX)
DEPTH CONTROL TANK	(DC)

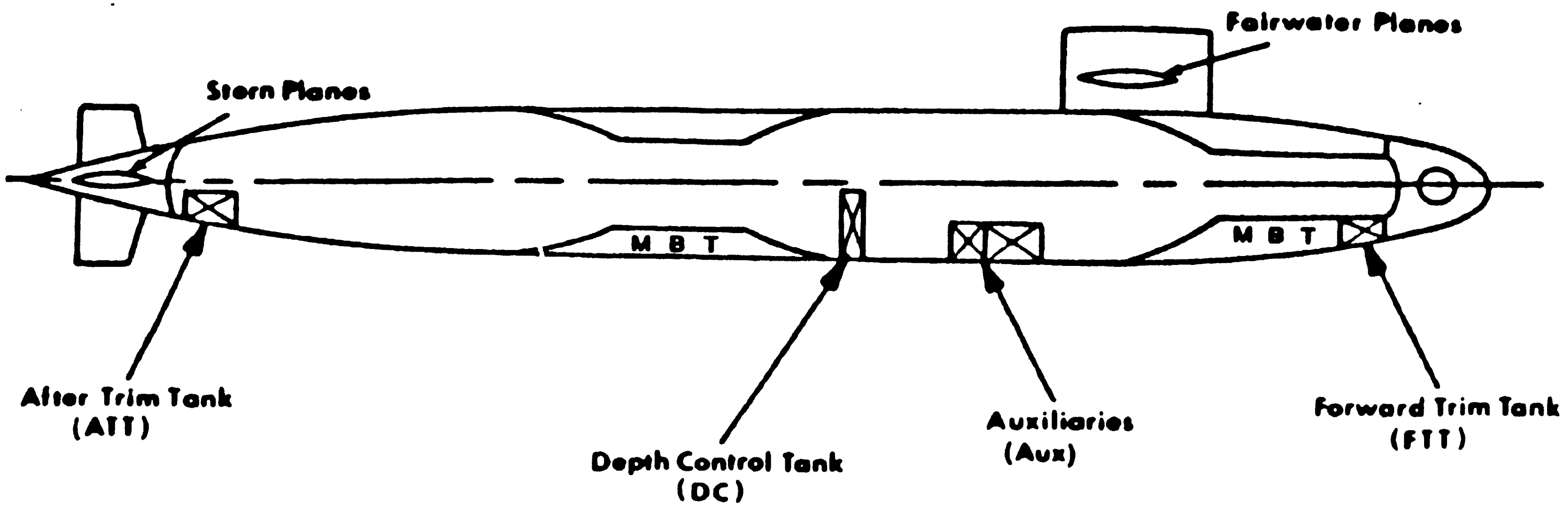
SUBMARINE HYDROSTATICS AND STABILITY

SUBMARINE FEATURES (CON'T)

- RESIDUAL WATER IS THE WATER LEFT IN A TANK AFTER DEBALLASTING.
- FAIRWATER PLANES ARE CONTROL SURFACES LOCATED ON THE FAIRWATER, OR SAIL, OF THE SUBMARINE AND ARE USED FOR DYNAMIC DEPTH AND TRIM CONTROL.
- STERN PLANES ARE CONTROL PLANES AT THE STERN OF THE SHIP AND ARE ALSO USED FOR DEPTH AND TRIM CONTROL.

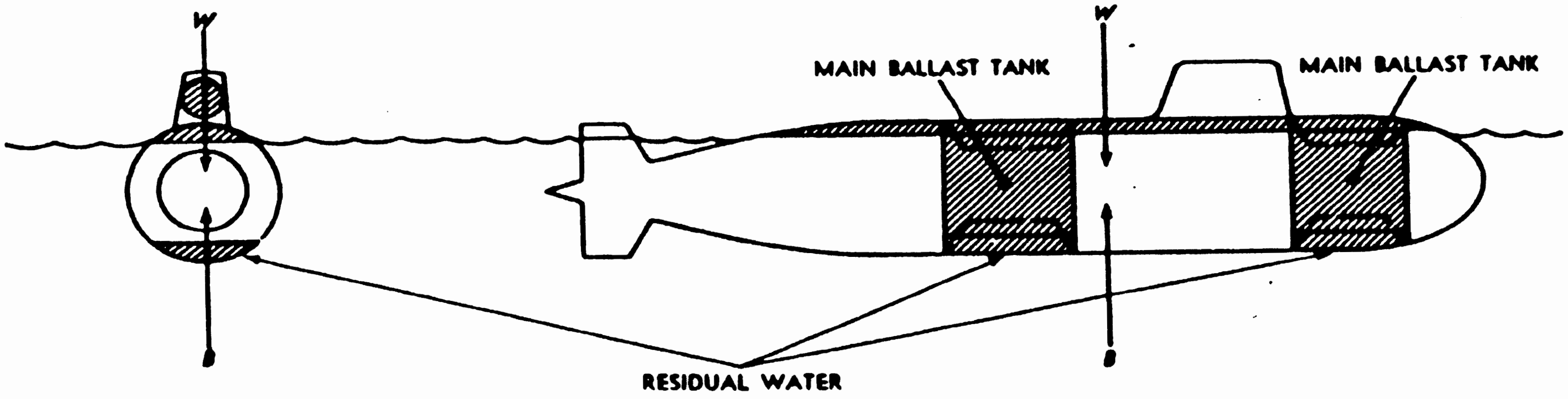
SUBMARINE HYDROSTATICS AND STABILITY

BALLAST TANKS - RECENT CLASSES:



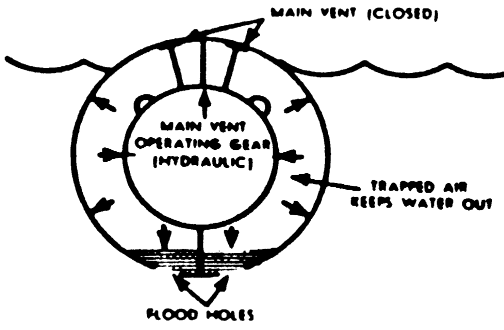
SUBMARINE HYDROSTATICS AND STABILITY

RESERVE BUOYANCY AND MBT'S

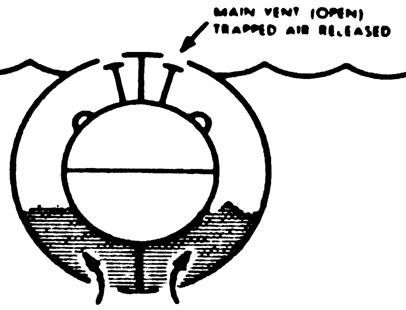


SUBMARINE HYDROSTATICS AND STABILITY

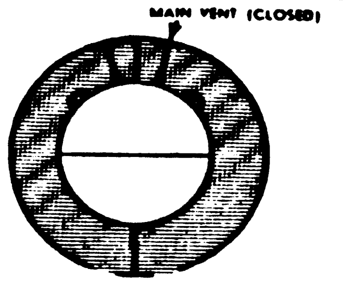
SUBMERGING AND SURFACING



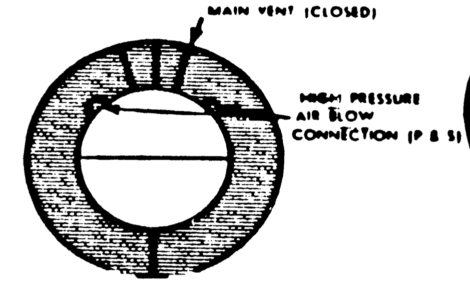
SURFACED



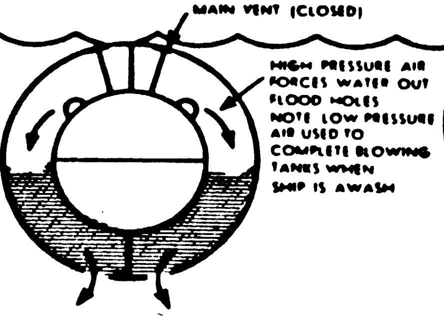
SUBMERGING



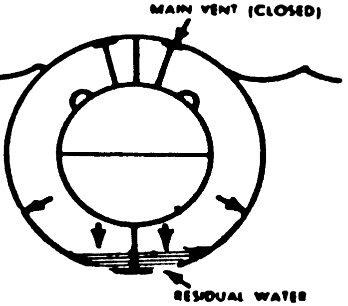
SUBMERGED



PREPARATION FOR SURFACING



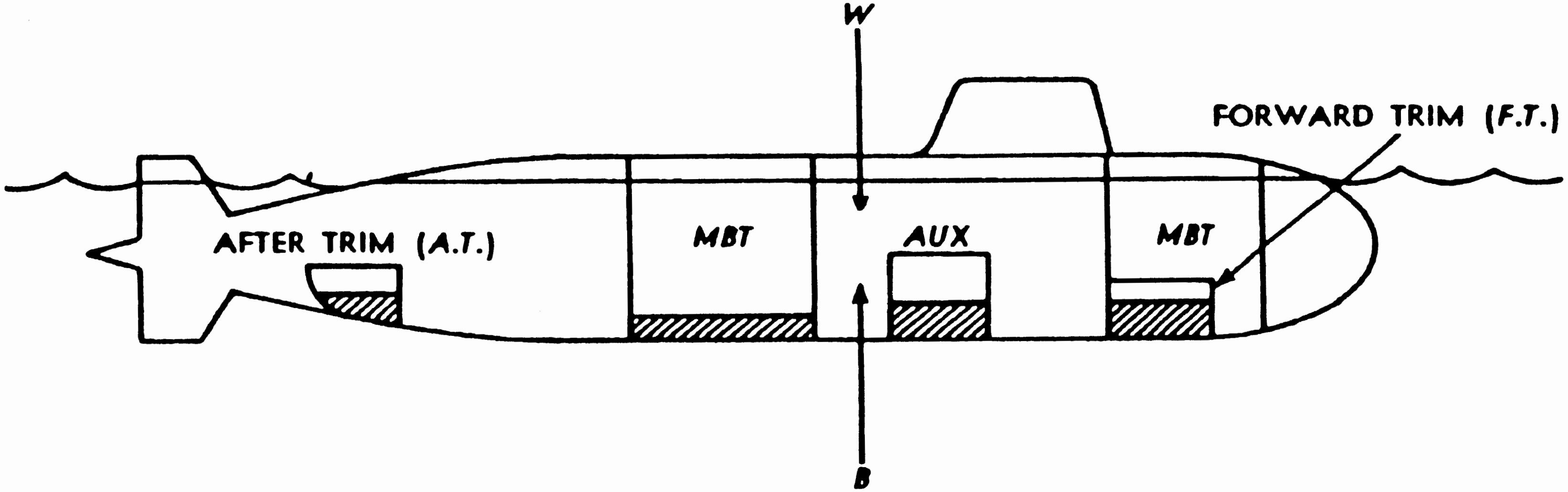
SURFACING



SURFACED

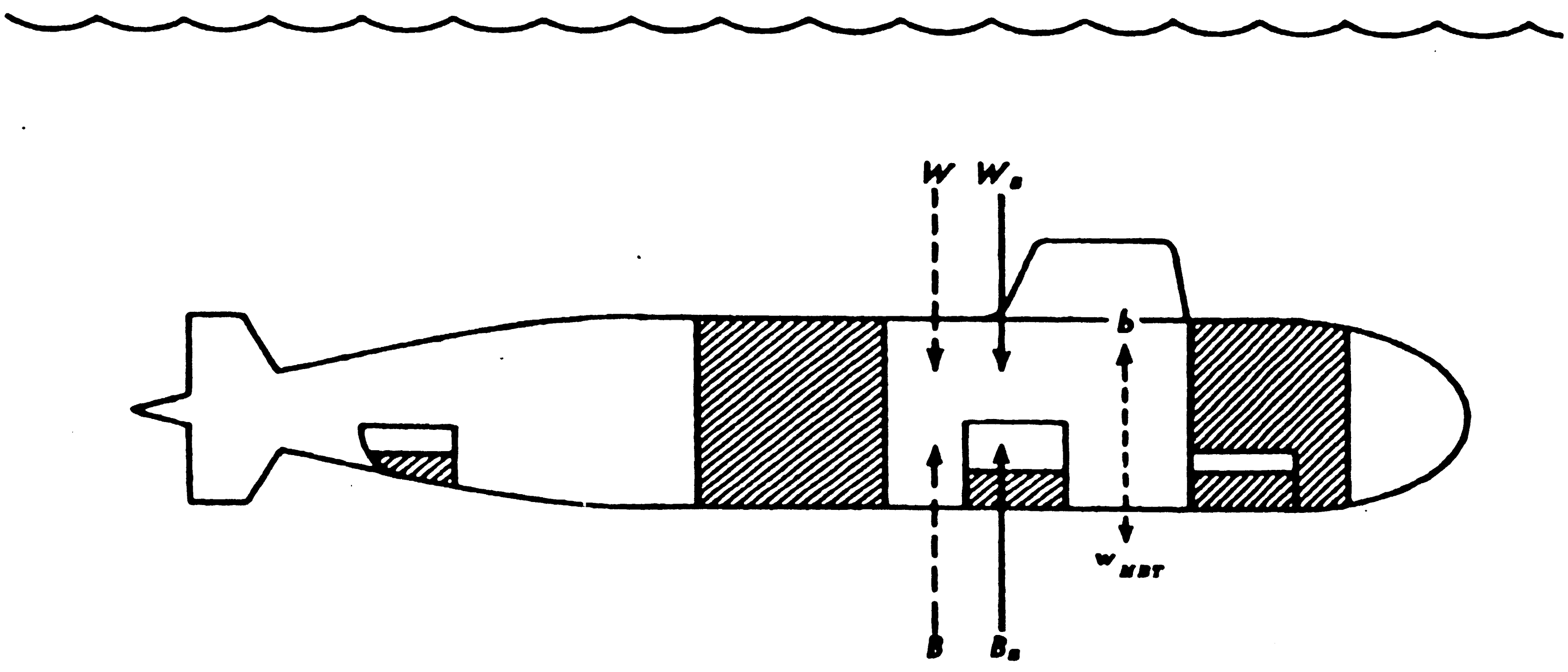
SUBMARINE HYDROSTATICS AND STABILITY

SURFACED SUBMARINE IN DIVING TRIM



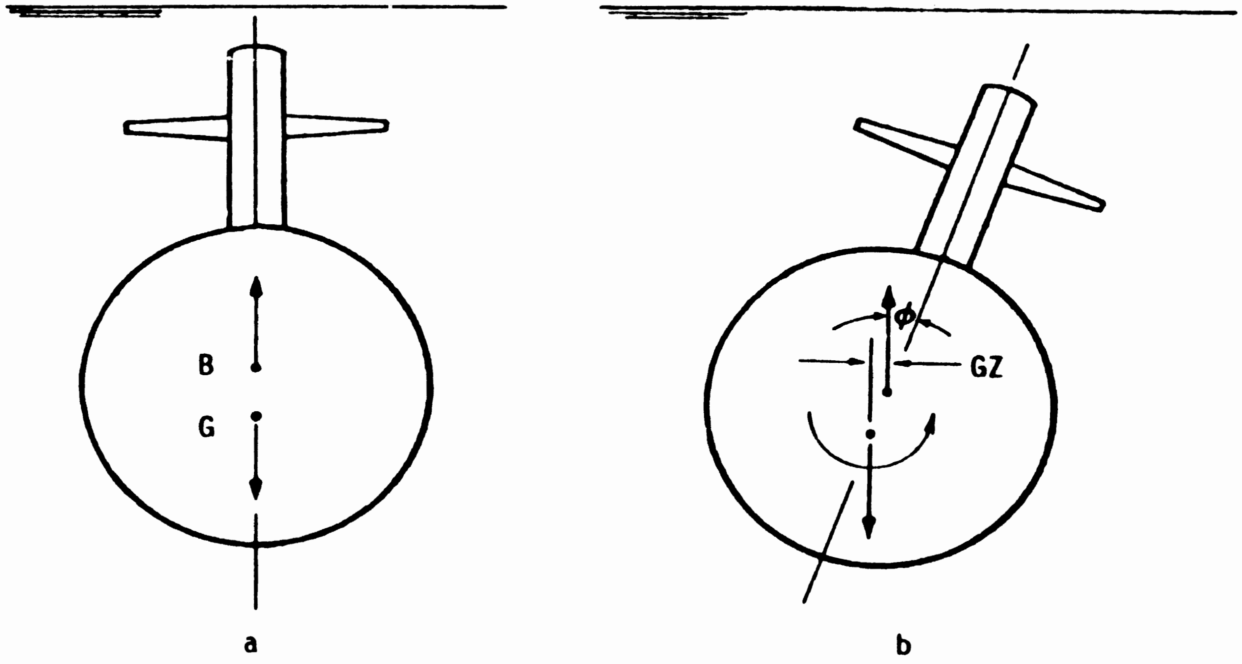
SUBMARINE HYDROSTATICS AND STABILITY

SUBMERGED SUBMARINE



SUBMARINE HYDROSTATICS AND STABILITY

SUBMARINE STABILITY

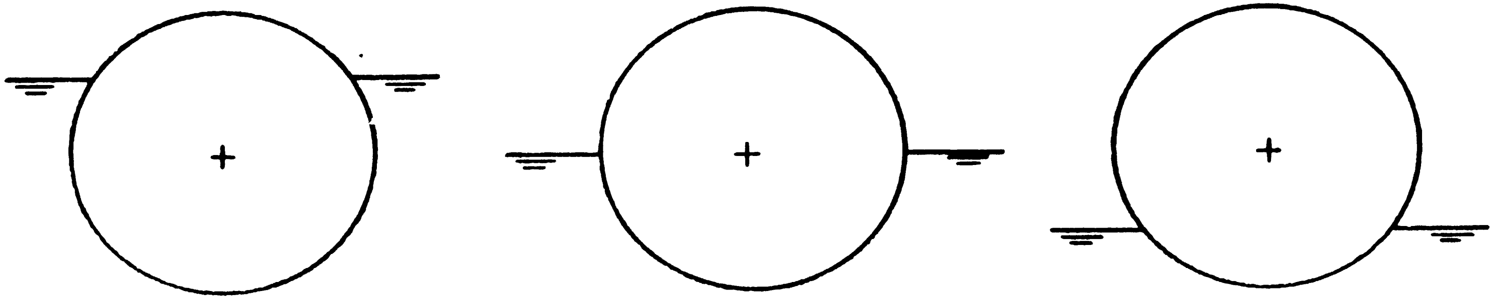


IN THE SUBMERGED CONDITION G MUST BE BELOW B.

SUBMARINE HYDROSTATICS AND STABILITY

QUESTION

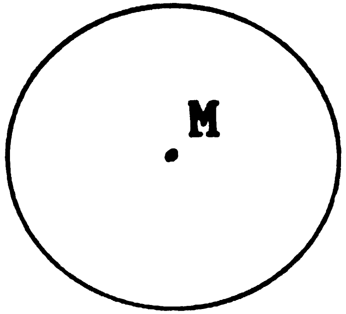
WHERE IS THE METACENTER FOR THE CIRCULAR CYLINDER AT THE THREE WATERLINES SHOWN?



SUBMARINE HYDROSTATICS AND STABILITY

ANSWER

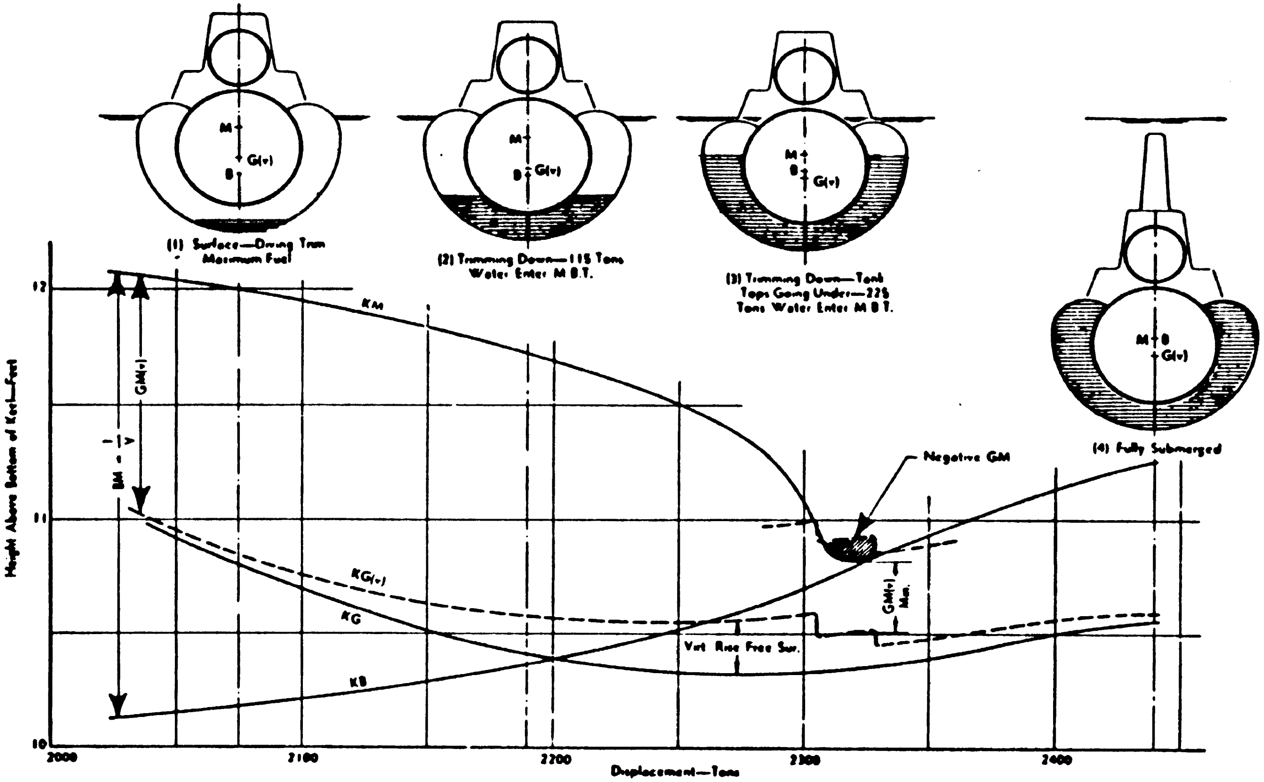
FOR A FLOATING CIRCULAR CYLINDER THE METACENTER WILL ALWAYS BE AT THE CENTER OF THE CIRCULAR SECTION.



P.L.T.S

SUBMARINE HYDROSTATICS AND STABILITY

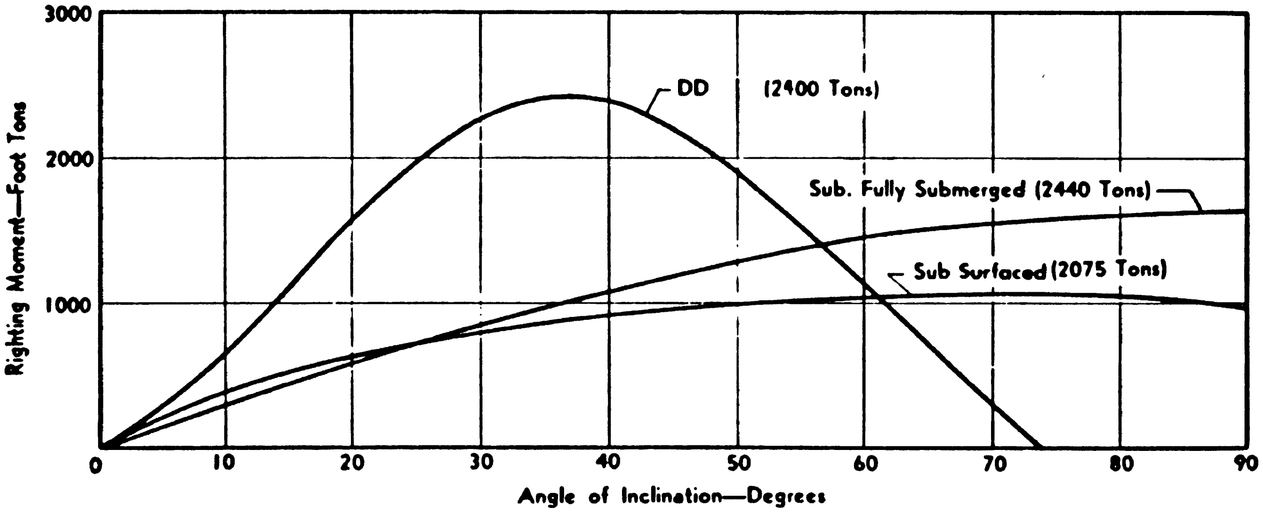
STABILITY WHEN SUBMERGING AND SURFACING



NOTE: FIGURE IS FOR WWII FLEET BOATS.

SUBMARINE HYDROSTATICS AND STABILITY

STABILITY CURVES - DD VS SUB



FORCES OPPOSED TO PROPULSION

RESISTANCE COEFFICIENTS

- RESISTANCE COEFFICIENTS ARE USED TO DETERMINE RESISTANCE COMPONENTS.

  - RESIDUARY RESISTANCE COEFFICIENT

$$C_r = \frac{R_r}{\frac{\rho}{2} S v^2}$$

  - FRICTIONAL RESISTANCE COEFFICIENT

$$C_f = \frac{R_f}{\frac{\rho}{2} S v^2}$$

  - TOTAL RESISTANCE COEFFICIENT

$$C_t = \frac{R_t}{\frac{\rho}{2} S v^2}$$

WHERE ρ = DENSITY OF WATER, LB·SEC^2/FT^4.
S = WETTED SURFACE OF MODEL OR SHIP, FT^2.
v = VELOCITY OF MODEL OR SHIP, FT/SEC.

BASIC NAVAL ARCHITECTURE

Problem 21

Problem Level: Basic

An attack submarine is in a shipyard in salt water (35.0 ft^3/ton). Four MK48 torpedoes weighing 4000 lbs. each are moved 25 feet forward and one MK37 weighing 1790 lbs is moved aft 30 feet. How many gallons of water must be shifted between forward and after trim tanks if the centers of the tanks are 270.0 feet apart? Take the weight of one gallon of sea water to be 8.55 lbs.

Problem 22

Problem Level: Intermediate

A submarine is underway at sea on the surface where the density of sea water is 1.9870 lb-sec^2/ft^4. The boat in this condition has a displacement of 7000 tons. The volume of reserve buoyancy is 24,500 ft^3. The boat now floods the main ballast tanks and submerges to periscope depth where it is just neutrally buoyant.

Find:

a) The density factor (specific volume) of the surface sea water in ft^3/ton. Carry your answer to two decimal places.

b) The weight of sea water in tons taken on in the main ballast tanks.

The boat now dives to a depth of 600 feet and encounters a layer of cold water where the density is 1.9970 lb-sec^2/ft^4.

Find:

c) The number of pounds of ballast water that must be taken on or discharged to compensate for the change in density.

Note: Take $g = 32.17$ ft/sec^2.

PROBLEM 21 | TDK/PRVMJR | 12 JAN 87 | 1 OF 1

THE NET MOMENT CAUSED BY SHIFTING THE TORPEDOES MUST BE JUST OFFSET BY THE MOMENT OF THE SHIFT OF THE BALLAST WATER

ITEM	WEIGHT, w LBS	SHIFT DISTANCE, d. FT	MOMENT OF SHIFT FT-LBS
FOUR MK 48 TOR @ 4000 LBS EA	16,000	25.0 F	400,000 F
ONE MK 37 @ 1790 LBS	1,790	30.0 A	53,700 A
			346,300 F
REQ'D BALLAST SHIFT, N GALLONS	8.55 N	270.0 A	346,300 A

$$8.55N \times 270.0 = 346{,}300$$

$$N = 150.0 \text{ GALS}$$

SHIFT 150 GALLONS FROM FWD TRIM TK. TO AFT TRIM TANK

REF: GILLMER, ~~PP~~ 41-46.

(a) GIVEN: $\rho_{SW} = 1.9870 \ \frac{LB\text{-}SEC^2}{FT^4}$

$$1.9870 \ \frac{\cancel{LB\text{-}SEC^2}}{\cancel{FT^4}\ FT^3} \times \frac{1\ LT}{2240\ \cancel{LB}} \times 32.17\ \frac{\cancel{FT}}{\cancel{SEC^2}} = ,02854\ \frac{LT}{FT^3}$$

DENSITY FACTOR (SPECIFIC VOLUME) = $\frac{1}{.02854}\ \frac{LT}{FT^3}$

$$\boxed{\text{DENSITY FACTOR} = 35.04\ \frac{FT^3}{TON}}$$

(b) VOLUME OF SEA WATER = VOLUME OF RESERVE BUOYANCY.

$$\boxed{\text{WEIGHT OF SEA WATER} = \frac{24,500\ FT^3}{35.04\ FT^3/LT} = 699\ LT}$$

(c) AT THE SURFACE, WITH THE BALLAST WATER ADDED THE DISPLACEMENT OF THE SUBMARINE IN THE NEUTRALLY BUOYANT CONDITION WILL BE ~

ORIGINAL DISPL = 7000 LT
BALLAST ADDED = 699 LT

Δ, NEUTRALLY BUOYANT SUB = 7,699 LT

THE TOTAL SUBMERGED VOLUME, ∇ =

$= 7,699\ LT \times 35.04\ \frac{FT^3}{LT}$
$= 269,773\ FT^3$

(CON'T)

THE DENSITY FACTOR (SPECIFIC VOLUME) AT THE 600-FT DEPTH WILL BE~

$$1.9970 \frac{LB\text{-}SEC^2}{FT^4} \times \frac{1 \quad LT}{2240 \quad LB} \times 32.17 \frac{FT}{SEC^2} = .02868 \frac{LT}{FT^3}$$

$$= 34.87 \frac{FT^3}{LT}$$

THE SUB WILL NOW DISPLACE~

$$\frac{269,773 \ FT^3}{34.87 \ FT^3/LT} = 7737 \ LT$$

BUT THE WEIGHT OF THE SUB = 7699 LT

DIFFERENCE = 38 LT

= 85,120 LB.

THE BUOYANT FORCE IS EQUAL TO THE WEIGHT OF THE DISPLACED WATER, 7737 LT. SINCE THIS IS GREATER THAN THE WEIGHT OF THE SUB JUST BELOW THE SURFACE, THE SUB WOULD RISE IF IT DID NOT TAKE ON ADDITIONAL BALLAST WATER

SUB MUST <u>ADD</u> 85,120 LB OF BALLAST WATER

BASIC NAVAL ARCHITECTURE

Unit Number: 20

Title: Forces opposed to propulsion - 1

Tape Running Time: $36^M \ 5^S$

Reading Assignment: MSD, pp 95-102, 106-110

Additional References: PNA, pp 288-312

Scope:

This is the first of seven units covering the resistance and propulsion of ships. Wave-making and frictional resistance components are discussed using Froude's work as a theme. The use of model testing is described. Froude's Law of Comparison is introduced. Residuary resistance is defined. Resistance coefficients are defined.

Key Points to Emphasize:

1. Introduce the basic types of resistance which will be discussed: wave-making, frictional, eddy-making, air.
2. Emphasize Froude's Law of Comparison.
3. Describe components of gravity wave systems and ship-generated wave systems. Emphasize that in ship-generated wave systems the ship speed establishes the wave speed and the length of the waves adjust accordingly in proportion to velocity squared.
4. Sketch ship wave profiles for various speed length ratios. Define hull speed.
5. Emphasize the definitions of resistance coefficients.
6. Describe laminar and turbulent flow regimes in viscous flow. Introduce Reynold's Number and ITTC friction formula.
7. Outline the basic method of expanding model test results.

Suggested Problem Assignment: Use this opportunity to assign previously unassigned problems.

FORCES OPPOSED TO PROPULSION

BACKGROUND

- THE PROBLEM OF PREDICTING CORRECTLY THE RESISTANCE OF A SHIP EVADED SCIENTISTS AND ENGINEERS UNTIL THE ADVENT OF WILLIAM FROUDE (1810-1879).

- SHIP MODEL TESTS HAD NEVER BEEN SUCCESSFUL UNTIL FROUDE DISCOVERED HOW TO EXPAND MODEL TEST RESULTS CORRECTLY TO PREDICT SHIP RESISTANCE.

FORCES OPPOSED TO PROPULSION

BACKGROUND (CON'T)

- BASED ON OBSERVATIONS OF DIFFERENT SIZED MODELS FROUDE OBSERVED THAT THE WAVE PATTERNS WERE SIMILAR AT THE SAME RATIO,

$\frac{V}{\sqrt{L}}$, WHERE V = MODEL SPEED
L = LENGTH OF MODEL.

- TODAY, THIS RATIO IS KNOWN AS THE SPEED-LENGTH RATIO, WHERE V IS IN KNOTS AND L IS IN FEET. SPEED-LENGTH RATIO IS CONVENIENT, BUT DIMENSIONALLY CORRUPT.

FORCES OPPOSED TO PROPULSION

BACKGROUND (CON'T)

- THE DIMENSIONALLY CORRECT FORM IS FROUDE NUMBER -

$$Fn = \frac{v}{\sqrt{gL}}$$

v = MODEL OR SHIP SPEED, FT/SEC.

g = ACCELERATION OF GRAVITY, 32.17 FT/SEC^2.

$$Fn = \frac{FT/SEC}{\sqrt{FT/SEC^2 \cdot FT}}$$

FORCES OPPOSED TO PROPULSION

BACKGROUND (CON'T)

- FROUDE RECOGNIZED THAT THERE WERE TWO MAJOR COMPONENTS OF SHIP RESISTANCE:
  - WAVE MAKING RESISTANCE
  - FRICTIONAL RESISTANCE

- ALTHOUGH OUR UNDERSTANDING OF SHIP HYDRODYNAMICS HAS EXPANDED GREATLY SINCE FROUDE'S TIME, HIS BASIC LAW OF COMPARISON REMAINS IN USE TODAY.

FORCES OPPOSED TO PROPULSION

FROUDE'S LAW OF COMPARISON

1. GEOMETRICALLY SIMILAR HULL FORMS MOVING AT CORRESPONDING SPEEDS (SO THAT THEIR WAVE MAKING PATTERNS ARE THE SAME) HAVE WAVE MAKING RESISTANCES THAT ARE PROPORTIONAL TO THEIR DISPLACEMENTS.

$$\left(\frac{R_W}{\Delta}\right)_{\text{MODEL}} = \left(\frac{R_W}{\Delta}\right)_{\text{SHIP}}$$

WHERE R_W = WAVE MAKING RESISTANCE.

FORCES OPPOSED TO PROPULSION

FROUDE'S LAW OF COMPARISON (CON'T)

2. FRICTIONAL RESISTANCE COULD BE SEPARATELY COMPUTED FOR MODEL AND SHIP. BY SUBTRACTING THE MODEL FRICTIONAL RESISTANCE FROM MODEL TOTAL RESISTANCE THE MODEL WAVE MAKING RESISTANCE COULD BE OBTAINED:

$$R_{t_m} - R_{f_m} = R_{w_m}$$

R_{t_m} = MODEL TOTAL RESISTANCE.

R_{f_m} = MODEL FRICTIONAL RESISTANCE.

R_{w_m} = MODEL WAVE MAKING RESISTANCE.

FORCES OPPOSED TO PROPULSION

FROUDE'S LAW OF COMPARISON (CON'T)

3. SINCE

$$\frac{R_{w_m}}{\Delta_m} = \frac{R_{w_s}}{\Delta_s}$$

THEN,

$$R_{w_s} = \frac{\Delta_s}{\Delta_m} \cdot R_{w_m}$$

4. FINALLY,

$$R_{t_s} = R_{w_s} + R_{f_s}$$

R_{t_s} = SHIP TOTAL RESISTANCE.

R_{w_s} = SHIP WAVE MAKING RESISTANCE.

R_{f_s} = SHIP FRICTIONAL RESISTANCE.

FORCES OPPOSED TO PROPULSION

MODEL TESTING

- FROUDE OBTAINED FUNDS FROM THE BRITISH ADMIRALTY TO BUILD A 300-FOOT SHIP MODEL TESTING TANK AT TORQUAY, ENGLAND.

- HE TESTED A VARIETY OF FLAT PLATES WHICH CREATED VERY LITTLE WAVE MAKING RESISTANCE TO MEASURE FRICTIONAL RESISTANCE.

- HE DEVELOPED A FORMULA FOR FRICTIONAL RESISTANCE OF BOTH MODELS AND SHIPS WHICH WAS USED THROUGH THE 1930'S.

FORCES OPPOSED TO PROPULSION

MODEL TESTING (CON'T)

- FROUDE ALSO CONDUCTED A VERY FAMOUS SERIES OF EXPERIMENTS ON A MODEL OF THE HMS GREYHOUND AND ON THE FULL SIZE SHIP.
- BASED ON THESE EXPERIMENTS HE REFINED HIS THEORIES OF SHIP RESISTANCE.
- TODAY, SHIP MODEL TESTING IS STILL THE PRIMARY TOOL IN PREDICTING SHIP RESISTANCE.

FORCES OPPOSED TO PROPULSION

OTHER COMPONENTS OF RESISTANCE

- **EDDIES** (OR VORTICES) ARE FORMED WHEN WATER TRIES TO CLOSE IN BEHIND REGIONS OF CURVATURE PARTICULARLY AROUND THE STERN OF A SHIP AND BEHIND APPENDAGES SUCH AS STRUTS, RUDDERS, BOSSINGS, ETC.

- **AIR RESISTANCE** DUE TO THE SHIP MOVING THROUGH STILL AIR IS VERY SMALL COMPARED TO **HYDRODYNAMIC RESISTANCE** AT NORMAL SHIP SPEEDS BUT MUST BE INCLUDED FOR HIGH SPEED SHIPS.

FORCES OPPOSED TO PROPULSION

RESISTANCE COEFFICIENTS

- RESISTANCE COEFFICIENTS ARE USED TO DETERMINE RESISTANCE COMPONENTS.

  - RESIDUARY RESISTANCE COEFFICIENT

    $$C_r = \frac{R_r}{\frac{\rho}{2} S v^2}$$

  - FRICTIONAL RESISTANCE COEFFICIENT

    $$C_f = \frac{R_f}{\frac{\rho}{2} S v^2}$$

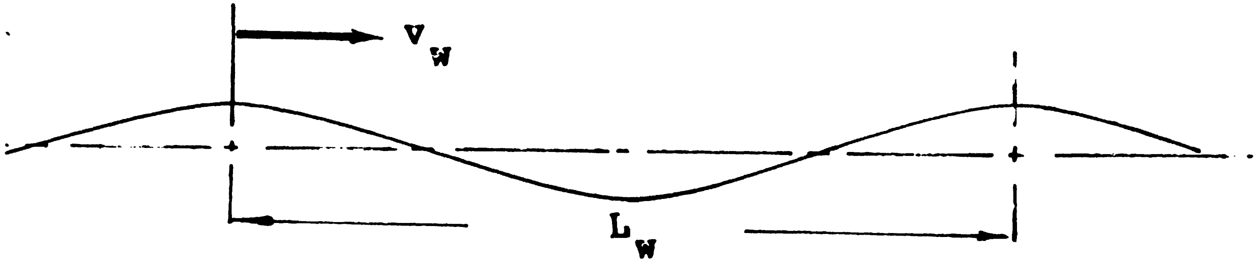
  - TOTAL RESISTANCE COEFFICIENT

    $$C_t = \frac{R_t}{\frac{\rho}{2} S v^2}$$

WHERE ρ = DENSITY OF WATER, LB·SEC^2/FT^4.
S = WETTED SURFACE OF MODEL OR SHIP, FT^2.
v = VELOCITY OF MODEL OR SHIP, FT/SEC.

FORCES OPPOSED TO PROPULSION

GRAVITY WAVES



THE VELOCITY (OR "CELERITY") OF A GRAVITY WAVE IS GIVEN BY

$$v_w = \sqrt{(g \cdot L_w / 2 \cdot \pi)} = 2.26 \sqrt{L_w}$$

WRITTEN ANOTHER WAY,

$$\frac{v_w}{\sqrt{g \cdot L_w}} = \sqrt{(1/2 \cdot \pi)} = 0.40$$

ALSO,

$$L_w = 0.195 \; v_w{}^2$$

FORCES OPPOSED TO PROPULSION

GRAVITY WAVES

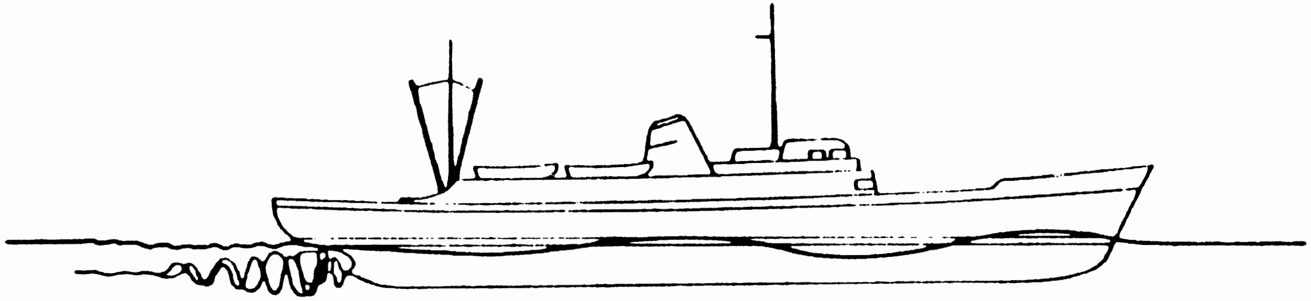
MESSAGE: THE VELOCITY OF A GRAVITY WAVE IS PROPORTIONAL TO THE SQUARE ROOT OF ITS LENGTH.

IN THE CASE OF SHIP WAVES THE SHIP IS FORCING THE WAVES TO TRAVEL AT THE SPEED OF THE SHIP.

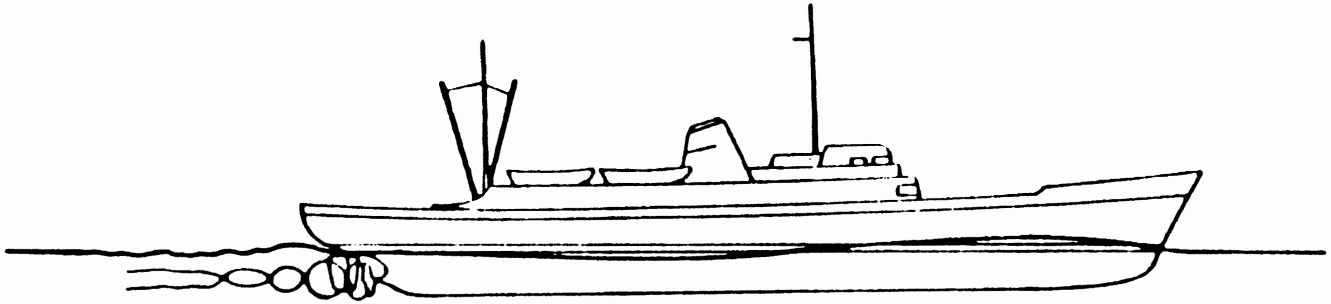
THE LENGTH OF THE SHIP WAVES WILL BE DETERMINED BY THE SPEED OF THE SHIP.

FORCES OPPOSED TO PROPULSION

WAVE LENGTH AND SPEED-LENGTH RATIO



$v = 0.6\sqrt{L}$



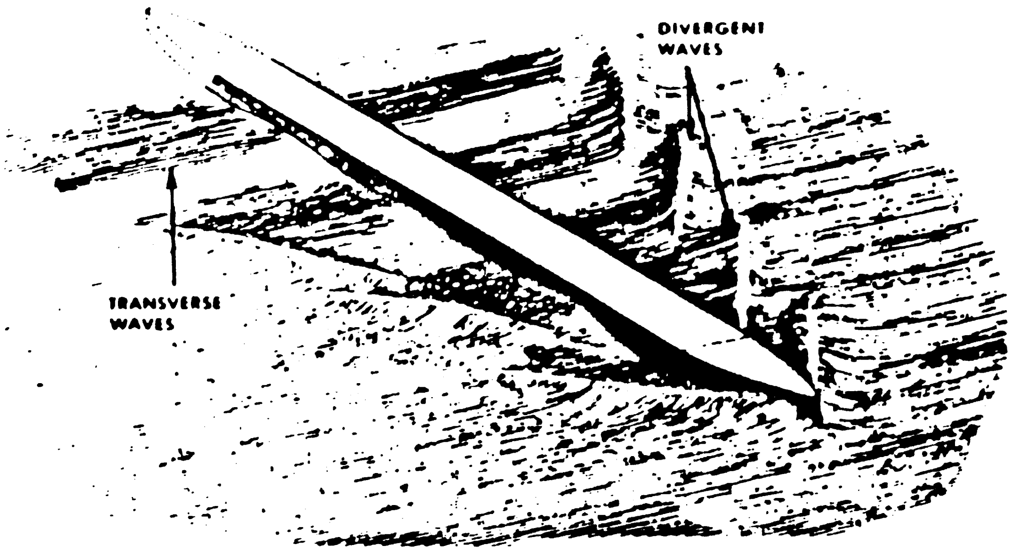
$v = 1.3\sqrt{L}$

NOTE: THE SHIP SPEED AT WHICH WAVE LENGTH = SHIP LENGTH IS KNOWN AS "HULL SPEED", APPROXIMATELY $1.2\sqrt{L}$ TO $1.3\sqrt{L}$.

FORCES OPPOSED TO PROPULSION

SHIP WAVE SYSTEMS

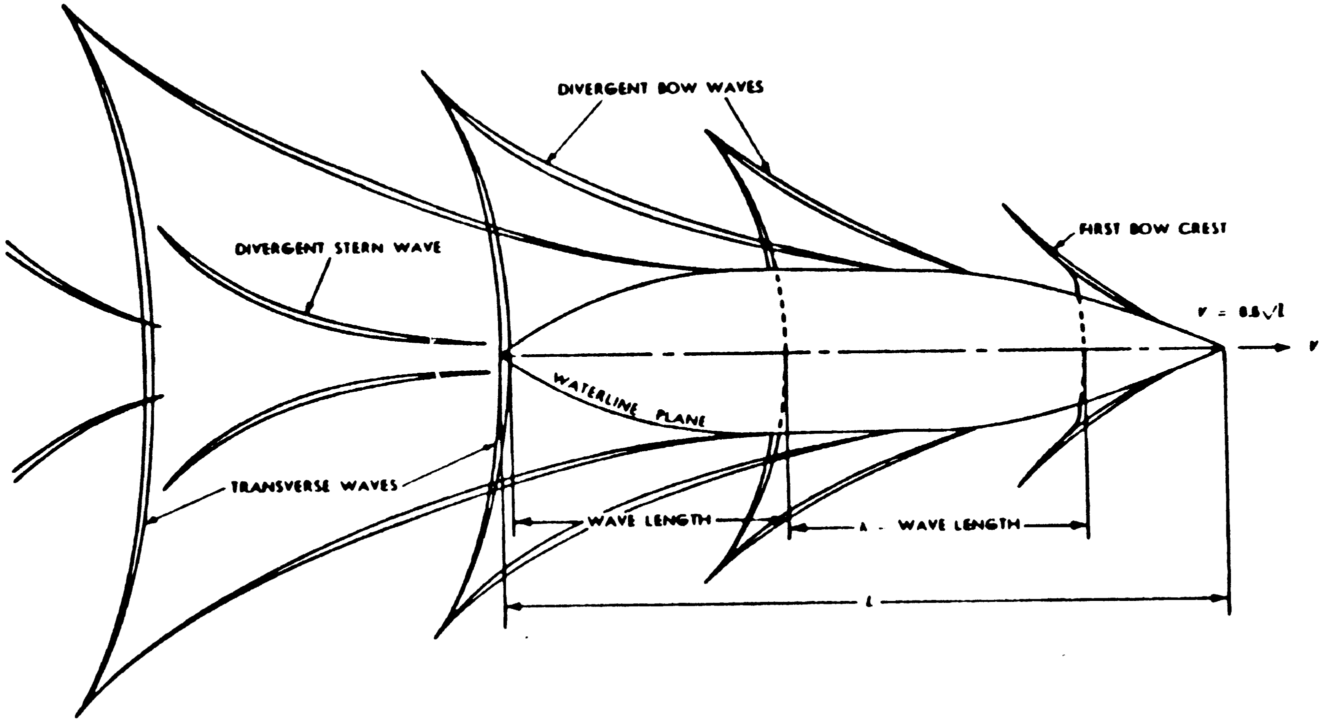
FROUDE'S SKETCH OF A SHIP'S WAVE SYSTEM:



NOTE: DIVERGENT WAVE SYSTEM AND TRANSVERSE WAVE SYSTEM.

FORCES OPPOSED TO PROPULSION

SHIP WAVE SYSTEM (CON'T)



FORCES OPPOSED TO PROPULSION

FRICTIONAL RESISTANCE

- JUST AS DIMENSIONAL ANALYSIS MAY BE USED TO SHOW THAT WAVE MAKING RESISTANCE IS A FUNCTION OF FROUDE NUMBER, IT MAY ALSO BE SHOWN THAT FRICTIONAL RESISTANCE IS A FUNCTION OF REYNOLDS NUMBER,

$$Rn = \frac{v \cdot L}{\nu}$$

v = MODEL OR SHIP VELOCITY, FT/SEC.

L = MODEL OR SHIP LENGTH, FT.

ν = KINEMATIC VISCOSITY OF FLUID, FT^2/SEC.

FORCES OPPOSED TO PROPULSION

FRICTIONAL RESISTANCE (CON'T)

- THERE ARE TWO TYPES OF FRICTIONAL FLOWS
  - LAMINAR FLOW
  - TURBULENT FLOW

- LAMINAR FLOW OCCURS AT LOWER REYNOLDS NUMBERS AND HAS A LOWER COEFFICIENTS OF FRICTION. LAMINAR FLOW IS SOMETIMES PRESENT ON PARTS OF SHIP MODEL HULLS AT LOWER SPEEDS.

- TURBULENT FLOW OCCURS AT HIGHER REYNOLDS NUMBERS AND HAS LARGER COEFFICIENTS OF FRICTION. FULL SIZE SHIPS HAVE NEARLY 100% TURBULENT FLOW.

FORCES OPPOSED TO PROPULSION

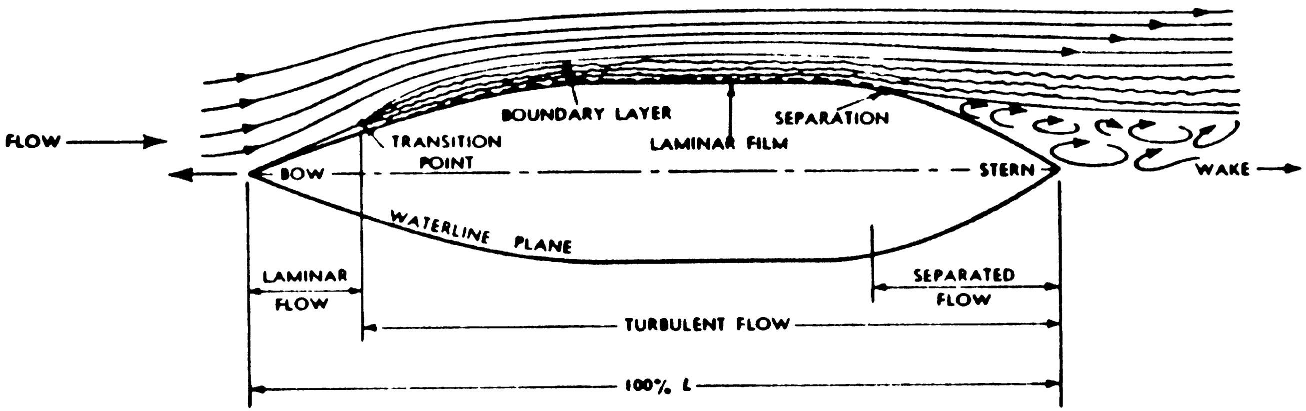
FRICTIONAL RESISTANCE (CON'T)

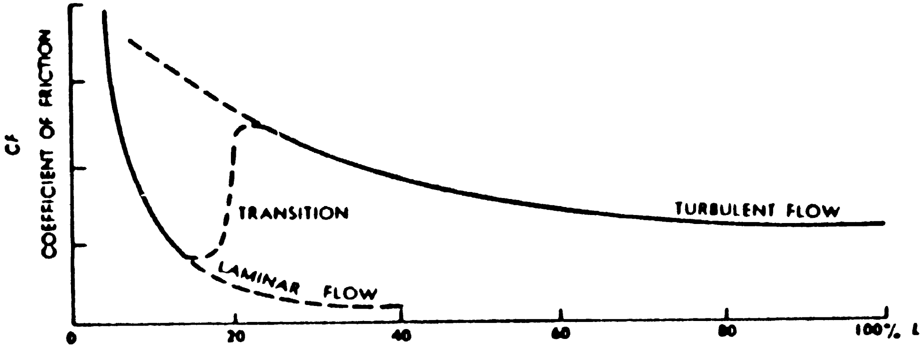
- THERE HAVE BEEN A NUMBER OF FORMULAS DEVELOPED FOR FRICTION RESISTANCE COEFFICIENTS, BUT THE FORMULA MOST COMMONLY USED TODAY IS KNOWN AS "THE 1957 I.T.T.C. (INTERNATIONAL TOWING TANK CONFERENCE) MODEL-SHIP CORRELATION LINE FORMULATION"

$$C_f = \frac{0.075}{(\log_{10} Rn - 2)^2}$$

FORCES OPPOSED TO PROPULSION

IMPORTANT FIGURE FROM TEXT (FIG 5.12)





BASIC NAVAL ARCHITECTURE

Unit Number: 21

Title: Forces opposed to propulsion - 2

Tape Running Time: $35^{M}\ 0^{S}$

Reading Assignment: MSD, pp 102-114

Additional References: PNA, pp 288-312 (repeated), 312-320

Scope:

The treatment of components of ship resistance continues. Correlation allowance, friction coefficients, residuary resistance, form drag are discussed. The action of a bulbous bow is discussed.

Key Points to Emphasize:

1. Residuary resistance includes other effects beside wave making resistance.

2. Emphasize definitions of resistance coefficients.

3. See PNA, pp 313, for explanation of form drag.

4. Emphasize Fig. 5-15, MSD, pp 112, Fig. 7-12, MSD, pp 135, Fig. 7-4, MSD, pp 140, Fig. 10, PNA, pp 303. Discuss choice of hull form as a function of speed-length ratio.

5. Emphasize that action of a bulbous bow is much more complex than just cancellation of surfe hull-generated waves.

Suggested Problem Assignment: Select from previously unassigned problems.

FORCES OPPOSED TO PROPULSION

RECAP

- GEOMETRICALLY SIMILAR MODELS AND SHIPS GENERATE GEOMETRICALLY SIMILAR WAVE PATTERNS WHEN OPERATING AT THE SAME FROUDE NUMBER (OR AT THE SAME SPEED-LENGTH RATIO)
- $$Fn = \frac{V}{\sqrt{gL}} \quad ; \quad \text{SPEED-LENGTH RATIO} = \frac{V_k}{\sqrt{L}}$$
- RESIDUARY RESISTANCE, $R_r = R_t - R_f$
- RESIDUARY RESISTANCE CONSISTS OF WAVE-MAKING RESISTANCE, EDDY-MAKING RESISTANCE, AND CERTAIN FORM EFFECTS

FORCES OPPOSED TO PROPULSION

CORRELATION ALLOWANCE

IN THE DAYS OF RIVETED SHIPS AN ADDITIONAL ALLOWANCE WAS APPLIED TO C_{f_s} TO ALLOW FOR THE DIFFERENCE IN SURFACE ROUGHNESS BETWEEN THE MODEL AND THE SHIP DUE TO RIVET HEADS, LAPS AND OTHER SURFACE IRREGULARITIES.

FORCES OPPOSED TO PROPULSION

CORRELATION ALLOWANCE

TODAY, WITH ALL-WELDED SHIPS THESE IRREGULARITIES ARE MUCH LESS IN EXTENT, BUT STILL IT HAS BEEN FOUND NECESSARY TO APPLY AN ALLOWANCE TO OBTAIN GOOD CORRELATION BETWEEN MODEL PREDICTIONS AND SHIP TRIAL RESULTS.

FORCES OPPOSED TO PROPULSION

CORRELATION ALLOWANCE

THE STANDARD CORRELATION ALLOWANCE IS

$$C_A = .400x10^{-3}$$

BUT THIS MAY VARY FROM

$$C_A = -.500x10^{-3} \text{ (FULL FORM TANKERS)}$$

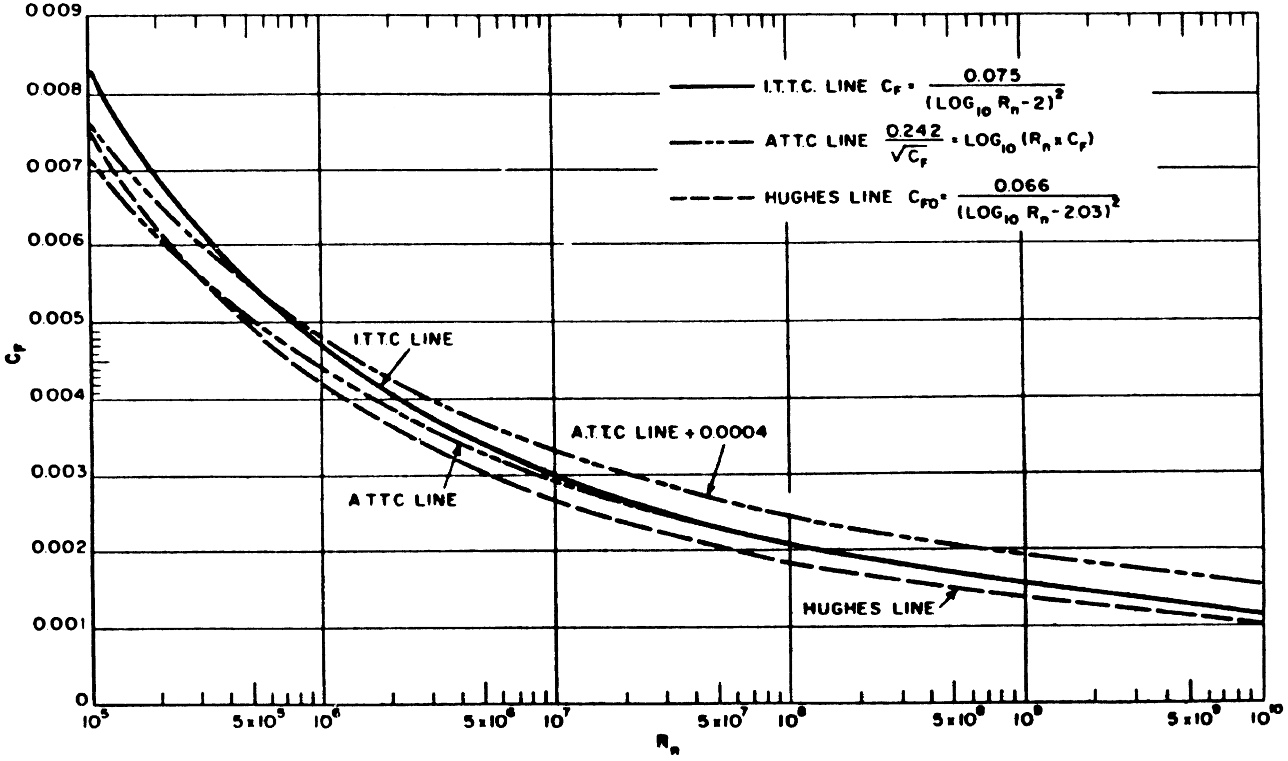
TO

$$C_A = +.500x10^{-3} \text{ (FINE FORM DESTROYERS)}$$

DEPENDING ON INDIVIDUAL SHIP MODEL TANK EXPERIENCE.

FORCES OPPOSED TO PROPULSION

MORE ABOUT FRICTION LINES



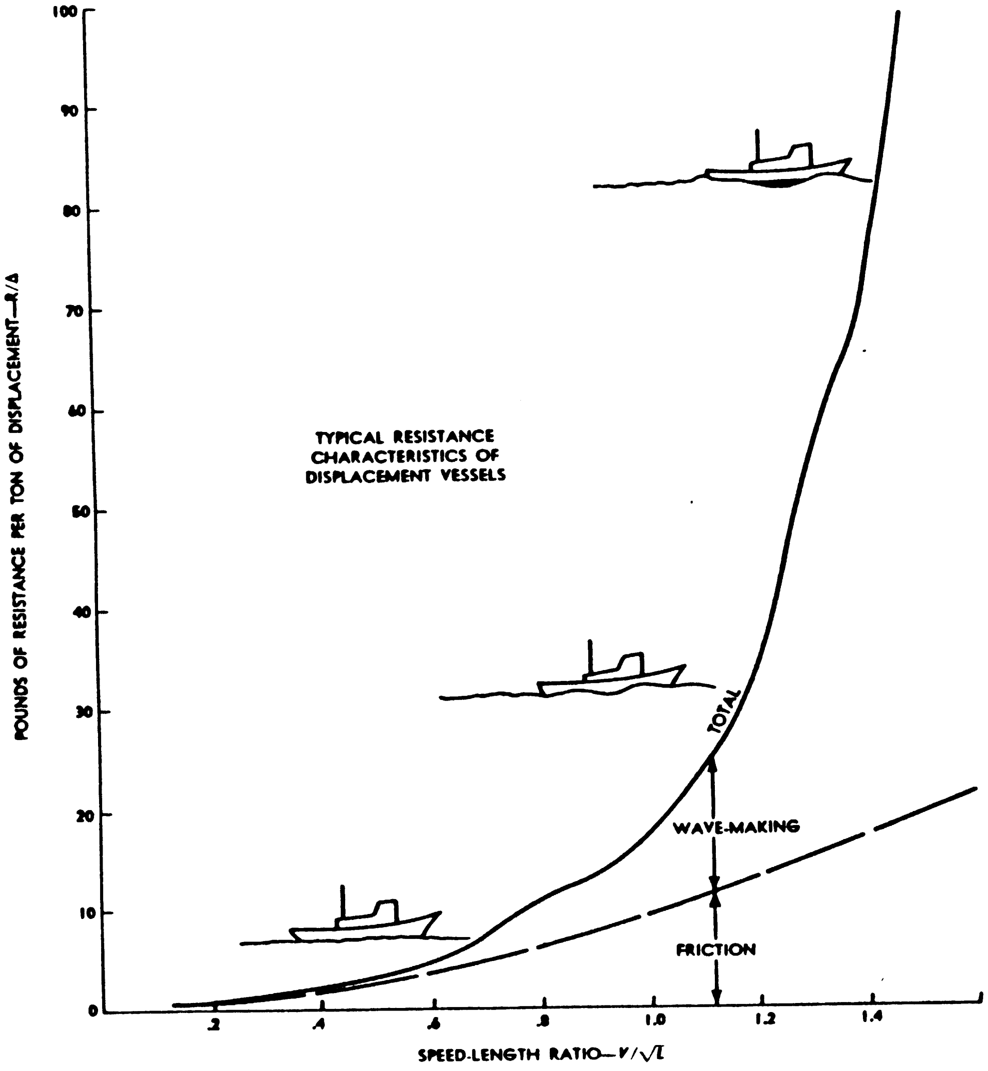
FORCES OPPOSED TO PROPULSION

FRICTION LINES - MESSAGES

- THE COEFFICIENT OF FRICTION FOR SHIPS IS MUCH LOWER THAN ON MODELS.
- THUS, THE PERCENTAGE OF TOTAL RESISTANCE DUE TO FRICTION IS LESS ON SHIPS THAN ON MODELS.
- THE BOUNDARY LAYER IS MUCH THICKER, PROPORTIONATELY, ON MODELS THAN ON SHIPS.
- THE FRICTION LINES ARE FOR FULLY TURBULENT FLOW. ERRORS ARE INTRODUCED IF PATCHES OF LAMINAR FLOW ARE PRESENT ON THE MODEL. SMALLER MODELS MAY REQUIRE THE USE OF TURBULENCE STIMULATORS TO AVOID LAMINAR FLOW.

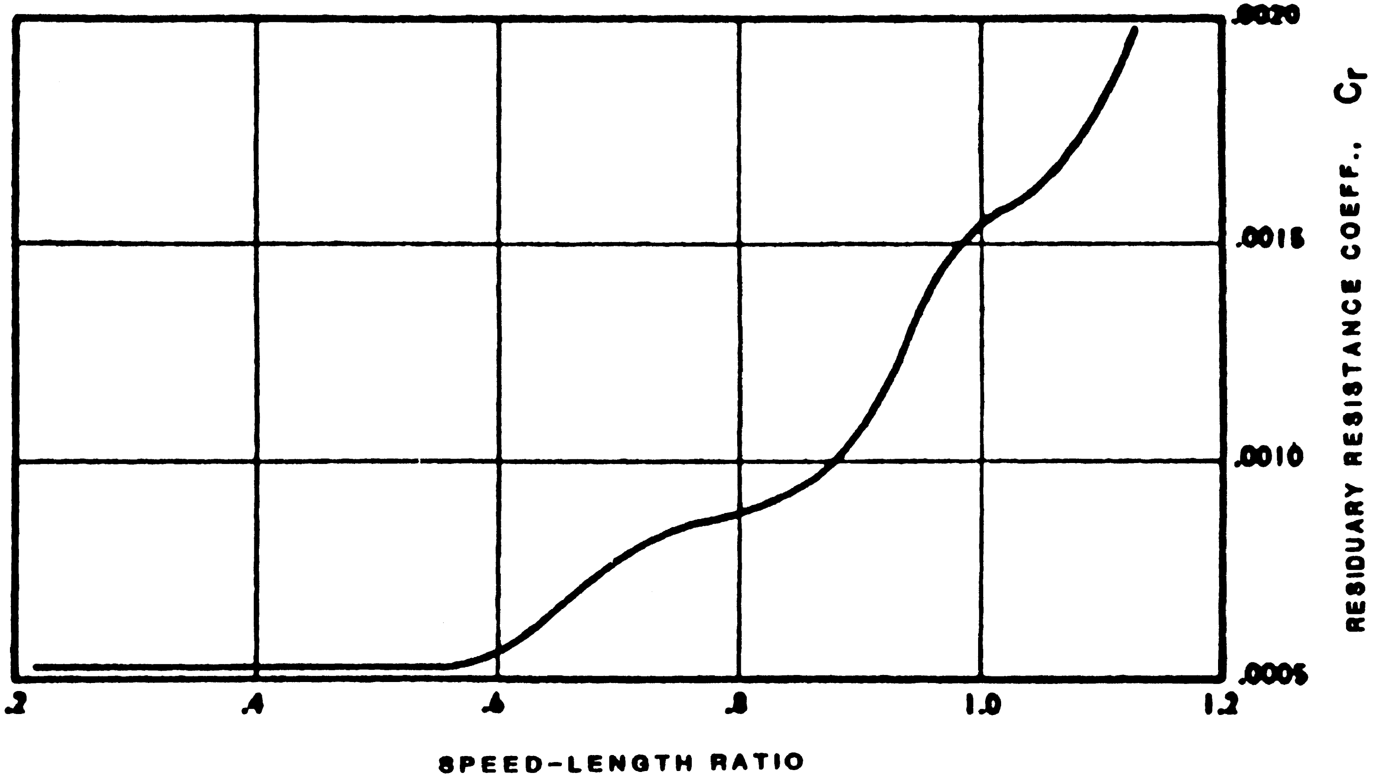
FORCES OPPOSED TO PROPULSION

RESIDUARY AND FRICTIONAL RESISTANCE



FORCES OPPOSED TO PROPULSION

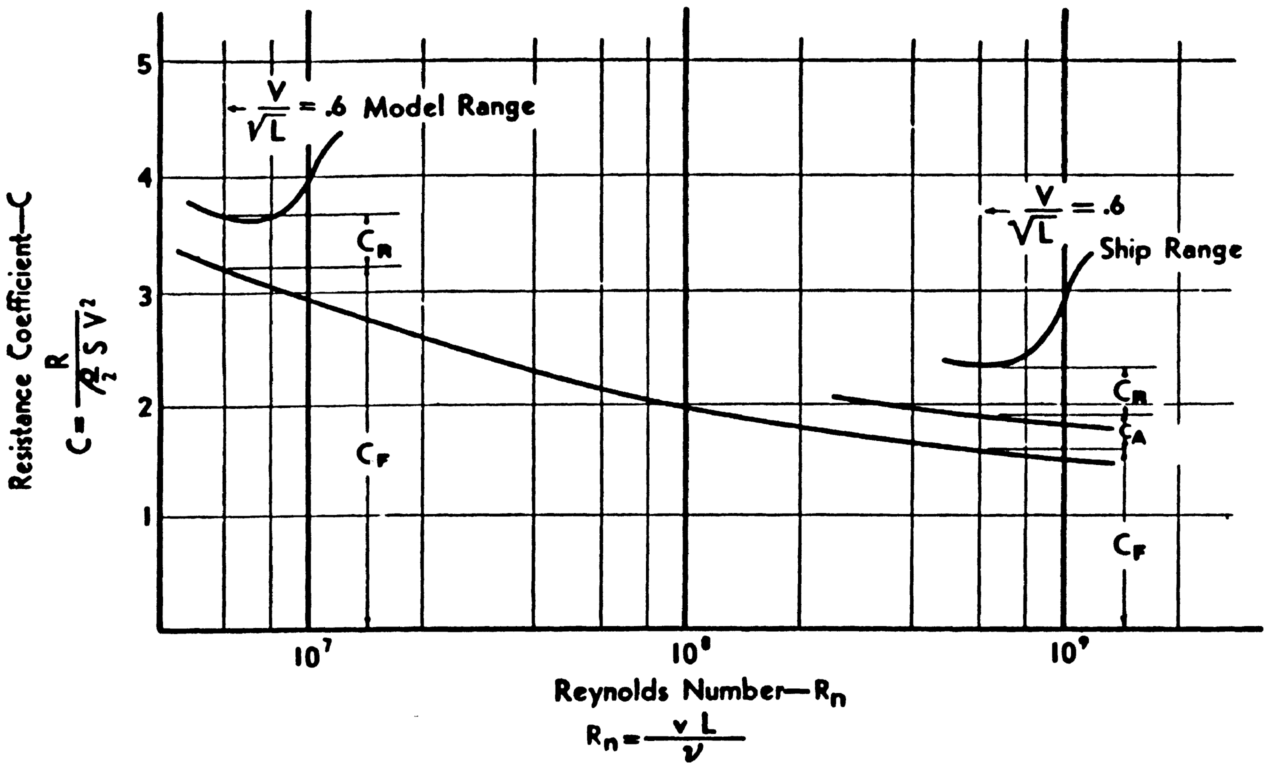
MORE ABOUT RESIDUARY RESISTANCE



NOTE THAT C_r IS A CONSTANT AT LOW SPEED-LENGTH RATIOS.

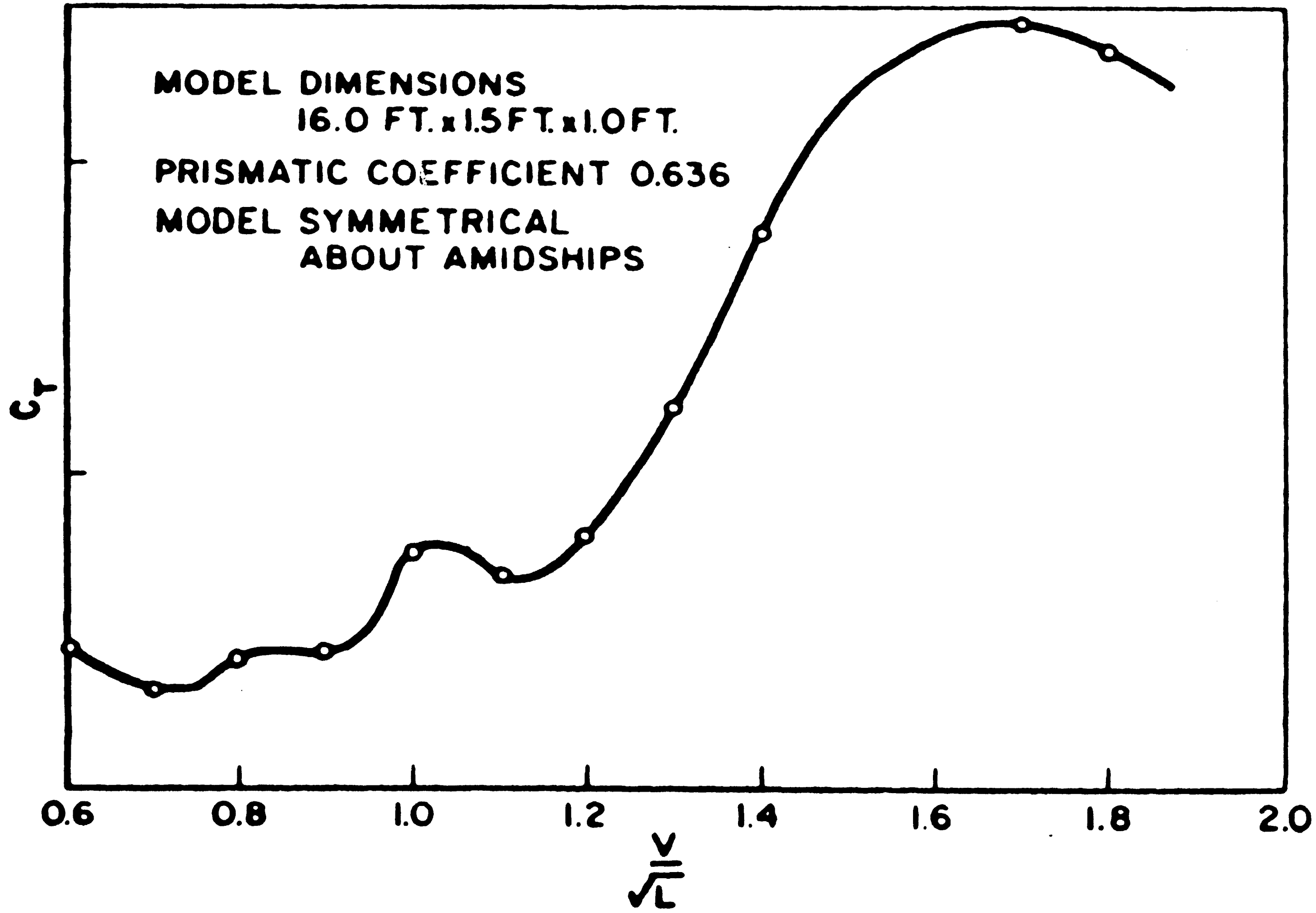
FORCES OPPOSED TO PROPULSION

MORE ABOUT RESIDUARY RESISTANCE



FORCES OPPOSED TO PROPULSION

IMPORTANT CHART! - C_T VS $V/\sqrt{L}$ DIAGRAM



FORCES OPPOSED TO PROPULSION

RESIDUARY RESISTANCE - MESSAGES

- THERE ARE HUMPS AND HOLLOWS IN THE C_r AND C_t CURVES.

- HOLLOWS OCCUR APPROXIMATELY WHEN A TRANSVERSE WAVE CREST IS AT THE STERN. HUMPS OCCUR APPROXIMATELY WHEN A TRANSVERSE WAVE TROUGH IS AT THE STERN.

- THE MOST SIGNIFICANT HOLLOWS OCCUR AT SPEED-LENGTH RATIOS OF .95-1.05 (WAVE LENGTH ≈ Lpp/2) AND AT 1.15-1.30 (WAVE LENGTH ≈ Lpp). THIS LAST HOLLOW IS CALLED "HULL SPEED".

FORCES OPPOSED TO PROPULSION

FORM DRAG

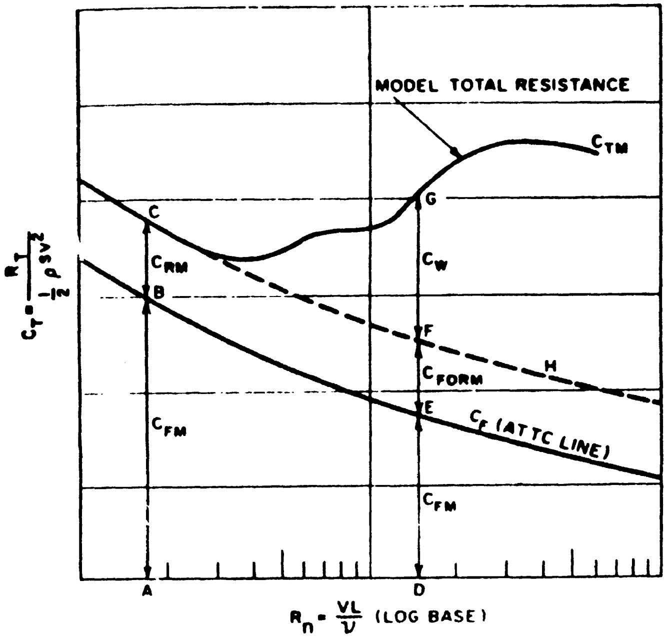
AT LOW SPEEDS WAVE MAKING RESISTANCE BECOMES VERY SMALL. FORM DRAG IS THE DIFFERENCE BETWEEN C_r AND C_f AT THESE LOW SPEEDS. FORM DRAG IS COMPRISED OF

- EDDY MAKING RESISTANCE
- FORM EFFECTS ON FRICTIONAL RESISTANCE. THE SHIP FORM IS NOT A FLAT PLATE

C_{FORM} IS ASSUMED TO BE CONSTANT OVER THE SPEED RANGE.

FORCES OPPOSED TO PROPULSION

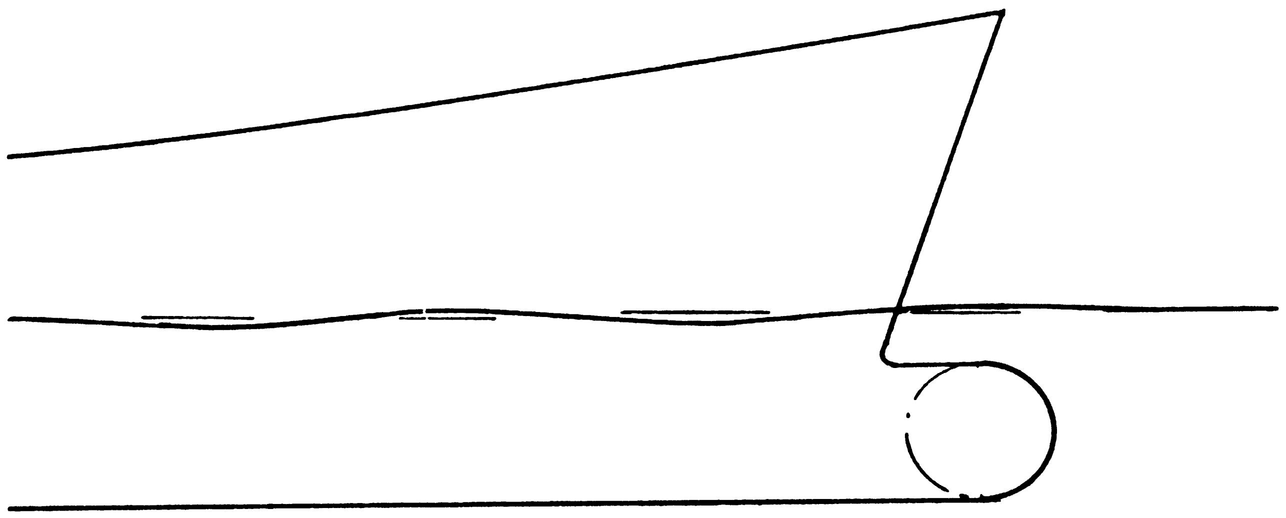
FORM DRAG



FORCES OPPOSED TO PROPULSION

BULBOUS BOWS

NOW PUT THE TWO TOGETHER



THE OBJECT IS TO CREATE WAVE CANCELATION, BUT THERE ARE ALSO OTHER MORE COMPLEX HYDRODYNAMIC INTERACTIONS WHICH ARE BENEFICIAL.

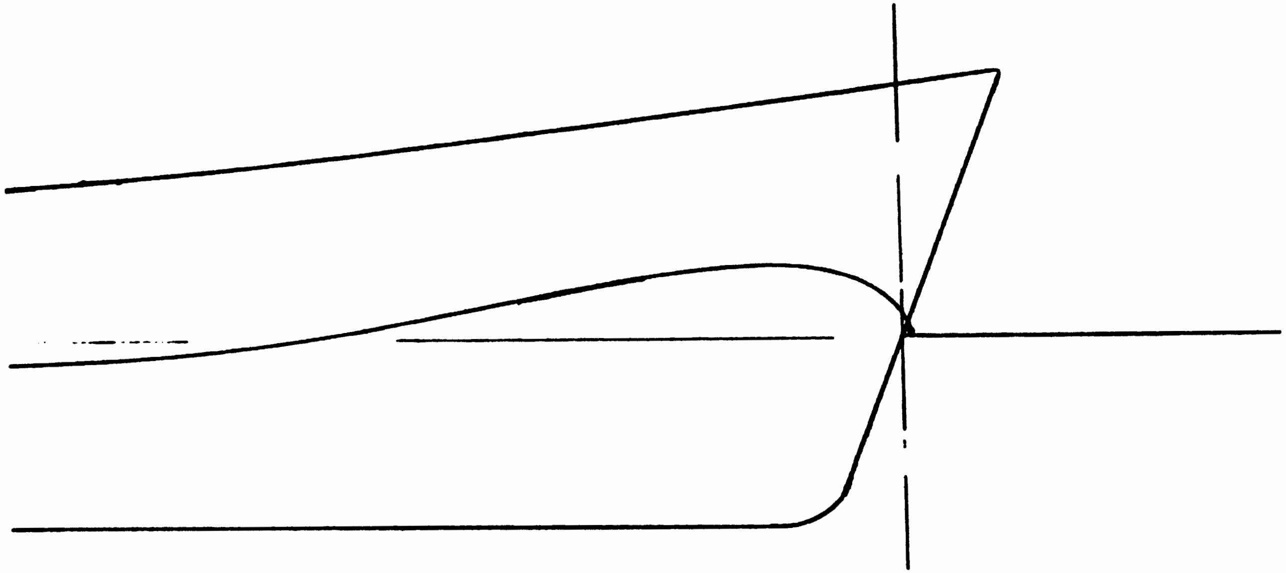
BUT IF THE BULB EMERGES FROM THE WATER AND SLAMS ON REENTRY - LOOK OUT!!!

21.15

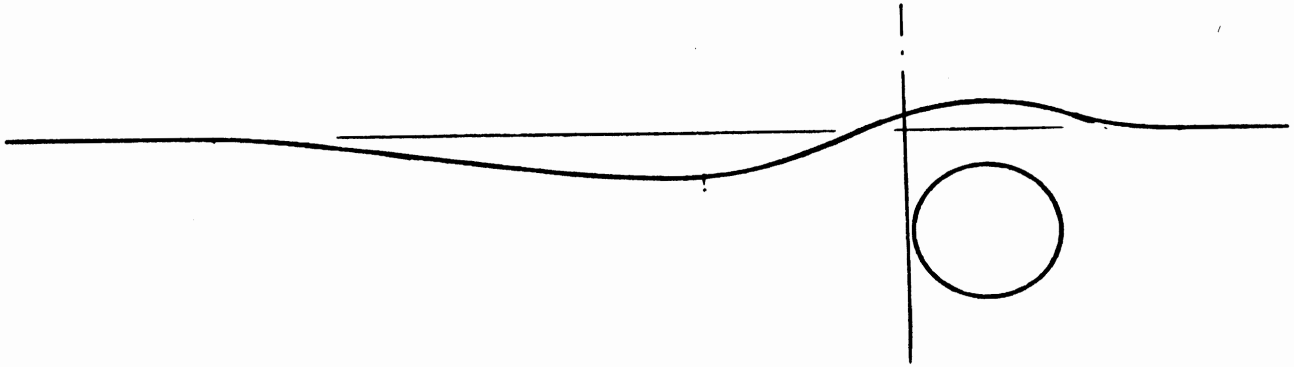
FORCES OPPOSED TO PROPULSION

BULBOUS BOWS

CONSIDER FIRST THE BOW WAVE OF A SHIP <u>WITHOUT</u> A BULBOUS BOW.



NOW CONSIDER THE WAVE CREATED BY A SUBMERGED SPHERE MOVING AT THE SAME SPEED.



BASIC NAVAL ARCHITECTURE

Unit Number: 22

Title: Forces opposed to propulsion - 3
Propulsive forces and propulsion systems - 1

Tape Running Time: $35^M\ 49^S$

Reading Assignment: MSD, pp 102-114 (repeated), 115-116

Additional References: PNA, pp 320-329, 370-382

Scope:

Special topics in resistance are discussed: resistance of deeply submerged submarines; appendage resistance; resistance in shallow water; added resistance in a seaway; hull roughness. Types of propulsors are listed. Powering and efficiency definitions are presented. Basic concepts of the propeller blade as a lifting surface are described.

Key Points to Emphasize:

1. Discuss the wave-making resistance of deeply-submerged submarines to emphasize the fact that wave-making is a phenomena that occurs at the interface of two fluids.

2. Discuss appendage resistance and shallow water resistance briefly. Discuss the cause and magnitude of added resistance in a seaway.

3. Emphasize the role of hull roughness in added power requirements and the influence of hull cleaning (in a shipyard) both drydocked and in situ, in reducing this power loss in service.

4. Emphasize the lift-drag concept of propeller blade action. Emphasize the fact that the propeller blade is a hydrofoil as is the rudder, and the hydrofoils of a hydrofoil craft. Emphasize the similarity between hydrofoils and airfoils. Fig. 84, PNA, pp 378 and Fig. 86, PNA, pp 379 are particularly important.

Suggested Problem Assignment: Select from previously unassigned problems.

FORCES OPPOSED TO PROPULSION

RESISTANCE OF SUBMARINES

- SURFACED SUBMARINES HAVE HORRIBLE RESISTANCE CHARACTERISTICS, BUT -
- DEEPLY SUBMERGED SUBMARINES (SAY 4 OR 5 DIAMETERS) HAVE NO SURFACE WAVE MAKING RESISTANCE.
- THEY DO HAVE -
  - FRICTIONAL RESISTANCE
  - FORM DRAG.
- FOR THIS REASON SUBMERGED SUBMARINES ARE IDEAL HIGH SPEED VEHICLES.

FORCES OPPOSED TO PROPULSION

APPENDAGE RESISTANCE

- APPENDAGES SUCH AS SHAFTS, STRUTS, BOSSINGS, BILGE KEELS ARE SMALL FEATURES ON A MODEL AND ARE SENSITIVE TO SCALE EFFECTS.
- TANKS WHICH USE SMALLER MODELS, SAY 5 TO 12 FEET LONG OFTEN TEST BARE HULL ONLY THEN ADD AN ESTIMATED PERCENTAGE TO ALLOW FOR APPENDAGES.
- TANKS WHICH USE LARGE MODELS, SAY 20 TO 30 FEET LONG TEST WITH APPENDAGES AND EXPAND THE RESULTS WITHOUT CORRECTION.
- FOR SINGLE SCREW SHIPS APPENDAGE RESISTANCE MAY BE 1 TO 3% OF BARE HULL. TWIN SCREW COULD BE 5 10%.

FORCES OPPOSED TO PROPULSION

RESISTANCE IN SHALLOW WATER

AS THE SHIP MOVES INTO SHALLOW WATER THE FLOW AROUND THE SHIP IS RESTRICTED, BOW WAVES BEGIN TO SPREAD OUT AT LARGER ANGLES AND THE WAVE MAKING RESISTANCE OF THE SHIP INCREASES. THE MAXIMUM INCREASE OCCURS WHEN

$$\frac{V}{\sqrt{gh}} = 1.0 \qquad h = \text{WATER DEPTH}$$

AT THIS SPEED THE BOW WAVE EXTENDS AT RIGHT ANGLES TO THE SHIP.

FORCES OPPOSED TO PROPULSION

ADDED RESISTANCE IN A SEAWAY

- ADDED RESISTANCE IN A SEAWAY IS A COMPLEX HYDRODYNAMIC PROBLEM WHICH DEPENDS, AMONG OTHER THINGS, ON SHIP MOTIONS, AND PARTICULARLY ON THE PHASE RELATIONSHIP BETWEEN PITCH AND HEAVE MOTIONS.

- ADDED RESISTANCE IN WAVES COMPUTER PROGRAMS HAVE NOW BEEN DEVELOPED AS PART OF SHIP MOTION COMPUTER PROGRAMS WHICH GIVE REASONABLE AGREEMENT WITH MODEL TESTS IN REGULAR WAVES.

- ADDED RESISTANCE IN SEVERE SEAWAYS MAY BE 15 TO 20 PERCENT OF CALM WATER RESISTANCE.

FORCES OPPOSED TO PROPULSION

HULL ROUGHNESS IN SERVICE

- HULL ROUGHNESS IN SERVICE INCREASES THE FRICTIONAL RESISTANCE OF THE SHIP WHICH MEANS THAT EITHER
  - THE SHIP MUST USE GREATER POWER AND MORE FUEL TO MAKE THE SAME SPEED, OR
  - IF THE SHIP TYPICALLY OPERATES AT MAXIMUM POWER THEN THERE WILL BE A REDUCTION IN SPEED.
- THE FREQUENCY WITH WHICH THE BOTTOM IS CLEANED HAS A REAL IMPACT ON SHIP ECONOMICS.

FORCES OPPOSED TO PROPULSION

HULL ROUGHNESS IN SERVICE

- FOULING BY MARINE GROWTH OCCURS -
  - PRIMARILY IN PORT - NOT MUCH WHEN UNDERWAY.
  - MUCH MORE RAPIDLY IN TROPICAL PORTS THAN IN COLDER WATER PORTS.
- FOULING MAY BE REMOVED BY
  - DRYDOCKING, SANDBLASTING AND RECOATING- NEARLY 100% EFFECTIVE (EXPENSIVE + LOST TIME).
  - IN SITU CLEANING SYSTEMS (HIGH PRESSURE WATER JET SYSTEMS, MOVING BRUSH SYSTEMS)- EFFECTIVE, BUT NOT 100%; CAUSES SOME DETERIORATION OF COATING (LESS EXPENSIVE - LESS LOST TIME - EXTENDS PERIOD BETWEEN DRYDOCKING).

FORCES OPPOSED TO PROPULSION

HULL ROUGHNESS IN SERVICE

- FOR SHIPS OPERATING ON A TWO-YEAR DRYDOCKING INTERVAL, ECONOMIC STUDIES SHOW THAT HULL ROUGHNESS POWER LOSSES CAN AMOUNT TO 10% - 15% OF SHAFT HORSEPOWER.

- IN SITU CLEANING AFTER ROUGHLY A YEAR AND A HALF CAN REDUCE THESE PERCENTAGES BY 1% TO 3%.

PROPULSIVE FORCES AND PROPULSION SYSTEMS

TYPES OF PROPULSORS

- SCREW PROPELLERS
  - FIXED PITCH
  - CONTROLLABLE PITCH
  - SHROUDED PROPELLERS
  - COUNTER-ROTATING PROPELLERS

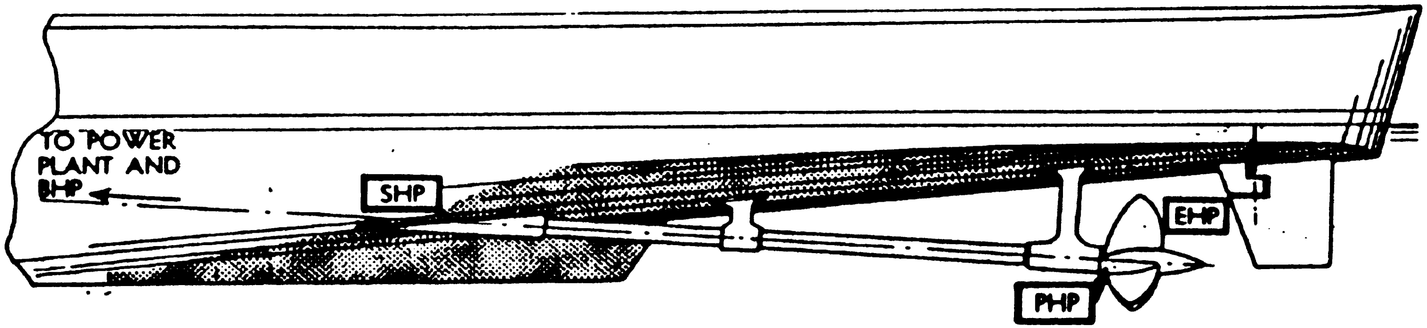
- PADDLE WHEELS

- WATER JET PROPULSORS
  - SUBMERGED
  - SURFACE

- VERTICAL AXIS PROPELLERS
  - VOITH-SCHNEIDER

PROPULSIVE FORCES AND PROPULSION SYSTEMS

POWERING DEFINITIONS



BHP - BRAKE HORSEPOWER

SHP - SHAFT HORSEPOWER

PHP - PROPELLER HORSEPOWER (ALSO KNOWN AS DHP, DELIVERED HORSEPOWER)

PROPULSIVE FORCES AND PROPULSION SYSTEMS

EFFICIENCIES

PROPULSIVE COEFFICIENT = $\eta_d = \frac{EHP}{SHP}$
(ALSO KNOWN AS "P.C.")

PROPULSIVE EFFICIENCY = $\eta_b = \frac{EHP}{PHP}$

TRANSMISSION EFFICIENCY = $\eta_s = \frac{PHP}{SHP}$

NOTE THAT $\eta_d = \eta_b \cdot \eta_s$

PROPULSIVE FORCES AND PROPULSION SYSTEMS

THE SCREW PROPELLER

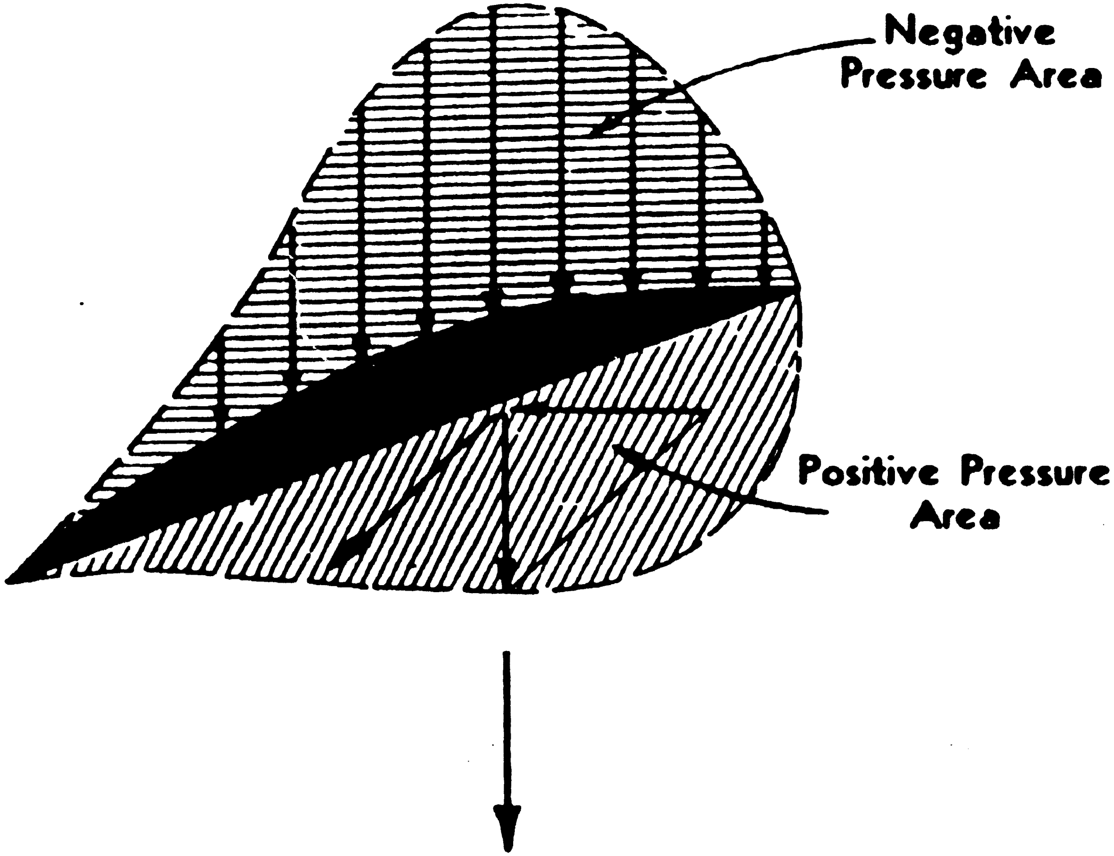
THE WING OF AN AIRPLANE AND THE BLADE OF A MARINE SCREW PROPELLER OPERATE ON THE SAME PRINCIPLE: ONE IS CALLED AN AIRFOIL - THE OTHER IS CALLED A HYDROFOIL.

THE BLADE SECTION OPERATES AT AN ANGLE OF ATTACK TO THE INCOMING FLOW.

FLUID TRAVELING OVER THE UPPER (FORWARD) SURFACE TRAVELS FASTER. FLUID TRAVELING OVER THE LOWER (AFT) SURFACE TRAVELS SLOWER. THE LOW PRESSURE CREATED ON THE UPPER SURFACE AND THE HIGHER PRESSURE ON THE LOWER SURFACE CREATE LIFT.

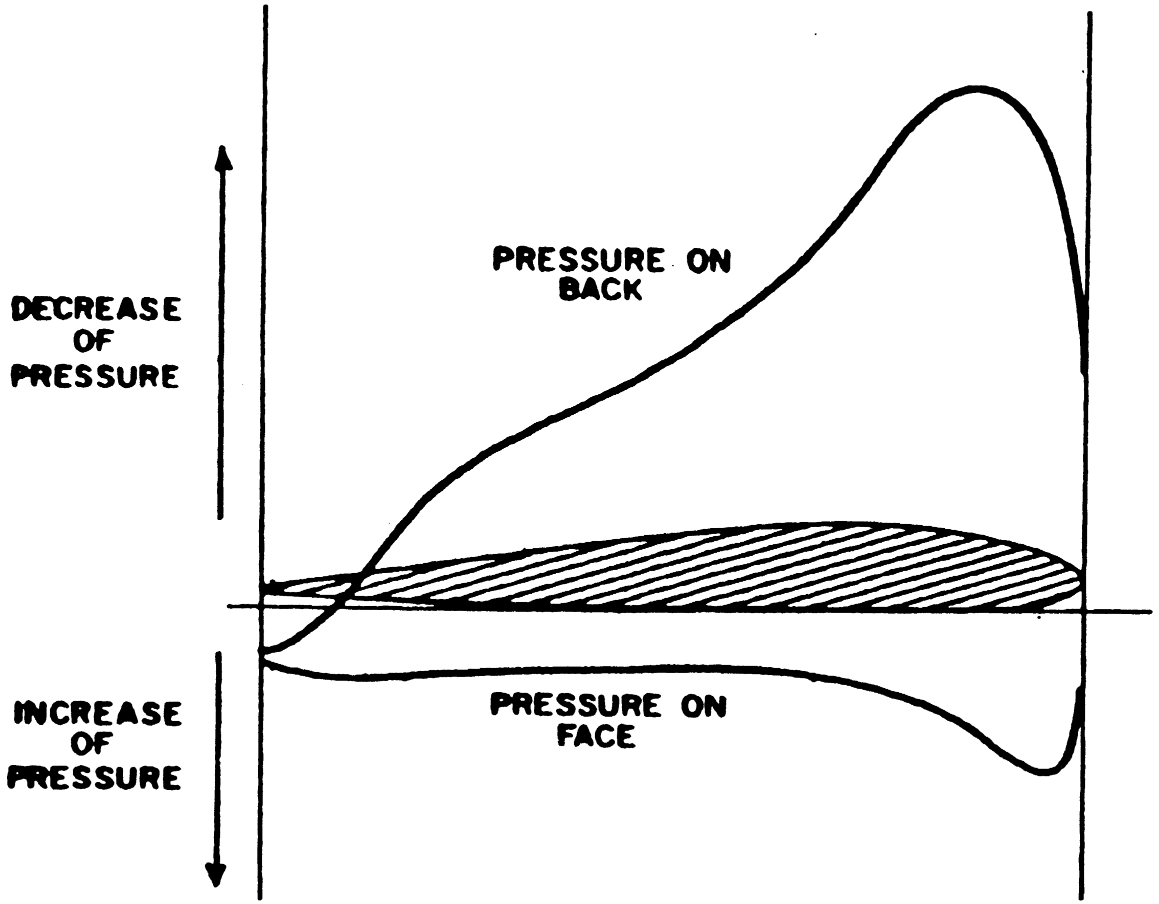
PROPULSIVE FORCES AND PROPULSION SYSTEMS

THE SCREW PROPELLER



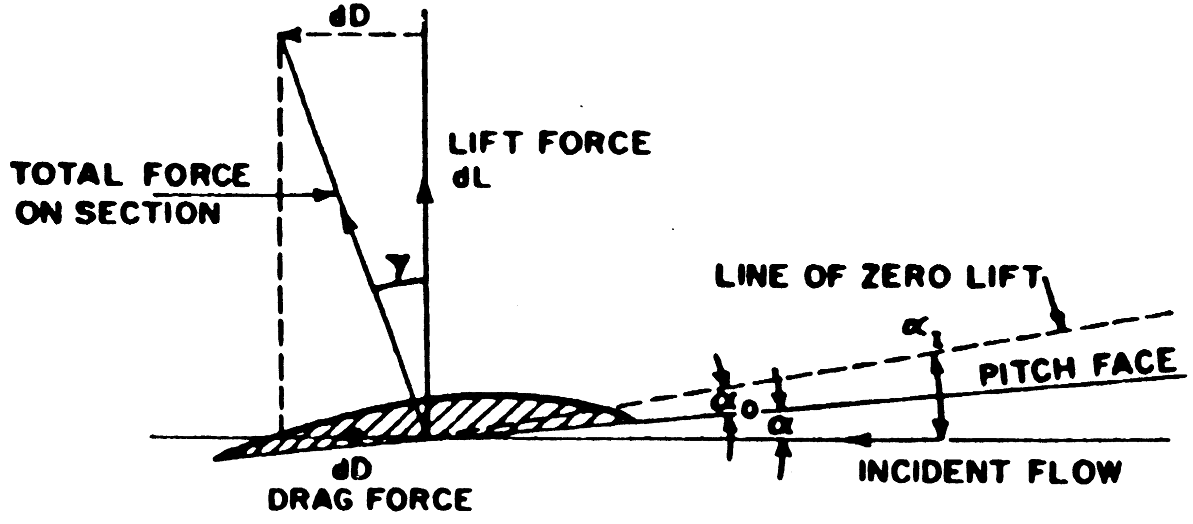
PROPULSIVE FORCES AND PROPULSION SYSTEMS

THE SCREW PROPELLER



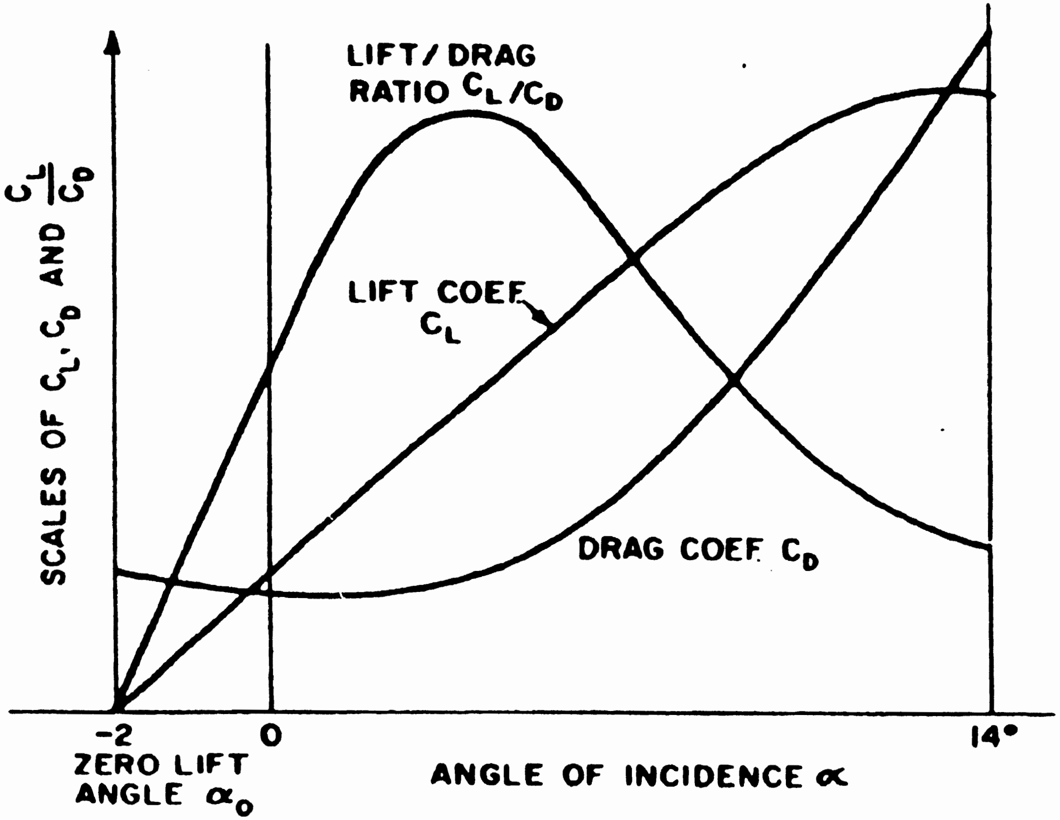
PROPULSIVE FORCES AND PROPULSION SYSTEMS

LIFT, DRAG AND ANGLE OF ATTACK



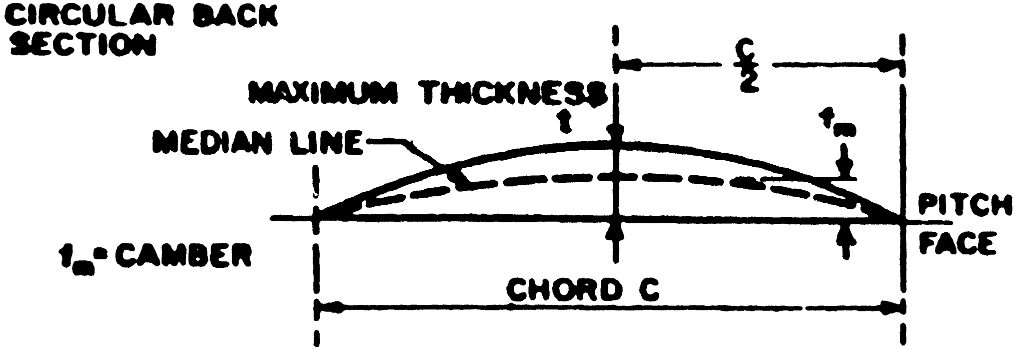
PROPULSIVE FORCES AND PROPULSION SYSTEMS

LIFT AND DRAG COEFFICIENTS

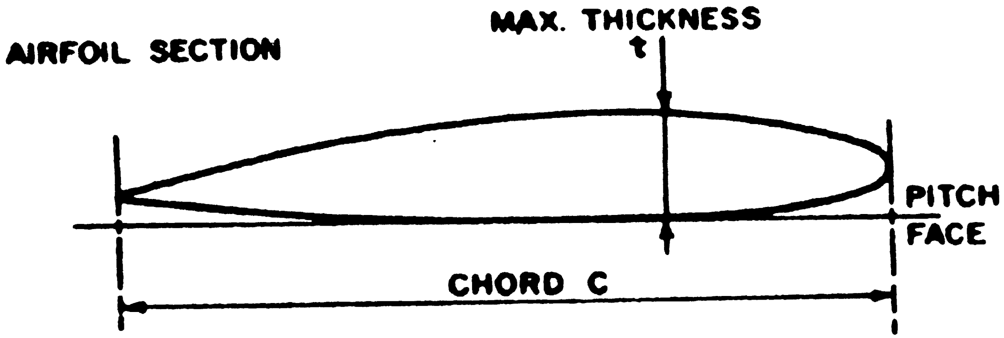


PROPULSIVE FORCES AND PROPULSION SYSTEMS

PROPELLER BLADE SECTIONS



PITCH FACE FLAT, EDGES SHARP



NOSE AND TAIL ROUNDED AND LIFTED FROM PITCH FACE. MAXIMUM THICKNESS NEARER NOSE THAN TAIL EXCEPT IN SPECIAL SECTIONS.

BASIC NAVAL ARCHITECTURE

Unit Number: 23

Title: Propulsive forces and propulsion systems - 1

Tape Running Time: 36^M 15^S

Reading Assignment: MSD, pp 116-124

Additional References: PNA, pp 373-376 (repeated), 397-399

Scope:

Momentum theory of propeller acting is introduced to give the student a physical feel for the generation of thrust by a screw propeller, but without mathematical treatment. Propeller geometry is introduced with emphasis on the blade as a lifting surface. Wake and slip are defined. Propeller design by theory and by design chart is introduced briefly. The arrangement of a propeller drawing is shown.

Key Points to Emphasize:

1. Introduce momentum theory and use to explain the generation of thrust by a screw propeller. Suggest that mathematical treatment not be stressed.

2. Use the basic ideas of hydrofoil lift and drag presented in Unit 22 to explain how a propeller blade section converts torque into thrust. See Fig. 6-2, MSD, pp 118 and Figs. 89, 90, 91, PNA, pp 380-381.

3. Explain how to recognize the direction of rotation of a propeller. Explain why a propeller blade appears to be twisted. See Fig. 87, PNA, pp 379.

4. Discuss wake and slip. Thrust deduction will be introduced in next unit.

5. Propeller design curves should be shown to illustrate that this is a method of propeller design, but without detailed explanation.

6. Propeller design drawing should be introduced simply so that the student will recognize one if he encounters it, but without any attempt to explain the projection that is involved.

7. Note serious errors in MSD, pp 122-123. Page 122, definition of K_T; delete "or T/V_a^2 ". Page 123, "Advance coefficient" should be $J = \frac{V}{nD}$. Delete "Propeller loading" coefficient entirely. (If anything it should be K_T/J^{2}_{9}, but it is misleading.) "Basic variable" should be $B_P = \frac{n(PHP)^{.5}}{V_a^{2.5}}$; δ is the Taylor advance coefficient, $\delta = \frac{nD}{V_a}$. See PNA, pp 386 bottom (note that V_A is in fps here) and pp 412 bottom (in this case V_A is in knots). Either distribute a correction insert or have students make pen and ink corrections. Also note that Gillmer uses the older term, PHP, propeller horsepower. Curent usage, as in PNA, is DHP, delivered horsepower.

Suggested Problem Assignment: 51

PROPULSIVE FORCES AND PROPULSION SYSTEMS

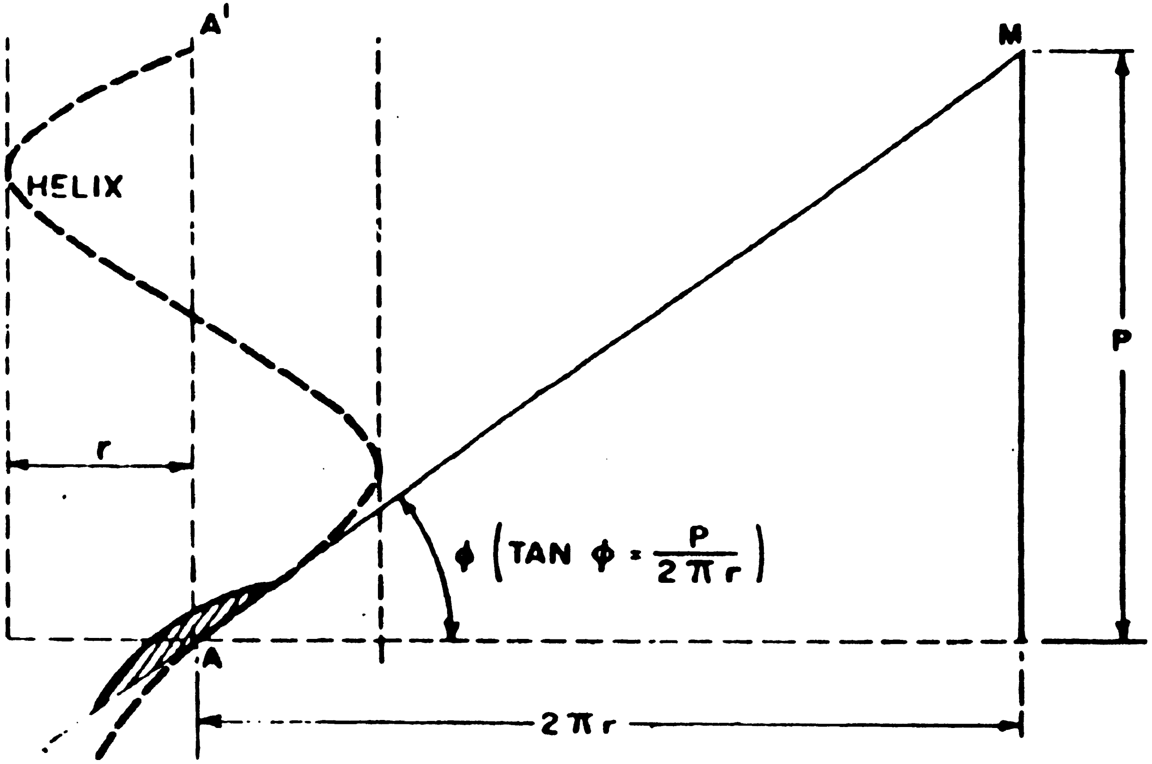
MOMENTUM THEORY

THE PROPELLER MAY ALSO BE THOUGHT OF A DEVICE WHICH GENERATES THRUST BY ACCELERATING THE WATER WHICH PASSES THROUGH IT AND INCREASING THE WATER VELOCITY IN THE PROPELLER RACE.

THIS ALSO MEANS THAT THE PROPELLER RACE MUST CONTRACT.

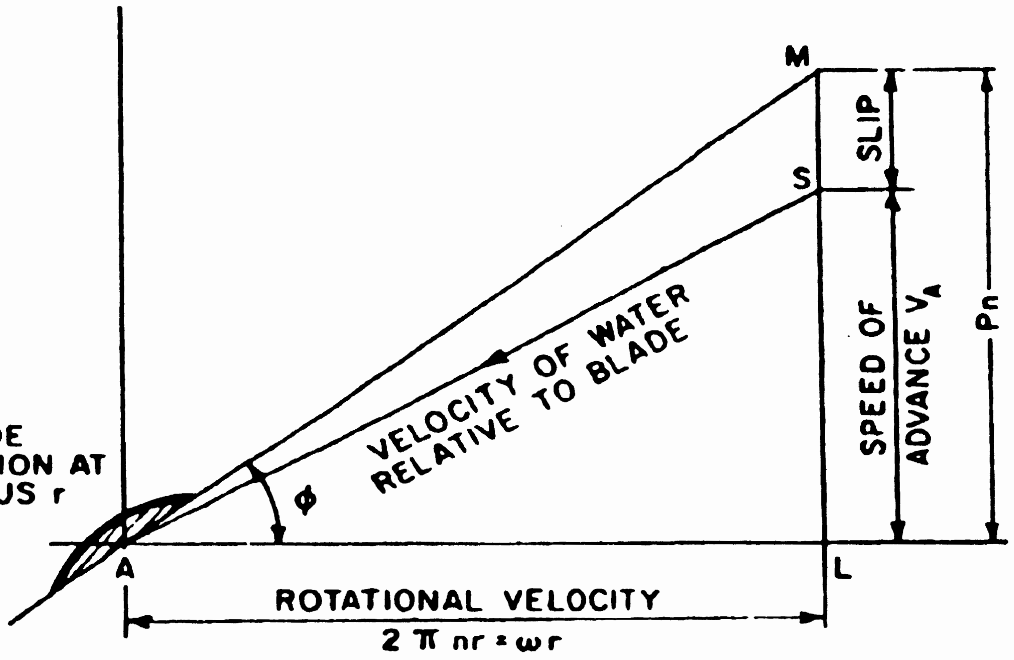
PROPULSIVE FORCES AND PROPULSION SYSTEMS

PITCH AND PITCH ANGLE



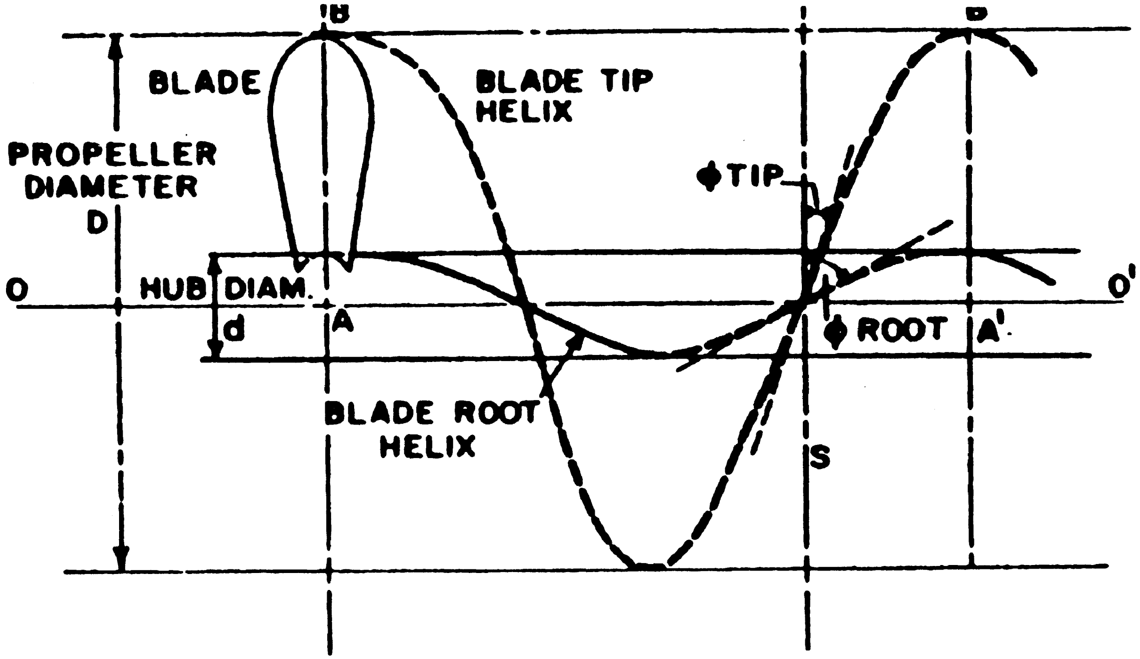
PROPULSIVE FORCES AND PROPULSION SYSTEMS

VELOCITY OF WATER RELATIVE TO BLADE



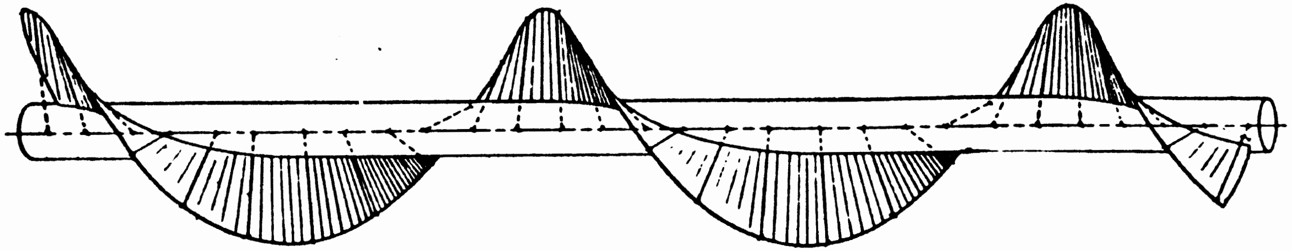
PROPULSIVE FORCES AND PROPULSION SYSTEMS

THE HELIX



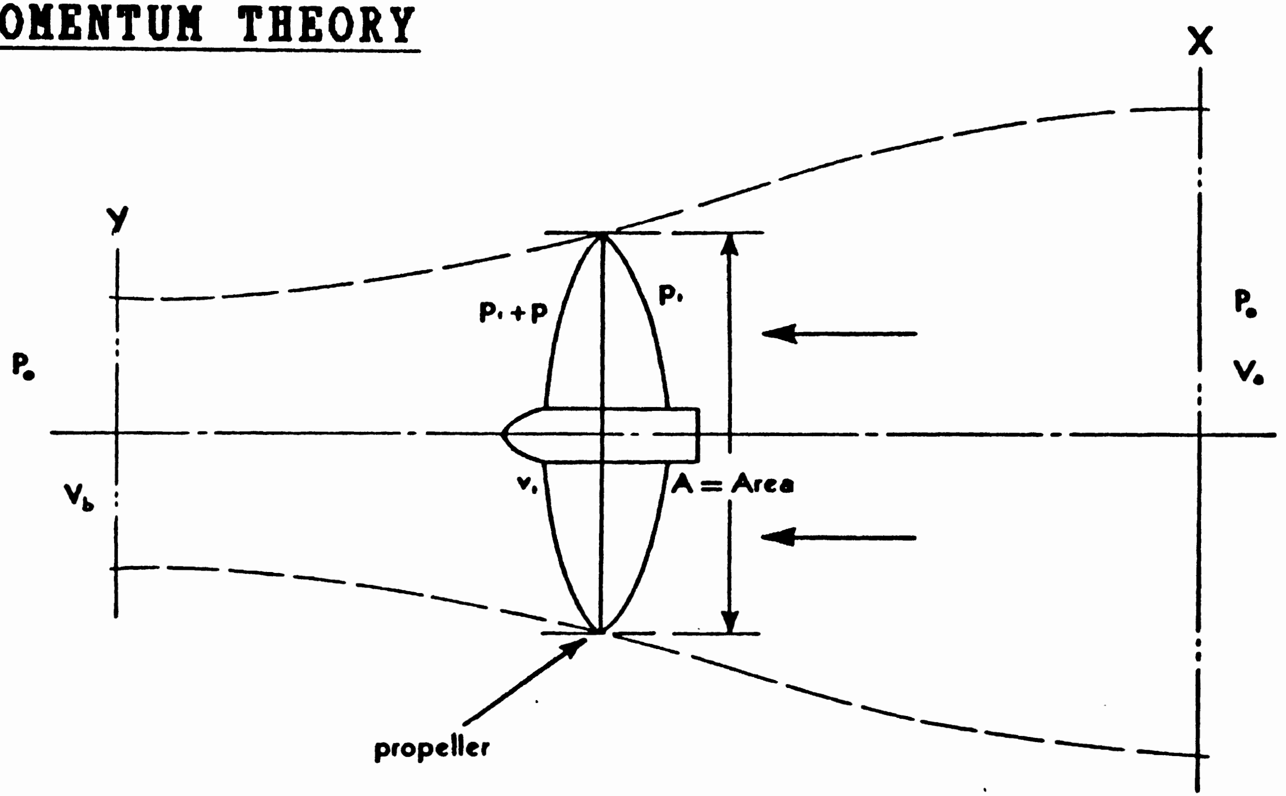
PROPULSIVE FORCES AND PROPULSION SYSTEMS

THE HELIX



PROPULSIVE FORCES AND PROPULSION SYSTEMS

MOMENTUM THEORY



$$\text{THRUST, } T = \rho \cdot A \cdot V_1 \cdot (V_b - V_a)$$

PROPULSION FORCES AND PROPULSION SYSTEM

WAKE

THE SHIP IS DRAGGING A BODY OF WATER ALONG WITH IT IN THE BOUNDARY LAYER.

THUS, THE WATER FLOWING INTO THE PROPELLER ALREADY HAS SOME FORWARD VELOCITY BECAUSE OF FRICTIONAL WAKE. THERE ARE ALSO CONTRIBUTIONS FROM STREAMLINE FLOW AND FROM SHIP WAVES.

THE VELOCITY OF THE WATER COMING INTO THE PROPELLER IS KNOWN AS WAKE VELOCITY.

PROPULSIVE FORCES AND PROPULSION SYSTEMS

SLIP

TRUE SLIP RATIO $= S_r = \dfrac{P \cdot n - V_a}{P \cdot n}$

BUT V_a IS OFTEN KNOWN ONLY TO THE MODEL TESTERS AND PROPELLER DESIGNERS.

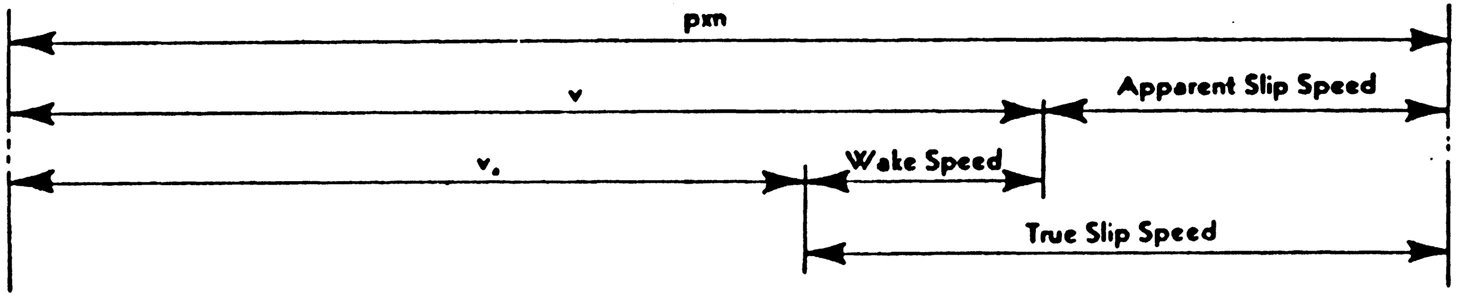
APPARENT SLIP RATIO IS MORE CONVENIENT TO USE:

$$S_a = \frac{P \cdot n - V}{P \cdot n}$$

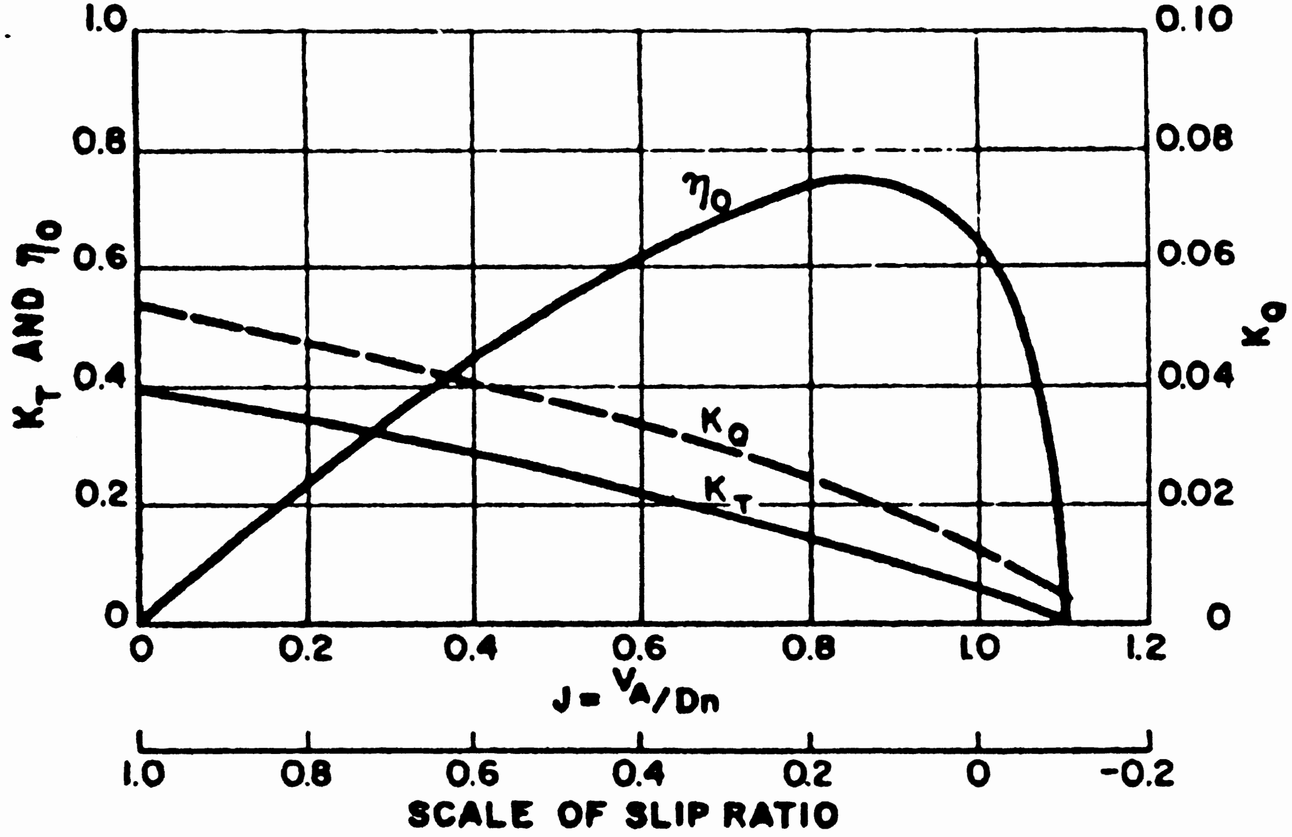
P = PROPELLER PITCH.
n = PROPELLER REVS/SEC.
V = SHIP SPEED, FT/SEC.
V_a = SPEED OF ADVANCE OF PROPELLER INTO WATER.

PROPULSIVE FORCES AND PROPULSION SYSTEMS

TRUE AND APPARENT SLIP



OPEN WATER PROPELLER CURVES



No. of blades = 4
Face pitch ratio = 1.00

PROPULSIVE FORCES AND PROPULSION SYSTEMS

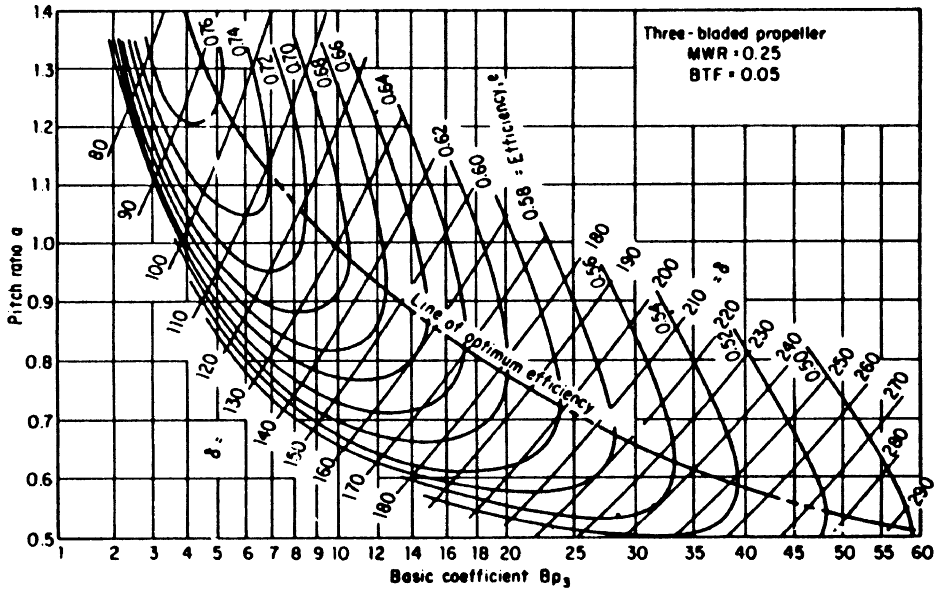
PROPELLER DESIGN

NAVAL COMBATANT SHIP PROPELLERS ARE PERFORMANCE AND CAVITATION-SENSITIVE. ALL NEW PROPELLERS ARE DESIGNED BY SOPHISTICATED COMPUTER PROGRAMS.

MERCHANT SHIP PROPELLER DESIGN IS NOW BEGINNING TO FOLLOW THIS SAME ROUTE, BUT MANY MERCHANT SHIP PROPELLERS ARE STILL DESIGNED USING DESIGN CHARTS.

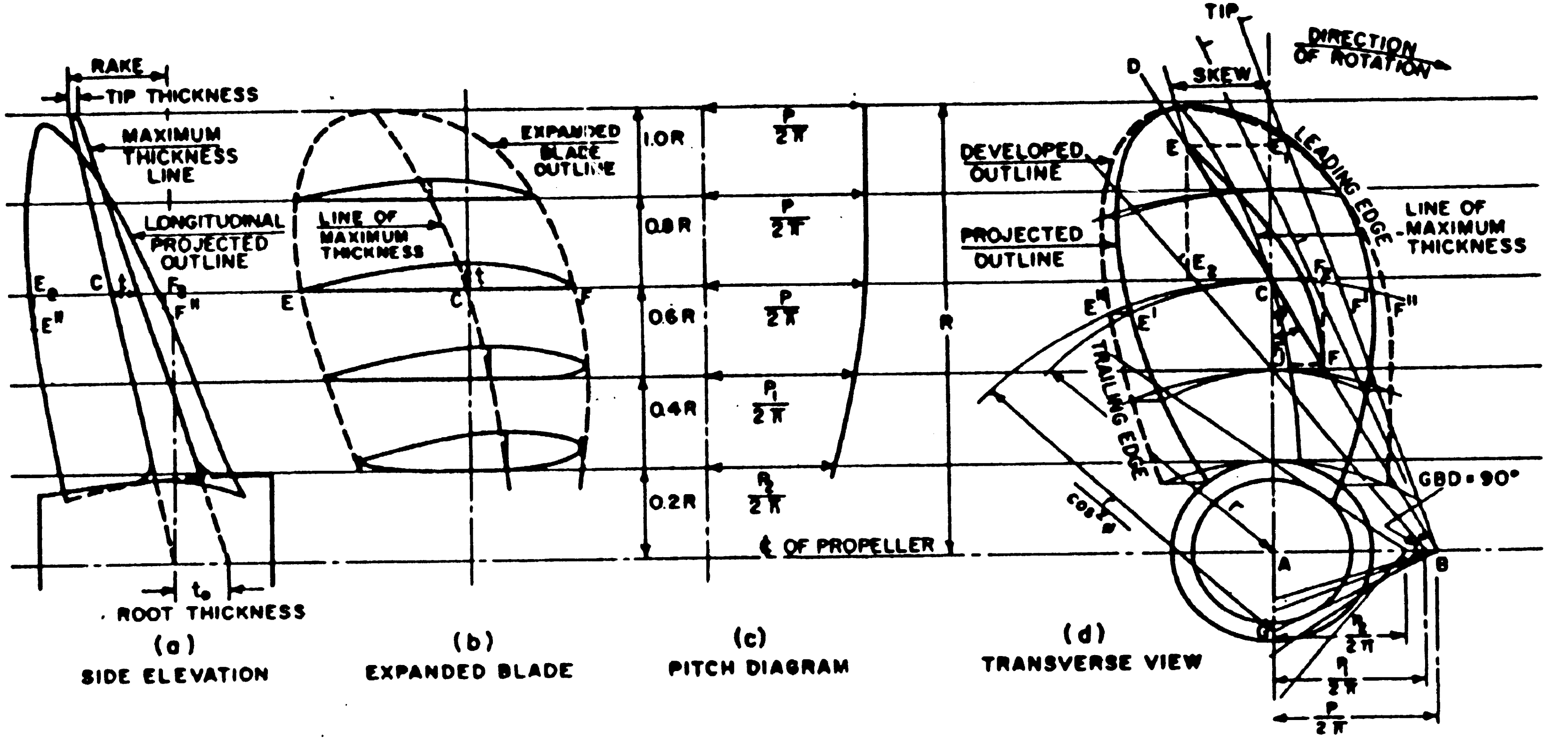
PROPULSIVE FORCES AND PROPULSION SYSTEMS

PROPELLER DESIGN CHARTS



PROPULSIVE FORCES AND PROPULSION SYSTEMS

PROPELLER DRAWING



(a) SIDE ELEVATION

(b) EXPANDED BLADE

(c) PITCH DIAGRAM

(d) TRANSVERSE VIEW

BASIC NAVAL ARCHITECTURE

Problem 51

Problem Level: Advanced

Background

The condition of a ship's underwater hull deteriorates in service due to an increase in roughness from corrosion of the hull steel and from the development of marine growth such as slime, grasses, and barnacles. Interestingly, this growth occurs only when the ship is in port. When a ship enters drydock for its routine availability, it is customary to sandblast the underwater hull and to apply anti-corrosion and anti-foulant coatings. The extent and the frequency of cleaning and recoating the underwater hull varies widely with different owners and different types of service conditions. Shipyards and ship operators have great interest in optimizing the economics of outer hull maintenance; however, the subject is much more complex than the problem that is presented here.

For the types of anti-corrosion and anti-foulant coatings that are most commonly used today, the effective life is about a year. There are cheaper coatings that do not last as long and more expensive coatings that last longer, and this in itself can be the subject of a trade-off study. During the effective life of the coating, there is very little corrosion and marine growth fouling. After the effective life has expired, the effectiveness of the coating will decline and corrosion and marine growth will increase. After a period of two to two-and-one-half times the effective life, the coating will have completely lost all its effectiveness.

One interim procedure that can be applied to reduce the added resistance of underwater hull roughness is to clean the underwater hull while the ship is alongside a dock. Several systems are available commercially using high pressure water jets or rotating brushes. These systems are very effective in removing slime and grasses, but less effective in removing encrusted barnacles. On the other hand, the interval between drydockings may be prolonged a bit, and there is minimal interference with the ship's schedule. In this problem, using some rather coarse assumptions, we will look for the time in the ship's operational cycle at which this procedure could profitably be employed.

Problem Statement

A diesel-powered cargo ship operates in regularly-scheduled liner service from the U.S. Gulf Coast to the Mediterranean. In one round trip, the ship will spend 30.0 days in port and 30.0 days at sea. At sea, the ship maintains an average speed of 18 knots. A plot of BHP against RPM is attached. In the ship's log book, the average RPM (and thus the average power) has been recorded. An analysis of this data is given below.

Problem 51 (continued)

Voyage	Months Since Drydocking	Average RPM for 18 knots
1-6	0-12	81.0
7	13-14	81.5
8	15-16	82.0
9	17-18	83.0
10	19-20	84.5
11	21-22	86.5
12	23-24	98.0
13	25-26	92.0
14	27-28	95.5
15	29-30	99.5

Assumptions:

(a) Assume the fuel rate for the plant is .34 lbs of diesel fuel per BHP per hour.

(b) Assume specific weight of fuel = 53 lb/ft^3.

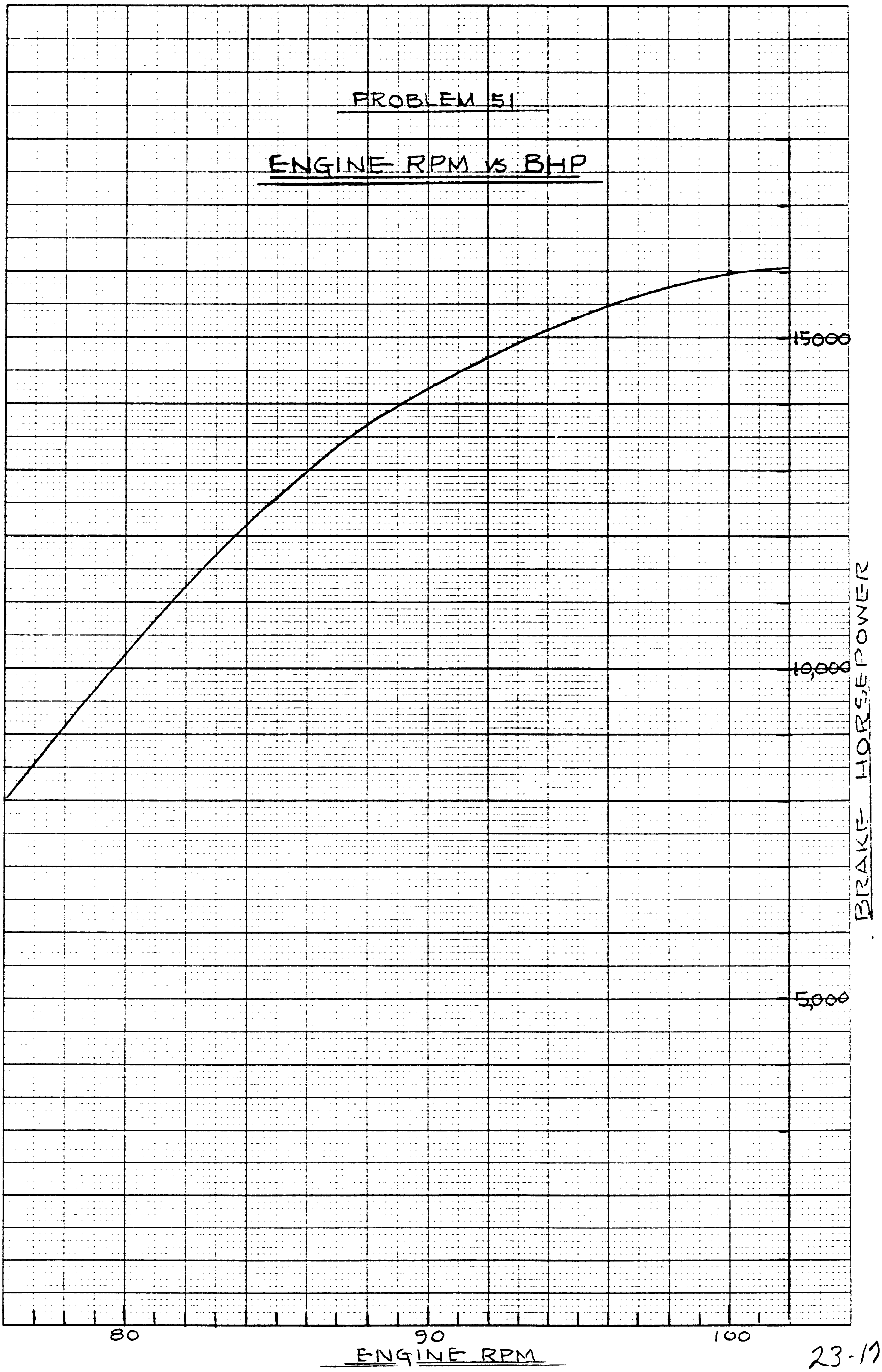
(c) Assume the cost of diesel fuel to be $34 per barrel (1 barrel = 36 gal).

(d) Assume that to clean the ship's underwater hull alongside a dock by high-pressure jet hosing will cost $25,000 and can be accomplished within a normal port time cycle.

(e) Assume that high-pressure hosing will reduce by 50% the added power required to overcome roughness.

(f) Assume that the criteria for deciding when to perform an interim dockside cleaning of the underwater hull is that the cost of cleaning must be recovered in savings on the added cost of fuel on the next round trip of the ship.

Based on the decision criteria in (f) above, find the voyage after which the interim underwater hull cleaning will be economically attractive to perform.



PROBLEM 51

ENGINE RPM vs BHP

COMMENT ON PROBLEM

THE APPROACH TO SOLVING THIS PROBLEM IS TO CALCULATE THE FUEL COSTS FOR EACH VOYAGE UNDER TWO CONDITIONS: CLEANING THE HULL AND NOT CLEANING THE HULL AND THEN COMPARE THE COSTS. THE VOYAGE AT WHICH THE FUEL COSTS FOR THE CLEANING OPTION ARE LESS THAN THE FUEL COSTS FOR THE NON-CLEANING OPTION IS THE ECONOMICAL VOYAGE PRIOR TO WHICH THE CLEANING SHOULD BE PERFORMED. THIS PROBLEM IS MOST EASILY WORKED IN TABULAR FORMAT.

SOLUTION

GIVEN: FUEL CONSUMPTION RATE $= 0.34 \frac{\text{lb}}{\text{BHP-Hr}}$

FUEL SPECIFIC WEIGHT $(\gamma_F) = 53\ \text{lb}/\text{FT}^3$

COST OF FUEL = \$34/BARREL

1 BARREL = 36 GALLONS

THE FIRST STEP IS TO DETERMINE THE FUEL COST EQUATION AS A FUNCTION OF BHP. THIS IS ACCOMPLISHED BY STARTING WITH THE UNITS OF FUEL CONSUMPTION AND WORKING TOWARD \$.

$$\underset{\underset{\substack{\text{CONSUMPTION}\\ \text{RATE}\\ \text{GIVEN}}}{\downarrow}}{\left(\frac{\text{lbs}}{\text{BHP-Hr}}\right)} \times \underset{\underset{\substack{\text{DEPENDS}\\ \text{ON VOYAGE}\\ \text{RPM}}}{\downarrow}}{(\text{BHP})} \times \underset{\underset{\substack{\text{SEA}\\ \text{TIME}}}{\downarrow}}{(\text{HR})} \times \underset{\underset{\frac{1}{\gamma_F}}{\downarrow}}{\left(\frac{\text{FT}^3}{\text{lb}}\right)} \times \underset{\underset{\substack{\text{CONVERSION}\\ \text{FACTOR}}}{\downarrow}}{\left(\frac{\text{Gallon}}{\text{FT}^3}\right)} \underset{\underset{\text{GIVEN}}{\downarrow}}{\left(\frac{\text{BARREL}}{\text{Gallon}}\right)} \underset{\underset{\text{GIVEN}}{\downarrow}}{\left(\frac{\$}{\text{BARREL}}\right)}$$

AS IS SHOWN, ALL UNITS CANCEL EXCEPT FOR COST ($).

$$\text{FUEL COSTS} = \left(0.34\,\frac{lb}{BHP\cdot Hr}\right)(BHP)\left(\overset{\text{30 DAYS x 24 HRS/DAY}}{720\,Hr}\right)\left(\frac{1}{55}\,\frac{FT^3}{lb}\right)\left(7.48\,\frac{GAL}{ft^3}\right) \times \left(\frac{1}{36}\,\frac{BARREL}{GAL}\right)\left(34\,\$/BARREL\right)$$

$$\text{FUEL COSTS} = \underline{\$32.6\,(BHP)}$$

THE NEXT STEP IS TO DETERMINE FUEL COSTS FOR EACH VOYAGE BEGINING WITH VOYAGE NUMBER 6. VOYAGES 1-5 CAN BE OMITTED BECAUSE THE FUEL COSTS REMAIN EQUAL (THE HULL COATING IS STILL EFFECTIVE). BHP IS DETERMINED FROM THE POWERING CURVE USING RPM AS THE ENTRY VARIABLE.

ASSUMING HULL IS <u>NOT</u> CLEANED

VOYAGE	RPM	BHP	FUEL COST ($)
6	81	10700	348,820
7	81.5	10950	356,970
8	82	11200	365,120
9	83	11700	381,420
10	84.5	12350	402,610
11	86.5	13150	428,690
12	98	15750	513,450
13	92	14700	479,220
14	95.5	15400	502,040
15	99.5	15900	518,340

ASSUMING HULL IS CLEANED

VOYAGE	RPM	BHP	FUEL COSTS	CLEANING COSTS	TOTAL COST
6	81	10700	348820	25000	373,820
7	81.25	10800	352080	25000	377,080
8	81.5	10950	356970	25000	381,970
9	82	11200	365120	25000	390,120
10	82.75	11550	376530	25000	401,530
11	83.75	12000	391200	25000	416,200
12	89.5	14100	459660	25000	484,660
13	86.5	13150	428690	25000	453,690
14	88.25	13750	448250	25000	473,250
15	90.25	14300	466180	25000	491,180

* ADJUSTED RPM = 81.0 + (0.5)(RPM − 81.0)

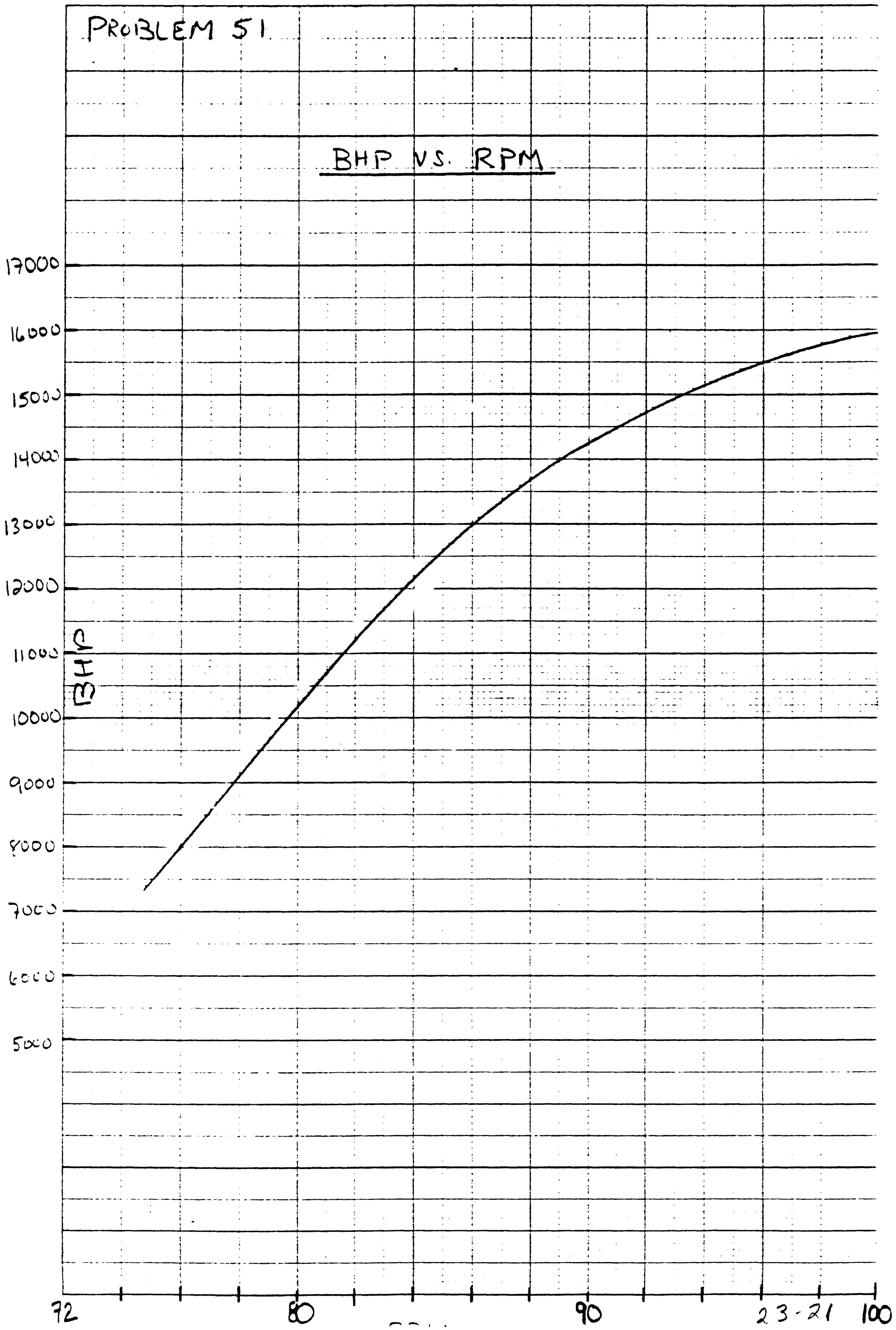
THIS IS DUE TO 50% POWER SAVINGS ABOVE THE ORIGINAL 81.0 RPM

* TOTAL VOYAGE COST = CLEANING COST + FUEL COST

COMPARING THE TOTAL COSTS WITH CLEANING TO THOSE COSTS WITHOUT CLEANING REVEALS THAT THE COSTS INCURRED ON THE 10th VOYAGE ARE LESSER WITH THE HULL CLEANING OPTION.

$401,530 < $402,610
CLEANING NO CLEANING

THEREFORE, IT IS ECONOMICALLY ATTRACTIVE TO PERFORM THE HULL CLEANING PRIOR TO VOYAGE #10 OR AFTER VOYAGE #9


PROBLEM 51
BHP VS. RPM
BHP
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
72
80
90
100
23-21

Unit Number:	24
Title:	Propulsive forces and propulsion systems - 3
Tape Running Time:	$36^M\ 18^S$
Reading Assignment:	MSD, pp 125-130
Additional References:	PNA, pp 387-397, 402-422, 428-439

Scope:

The influence of the number of blades is discussed. Wake fraction, thrust deduction, hull efficiency and relative rotative efficiency are defined. The efficiency chain is introduced. Cavitation is described. Other propulsion devices including supercavitating propellers, water jets, controllable pitch propellers, kort nozzles, vertical axis propellers and counter rotating propellers are briefly described.

Key Points to Emphasize:

1. Discuss the influence of the number of blades (vibration), blade shape (skew, vibration) and blade area (cavitation).
2. Emphasize a physical interpretation of wake fraction, thrust deduction, and cavitation.
3. The student should understand the efficiency chain and the elements that go into it.

Suggested Problem Assignment: 52

PROPULSIVE FORCES AND PROPULSION SYSTEMS

NUMBER OF BLADES

- THERE IS A SLIGHT LOSS OF EFFICIENCY IN INCREASING THE NUMBER OF BLADES - 1% TO 2% LOSS FOR ADDING ONE BLADE. (OTHER FACTORS REMAINING CONSTANT).

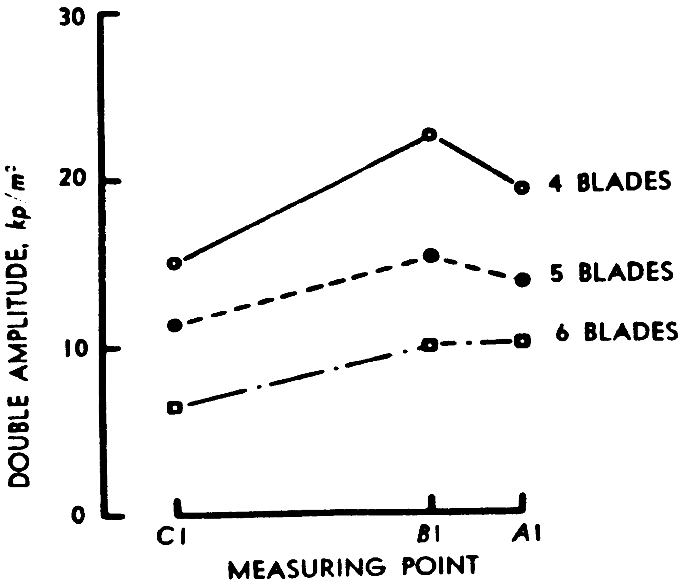
- HULL VIBRATIONS ARE CAUSED BY THE BLADE PRESSURE PULSE ENCOUNTERING HULL FEATURES - DEADWOOD, STRUTS, ETC.

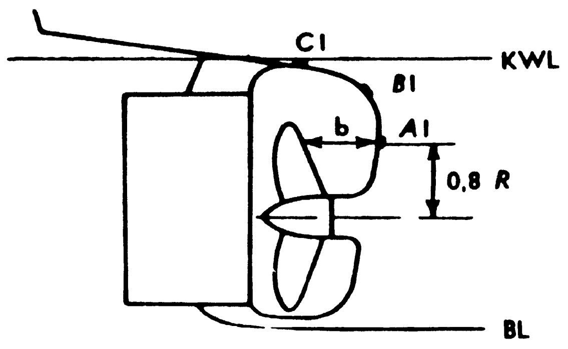
- AN ODD NUMBER OF BLADES WILL USUALLY BE SMOOTHER THAN AN EVEN NUMBER.

- FOR DIRECT COUPLED DIESELS TRY TO AVOID A NUMBER OF BLADES THAT IS AN EVEN FRACTION OF THE NUMBER OF CYLINDERS, E.G. FOR 6-CYLINDER DIESEL DO NOT USE A 3-BLADED PROPELLER.

PROPULSION FORCES AND PROPULSION SYSTEM

NUMBER OF BLADES





Courtesy of Stal-Laval

PROPULSIVE FORCES AND PROPULSION SYSTEMS

HULL-PROPELLER INTERACTIONS - WAKE FRACTION

THE SHIP CARRIES A BODY OF WATER ALONG WITH IT. THERE ARE THREE PRINCIPAL CAUSES:

1) FRICTIONAL DRAG IN THE BOUNDARY LAYER WILL CAUSE THE INFLOW WATER ALREADY TO HAVE A FORWARD VELOCITY BY THE TIME IT GETS TO THE PROPELLER.

2) STREAMLINE FLOW AROUND THE HULL WILL CAUSE A RELATIVE VELOCITY AT THE STERN WHICH IS IN THE FORWARD DIRECTION AND AUGMENTS FRICTIONAL WAKE.

3) THE SHIPS TRANSVERSE WAVE PATTERN CAUSES AN ORBITAL MOTION OF WATER PARTICLES WHICH MAY INCREASE OR DECREASE FRICTIONAL AND STREAMLINE WAKE.

4) $$V_a = V\ (1-w)$$

w = WAKE FRACTION.

PROPULSIVE FORCES AND PROPULSION SYSTEMS

HULL-PROPELLER INTERACTIONS - THRUST DEDUCTION

THE PROPELLER CREATES A LOW PRESSURE REGION FORWARD OF THE PROPELLER AND A HIGH PRESSURE REGION AFT. THE LOW PRESSURE REGION ACTING ON THE STERN OF THE SHIP ACTS LIKE A RESISTANCE AUGMENT, OR ALTERNATIVELY, A THRUST DEDUCTION

$$T - R_t = tT; \quad R_t = (1 - t)T$$

t = THRUST DEDUCTION COEFFICIENT.

$1 - t$ = THRUST DEDUCTION FACTOR.

PROPULSIVE FORCES AND PROPULSION SYSTEMS

HULL-PROPELLER INTERACTIONS - HULL EFFICIENCY

THE NET EFFECT OF WAKE FRACTION AND THRUST DEDUCTION IS η_h, HULL EFFICIENCY.

$$\eta_h = \frac{1-t}{1-w}$$

NOTE THAT IF t IS SMALLER THAN w THE HULL EFFICIENCY IS GREATER THAN ONE, WHICH IS OFTEN TIMES THE CASE.

- A LARGE VALUE OF w IS GOOD.
- A LARGE VALUE OF t IS BAD.

PROPULSIVE FORCES AND PROPULSION SYSTEMS

HULL-PROPELLER INTERACTIONS - RELATIVE ROTATIVE EFFICIENCY

- THE PROPELLER IN UNDISTURBED WATER IN A TOWING TANK OR IN A PROPELLER TUNNEL. TORQUE AND THRUST CHARACTERISTICS ARE MEASURED AND η_o, THE PROPELLER'S OPEN WATER EFFICIENCY IS CALCULATED.

- WHEN THE SHIP MODEL IS SELF-PROPELLED AND TORQUE AND THRUST TO THE PROPELLER ARE MEASURED THE TORQUE AND THRUST CHARACTERISTICS ARE NOT QUITE THE SAME BECAUSE OF DIFFERENT INFLOW CONDITIONS BEHIND THE MODEL.

- THE CORRECTION FACTOR IS CALLED η_r, RELATIVE ROTATIVE EFFICIENCY.

PROPULSIVE FORCES AND PROPULSION SYSTEMS

THE EFFICIENCY CHAIN

$$SHP \cdot \eta_t = PHP$$

$$PHP \cdot \eta_o \cdot \eta_h \cdot \eta_r = EHP$$

THE PROPULSIVE COEFFICIENT IS

$$\boxed{\eta_d = \frac{EHP}{SHP} = \eta_t \cdot \eta_o \cdot \eta_h \cdot \eta_r}$$

PROPULSIVE FORCES AND PROPULSION SYSTEMS

CAVITATION

- THE PRESSURE ON THE SUCTION SIDE OF THE PROPELLER BLADE IS REDUCED BELOW ATMOSPHERIC.

- IF THE PROPELLER IS HEAVILY LOADED THIS PRESSURE MAY FALL BELOW THE VAPOR PRESSURE OF THE SURROUNDING WATER.

- BUBBLES OF WATER VAPOR FORM ON THE SURFACE OF THE BLADE, THEN COLLAPSE AS THE LOCAL PRESSURE CHANGES.

PROPULSIVE FORCES AND PROPULSION SYSTEMS

CAVITATION

- IT IS OFTEN THE CASE THAT THE BEST EFFICIENCY FOR A PROPELLER OCCURS AT THE THRESHOLD OF CAVITATION.

- CAVITATION MUST BE QUITE EXTENSIVE OVER THE FACE AND BACK OF A BLADE BEFORE THRUST LOSS OCCURS, BUT -

- CAVITATION, OVER A PERIOD OF TIME WILL CAUSE PITTING ON THE SURFACE OF THE BLADE, AND

- FOR NAVAL SHIPS CAVITATION IS NOISY AND INCREASES THE ACOUSTIC DETECTABILITY OF THE SHIP.

PROPULSIVE FORCES AND PROPULSION SYSTEMS

SUPERCAVITATING PROPELLERS

- CONVENTIONAL PROPELLER, EVEN THOUGH DESIGNED FOR HIGH SPEED, WILL ENCOUNTER SERIOUS CAVITATION PROBLEMS AT SPEEDS ABOVE 40-45 KNOTS.

- FOR HIGH SPEED APPLICATIONS SUPERCAVITATING PROPELLERS MAY BE DESIGNED. THE WEDGE-SHAPED PROPELLER BLADE SECTION CAUSES THE ENTIRE BACK FACE TO BE ENVELOPED IN A CAVITATION CAVITY, ELIMINATING THE PROBLEM CAUSED BY CAVITATION BUBBLE COLLAPSE.

- SUPERCAVITATING PROPELLER PEAK EFFICIENCIES ARE NEARLY AS GOOD AS SUBCAVITATING AND MUCH BETTER IN THEIR RANGE OF APPLICATION.

PROPULSION FORCES AND PROPULSION SYSTEM

WATER JET PROPULSION

- WATER JETS OPERATE ON THE SAME PRINCIPLE AS SCREW PROPELLER, JET AIRCRAFT ENGINES, AND ROCKETS.
- THE MOMENTUM OF THE INCOMING FLUID IS INCREASED BY THE PROPULSION DEVICE. THE REACTION FORCE PROPELS THE SHIP AND IS EQUAL TO THE CHANGE OF MOMENTUM OF THE FLUID.

PROPULSION FORCES AND PROPULSION SYSTEM

WATER JET PROPULSION

- CHANGE IN MOMENTUM, δMV, IS ACHIEVED BY A SCREW PROPELLER BY ACCELERATING A LARGE MASS OF WATER THROUGH A RELATIVELY SMALL CHANGE IN VELOCITY. WATER JETS ACHIEVE CHANGE IN MOMENTUM THROUGH ACCELERATING A MUCH SMALLER MASS OF WATER THROUGH A MUCH LARGER CHANGE IN VELOCITY.

- WATER JET PROPULSION SYSTEMS OPERATE AT LOWER EFFICIENCIES THAN SCREW PROPELLERS, SAY, 35% - 45%, COMPARED TO 50% - 65%, BUT ARE WELL SUITED TO HIGH SPEED APPLICATIONS.

- THERE ARE INHERENT DUCTING LOSSES ASSOCIATED WITH WATER JET PROPULSION SYSTEMS.

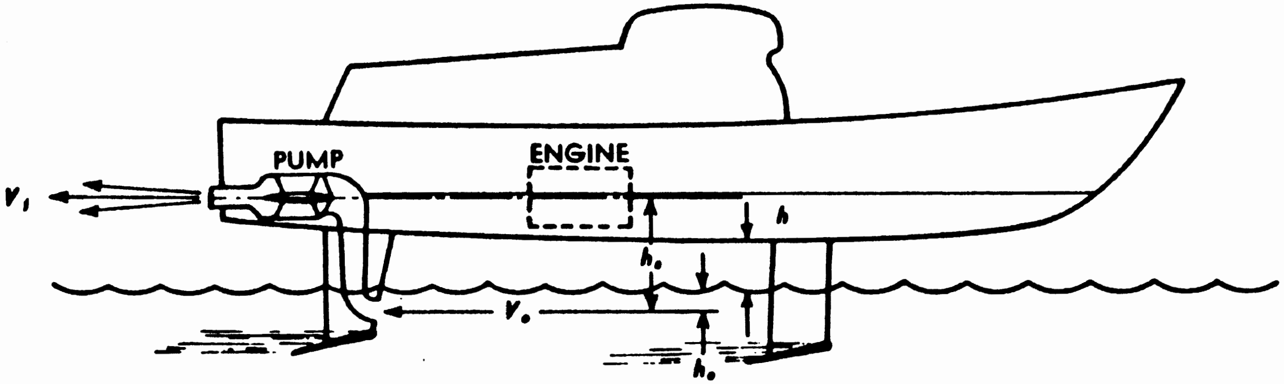
PROPULSION FORCES AND PROPULSION SYSTEM

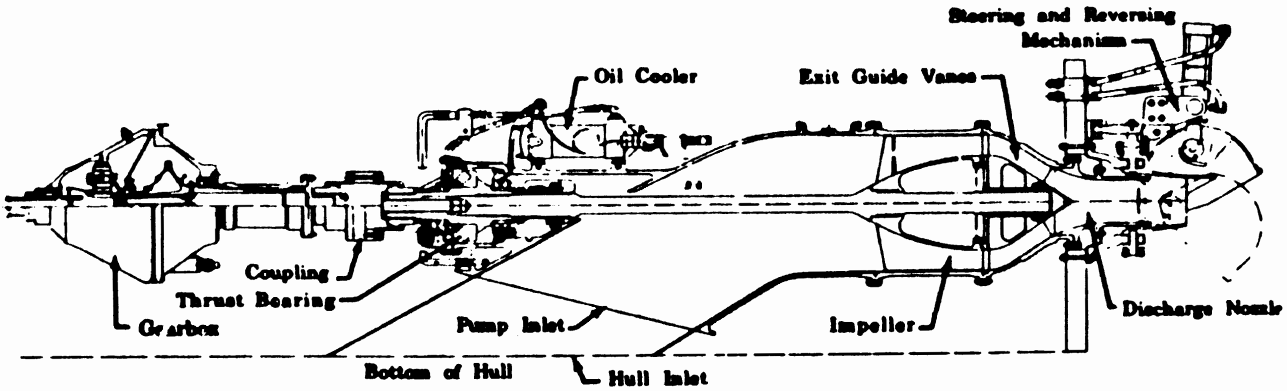
WATER JET PROPULSION

- MOST WATERJET SYSTEMS DISCHARGE ABOVE THE SURFACE OF THE WATER.
- THE FEATURE OF BEING ABLE TO DEFLECT THE WATER JET SIDEWISE OR IN REVERSE MAKES WATER JET PROPELLED CRAFT VERY MANEUVERABLE.
- BEST APPLICATIONS:
  - HYDROFOIL CRAFT.
  - HIGH SPEED POWER BOATS.
  - BOOST POWER FOR HIGH SPEED SURFACE SHIPS.

PROPULSION FORCES AND PROPULSION SYSTEM

WATER JET PROPULSION





Courtesy of Pratt & Whitney, AIAA/SNAME

PROPULSIVE FORCES AND PROPULSION SYSTEMS

CONTROLLABLE PITCH PROPELLERS

- CONTROLLABLE PITCH PROPELLERS HAVE BLADES WHICH CAN BE ROTATED BY A MECHANISM FROM FULL AHEAD PITCH TO FULL ASTERN PITCH.

- CONTROLLABLE PITCH PROPELLERS PROVIDE A VERY HIGH DEGREE OF SPEED CONTROL.

- THE NEED FOR A REVERSING GEAR IS ELIMINATED.

- CONTROLLABLE PITCH PROPELLERS ARE USED ON ALL RECENT CLASSES OF FRIGATES, DESTROYERS AND CRUISERS WHICH ARE EQUIPPED GAS TURBINE PLANTS.

PROPULSIVE FORCES AND PROPULSION SYSTEMS

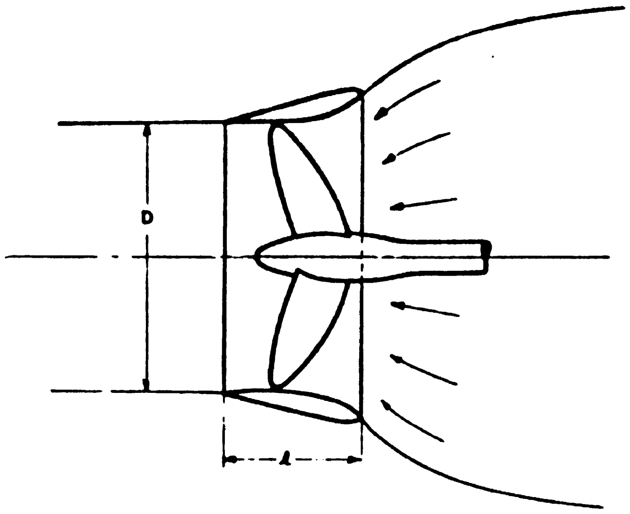
KORT NOZZLES

- KORT NOZZLES ARE WIDELY USED IN RIVER TOWBOATS, SOME TUGBOATS, AND OTHER APPLICATIONS IN WHICH PROPELLERS OF RESTRICTED DIAMETER ARE VERY HIGHLY LOADED. GENERALLY LIMITED TO LOW AND MODERATE SPEED VESSELS. THE PROPELLER IS MOUNTED IN A NOZZLE, OR SHROUD, WHICH SURROUNDS THE PROPELLER, DIRECTS THE FLOW DIRECTLY INTO THE PROPELLER DISK, AND TENDS TO SUPPRESS PROPELLER TIP LOSSES.

- A PROPERLY DESIGNED NOZZLE WILL ITSELF DELIVER THRUST TO THE SHIP.

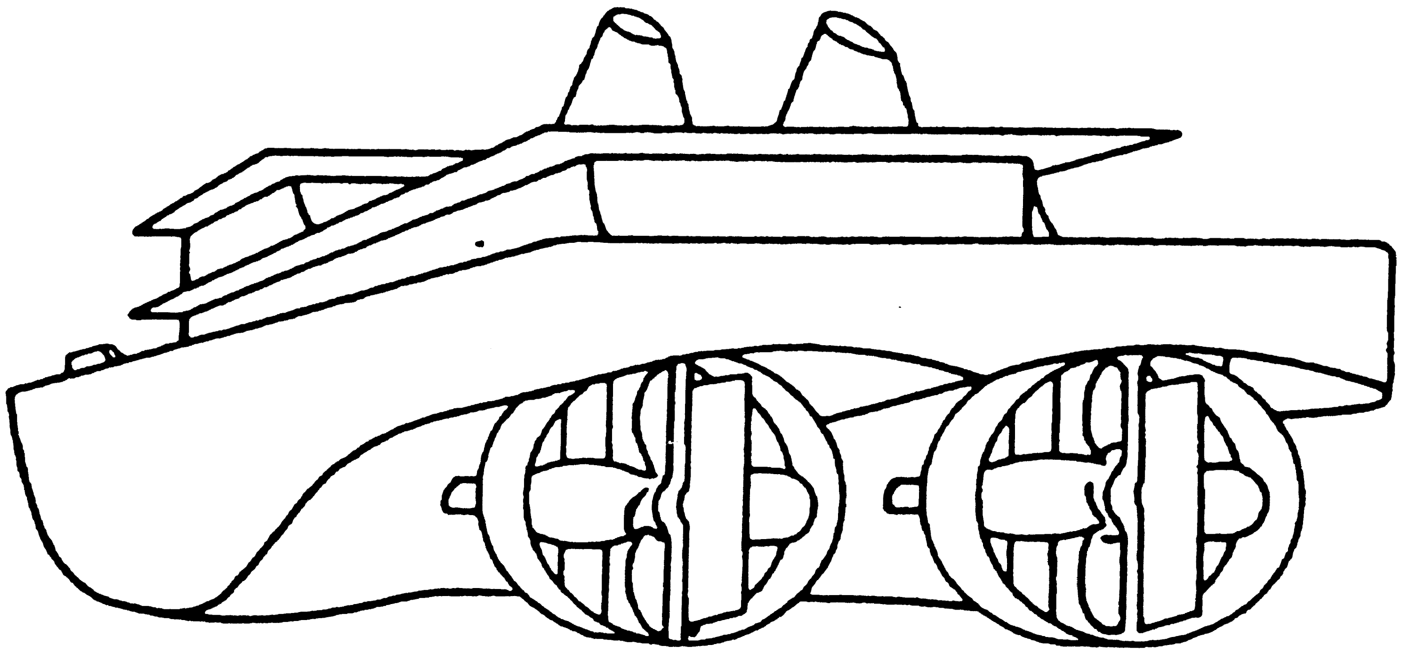
PROPULSIVE FORCES AND PROPULSION SYSTEMS

KORT NOZZLES



PROPULSIVE FORCES AND PROPULSION SYSTEMS

KORT NOZZLES



PROPULSIVE FORCES AND PROPULSION SYSTEMS

VERTICAL AXIS PROPELLERS

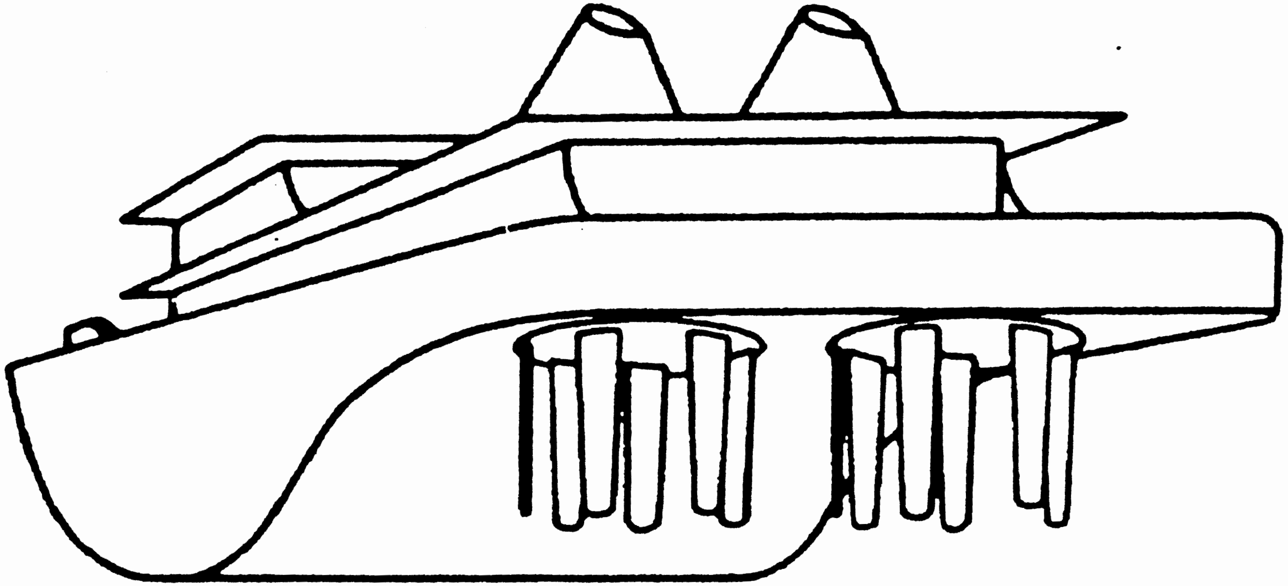
THE MOST COMMON TYPE TODAY IS THE VOITH SCHNEIDER PROPELLER.

VERTICALLY ORIENTED BLADES ARE MOUNTED ON A DISK WHICH ROTATES. THE BLADES ALSO GO THROUGH ONE COMPLETE REVOLUTION FOR EACH REVOLUTION OF THE DISK. BY MEANS OF A LINKAGE THE ATTITUDE OF THE BLADES IS CONTROLLED, SO THAT THRUST MAY BE PRODUCED IN ANY DIRECTION.

THE HELMSMAN, OR CAPTAIN ON THE BRIDGE OPERATES THE SHIP WITH A JOYSTICK. MOTION OF THE SHIP IN ALMOST ANY DESIRED DIRECTION IS CONTROLLED BY THE JOYSTICK. CONTROL IS SUPERB BUT EFFICIENCY IS PROBABLY ABOUT 30% LOWER THAN A CONVENTIONAL PROPELLER.

PROPULSIVE FORCES AND PROPULSION SYSTEMS

VERTICAL AXIS PROPELLERS



PROPULSIVE FORCES AND PROPULSION SYSTEMS

COUNTER-ROTATING PROPELLERS

- THE PROPELLER BLADES IMPART A ROTARY MOTION TO THE WATER IN THE PROPELLER RACE.

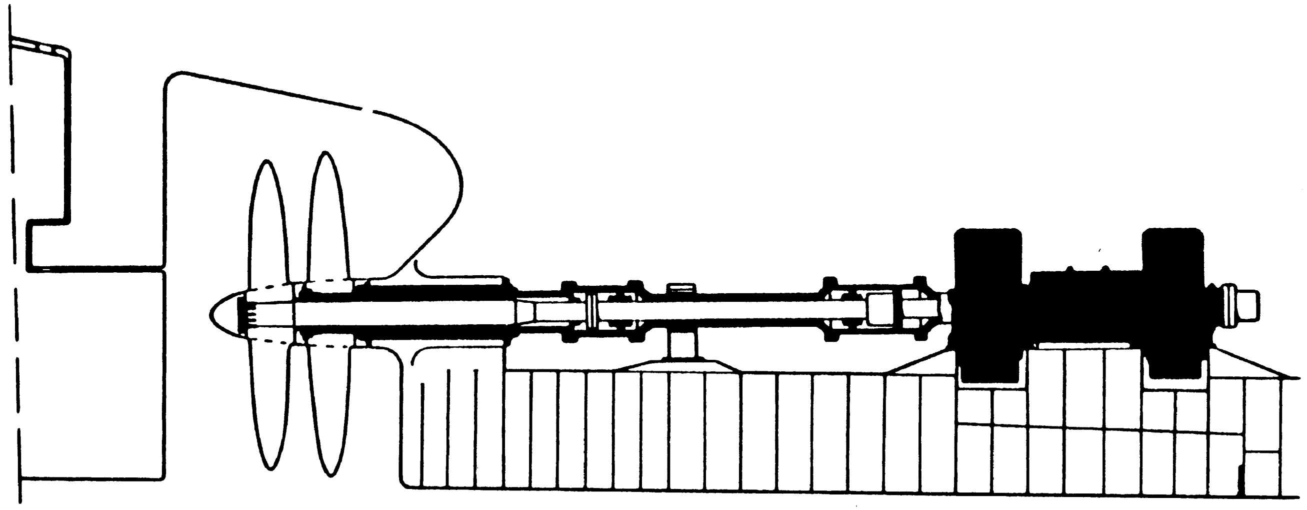
- ONE SCHEME TO RECOVER THE ENERGY LOST IN THIS ROTATIONAL MOTION IS TO USE TANDEM PROPELLERS ROTATING IN OPPOSITE DIRECTIONS.

- THE IDEA HAS LONG BEEN USED IN TORPEDOES.

- THE EFFICIENCY OF COUNTER-ROTATING PROPELLER SETS IS BETTER THAN A SINGLE PROPELLER BUT THE MECHANICAL COMPLEXITY OF THE GEARING AND SHAFTING AND ITS HIGH COST HAVE LIMITED THE APPLICATIONS.

PROPULSION FORCES AND PROPULSION SYSTEM

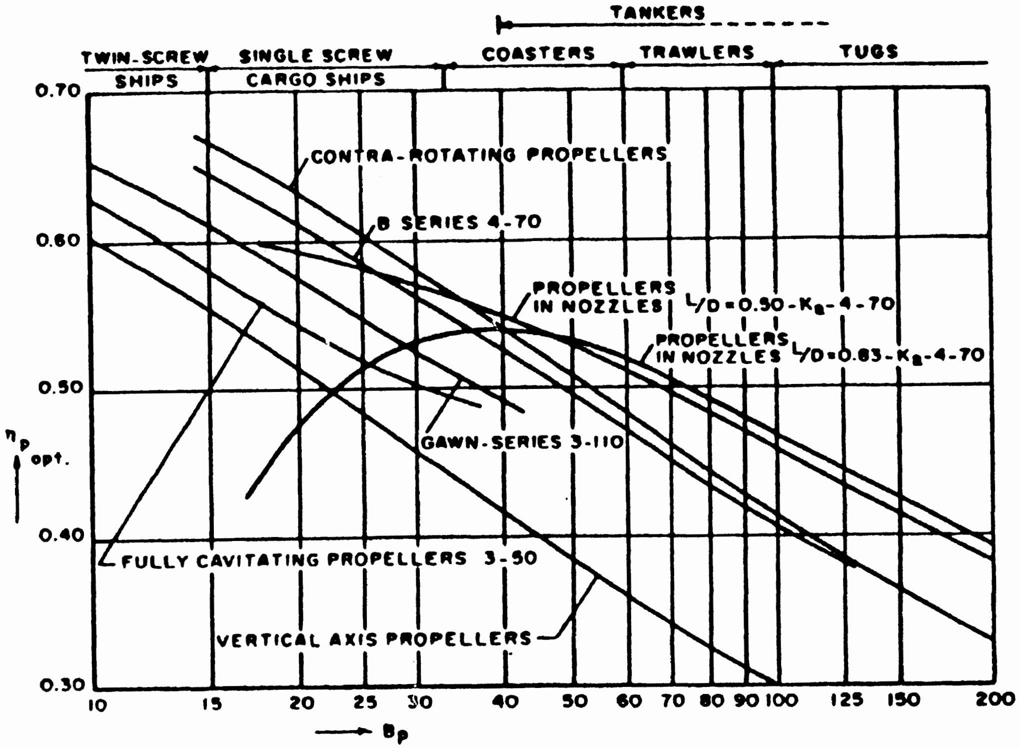
COUNTER-ROTATING PROPELLERS



Courtesy of Stal-Laval

PROPULSION FORCES AND PROPULSION SYSTEM

COMPARISON OF PROPULSOR EFFICIENCIES



$$B_p = \frac{n \cdot (PHP)^{0.5}}{V_A^{2.5}}$$

BASIC NAVAL ARCHITECTURE

Problem 52

Problem Level: Basic

The following particulars apply to the propeller of a patrol boat operating at 22.0 knots:

Propeller Diameter D = 12.00 ft

Pitch/Diameter Ratio = $\frac{P}{D}$ = 1.10

Ship Speed = v = 37.14 ft/sec

Speed of Advance of Water into Propeller = v_a = 33.43 ft/sec

Propeller RPM N = 240 revs/min

Find:

Pitch Angle at radius, r/R = .70,

Apparent Slip Ratio, S_a

True Slip Ratio, S_r

Apparent Slip Speed

True Slip Speed

Wake Speed

(Remember that RPM must be converted to RPS)

GIVEN: PROPELLER D = 12.00 FT

$P/D = 1.10$

SHIP SPEED = 22.0 KTS = 37.14 FT/SEC

(1 KNOT = 1.688 FT/SEC)

SPEED OF ADVANCE = V_a = 33.43 FT/SEC

PROPELLER RPM = 240 revs/MIN.

FIND: PITCH ANGLE ϕ AT $\frac{r}{R} = .70$

AT $r/R = .70$, $r = .70 \times \frac{12.00}{2} = 4.20$ FT

$$\tan\phi = \frac{P}{2\pi r} = \frac{1.10 \times 12.00}{2\pi \times 4.20}$$

$$\tan\phi = .500$$

$$\underline{\phi = 26.6^\circ}$$

PITCH = P = 1.10 × 12.00 = 13.20 FT

RPS = n = $\frac{240 \text{ RPM}}{60 \text{ SEC/MIN}}$ = 4 REV/SEC

$P \times n$ = 13.2 FT × 4 REV/SEC

$P \times n$ = 52.8 FT/SEC

REFER TO GILLMER, PP 118-119.

APPARENT SLIP RATIO = $S_a = \frac{P \times n - V}{P \times n}$

$$= \frac{52.8 \text{ FT/SEC} - 37.14 \text{ FT/SEC}}{52.8 \text{ FT/SEC}}$$

APPARENT SLIP RATIO $\underline{= S_a = .297}$

TRUE SLIP RATIO $= S_r = \dfrac{P \times n - V_a}{P \times n}$

$S_r = \dfrac{52.8 \text{ FT/SEC} - 33.43 \text{ FT/SEC}}{52.8 \text{ FT/SEC}}$

TRUE SLIP RATIO $= S_r = .367$

APPARENT SLIP SPEED $= P \times n - V$ (REF FIG 6-4)

$= 52.8 \text{ FT/SEC} - 37.14 \text{ FT/SEC}$

APPARENT SLIP SPEED $= 14.86 \text{ FT/SEC} = 8.80 \text{ KTS}$

TRUE SLIP SPEED $= P \times n - V_a$

$= 52.8 \text{ FT/SEC} - 33.43 \text{ FT/SEC}$

TRUE SLIP SPEED $= 19.37 \text{ FT/SEC} = 11.48 \text{ KTS}$

WAKE SPEED $= V - V_a$

$= 37.14 \text{ FT/SEC} - 33.43 \text{ FT/SEC}$

WAKE SPEED $= 3.71 \text{ FT/SEC} = 2.20 \text{ KTS}$

BASIC NAVAL ARCHITECTURE

Unit Number: 25

Title: Propulsive requirements and power selection - 1

Tape Running Time: 29^M 40^S

Reading Assignment: MSD, pp 133-141

Additional References: PNA, pp 447-453

Scope:

The choice of hull form for a given speed regime is again discussed. Scaling laws, both geometric and temporal (Froude), are defined and an example given. An example of the expansion of model resistance is then presented. (The example will be continued in Unit 26.)

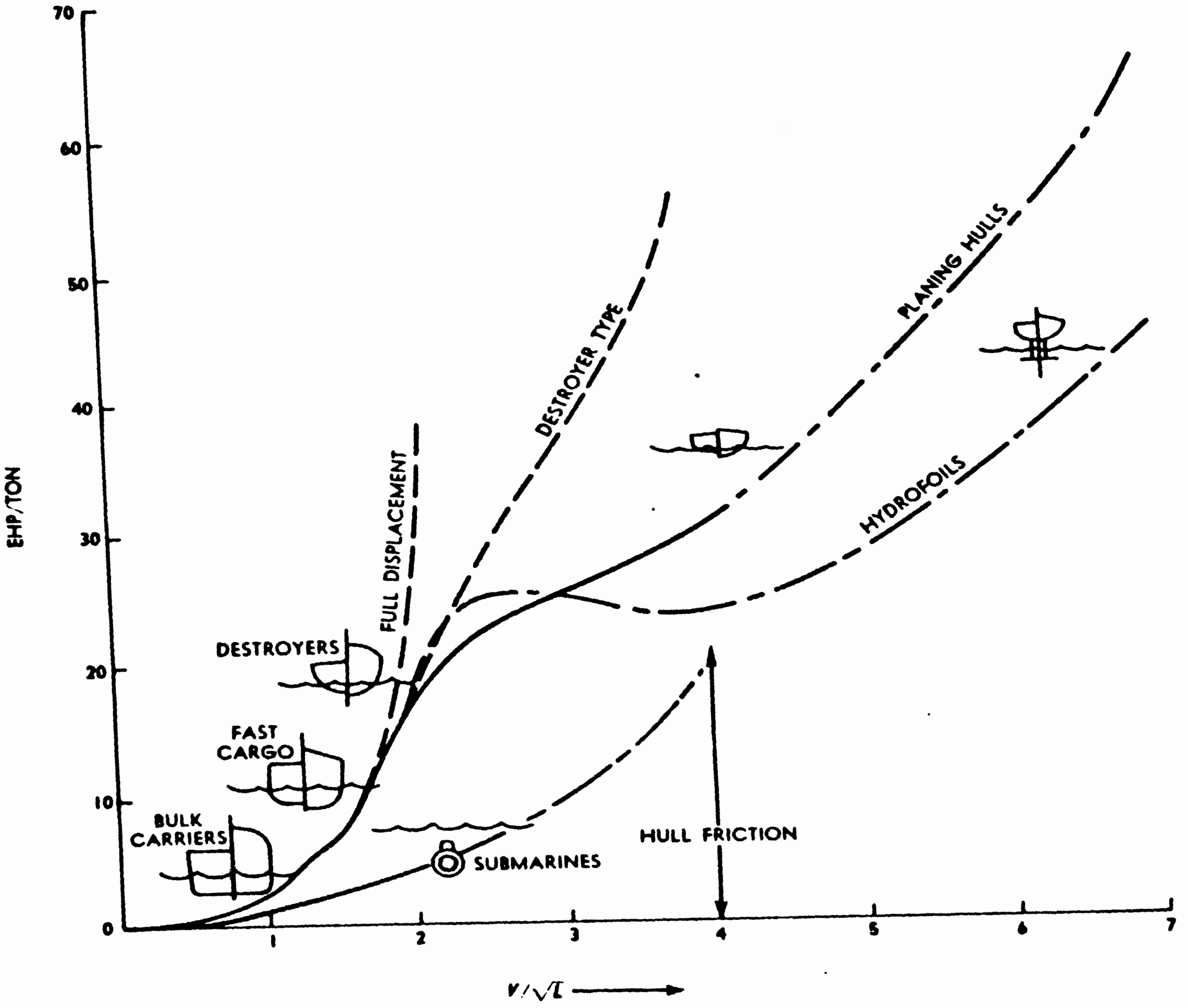
Key Points to Emphasize:

1. Use the entire time available to go over scaling laws, the scaling law example, and model resistance expansion example. The example will be continued in Unit 26 to predict SHP for the example ship.

Suggested Problem Assignment: 53, 54

PROPULSIVE REQUIREMENTS & POWER SELECTION

HULL TYPES AND SPEED REGIMES



PROPULSIVE REQUIREMENTS & POWER SELECTION

SCALING LAWS

LET $\frac{L_s}{L_m} = \lambda$, THE SCALE RATIO.

THEN ALL LINEAR DIMENSIONS ALSO VARY AS λ

$$B_s = \lambda \cdot B_m$$
$$T_s = \lambda \cdot T_m, \text{ ETC.}$$

ALL SQUARE DIMENSIONS, E.G. WETTED SURFACE, VARY AS λ^2,

$$S_s = \lambda^2 \cdot S_m$$

ALL CUBIC DIMENSIONS, E.G. VOLUMES, VARY AS λ^3,

$$\nabla_s = \lambda^3 \cdot \nabla_m$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

SCALING LAWS

SO FAR ALL SCALING HAS BEEN PURELY GEOMETRIC.

NOW, TO SCALE SPEED WE USE FROUDES LAW OF COMPARISON, THAT IS AT CORRESPONDING SPEEDS

$$\frac{V_s}{\sqrt{L_s}} = \frac{V_m}{\sqrt{L_m}}$$

OR,

$$V_s = V_m \cdot \frac{\sqrt{L_s}}{\sqrt{L_m}}$$

$$V_s = \sqrt{\lambda} \cdot V_m$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

SCALING LAWS

DISPLACEMENT IN WATER OF THE SAME DENSITY ALSO VARIES AS λ^3

$$\Delta_s = \lambda^3 \cdot \Delta_m$$

HOWEVER, IF THE MODEL IS TESTED IN FRESH WATER AND THE SHIP IS TO OPERATE IN SALT WATER A DENSITY CORRECTION IS NECESSARY.

$$\Delta_s = \lambda^3 \cdot \Delta_m \cdot \frac{35.9 \text{ FT}^3/\text{TON}}{35 \text{ FT}^3/\text{TON}}$$

$$\Delta_s = \lambda^3 \cdot \Delta_m \cdot 1.026$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

QUESTION

WHAT IS THE SCALING FACTOR FOR HORSEPOWER?
(1 HORSEPOWER = 550 FT·LBS/SEC)

ANSWER

$$\frac{(HP)_1}{(HP)_2} = \lambda^{7/2} \qquad \text{(P.L.T.S.)}$$

NOTE: USE THIS ONLY BETWEEN SHIPS OF SIMILAR SIZE AND PROPORTIONS AT THE SAME SPEED LENGTH RATIO.

PROPULSIVE REQUIREMENTS & POWER SELECTION

SCALING LAWS - EXAMPLE

A SHIP HAS THE FOLLOWING DIMENSIONS AND DESIGN SPEED.

L_{oa} = 425'-0"

L_{pp} = 400'-0"

B = 40'-0"

T = 15'-0"

W.S. = 18,750 FT^2

I_t = 1,700,000 FT^4

$\triangle$ = 3,500 LT

V_k = 27 KNOTS

FIND THE CORRESPONDING MODEL DIMENSIONS AND SPEED FOR A $\lambda = 25$.

PROPULSIVE REQUIREMENTS & POWER SELECTION

SCALING LAWS - SOLUTION

$$L_{oa_m} = \frac{425.0}{25} \text{ FT} = 17.00 \text{ FT}$$

$$L_{pp_m} = \frac{400.0}{25} \text{ FT} = 16.00 \text{ FT}$$

$$B_m = \frac{40.0}{25} \text{ FT} = 1.60 \text{ FT}$$

$$T_m = \frac{15.0}{25} \text{ FT} = 0.60 \text{ FT}$$

$$W.S._m = \frac{18,750}{(25)^2} \text{ FT}^2 = 30.00 \text{ FT}^2$$

$$I_t = \frac{1,700,000}{(25)^4} \text{ FT}^4 = 4.35 \text{ FT}^4$$

$$\triangle_m = \frac{3,500 \times 2,240}{(25)^3 \times 1.026} \text{ LBS} = 489.0 \text{ LBS}$$

$$V_{k_m} = \frac{27}{\sqrt{25}} = 5.40 \text{ KNOTS}$$

$$V_m = 5.40 \text{ KTS} \times 1.688 \frac{\text{FT/SEC}}{\text{KTS}} = 9.12 \text{ FT/SEC}$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

MODEL TEST EXPANSION - EXAMPLE

THE MODEL OF THE SHIP OF THE PREVIOUS EXAMPLE HAS BEEN TESTED AT DESIGN SPEED WITH THE FOLLOWING RESULTS

$$\text{AT } V_m = 9.12\ \frac{\text{FT}}{\text{SEC}}\ , \qquad R_{t_m} = 16.43 \text{ LBS}$$

TEST CONDITIONS:

FRESH WATER AT 70°F

$$\rho_m = 1.9362\ \frac{\text{LBS}\cdot\text{SEC}^2}{\text{FT}^4}$$

$$\nu_m = 1.0519 \times 10^{-5}\ \frac{\text{FT}^2}{\text{SEC}}$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

MODEL TEST EXPANSION - EXAMPLE

FIND R_{t_s} OF THE SHIP IN SALT WATER AT 59°F

$$\rho_s = 1.9905 \ \frac{\text{LBS} \cdot \text{SEC}^2}{\text{FT}^4}$$

$$\nu_s = 1.2260 \times 10^{-5} \ \frac{\text{FT}^2}{\text{SEC}}$$

APPLY A CORRELATION ALLOWANCE,

$$C_A = .400 \times 10^{-3}$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

MODEL TEST EXPANSION - EXAMPLE (CON'T)

STEP 1. CALCULATE $C_{t_m} = \dfrac{R_{t_m}}{\frac{\rho_m}{2} S_m V_m^2}$

$$C_{t_m} = \frac{16.43 \text{ LB}}{1.9362 \frac{\text{LB} \cdot \text{SEC}^2}{\text{FT}^4} \times 30.0 \text{ FT}^2 \times (9.12 \frac{\text{FT}}{\text{SEC}})^2}$$

$$C_{t_m} = 6.802 \times 10^{-3}$$

STEP 2. CALCULATE $R_{n_m} = \dfrac{V_m \cdot L_m}{\nu_m}$

$$R_{n_m} = \frac{9.12 \frac{\text{FT}}{\text{SEC}} \times 16.0 \text{ FT}}{1.0519 \times 10^{-5} \frac{\text{FT}^2}{\text{SEC}^2}}$$

$$R_{n_m} = 1.387 \times 10^{7}$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

MODEL TEST EXPANSION - EXAMPLE (CON'T)

STEP 3. **CALCULATE** $C_{f_m} = \dfrac{.075}{(\log_{10} Rn_m - 2)^2}$

$$C_{f_m} = \frac{.075}{(7.1421 - 2)^2}$$

$$C_{f_m} = 2.837 \times 10^{-3}$$

STEP 4. **FIND** $C_{r_m} = C_{t_m} - C_{f_m}$

$$C_{t_m} = 6.802 \times 10^{-3}$$

$$\underline{C_{f_m} = 2.837 \times 10^{-3}}$$

$$C_{r_m} = 3.965 \times 10^{-3}$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

MODEL TEST EXPANSION - EXAMPLE (CON'T)

STEP 5. FIND $C_{r_s} = C_{r_m}$

$$C_{r_s} = 3.965 \times 10^{-3}$$

STEP 6. CALCULATE $R_{n_s} = \frac{v_s \cdot L_s}{\nu_s}$

$$R_{n_s} = \frac{27.0 \text{ KTS} \times 1.688 \frac{\text{FT/SEC}}{\text{KTS}} \times 400 \text{ FT}}{1.2260 \text{ FT}^2/\text{SEC}}$$

$$R_{n_s} = 1.487 \times 10^{9}$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

MODEL TEST EXPANSION - EXAMPLE (CON'T)

STEP 7. **FIND**

$$C_{f_s} = \frac{.075}{(\log_{10} Rn_s - 2)^2}$$

$$C_{f_s} = \frac{.075}{(9.172 - 2)^2}$$

$$C_{f_s} = 1.458 \times 10^{-3}$$

STEP 8. **CALCULATE** $C_{t_s} = C_{r_s} + C_{f_s} + C_A$

$$\begin{aligned} C_{r_s} &= 3.965 \times 10^{-3} \\ C_{f_s} &= 1.458 \times 10^{-3} \\ C_A &= .400 \times 10^{-3} \\ \hline C_{t_s} &= 5.823 \times 10^{-3} \end{aligned}$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

MODEL TEST EXPANSION - EXAMPLE (CON'T)

STEP 9. CALCULATE R_{t_s}.

$$R_{t_s} = C_{t_s} \cdot \frac{\rho_s}{2} S_s V_s^2$$

$$R_{t_s} = (5.823 \times 10^{-3})\left(\frac{1.9905}{2} \cdot \frac{\text{LB} \cdot \text{SEC}^2}{\text{FT}^4}\right)(18{,}750\,\text{FT}^2)\left(27.0\,\text{KTS} \times 1.688\,\frac{\text{FT/SEC}}{\text{KTS}}\right)^2$$

$$\boxed{R_{t_s} = 225{,}711\ \text{LBS.}}$$

Problem 53

Problem Level: Basic

The following hull-propeller interactions have been estimated for a proposed ship design at 16.0 knots:

Thrust deduction coefficient = t = 0.12

Wake fraction = w = 0.20

Relative rotative efficiency = η_r = 1.02

The propeller efficiency at the 16-knot speed has been estimated to be:

Open water propeller efficiency = η_o = 0.58

The horsepower the propeller must deliver to the water to achieve the 16-knot speed has been estimated to be:

EHP = 8500 HP

(1) Find:
Hull efficiency, η_h
Propulsive efficiency, η_b
Propeller horsepower, PHP

The transmission efficiency, η_t. is estimated to be 0.97.

(2) Find: Shaft horsepower, SHP

25 16

BASIC NAVAL ARCHITECTURE

Problem 54

Problem Level: Basic

For the model and ship particulars given on pp 331-332 of Gillmer find the following for a model speed of 4.100 knots.

C_{t_m}

C_{f_m} using ITTC friction formula at fresh water = 61° F

C_{r_m}

Take $C_a = .400 \times 10^{-3}$. Expand the model results to predict ship EHP in sea water of 59° F. Find:

V_s (knots)

C_{r_s}

C_{t_s}

R_{t_s}

EHP_s

Note that the subscripts, m, and s, refer to model and ship respectively.

25-17

PROBLEM 53 PRVMJR 23 FEB 87 1 of 1

GIVEN:

$t = 0.12$

$w = 0.20$

$\eta_r = 1.02$

$\eta_o = 0.58$

$EHP = 8500 \text{ HP}$

$\eta_t = 0.97$

FIND: η_h, η_b, PHP, SHP

(1) $$\eta_h = \frac{1-t}{1-w} = \frac{1-0.12}{1-0.20} = \frac{0.88}{0.80} = 1.10$$

$$\underline{\underline{\eta_h = 1.0}}$$

$$\eta_b = \eta_o \times \eta_r \quad \text{(SEE PNA pp 390-391)}$$

$$\eta_b = (0.58)(1.02) \qquad \underline{\underline{\eta_b = 0.59}}$$

$$\frac{EHP}{PHP} = \eta_o \times \eta_h \times \eta_r = (0.58)(1.10)(1.02) = 0.651$$

$$PHP = \frac{EHP}{0.651} = \frac{8500}{0.651} = 13057 \text{ HP}$$

$$\underline{\underline{PHP = 13,057 \text{ HP}}}$$

$$\frac{PHP}{SHP} = \eta_t$$

$$SHP = \frac{13,057 \text{ HP}}{0.97} \qquad \underline{\underline{SHP = 13,461 \text{ HP}}}$$

PROBLEM 54 | PRVMJR/TDK | 28 ~~FEB~~ 87 | 1 OF 2

GIVEN: MODEL AND SHIP PARTICULARS ON PP 331-332, GILLMER.

L_m = 20.76 FT

S_m = 66.19 FT^2

Δ_m = 2027 LBS

L_s = 519 FT

λ = 25

t_m = 61° F

t_s = 59° F

ρ_m = 1.938 $\frac{\text{LB SEC}^2}{\text{FT}^4}$

ρ_s = 1.991 $\frac{\text{LB SEC}^2}{\text{FT}^4}$

$S_s = S_m \times \lambda^2 = 66.19 \times 625 =$ 41,370 FT^2

$\Delta_s = \Delta_m \times \lambda^3 \times \frac{\rho_s}{\rho_m} \times \frac{1}{2240} =$ 14,520 LT

V_m = 4.100 KNOTS = 6.921 FT/SEC

R_{t_m} = 12.15 LBS

THEN,
$$C_{t_m} = \frac{R_{t_m}}{\frac{\rho}{2} V_m^2 S_m} = \frac{12.15 \text{ LB}}{\left(\frac{1.938}{2} \cancel{\frac{\text{LB SEC}^2}{\text{FT}^4}}\right)\left(6.921 \frac{\text{FT}}{\text{SEC}}\right)^2 \left(66.19 \text{ FT}^2\right)}$$

$$\underline{C_{t_m} = 3.961 \times 10^{-3}}$$

$$C_{f_m} = \frac{.075}{(\log_{10} R_n - 2)^2}$$

$$R_{n_m} = \frac{V_m L_m}{\nu_m}$$
; FROM KINEMATIC VISCOSITY TABLES IN APPENDIX
$\nu = 1.1937 \times 10^{-5}$ FT^2/SEC

(NOTE: EXPLAIN TO STUDENTS HEADING OF COLUMN IN TABLES, WHICH READS $\nu \times 10^5$.)

$$R_{n_m} = \frac{(6.921 \frac{FT}{SEC})(20.76 \, FT)}{(1.1937 \times 10^{-5} \, FT^2/SEC)}$$

$$R_{n_m} = 120.36 \times 10^5 = 1.2036 \times 10^7$$

$$\log_{10} R_{n_m} = 7.08048$$

$$C_{f_m} = \frac{.075}{(7.08048 - 2)^2}$$

$$\underline{\underline{C_{f_m} = 2.901 \times 10^{-3}}}$$

$$C_{t_m} = 3.961 \times 10^{-3}$$

$$- C_{f_m} = 2.901 \times 10^{-3}$$

$$\underline{\underline{C_{r_M} = 1.060 \times 10^{-3}}}$$

$$V_s = V_m \times \sqrt{\lambda} = 4.100 \, KTS \sqrt{25}$$

$$\underline{\underline{V_s = 20.50 \, KTS = 34.60 \, FT/SEC}}$$

$$R_{n_s} = \frac{V_s L_s}{\nu_s} = \frac{(34.60 \, FT/SEC)(519 \, FT)}{(1.2817 \times 10^{-5} \, FT^2/SEC)}$$

$$R_{n_s} = 14011 \times 10^{-5} = 1.4011 \times 10^9$$

$$\log_{10} R_{n_s} = 9.14647$$

$$\underline{C_{f_s}} = \frac{.075}{(7.14647)^2} = 1.4685 \times 10^{-3}$$

$$C_{f_s} = 1.469 \times 10^{-3}$$

$$\underline{\underline{C_{r_m} = C_{r_s}}} = 1.060 \times 10^{-3}$$

$$C_a = 0.400 \times 10^{-3}$$

$$C_{t_s} = C_{f_s} + C_{r_s} + C_a = 2.929 \times 10^{-3}$$

$$R_{t_s} = C_{t_s}\left(\frac{\rho_s}{2} V_s^2 S_s\right) = (2.929 \times 10^{-3})\left(\frac{1.991}{2} \frac{LB\,SEC^2}{FT^4}\right)\left(34.60 \frac{FT}{SEC}\right)^2 (41,370 \, FT^2)$$

$$\underline{\underline{R_{t_s} = 144,410 \, LBS}}$$

$$\underline{\underline{EHP_s = R_{t_s} V_s / 550}} = (144,410 \, LBS)(34.60 \frac{FT}{SEC})/550 = \underline{\underline{9,085 \, HP}}$$

BASIC NAVAL ARCHITECTURE

Unit Number: 26

Title: Propulsive requirements and power selection - 2

Tape Running Time: $36^M\ 5^5$

Reading Assignment: MSD, pp 141-149

Additional References: PNA, pp 447-453 (repeated)

Marine Engineering (ME), 1971, R.L. Harrington, Ed., SNAME, pp 1-18

Scope:

The example of the previous unit is continued to predict the required BHP for the example ship. Service power margins and trial speed are discussed. Engine selection is then discussed. Type, advantages and disadvantages of diesel engines. Combined plants, diesel electric drives, gas turbines, steam plants, and nuclear plants are described briefly and comparisons given.

Key Points to Emphasize:

1. Complete the explanation of the powering prediction example.
2. With any time remaining supplement the comparisons of the various types of propulsion plants with additional information on performance, costs, weights and cubics, and fuel consumption.

Suggested Problem Assignment: one or two of 55, 56, 57

PROPULSIVE REQUIREMENTS & POWER SELECTION

POWER PREDICTION

INFORMATION NEEDED:	R_{t_s}, v_s
TRANSMISSION LOSSES OR TRANSMISSION EFFICIENCY	η_t
HULL-PROPELLER INTERACTIONS	ω, t
RELATIVE ROTATIVE EFFICIENCY	η_r
OPEN-WATER PROPELLER EFFICIENCY	η_o

KEY RELATIONSHIP:

$$\boxed{EHP = \frac{R_{t_s} \cdot v_s}{550}}$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

POWER-PREDICTION EXAMPLE

CONTINUE THE PREVIOUS EXAMPLE.

ADDITIONAL INFORMATION:

- SHIP IS SINGLE SCREW
- TRANSMISSION LOSSES:

  REDUCTION GEAR - 1%
  2 SHAFT BEARINGS - 1/4% EACH
  STERN TUBE - 1/2%

- FROM SHIP MODEL TESTS: $\omega = 0.12$

  $t = 0.02$

  $\eta_r = 1.02$

  $\eta_o = 0.59$

FIND EHP, SHP, BHP.

PROPULSIVE REQUIREMENTS & POWER SELECTION

POWER PREDICTION EXAMPLE - SOLUTION

STEP 1. CALCULATE EHP. $EHP = \frac{R_{t_s} \cdot V_s}{550}$

FROM PREVIOUS EXAMPLE

$R_{t_s} = 225,711 \text{ LBS}$

$V_s = 27.0 \text{ KTS} \times 1.688 \frac{\text{FT/SEC}}{\text{KTS}}$

$V_s = 45.58 \text{ FT/SEC}$

$$EHP = \frac{(225,711 \text{ LBS})(45.58 \text{ FT/SEC})}{550 \frac{\text{FT-LBS/SEC}}{\text{HP}}}$$

$$\boxed{EHP = 18,704 \text{ HP}}$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

POWER PREDICTION EXAMPLE - SOLUTION

STEP 2. CALCULATE HULL EFFICIENCY.

$$\eta_h = \frac{1-t}{1-w}$$

$$\eta_h = \frac{1-.02}{1-.12}$$

$$\eta_h = 1.114 = 111.4\%$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

POWER PREDICTION EXAMPLE - SOLUTION

STEP 3. FIND η_t

FROM ENGINE TO STERN TUBE

$$\eta_{t_1} = 1.00 - .01 - .005$$

$$\eta_{t_1} = .985 = 98.5\%$$

FROM STERN TUBE TO PROPELLER

$$\eta_{t_2} = 1.00 - .005$$

$$\eta_{t_2} = .995 = 99.5\%$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

POWER PREDICTION EXAMPLE - SOLUTION

STEP 4. CALCULATE SHP.

(SHP IS MEASURED FORWARD OF THE STERN TUBE)

$$P.C. = \frac{EHP}{SHP} = \eta_{t_2} \cdot \eta_o \cdot \eta_h \cdot \eta_r$$

$$P.C. = (.995)(.59)(1.114)(1.02)$$

$$P.C. = .665$$

$$SHP = \frac{18,704 \text{ HP}}{.665}$$

$$\boxed{SHP = 28,126 \text{ HP}}$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

POWER PREDICTION EXAMPLE - SOLUTION

STEP 5. CALCULATE BHP.

(BHP IS MEASURED AT THE OUTPUT STUB OF THE ENGINE)

$$BHP = \frac{SHP}{\eta_{t_1}}$$

$$BHP = \frac{28{,}126}{.985}$$

$$\boxed{BHP = 28{,}555 \text{ HP}}$$

PROPULSIVE REQUIREMENTS & POWER SELECTION

SERVICE POWER MARGIN

TO ALLOW FOR:

- ADDED RESISTANCE IN A SEAWAY
- ADDED RESISTANCE DUE TO FOULING
- DETERIORATION OVER TIME OF THE ENGINE OUTPUT
- OTHER POWER LOSS FACTORS

IT IS USUAL ON MERCHANT SHIPS TO INCREASE THE POWER ESTIMATED FOR TRIAL SPEED BY 25%.

IN OTHER WORDS THE SHIP WILL BE REQUIRED TO DEMONSTRATE ON TRIALS THE TRIAL SPEED AT 80% OF FULL CONTINUOUS TRIAL POWER.

PROPULSIVE REQUIREMENTS & POWER SELECTION

CONSIDERATIONS IN THE SELECTION OF ENGINES

1. INITIAL COST.
2. OPERATING COSTS INCLUDING:
    - FUEL COSTS.
    - MAINTENANCE COSTS.
3. RELIABILITY.
4. SPACE AND ARRANGEMENT REQUIREMENTS.
5. TOTAL PLANT WEIGHT.
6. PERFORMANCE AT PARTIAL LOAD CONDITIONS.
7. PERFORMANCE UNDER TRANSIENT LOAD CONDITIONS.
8. NUMBER AND TYPE OF OPERATING PERSONNEL.
9. REVERSING CAPABILITY.

PROPULSIVE REQUIREMENTS & POWER SELECTION

ENGINE SELECTION - DIESEL ENGINES

TYPES - BY ENGINE SPEED

HIGH SPEED - 1200-2400 RPM
MEDIUM SPEED - 600-1200 RPM
LOW SPEED - 100-600 RPM

TYPES BY CYCLE

TWO-CYCLE - LOW AND MEDIUM SPEED ENGINES
FOUR-CYCLE - HIGH SPEED ENGINES

PROPULSIVE REQUIREMENTS & POWER SELECTION

ENGINE SELECTION - DIESEL ENGINES

TYPES BY CYLINDER ARRANGEMENT

- IN-LINE ENGINES
- VEE ENGINES
- OPPOSED PISTON ENGINES

TYPES BY TYPE OF ASPIRATION

NATURALLY ASPIRATED

TURBOCHARGED - INTERCOOLED - AFTERCOOLED	FOUR CYCLE
SCAVENGED TURBOCHARGED	TWO CYCLE

DIESEL ENGINES - ADVANTAGES AND DISADVANTAGES

LOW-SPEED DIESELS (CON'T)

- WELL-SUITED FOR PROLONGED CONSTANT SPEED OPERATION.
- SLOW TO REVERSE, ENGINE MUST BE STOPPED AND STARTED IN OPPOSITE DIRECTION.
- LOW MAINTENANCE, LONG LIFE.
- CAN BE OPERATED ON HEAVY FUEL (BUNKER C) INSTEAD OF DIESEL FUEL.
- AVAILABLE IN LARGE HORSEPOWERS, 10,000-60,000 HP.
- BIG, HEAVY AND EXPENSIVE BUT,
- EXCELLENT FUEL ECONOMY, AS LOW AS .29 LBS/HP-HR.
- LEND THEMSELVES TO SMALL OPERATING CREWS OR UNMANNED ENGINE ROOMS.
- USUALLY DIRECT-COUPLED TO PROPELLER (NO REDUCTION GEAR).

PROPULSIVE REQUIREMENTS & POWER SELECTION

DIESEL ENGINES - ADVANTAGES AND DISADVANTAGES

MEDIUM SPEED DIESELS

- AVAILABLE IN INTERMEDIATE POWERS 900-5000 HP.
- LIGHTER AND SMALLER THAN LOW SPEED DIESELS.
- GOOD FUEL ECONOMY, .32-.38 LBS/SHP-HR.
- NORMALLY REQUIRE REDUCTION GEAR.
- WELL-SUITED FOR SMALL OPERATING CREWS OR UNMANNED OPERATION.
- LOWER COST PER HORSEPOWER THAN LOW-SPEED DIESELS.
- GOOD MAINTAINABILITY, 12,000-20,000 HRS BETWEEN OVERHAUL.
- WELL SUITED FOR A WIDE RANGE OF SHIP SIZES AND APPLICATIONS.
- MANY MODELS CAN BE OPERATED ON HEAVY FUEL.

PROPULSIVE REQUIREMENTS & POWER SELECTION

DIESEL ENGINES - ADVANTAGES AND DISADVANTAGES

HIGH-SPEED DIESELS

- AVAILABLE IN POWER RANGES FROM 100-1800 HP.
- LIGHT WEIGHT, COMPACT, BUT RESPONSIVE.
- NOISY.
- FUEL ECONOMY IS ONLY FAIR, .38-.45 LBS/SHP-HR.
- REQUIRE A REDUCTION GEAR USUALLY SOLD WITH ENGINE.
- NORMALLY UNMANNED ENGINE ROOM.
- WELL SUITED FOR WORK BOATS, YACHTS, OTHER SMALL TO MEDIUM SIZED CRAFT.
- MAINTAINABILITY DEPENDS ON SERVICE - AS LOW AS 1,000 HRS AND AS HIGH AS 8,000 HRS BETWEEN OVERHAULS DEPENDING ON SEVERITY OF USAGE.
- USE DIESEL FUEL ONLY.

PROPULSIVE REQUIREMENTS & POWER SELECTION

DIESEL ENGINES - ADVANTAGES AND DISADVANTAGES

COMBINED PLANTS

WHERE THE DESIGN REQUIREMENTS CALL FOR A WIDE RANGE OF SPEEDS AND POWER COMBINED PLANTS OFFER SOME ADVANTAGES.

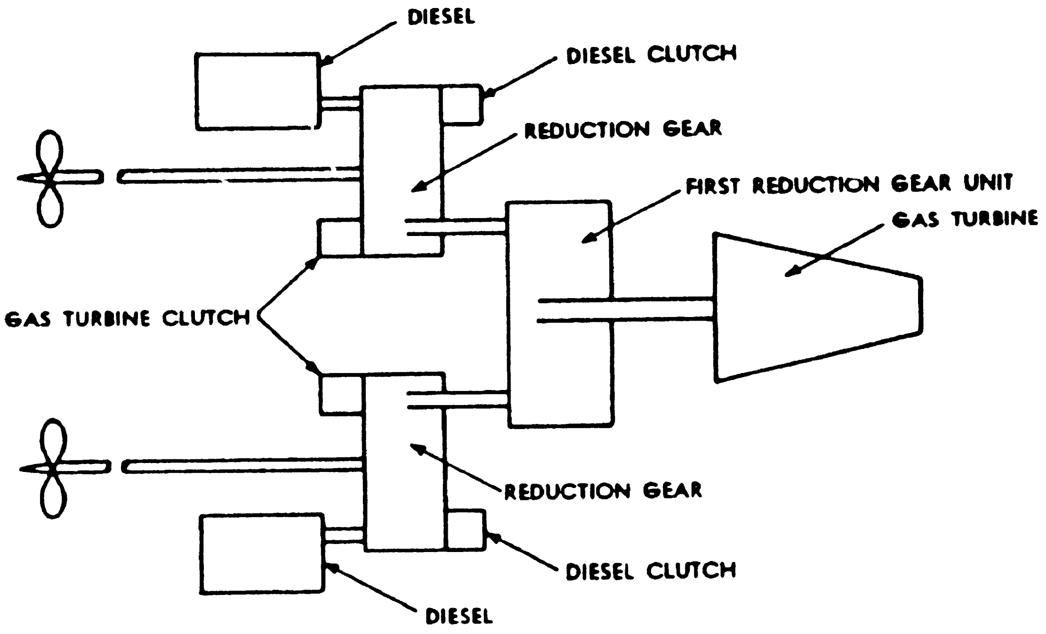
• CODAG	COMBINED DIESEL AND GAS TURBINE.
• COSAG	COMBINED STEAM AND GAS TURBINE.
• COGAG	COMBINED GAS TURBINE AND GAS TURBINE.
• CODOG	COMBINED DIESEL OR GAS TURBINE.

THE TWO DIFFERENT PRIME MOVERS ARE NORMALLY INDEPENDENT, BUT THEY MAY BE GEARED TO THE SAME PROPELLER SHAFT. ONE PRIME MOVER IS DEDICATED TO SERVICE AT CRUISING SPEED. THE ADDITIONAL GAS TURBINE IS KICKED IN TO PROVIDE BOOST POWER FOR MAXIMUM SPEED.

PROPULSIVE REQUIREMENTS & POWER SELECTION

COMBINED PLANTS

- REF: MSD, CHAPTER 8, PP 168-169 (NOTE: PGM-84 CLASS ARE CODOG, NOT CODAG)



PROPULSIVE REQUIREMENTS & POWER SELECTION

DIESEL ENGINES - ADVANTAGES AND DISADVANTAGES

COMBINED PLANTS

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PROPULSIVE REQUIREMENTS & POWER SELECTION

DIESEL ELECTRIC DRIVES - ADVANTAGES AND DISADVANTAGES

- DIESEL GENERATOR SETS RUN AT CONSTANT SPEED AND GENERATE AC ELECTRICITY.
- CONVERTED TO DC ELECTRICITY BY SILICONE-CONTROLLED RECTIFIER (SCR) CONVERTERS.
- DC MOTORS ARE USED FOR PROPULSION MOTORS.
- HIGHER TRANSMISSION LOSSES DUE TO AC-DC CONVERSION.
- NORMALLY DO NOT REQUIRE REDUCTION GEAR.
- SYSTEM IS BIGGER AND HEAVIER AND MORE EXPENSIVE THAN SIMILAR MEDIUM SPEED GEARED DIESEL PLANT.
- MAINTAINABILITY IS EXCELLENT BECAUSE OF CONSTANT SPEED OPERATION.
- ECONOMICS BECOME COMPETITIVE WITH GEARED DIESEL WHEN THERE IS A HIGH PERCENTAGE OF PARTIAL LOAD OPERATION.
- DIESEL GENERATORS CAN BE LOCATED REMOTE FROM PROPULSION MOTOR ROOM.
- ALMOST INFINITE CONTROL OF SHAFT RPM.

PROPULSIVE REQUIREMENTS & POWER SELECTION

GAS TURBINES - ADVANTAGES AND DISADVANTAGES

- GAS TURBINES ARE USED EXTENSIVELY FOR NAVAL SHIP PROPULSION. FFG-7, DD-963, CG-47, DDG-51, PHM CLASSES ALL USE GAS TURBINES.
- AVAILABLE IN POWER SIZES FROM 500-40,000 HP. ALSO SMALL AUXILIARY UNITS.
- SMALL, LIGHTWEIGHT, COMPACT.
- EXTREMELY NOISY WITH A HIGH-PITCHED WHINE. ENGINE ROOMS MUST BE EXTENSIVELY SOUND-PROOFED.
- FAST START-UP. COLD PLANT TO MAX SPEED IN A MATTER OF MINUTES.
- FUEL ECONOMY IS ONLY FAIR - .41 TO .55 LBS/SHP-HR.
- MAINTAINABILITY. ONLY LIMITED SHIPBOARD MAINTENANCE IS FEASIBLE. USUALLY NECESSARY TO REMOVE ENTIRE ROTOR UNIT AND REPLACE.
- REQUIRE REDUCTION GEAR AND CONTROLLABLE-PITCH PROPELLER (OR WATER JET).
- DO NOT OPERATE WELL AT PARTIAL LOADS.

PROPULSIVE REQUIREMENTS & POWER SELECTION

STEAM PROPULSION

AT ONE TIME ALMOST ALL MERCHANT AND NAVAL SHIPS WERE POWERED BY STEAM TURBINE PROPULSION PLANTS. MANY OF THESE SHIPS ARE STILL IN SERVICE, HOWEVER -

WITH THE AVAILABILITY OF LARGER, MORE EFFICIENT MEDIUM AND LOW SPEED DIESEL ENGINES WITH EXCELLENT RELIABILITY AND MAINTAINABILITY, STEAM PLANTS HAVE BEEN REPLACED BY DIESELS IN COMMERCIAL SHIPS.

STEAM PLANTS ARE STILL THE PRIME MOVER OF CHOICE WITH NUCLEAR POWERED NAVAL SHIPS AND SUBMARINES.

PROPULSIVE REQUIREMENTS & POWER SELECTION

NUCLEAR POWER

NUCLEAR POWER IS UTILIZED BY THE U.S. NAVY FOR FOUR ACTIVE AIRCRAFT CARRIERS AND THREE MORE UNDER CONSTRUCTION, AND NINE CRUISERS.

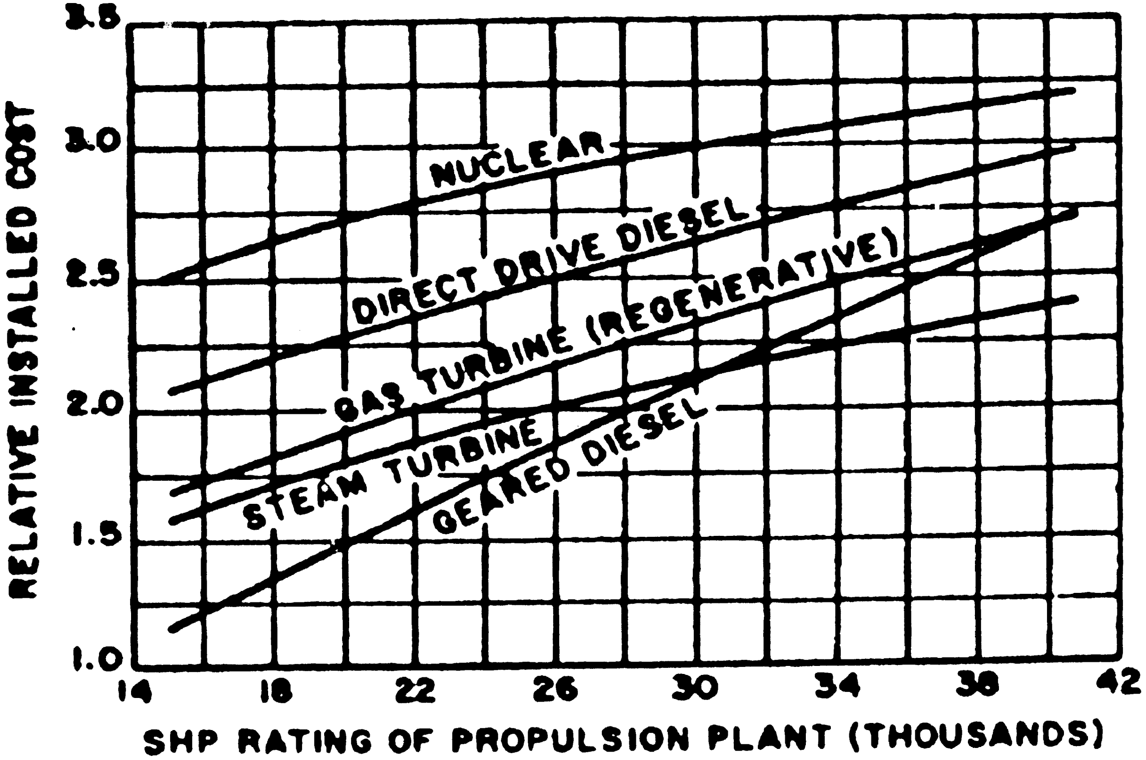
FURTHER USE OF NUCLEAR POWER FOR SURFACE SHIPS IS CONTROVERSIAL BECAUSE OF THE HIGH COST OF THE NUCLEAR PLANT.

ALL MODERN U.S. SUBMARINES, BOTH GUIDED MISSILE AND ATTACK TYPES ARE NUCLEAR POWERED AND THERE IS NO CONTROVERSY ABOUT CONTINUING THIS PRACTICE.

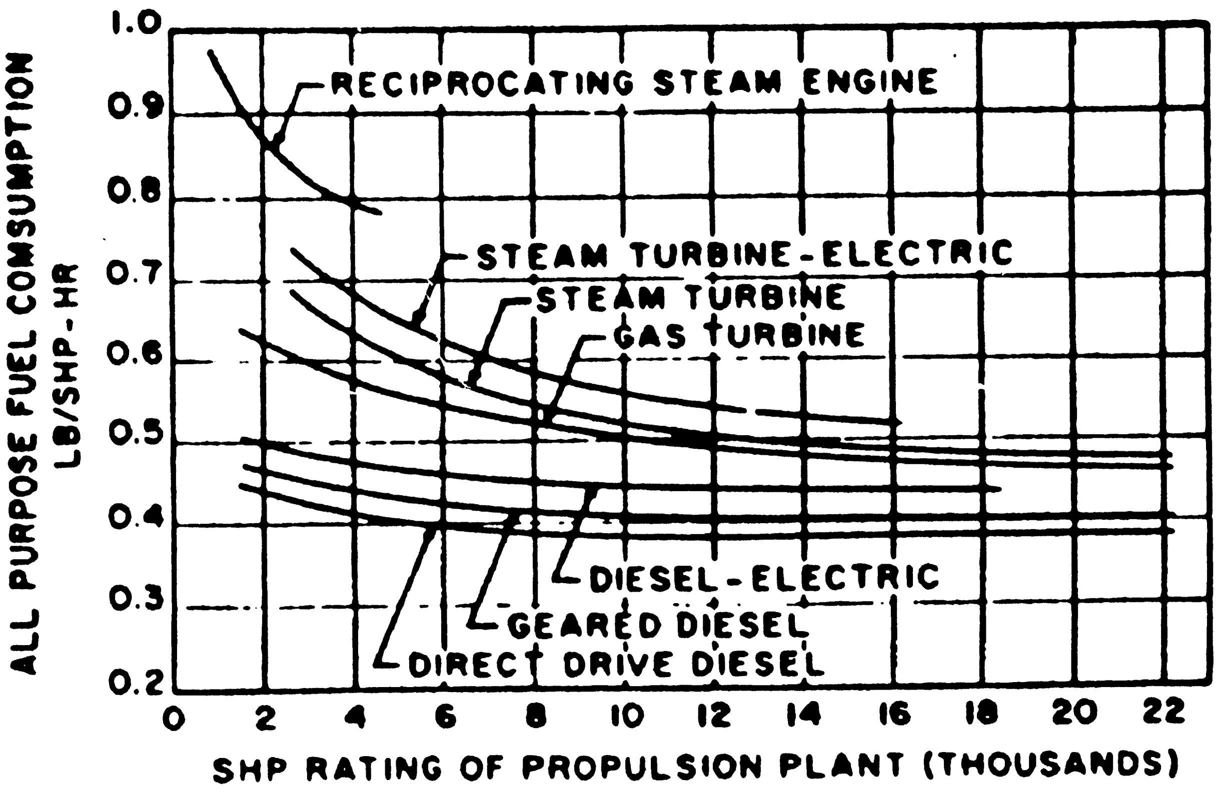
REACTORS ARE OF THE PRESSURIZED WATER TYPE AND CONSTITUTE THE HEAT SOURCE FOR A STEAM TURBINE POWER PLANT.

MANY STUDIES HAVE BEEN DONE IN THE PAST ON THE FEASIBILITY OF USING NUCLEAR POWER FOR MERCHANT SHIPS, AND ONE DEMONSTRATION SHIP, THE U.S.N.S. SAVANNAH, WAS BUILT. AT THIS TIME THERE IS LITTLE INTEREST BECAUSE OF THE HIGH INITIAL COST.

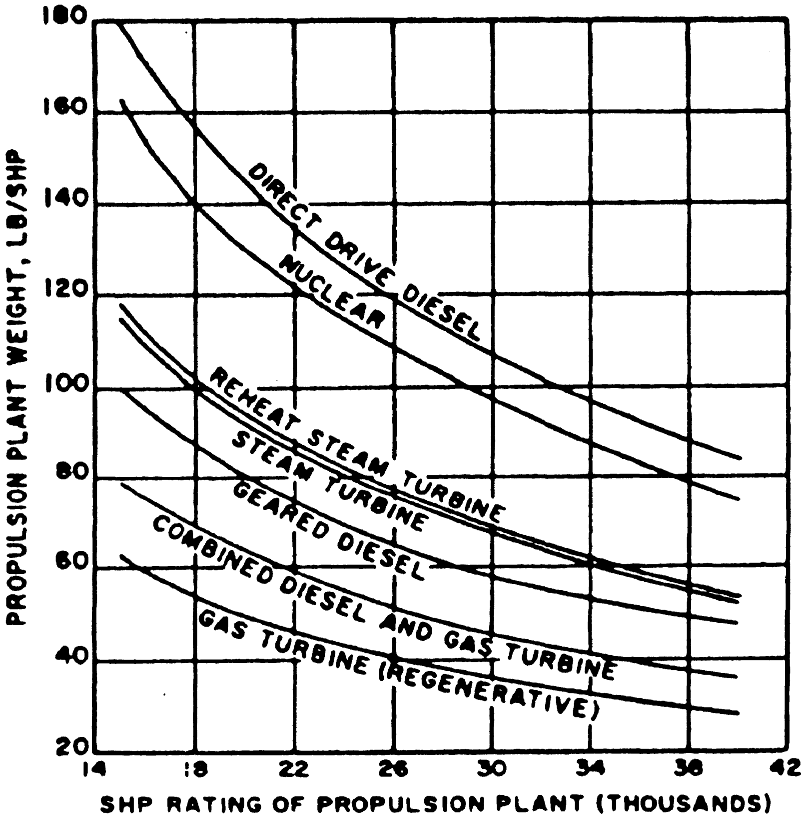
PROPULSIVE REQUIREMENTS & POWER SELECTION



PROPULSIVE REQUIREMENTS & POWER SELECTION



PROPULSIVE REQUIREMENTS & POWER SELECTION



GRAPHICS NOT USED IN PRESENTATION

PROPULSIVE REQUIREMENTS & POWER SELECTION

STANDARD SERIES

SHIP MODELS

1. TAYLOR STANDARD SERIES (NAVAL SHIPS, TWIN SCREW).
2. SERIES 60 (MERCHANT SHIPS).
3. BSRA (BRITISH SHIPBUILDING RESEARCH ASSOCIATION) STANDARD SERIES (MERCHANT SHIPS).
4. SERIES 63 (ROUND BILGE PLANING BOATS).
5. SERIES 64 (DESTROYERS).
6. SERIES 65 (HYDROFOIL HULLS).
7. SSPA (SWEDISH STATE SHIPBUILDING ASSOCIATION) STANDARD SERIES.

PROPULSIVE REQUIREMENTS & POWER SELECTION

STANDARD SERIES

PROPELLER SERIES

1. TAYLOR STANDARD SERIES
2. WAGENINGEN STANDARD SERIES (MERCHANT, DUTCH)
3. GAWN-BURRILL STANDARD SERIES (HIGH SPEED CRAFT, BRITISH)

PROPULSIVE REQUIREMENTS & POWER SELECTION

AUTOMATION

- INCREASING LABOR COSTS ARE DRIVING THE SHIPPING INDUSTRY, AS IN MANY OTHER INDUSTRIES, TOWARD INCREASING AUTOMATION.

- THE TRADE-OFF BETWEEN HIGHER LABOR COST AND HIGHER CAPITAL COST FAVORS AUTOMATION (IN THIS COUNTRY).

- THE SAME PRESSURES EXIST IN NAVAL SHIP DESIGN.

PROPULSIVE REQUIREMENTS & POWER SELECTION

AUTOMATION (CON'T)

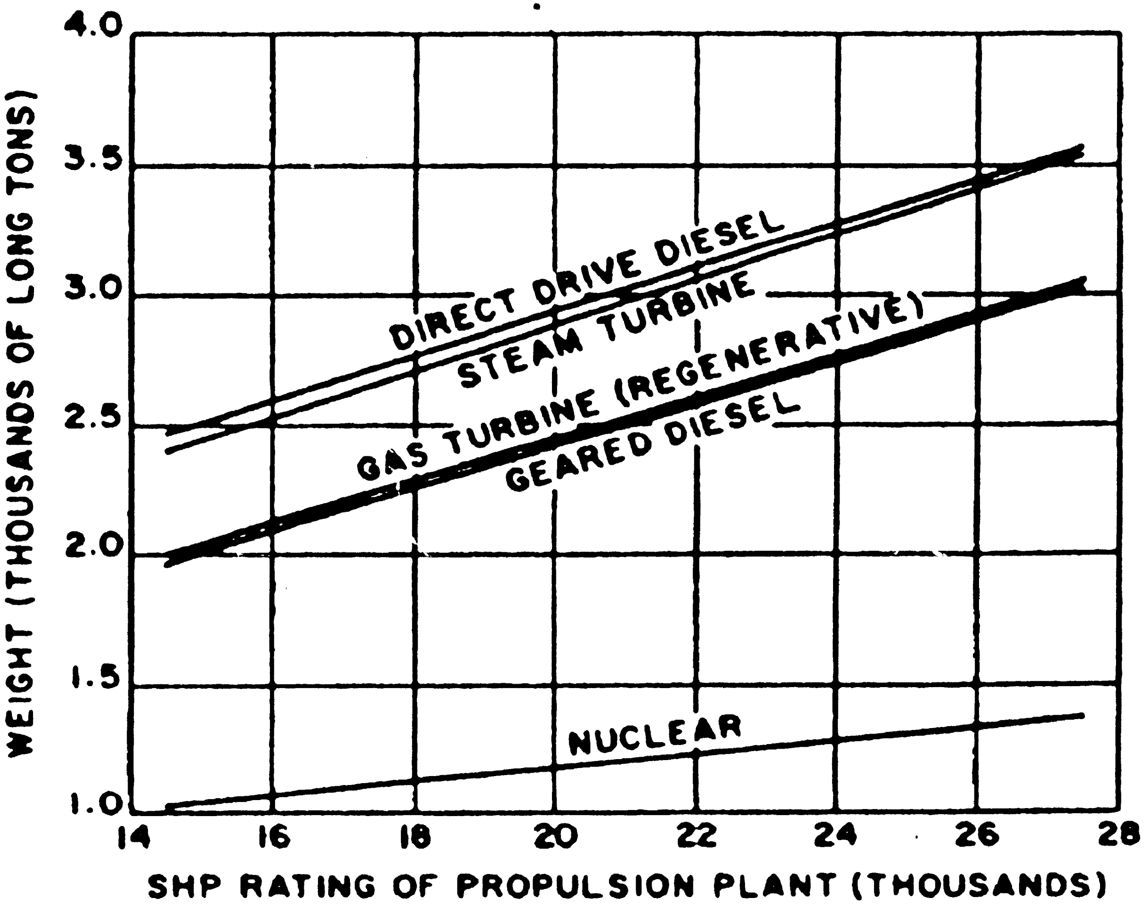
- DIESEL PLANTS AND DIESEL-ELECTRIC PLANTS LEND THEMSELVES WELL TO AUTOMATION.

- UNMANNED ENGINE ROOMS WITH FULL BRIDGE CONTROL OF THE ENGINEERING PLANT ARE BECOMING MORE COMMON.

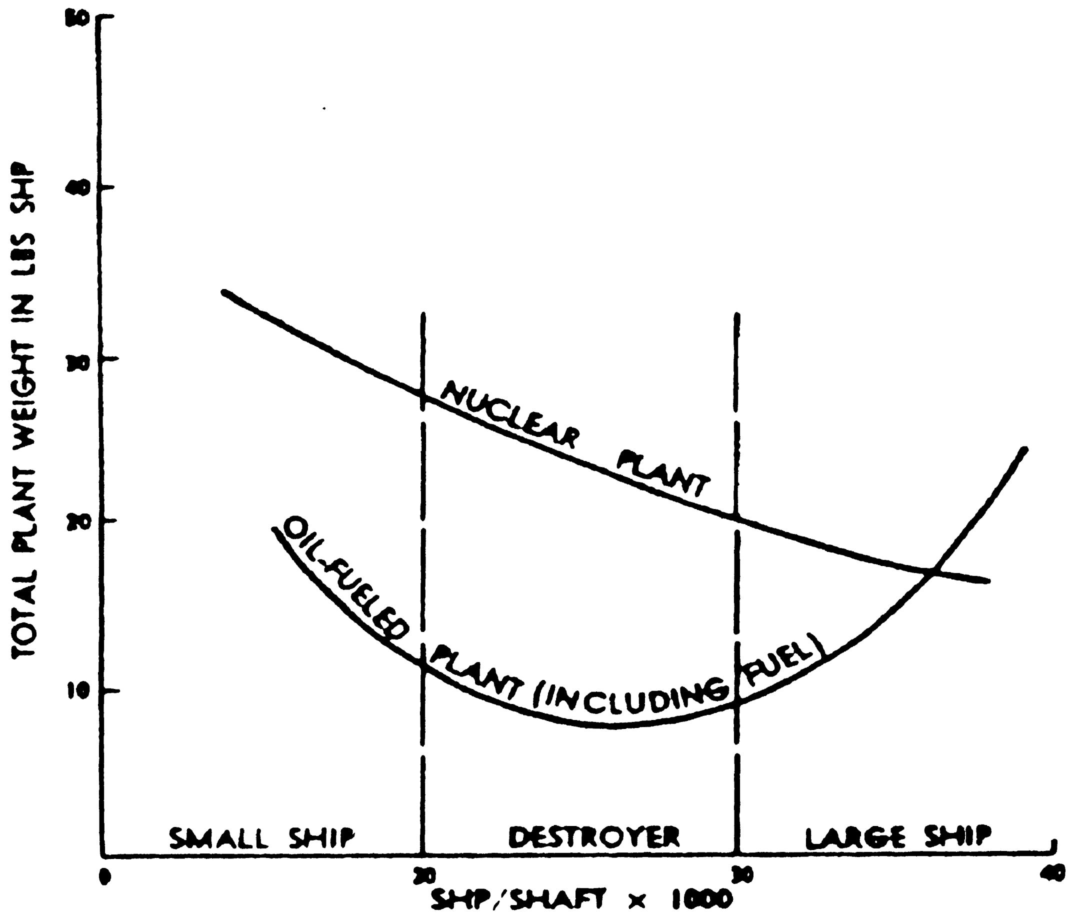
- FOR NAVAL SHIPS, GAS TURBINE PLANTS ARE ALSO WELL-SUITED TO AUTOMATION.

- STEAM PLANTS ARE MUCH MORE DIFFICULT TO AUTOMATE. THE LARGE ENGINE ROOM CREW REQUIRED AND THE INFERIOR FUEL ECONOMY ACCOUNT FOR THE LOSS OF POPULARITY OF STEAM PLANTS.

PROPULSIVE REQUIREMENTS & POWER SELECTION



PROPULSIVE REQUIREMENTS & POWER SELECTION



Problem 55

Problem Level: Intermediate

A model of a destroyer escort is built to a scale ratio, $\lambda = 61.6$.
The model characteristics are:

L_{pp} = 60.00"

B = 7.00"

T = 2.24"

Δ = 17.90 lb in fresh water

Wetted Surface = 459.4 in^2

(a) Find the corresponding characteristics of the full size DE floating at the same waterline in salt water

The model was tank tested and the following data were taken at the DE's maximum speed.

V_m = 3.30 knots

R_{t_m} = .760 lbs

$$\rho = 1.9360 \; \frac{\text{lb sec}^2}{\text{ft}^4}$$

C_{f_m} = 3.764×10^{-3}

(b) Expand this result to find the EHP required for the ship at the corresponding speed. What is this speed? Include a correlation allowance of $.4 \times 10^{-3}$. Take:

$$\rho = 1.9905 \; \frac{\text{lb sec}^2}{\text{ft}^4}$$

C_{f_s} = 1.462×10^{-3}

Problem 55 (continued)

Problem Level: Intermediate

(c) The following efficiencies are estimated:

transmission efficiency = .98

hull efficiency = .92

relative rotative efficiency = 1.03

propeller efficiency = .59

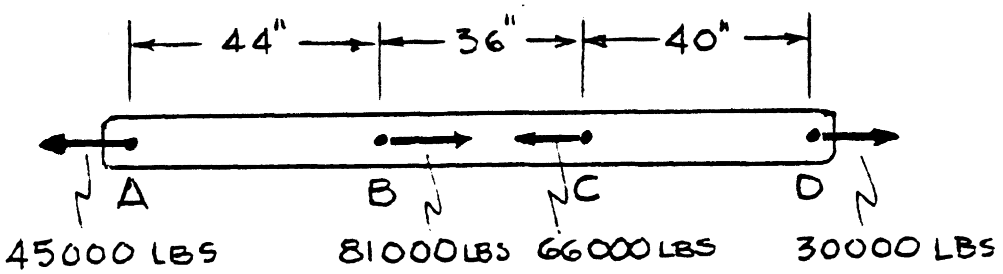
Find the propulsive coefficient and the SHP required for the DE at its maximum speed.

BASIC NAVAL ARCHITECTURE

Problem 56

Problem Level: Basic

The strut shown below carries four loads applied at points A, B, C, and D. The strut is 3/4" x 4" flat bar.



(a) Is the strut in equilibrium with the force system shown?

(b) Find the stress in lbs/in^2 and the strain in in/in at the midpoints between A and B, B and C, and C and D. For steel take $E = 30 \times 10^6$ lbs/in^2.

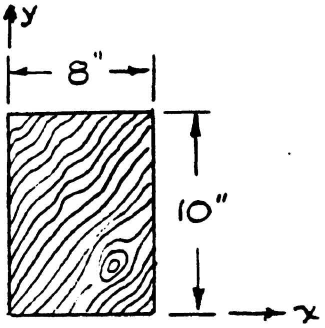
(c) Find the total extension or contraction in the length of the strut under load. (Note: Assume for the purpose of the problem that the stresses and the strains are uniform from point A to point B, from point B to point C, and from point C to point D. (Actually, stresses and strains will vary in the vicinity of the points of load application).

26-35

Problem 57

Problem Level: Basic

The cross section of a rectangular beam is shown below:



(a) Find the height of the neutral axis above the x-axis (Units: inches)

(b) Find the Moment of Inertia and the Section Modulus of the beam section (Units: in^4 and in^3)

(c) The beam at this location is acted upon by a bending moment of 20,000 ft-lbs (Note: convert to in-lb). Find the maximum bending stress and the location of the maximum bending stress under these conditions. (Units: lbs per in^2)

(d) The material (wood) has a yield point of 2500 lbs/in^2. The allowable stress for this service is 60% of yield stress.

Will the beam be within allowable stress levels?

Will the beam fail?

26-36

(a) GIVEN. MODEL DIMENSIONS, $\lambda = 61.6$

FIND: SHIP DIMENSIONS

MODEL	SCALING	SHIP
$L_{PP_m} = 60.00''$	$\frac{60.00 \text{ IN}}{12 \text{ IN/FT}} \times (61.6)$	$L_{PP_S} = 308.0$ FT
$B_m = 7.00''$	$\frac{7.00 \text{ IN}}{12 \text{ IN/FT}} \times (61.6)$	$B_S = 35.93$ FT
$T_m = 2.24''$	$\frac{2.24 \text{ IN}}{12 \text{ IN/FT}} \times (61.6)$	$T_S = 11.50$ FT
$\Delta_m = 17.90$ LB(FW)	$\frac{17.90 \text{ LB} \times (61.6)^3 \times 1.026}{2240 \text{ LB/LT}}$	$\Delta_S = 1916.4$ LT

NOTE: MODEL AND SHIP WILL BE TESTED AT THE SAME CORRESPONDING WATERLINE, THUS,

$$\nabla_S = \nabla_m \times \lambda^3$$

$$\Delta_S \times 35 \frac{FT^3}{TON} = \Delta_m \times 35.9 \frac{FT^3}{TON} \times \lambda^3$$

$$\Delta_S = \Delta_m \times \frac{35.9 \text{ FT}^3/\text{TON}}{35 \text{ FT}^3/\text{TON}} \times \lambda^3$$

$$\Delta_S = \Delta_m \times \lambda^3 \times 1.026 \quad (\text{BOTH } \Delta\text{'s IN LT})$$

$S_M = WS_m = 459.4 \text{ IN}^2$ $\quad \frac{459.4 \text{ IN}^2 \times (61.6)^2}{144 \text{ IN}^2/\text{FT}^2}$ $\quad WS_S = 12,106 \text{ FT}^2$

(b) GIVEN: V_m, R_{t_m}, ρ_m, C_{f_m}

FIND: V_S, EHP_S

MODEL	SCALING	SHIP
$V_m = 3.30$ KTS	$3.30 \times \sqrt{61.6}$	25.90 KNOTS

RESISTANCE EXPANSION AND EHP PREDICTION:

FIND $C_{t_m} = \dfrac{R_{t_m}}{\frac{\rho_m}{2} S_m V_m^2}$ $\qquad V_m = V_m \times 1.688 \frac{\text{FT/SEC}}{\text{KNOT}}$

$V_m = 3.30 \text{ KTS} \times 1.688 \frac{\text{FT/SEC}}{\text{KNOT}}$

$\rho_m = 1.9360 \frac{\text{LB SEC}^2}{\text{FT}^4}$ $\qquad V_m = 5.57$ FT/SEC.

$S_m = \dfrac{459.4 \text{ IN}^2}{144 \text{ IN}^2/\text{FT}^2} = 3.19 \text{ FT}^2$ $\qquad R_{t_m} = 0.760$ LBS.

$$C_{t_m} = \frac{0.760 \text{ LBS}}{\left(\frac{1.9360}{2} \frac{\text{LB SEC}^2}{\text{FT}^4}\right)\left(3.19 \text{ FT}^2\right)\left(5.57 \frac{\text{FT}}{\text{SEC}}\right)^2}$$

NOTE! CHECK TO CONFIRM THAT UNITS DO CANCEL AND THAT C_{tm} IS, IN FACT, NON-DIMENSIONAL.

$$C_{t_m} = .007933 = 7.933 \times 10^{-3}$$

(GIVEN) $C_{f_m} = \quad = 3.764 \times 10^{-3}$

$C_{t_m} - C_{f_m} = C_{r_m} = \quad = 4.169 \times 10^{-3}$

$C_{r_m} = C_{r_s} = \quad = 4.169 \times 10^{-3}$

(GIVEN) $C_{f_s} = \quad = 1.462 \times 10^{-3}$

(GIVEN) $C_A = \quad = 0.400 \times 10^{-3}$

$C_{r_s} + C_{f_s} + C_A = C_{t_s} = \quad = 6.031 \times 10^{-3}$

$$R_{t_s} = C_{t_s} \times \frac{\rho_s}{2} \times S_s \times V_s^2 \; ; \quad V_s = 25.90 \text{ KTS} \times 1.688 \frac{\text{FT/SEC}}{\text{KT}}$$

$$V_s = 43.72 \text{ FT/SEC}$$

$$R_{t_s} = \left(6.031 \times 10^{-3}\right)\left(\frac{1.9905}{2} \frac{\text{LB SEC}^2}{\text{FT}^4}\right)\left(12{,}106 \text{ FT}^2\right)\left(43.72 \frac{\text{FT}}{\text{SEC}}\right)^2$$

$$R_{t_s} = 138{,}894 \text{ LBS}$$

$$EHP_s = \frac{R_{t_s} \times V_s}{550} = \frac{(138{,}894 \text{ LBS})(43.72 \text{ FT/SEC})}{550 \frac{\text{FT-LBS/SEC}}{\text{HP}}}$$

$$\underline{\underline{EHP_s = 11{,}041 \text{ HP}}}$$

PROPULSIVE COEFF = $\eta_o \times \eta_h \times \eta_r \times \eta_t = (.59)(.92)(1.03)(.98)$

$$P.C. = 0.548$$

$$P.C. = \frac{EHP}{SHP}$$

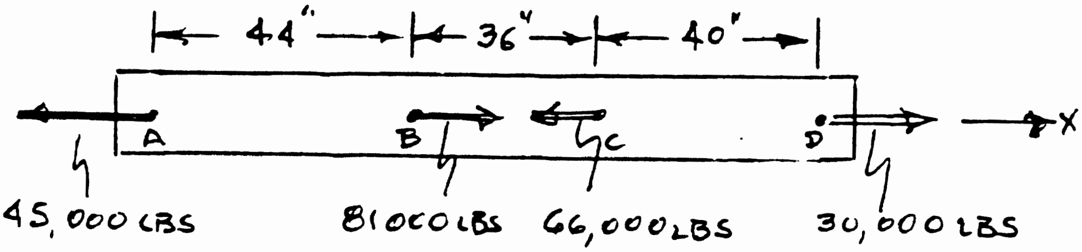
$$SHP = \frac{EHP}{P.C.} = \frac{11{,}041 \text{ HP}}{0.548}$$

$$\underline{\underline{SHP_s = 20{,}148 \text{ HP}}}$$

GIVEN: STRUT IS 3/4" × 4" FLAT BAR.

FORCES AS SHOWN IN SKETCH.

FIND: STRESSES, STRAINS, AND EXTENSIONS IN BAR



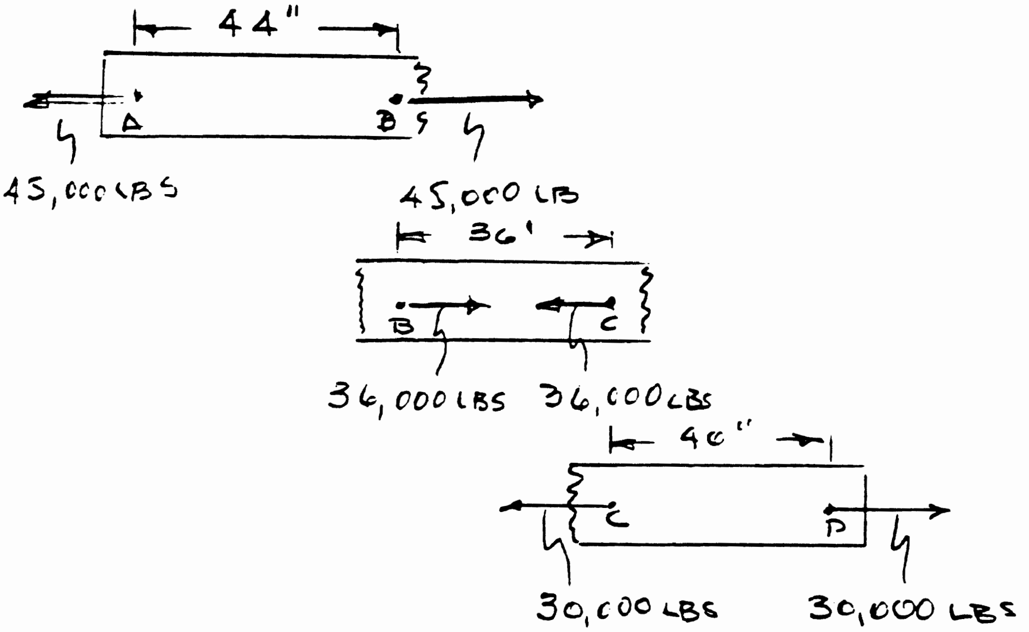
(a) CHECK FOR EQUILIBRIUM. +x TO THE RIGHT

$$-45{,}000 \text{ LBS} + 81{,}000 \text{ LBS} - 66{,}000 \text{ LB} + 30{,}000 \text{ LB} \overset{?}{=} 0$$

$$0 \equiv 0$$

THE STRUT IS IN EQUILIBRIUM (SINCE $\Sigma F_x = 0$)

(b)



DECOMPOSE THE STRUT INTO THE FORCE SYSTEMS SHOWN. EACH SEGMENT IS IN EQUILIBRIUM.

THE STRUT HAS A CROSS SECTIONAL AREA OF $3/4" \times 4" = 3.00 \text{ IN}^2$

FROM A TO B:

$$\sigma_{AB} = \frac{P_{AB}}{A} = \frac{45{,}000 \text{ LBS}}{3.00 \text{ IN}^2} = 15{,}000 \text{ LBS/IN}^2 \text{ (TENSION)}$$

$$\sigma_{AB} = E\epsilon; \quad \epsilon_{AB} = \frac{\sigma_{AB}}{E} = \frac{15{,}000 \text{ LBS/IN}^2}{30 \times 10^6 \text{ LBS/IN}^2}$$

$$\epsilon_{AB} = .5 \times 10^{-3} \text{ IN/IN} = +.0005 \text{ IN/IN (EXTENSION)}$$

(NOTE: EXPLAIN UNITS OF STRAIN TO STUDENT.)

TOTAL EXTENSION, δ_{AB}, IN SEGMENT AB = $\epsilon_{AB} l_{AB}$

$$\delta_{AB} = .0005 \text{ IN/IN} \times 44 \text{ IN} = +.022 \text{ IN (EXT.)}$$

FROM B TO C:

$$\sigma_{BC} = \frac{P_{BC}}{A} = \frac{36{,}000 \text{ LBS}}{3.00 \text{ IN}^2} = 12{,}000 \text{ LBS/IN}^2 \text{ (COMP)}$$

$$\epsilon_{BC} = \frac{\sigma_{BC}}{E} = \frac{12{,}000 \text{ LB/IN}^2}{30 \times 10^6 \text{ LB/IN}^2} = -.4 \times 10^{-3} = .0004 \frac{\text{IN}}{\text{IN}} \text{ (CONTR.}$$

$$\delta_{BC} = \epsilon_{BC} l_{BC} = .0004 \text{ IN/IN} \times 36 \text{ IN} = -.0144 \text{ IN (CONTR.}$$

FROM C TO D:

$$\sigma_{CD} = \frac{P_{CD}}{A} = \frac{30{,}000 \text{ LBS}}{3.00 \text{ IN}^2} = 10{,}000 \text{ LB/IN}^2 \text{ (TENSION)}$$

$$\epsilon_{CD} = \frac{\sigma_{CD}}{E} = \frac{10{,}000 \text{ LBS/IN}^2}{30 \times 10^6 \text{ LB/IN}^2} = +.333 \times 10^{-3} = +.000333 \text{ (EXT)}$$

$$\delta_{CD} = \epsilon_{CD} l_{CD} = .000333 \frac{\text{IN}}{\text{IN}} \times 40'' = +.012 \text{ IN (EXT.)}$$

TOTAL E TENSION

AB = +.022 IN
BC = −.014 IN
CD = +.012 IN

AD = .020 IN.

26.40

RECAP!

(b)

$\sigma_{AB} = 15{,}000 \text{ LBS/IN}^2$ (TENSION)

$\epsilon_{AB} = .0005 \text{ IN/IN}$ (EXTENSION)

$\sigma_{BC} = 12{,}000 \text{ LBS/IN}^2$ (COMP)

$\epsilon_{BC} = .0004 \text{ IN/IN}$ (CONTR.)

$\sigma_{CD} = 10{,}000 \text{ LBS/IN}^2$ (TENSION)

$\epsilon_{CD} = .000333 \text{ IN/IN}$ (EXT.)

(c)

$\delta_{AD} = .020$

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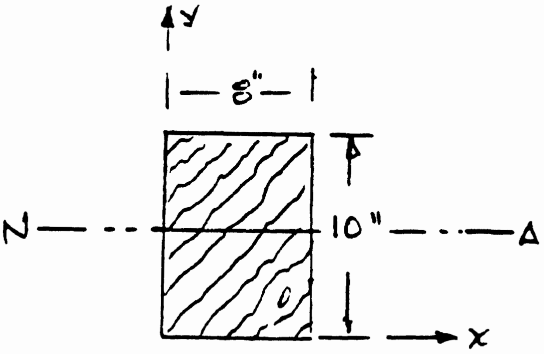
GIVEN: RECTANGULAR WOOD BEAM OF DIMENSIONS SHOWN

$\sigma_y = 2500$ LBS/IN^2

$\sigma_{all} = .60 \times 2500 = 1500$ LBS/IN^2

$M_b = 20{,}000$ FT-LBS $= 240{,}000$ IN-LB



(a) BY SYMMETRY THE NEUTRAL AXIS IS AT THE CENTROID OF THE SECTION 5.00" ABOVE THE X-AXIS.

$\bar{y}$ = N.A. = 5.00" ABOVE X-AXIS

(b) MOMENT OF INERTIA OF A RECTANGULAR SECTION ABOUT ITS CENTROID IS, $I = bh^3/12$

$$I_{NA} = \frac{(8\text{ IN})(10\text{ IN})^3}{12} = 666.7 \text{ IN}^4$$

$$S.M = \frac{I}{c} \; ; \quad c_{TOP} = c_{BOT} = 5.00 \text{ IN}$$

$$SM = \frac{666.7 \text{ IN}^4}{5.00 \text{ IN}} = 133.3 \text{ IN}$$

(a) $I_{NA} = 666.7 \text{ IN}^4$

$SM_{top} = SM_{bot} = 133.3 \text{ IN}^3$

(c) $$\sigma_{MAX} = \frac{M_b}{I/c} \; ; \quad \sigma_{MAX} = \frac{240{,}000 \text{ IN-LB}}{133.3 \text{ IN}^3} = 1800 \frac{\text{LBS}}{\text{IN}^2}$$

(d) THE MAXIMUM STRESS WILL OCCUR AT $y=0$, $y=10$ AND WILL BE 1800 LBS/IN^2 (TENSION, COMPRESSION) THE ALLOWABLE STRESS WILL BE EXCEEDED BUT THE YIELD STRESS WILL NOT BE EXCEEDED. BEAM WILL NOT FAIL