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BASIC NAVAL ARCHITECTURE
INSTRUCTOR'S GUIDE
AND PROBLEM SET

Prepared by

Giannotti & Associates of Texas, Inc.

703 Giddings Ave.

Annapolis, MD 21401

for

The University of Michigan

Transportation Research Institute

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Volume I Units 1-11

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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 II and III, 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: Introduction, Ship Types and Ship Systems, Nomenclature, Dimension Form and Flotation, and Static Stability.

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.

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Many persons were instrumental in the development of this education material. The seeds that started it growing came from the membership of the Education and Training Panel of the Society of Naval Architects and Marine Engineers' Ship Production Committee. Those seeds were planted by dedicated Panel members in 1982, who then saw the project through to its completion. Their initial effort in concept development, and subsequent follow through in monitoring of the project are gratefully acknowledged.

Appreciation is also expressed to the sub-contractor who developed the project: Giannotti and Associates. The Education and Training Panel feels it was fortunate to have selected this firm to perform the project. The performance of all their personnel was an inspiration to those who monitored its progress. Three persons on Giannotti staff, however, must be given special mention: Dr. Julio Giannotti, Dr. Paul Van Mater, and Mr. David Gardy (of Gardy/McGrath International, Inc.). Dr. Giannotti saw the project as a significant contribution to the profession, and continued to support the effort long after the available funds had been exhausted. Dr. Paul Van Mater, as the project director, provided the extra percentage of effort that has made this instruction set a unique teaching resource on naval architecture. And Mr. David Gardy skillfully produced the video tapes on a low budget.

BASIC NAVAL ARCHITECTURE

CONTENTS

Section

NOTE: Homework Problems are located at the end of each Unit Lesson Plan. If a homework problem is assigned in more than one lesson plan, then it is located with the Unit where it is first assigned.

Basic Naval Architecture

Section 1.0

Topical Coverage of Course

Basic Naval Architecture

Section 2.0

Notes To Instructors

2.1 DESCRIPTION OF COURSE.

This course consists of 45 videotapes covering basic topics in naval architecture, as well as an *Instructor Guide and Problem Set* containing notes to instructors, suggested lesson plans, problems and solutions. The level of material presented also makes it suitable for: graduate engineers transferring into the field of naval architecture; a college level study course for students not majoring in the field (i.e. Ocean Engineering majors) or a naval or merchant marine officer candidate program.

The mathematical background required of the students is two years of high school algebra (including an introduction to trigonometry) and one year of high school geometry. Problems in the course, including topics in numerical integration, are introduced assuming this background. Diagnostic examples are included in the first unit to enable the student to evaluate whether or not his mathematical skills are adequate to cope with the mathematics in the course.

2.2 WAYS IN WHICH THIS COURSE MAY BE USED.

The course is designed so that it may be used in a variety of ways.

(1) In an organized classroom presentation the videotape may be played at the beginning of a class period followed by a classroom instructor presentation in which key points are emphasized, supplementary material is presented, and questions on problems are addressed. The videotapes are not uniform in length; most run between thirty and thirty-five minutes. A class period of one hour to one hour and fifteen minutes will allow the instructor about a half-hour to present his material. <u>A class period of an hour and half, or two fifty-minute periods would be optimal</u>.

(2) The instructor also may elect to tailor the course to the specific career areas of his students. For example, for an audience which in the future will be heavily involved in the design or erection of ship structures and will have very little contact with propulsion machinery, the section of the course on ship structures could be heavily emphasized, (perhaps with the addition of supplementary material) while the section on propulsion could be drastically curtailed and perhaps limited to reading assignments with no problems or videotapes. However, if the full course coverage is elected together with 30 or more assigned problems, the student can look forward to an intensive learning experience.

(3) Finally, the tapes and the text may be used in a self-instruct mode. To complete the course through self instruction requires a mature student with determination. For this application, the videotapes would be issued by the sponsoring institution's library or training office to the student to be used at his own pace. An experienced engineer or naval architect should be assigned as the student's monitor to issue and correct problems, and give tests if appropriate.

2.3 TEXT AND RECOMMENDED REFERENCES.

The text selected for this course is:

Modern Ship Design, Second Edition, 1977, Thomas C. Gillmer, United States Naval Institute, Annapolis, MD 21402 (1987 list price - $21.95, USNI members get 20% discount)

The text was written primarily for midshipmen and naval officer candidates with some college math but without an engineering background. It has been selected because the reading level of the book is appropriate to the anticipated level of students in this course. In addition, the book emphasizes the total process of ship design. Giving the student a perspective on the ship design process is a collateral objective of the course. Certain sections of the book are now obsolescent or obsolete (e.g., the discussion of Navy Department ship procurement procedures), but this has only a very small impact on the value of the book for our purposes.

The text includes a sheet of "Displacement and other Curves: for the DD692 class destroyer." Problems are included in the problem set which use these curves.

A similar book using many of the same text passages and illustrations but aimed at sophomore-level engineering students is recommended as a reference:

> *Introduction to Naval Architecture*, 1982, Thomas C. Gillmer and Bruce Johnson, Naval Institute Press, Annapolis, MD 21402 ($23.95 list price, USNI members get 20% discount).

There are two books published by the Society of Naval Architects and Marine Engineers which are extremely valuable as references for the instructor, but which are expensive and technically above the level of most of the students who will take this course. Many of the figures used in the videotapes have been taken from one of these two sources.

> *Principles of Naval Architecture*, 1967, John P. Comstock, Editor, Society of Naval Architects and Marine Engineers, 601 Pavonia Avenue, Jersey City, NJ 07306 (list price $60.00, SNAME members $40.00)

> *Ship Design and Construction*, 1980, Robert Taggart, Editor, Society of Naval Architects and Marine Engineers, 601 Pavonia Avenue, Jersey City, NJ 07306 (list price $75.00, SNAME members $55.00)

The new edition of Principles of Naval Architecture, Volumes I, II, III, 1988-89, Editor Edward V. Lewis, is also available from the Society of Naval Architects and Marine Engineers. Other references which would be useful to the instructor are listed in the lesson plans.

2.4 TIME REQUIREMENTS FOR THE COURSE.

Naval architectural calculations tend to be time consuming, and, as will be emphasized below, the write-up of the calculations in an acceptable engineering format is an important part of the learning experience. Many problems included in this course will require approximately two to three hours to solve and write up. A few are shorter and some are longer. Suggested problem assignments are listed in the lesson; however, the instructor should be selective in choosing the problems he assigns so that the maximum learning value will be achieved in a realistic study time.

The amount of emphasis to be placed on problems is strictly a matter of judgement on the part of the instructor. Some audiences may never have occasion to do engineering calculations in the course of their careers. For this type of audience the simpler and less time consuming problems will provide adequate reinforcement to the course material. For other audiences whose destiny is to provide a more technical level of engineering, calculations will be invaluable.

Pre-reading of the assigned material in the text is important and should be stressed by the instructor. Often the videotapes will go into greater depth or present more material than is presented in the text. Pre-reading of the assigned pages in the text will definitely improve assimilation of the material presented on the tapes. The instructor should be prepared to point his students toward important points to study in the text in order to prepare for the following period's tape and instructor presentations. This requires that the instructor stay well ahead of the class in previewing the tapes, text, and problems to be assigned.

For the full course coverage described above with videotapes and instructor lectures, probably a minimum time investment by the student of 120 hours, (including class, study time and problem time) would be required to achieve the minimum course objectives. In most settings, very few students would be able to commit more than 180 hours to the course. Course coverage and problem assignments should be selected by keeping realistic time limitations.

2.5 MATERIALS REQUIRED FOR THE COURSE.

The Instructor Guide and Problem Set and a set of 45 VHS videotapes will be supplied by The University of Michigan Transportation Research Institute. The Instructor Guide and Problem Set includes four sheets of Curves of Form* approximately 18" x 36" in size (for three example ships used in the problems), course information, and notes to the instructor. A set of seventy problems with worked solutions is included together with a note entitled "Engineering Calculations" intended to be used as a handout to students.

> REPRODUCTION OF ALL MATERIALS TO BE DISTRIBUTED TO STUDENTS IS THE RESPONSIBILITY OF THE SPONSORING INSTITUTION.

The student should provide a "scientific-type" calculator which, today, is widely available at nominal cost. The calculator must have capabilities for trigonometric functions, logarithms (base 10) and powers (y^x), all of which are used in the problems. Other features (such as statistical analysis) are commonly found on scientific calculators, but are not necessary for the course.

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* These curves are provided in the mailing tube that accompanies the Instructor Guide. The drawings are on mylar and should be reproduced for the student in full scale. The curves include:
  1) Curves of Form, FFG-7 Class Frigate
  2) Bonjean Curves and Cross Curves of Intact Stability, FFG-7
  3) Curves of Form, U.S.C.G. Bear Class Cutter
  4) Curves of Form, MARAD PD-214 Mobilization Container Ship

It is strongly urged that all problems be submitted on cross-section paper following good procedure for engineering calculations. The instructor may wish to request a specific type of cross-section for uniformity, or he may even wish to distribute pre-printed calculation sheets used by the sponsoring institution. However, a simple 5x5 quadrille paper (available wherever school supplies are sold) will serve the purposes of the course. Use of tabular formats in calculations is stressed repeatedly in the tapes, and the use of cross-section paper will simplify the preparation of these tables and sketches.

Although not strictly required for the course, the student may find it convenient to purchase several French curves. A #60 and a #109 should be all that are needed to plot the curves required in several of the problems.

2.6 PROBLEMS.

Problems worked by the students serve several important purposes:

(1) problems reinforce the concepts presented in the course,

(2) problem solutions develop specific skills in the naval architectural topics presented in the course, and

(3) working problems and writing up the solution in standard engineering format develops the discipline required to perform any type of engineering calculation.

Concept reinforcement may be achieved by use of the simpler and less time-consuming problems, but specific skill development and engineering calculation discipline require more practice and a greater time investment. The instructor should select problems with the specific needs of the student in mind.

The student should be encouraged to keep a notebook of corrected problems. The instructor may wish to require that the problem statement be submitted with the solution to ensure that the student's notebook includes the problem statement as well as the solution. The instructor may even wish to return a copy of the correct solution appended to the student's submission. However, if the course is to be offered on a regular basis, the instructor may be assured that these solutions will find their way into the hands of future students.

It takes time to cultivate accuracy. The instructor should not be surprised if very few of his beginning students get exactly the right answer to the problem as they start in the learning process. With time, the student learns to avoid some of the computational pitfalls and his accuracy improves.

The use of tabular formats in performing standard calculations is very useful in avoiding errors before they happen, and this should be emphasized in classroom presentations. Errors in the conversion of physical units are also common -- even in the case of experienced engineers. Difficulties in this area can be reduced by requiring the students to carry the units in each quantity involved in the calculation and to cancel units to ensure consistency of units in the result.

The instructor may also wish to provide the students with check values for various stages of the solution. It is very frustrating to a student to spend several hours in developing a solution only to find that he made a mistake in the first step. As students develop computational maturity, this type of assistance can be gradually discontinued.

Problems are listed in the Course Outline for the first unit to which they are relevant. It is not intended that all problems listed be assigned concurrently with the unit. Rather, the instructor should prepare problem assignments which maintain a uniform outside working load for the student. Note that there are periods in the course (e.g. Units 20, 21 and 22) which can be used to assign previously unassigned problems.

Notes entitled "ENGINEERING CALCULATIONS" are presented at the beginning of Section 5.0 . The instructor may wish to distribute these, or a similar document of his own selection, at the beginning of the course.

2.7 USE OF COMPUTERS.

Oftentimes, students will have their own personal computers and may ask if computers can be used in the solution of problems.

There are many standard computer programs which can be applied to all the topical areas covered in this course. Today's engineer or engineering technician must become a skilled user of the computer tools available to him, but this does not imply that he must become a skilled computer programmer.

This course is not a course in computer programming. Rather, it is intended to develop the computational skills which still form a large part of engineering practice and which provide the background logic upon which computer programs are written. THE USE OF COMPUTERS AND THE PREPARATION OF COMPUTER PROGRAMS TO SOLVE THE PROBLEMS IN THIS COURSE IS NOT RECOMMENDED. If the development of computer programming will be important in the future to students of the course, then these skills should be taught separately.

As a practical matter the instructor will find that if he accepts computer print-outs for problem solutions it will require untenable amounts of time to correct the problems and trace the student's logic through the maze of variable names and subroutines contained in a program listing.

2.8 SPONSORSHIP

The production of the videotapes and course materials has been done by Giannotti & Associates, Inc. and its successor firm, Giannotti & Associates of Texas, Inc., of Annapolis, Maryland and Ventura, California. Video production was done in the studios of Gardy McGrath International, Inc. of Newington, Virginia. Direct sponsorship of the project has been through:

The University of Michigan
Transportation Research Institute
Marine Systems Division
2901 Baxter Rd.
Ann Arbor, Michigan 48109-2150

Distribution of the videotapes and the instructor Guide will be done by the AVMAST (Audio-Visual-Material-Available-for-Shipyard-Training) Library managed by UMTRI. Inquiries regarding the course or the course materials should be addressed to UMTRI.

2.9 GRAPHICS

A complete set of graphics used in the videotapes are included in the unit lesson plans. The instructor may use these for transparencies to reinforce the videotape presentation.

Unit 1 *Basic Naval Architecture - Introduction* Scope and coverage of course. Text, references, materials required. Background required. Math diagnostic examples.	**Homework** Problems - None Readings Gillmer pages - None **Videotape Information** Time= 45 minutes AVMAST# ED23
Unit 2 *Basic Naval Architecture - Ship Types and Ship Systems - 1* The ship as an element in a transportation system. Photos of ship types. General cargo, container, RO/RO, passenger/car ferries, Seabee and Lash, tankers, various types of bulk carriers, QE2, cruise ships.	**Homework** Problems - articles Readings Gillmer pages 3-10 **Videotape Information** Time= 34 minutes AVMAST# ED24
Unit 3 *Basic Naval Architecture - Ship Types and Ship Systems - 2* Photos of ship types continued. Tugs, offshore supply boats, integrated tug-barge, river towboats. SWATH, catamaran, SES, ACV, planing boats, hydrofoil craft, offshore drilling and production rigs. Naval ships, submarines, battleship,aircraft carrier.	**Homework** Problems - articles Readings Gillmer pages 11-12 **Videotape Information** Time= 34 minutes AVMAST# ED25
Unit 4 *Basic Naval Architecture - Ship Types and Ship Systems - 3 Nomenclature - 1* Merchant ship types by trade. Naval ships as elements in a warfare system. Ship types classified by type of support. Nomenclature - units. Directions on board ship. Ship dimensions. Weight, displacement, tonnage, load lines.	**Homework** Problems - Nomencla-ture Readings Gillmer pages 13-15 **Videotape Information** Time= 37 minutes AVMAST# ED26

Unit 5

Basic Naval Architecture - Nomenclature - 2

Parts of a ship. Decks and bulkheads. Doors, hatches, scuttles, manholes. Spaces on board ship. Anchoring and mooring.

Homework
Problems - None

Readings
Gillmer pages - None

Videotape Information
Time= 39 minutes
AVMAST# ED27

Unit 6

Basic Naval Architecture - Nomenclature - 3

Boat handling equipment. Cargo handling equipment. Dunnage, sparring and ceiling. Structural nomenclature. Strakes, stringers, floors, double and single bottoms, keels, stem castings, stern castings.

Homework
Problems - None

Readings
Gillmer pages - None

Videotape Information
Time= 37 minutes
AVMAST# ED28

Unit 7

Basic Naval Architecture - Dimension, Form and Flotation - 1

Ship geometry. Dimensions. Freeboard and draft. Displacement and tonnage. Lines drawing. Form coefficients.

Homework
Problems - None

Readings
Gillmer pages 21-27

Videotape Information
Time= 28 minutes
AVMAST# ED29

Unit 8

Basic Naval Architecture - Dimension, Form and Flotation - 2

Form coefficients example. Centers - CG, CB, metacenter, GM. Moments. Example of LCG calculation.

Homework
Problems - 1, 2, 3, 4, 5

Readings
Gillmer pages 27-37

Videotape Information
Time= 34 minutes
AVMAST# ED30

Unit 9 *Basic Naval Architecture - Dimension, Form and Flotation - 3* Archimedes Principle. Curves of form and hydrostatic parameters. Bonjean's curves.	**Homework** Problems - 6, 7,10,11, 12 Readings Gillmer pages 37-41 **Videotape Information** Time= 28 minutes AVMAST# ED31
Unit 10 *Basic Naval Architecture - Dimension, Form and Flotation - 4* Differentiation and integration. Trapezoidal rule. Simpson's rule. Sectional area curve. Displacement calculation example.	**Homework** Problems - 13, 14, 15 Readings Gillmer pages 322-328 **Videotape Information** Time= 43 minutes AVMAST# ED32
Unit 11 *Basic Naval Architecture - The Ship at Rest - Static Stability - 1* Stable, neutral, unstable equilibrium. Position of the metacenter and equilibrium. GM, GZ, righting moment. Static stability curve. Weight shifts. BM. Moment of inertia. Rectangular barge example.	**Homework** Problems - 8, 9, 16, 17, 18, 23 Readings Gillmer pages 51-58 **Videotape Information** Time= 32 minutes AVMAST# ED33
Unit 12 *Basic Naval Architecture - The Ship at Rest - Static Stability - 2* Transverse weight shift example. Inclining experiment, example. Cross curves of stability. Corrections for actual KG. Corrections to static stability curve.	**Homework** Problems - 29, 30, 31, 34 Readings Gillmer pages 58-68 **Videotape Information** Time= 34 minutes AVMAST# ED34

Unit	Homework / Readings / Videotape Information
Unit 13 *Basic Naval Architecture - The Ship at Rest - Static Stability - 3* Negative GM. Longitudinal weight shift example, change of trim. Small weight additions.	**Homework** Problems - 27, 28, 32, 35, 36, 37, 38 Readings Gillmer pages 68-70 **Videotape Information** Time= 27 minutes AVMAST# ED35
Unit 14 *Basic Naval Architecture - The Ship at Rest - Static Stability - 4* Multiple weight additions. Tabular format, example. New drafts. Angle of list. Weight removals.	**Homework** Problems - 19, 20, 33, 39, 40, 41 Readings Gillmer pages 329-331 **Videotape Information** Time= 27 minutes AVMAST# ED36
Unit 15 *Basic Naval Architecture - Ship Hazards and Vulnerability - 1* Floodable length definitions. Floodable length curve. Free surface. Virtual rise of G. Pocketing.	**Homework** Problems - 26, 42, 43 Readings Gillmer pages 71-76 **Videotape Information** Time= 30 minutes AVMAST# ED37
Unit 16 *Basic Naval Architecture - Ship Hazards and Vulnerability - 2* Free communication effect. Added weight versus lost buoyancy. Shock. USN intact stability criteria. CFR 46 stability criteria.	**Homework** Problems - 44, 45 Readings Gillmer pages 79-85, 91-93, 253-255, 333-339 **Videotape Information** Time= 36 minutes AVMAST# ED38

Unit 17 *Basic Naval Architecture - Ship Hazards and Vulnerability - 3* Subdivision of naval ships. Protection of vital spaces. Assumed damage conditions. CFR 46 requirements. Grounding and stranding.	**Homework** Problems - 47, 48, 49, 50 Readings Gillmer pages 85-90 **Videotape Information** Time= 36 minutes AVMAST# ED39
Unit 18 *Basic Naval Architecture - Ship Hazards and Vulnerability - 4* Dry docking. Stability during docking. Example. Freeboard and load lines, merchant ships and naval ships.	**Homework** Problems - 46, 48, 49, 50 Readings Gillmer pages 90-91 **Videotape Information** Time= 28 minutes AVMAST# ED40
Unit 19 *Basic Naval Architecture - Submarine Hydrostatics and Stability* Submarine types and features. Ballast tanks. Submerging and surfacing. Submarine stability.	**Homework** Problems - 21, 22 Readings Gillmer pages 41-49, 76-79 **Videotape Information** Time= 30 minutes AVMAST# ED41
Unit 20 *Basic Naval Architecture - Forces Opposed to Propulsion - 1* Background. Wave making resistance. Frictional resistance. Froude's Law of Comparison. Residuary resistance. Model testing. Ship wave systems. Resistance coefficients.	**Homework** Problems - Previously Unassigned Readings Gillmer pages 95-102, 106-110 **Videotape Information** Time= 36 minutes AVMAST# ED42

Unit 21 *Basic Naval Architecture - Forces Opposed to Propulsion - 2* Correlation allowance. Friction formulations. Cf, Cw, Ct curves. Form drag. Bulbous bows.	**Homework** Problems - Previously Unassigned Readings Gillmer pages 102-114 **Videotape Information** Time= 35 minutes AVMAST# ED43
Unit 22 *Basic Naval Architecture - Forces Opposed to Propulsion - 3 Propulsive Forces and Propulsion Systems - 1* Resistance of submarines. Appendage resistance. Resistance in shallow water. Added resistance in a seaway. Hull roughness. Types of propulsors. Powering definitions and efficiencies. The screw propeller.	**Homework** Problems - Previously Unassigned Readings Gillmer pages 102-106, 110-114, 115-118 **Videotape Information** Time= 36 minutes AVMAST# ED44
Unit 23 *Basic Naval Architecture - Propulsive Forces and Propulsion Systems - 2* Momentum theory. Propeller geometry, wake, slip. Propeller curves. Propeller design.	**Homework** Problems - 51 Readings Gillmer pages 115-124 **Videotape Information** Time= 36 minutes AVMAST# ED45
Unit 24 *Basic Naval Architecture - Propulsive Forces and Propulsion Systems - 3* Number of blades. Hull-propeller interactions. The efficiency chain. Cavitation, super-cavitating propellers. Water jets, controllable pitch propellers, Kort nozzles. Vertical axis propellers.	**Homework** Problems - 52 Readings Gillmer pages 125-130 **Videotape Information** Time= 37 minutes AVMAST# ED46

Unit 25

Basic Naval Architecture - Propulsive Requirements and Power Selection - 1

Hull types and speed regimes. Scaling laws. Example. Model test expansion - example.

Homework
Problems - 53, 54

Readings
Gillmer pages 133-141

Videotape Information
Time= 30 minutes
AVMAST# ED47

Unit 26

Basic Naval Architecture - Propulsive Requirements and Power Selection - 2

Power prediction example. Standard series. Service power margin. Engine selection. Diesel engines. Combined plants. Gas turbines. Steam propulsion. Nuclear power. Comparisons.

Homework
Problems - 55, 56, 57

Readings
Gillmer pages 141-149

Videotape Information
Time= 37 minutes
AVMAST# ED48

Unit 27

Basic Naval Architecture - Maneuverability and Ship Control

The rudder; force, lift-drag, torque, aspect ratio. Rudder types. Motion of a ship in a turn. Thrusters. Z-drive systems. Active rudders. Comparisons.

Homework
Problems - Previously Unassigned

Readings
Gillmer pages 151-169

Videotape Information
Time= 37 minutes
AVMAST# ED49

Unit 28

Basic Naval Architecture - The Ship in Motion with the Sea - 1

Definitions. Sinusoidal waves. Trochoidal waves. Regular and irregular waves. Long-crested and short-crested waves. Seaway descriptions. Sea spectra. Ship motion computer programs.

Homework
Problems - Previously Unassigned

Readings
Gillmer pages 235-243

Videotape Information
Time= 38 minutes
AVMAST# ED50

Unit 29

Basic Naval Architecture - The Ship in Motion with the Sea - 2

Designing for ship motions. Rolling. Pitching. Yawing. Translational motions. SWATH ships.

Homework
Problems - PNA

Readings
Gillmer pages 243-253

Videotape Information
Time= 36 minutes
AVMAST# ED51

Unit 30

Basic Naval Architecture - The Strength and Structure of Ships - 1

Basic concepts, stress, strain. Stress-strain diagram. Hooke's Law. Neutralaxis. The flexure formula. Secion Modulus. Beams in bending.

Homework
Problems - 56, 57

Readings
Gillmer pages 205-207

Videotape Information
Time= 36 minutes
AVMAST# ED52

Unit 31

Basic Naval Architecture - The Strength and Structure of Ships - 2

Bending moment. Simple supports. Fixed-end supports. Bending moment and shear force diagrams. Steel handbook.

Homework
Problems - 58, 59

Readings
Gillmer pages 208-209

Videotape Information
Time= 29 minutes
AVMAST# ED53

Unit 32

Basic Naval Architecture - The Strength and Structure of Ships - 3

Section modulus example. Stress analysis example.

Homework
Problems - 60, 61

Readings
Gillmer pages - None

Videotape Information
Time= 33 minutes
AVMAST# ED54

Unit 33 *Basic Naval Architecture - The Strength and Structure of Ships - 4* Loads on the ship's structure. Barge bending moment and shear force example. Stresses in deck and bottom.	**Homework** Problems - 62, 63, 64 Readings Gillmer pages 210-212 **Videotape Information** Time= 35 minutes AVMAST# ED55
Unit 34 *Basic Naval Architecture - The Strength and Structure of Ships - 5* Ship bending moment, shear force and stress diagrams in still water and in trochoidal waves. ABS requirements. Bending moment estimates. Strength and stiffness.	**Homework** Problems - 65 Readings Gillmer pages 212-216 **Videotape Information** Time= 34 minutes AVMAST# ED56
Unit 35 *Basic Naval Architecture - The Strength and Structure of Ships - 6* Properties of shipbuilding materials. Shipbuilding steels, ductility, toughness, Aluminum, GRP. Steel shapes, designation. Steel plate. Stiffened plating.	**Homework** Problems - 66, 67 Readings Gillmer pages 216-219 **Videotape Information** Time= 35 minutes AVMAST# ED57
Unit 36 *Basic Naval Architecture - The Strength and Structure of Ships - 7* Failure modes for steel structures. Plasticity. Buckling. Fracture, fatigue. Stress concentrations. Structural continuity. Crack arrestors. Causes for cracking.	**Homework** Problems - 68 Readings Gillmer pages 219-220 **Videotape Information** Time= 34 minutes AVMAST# ED58

Unit	Content	Homework / Readings / Videotape Information
Unit 37	*Basic Naval Architecture - The Strength and Structure of Ships - 8* Framing systems. Structural terminology. Double bottom, single bottom construction. Bow and stern construction.	**Homework** Problems - 69 Readings Gillmer pages 221-227 **Videotape Information** Time= 31 minutes AVMAST# ED59
Unit 38	*Basic Naval Architecture - The Strength and Structure of Ships - 9* Bulkheads. ABS requirements. Hatch corners, intersections, connections, brackets. Deckhouses. Foundations.	**Homework** Problems - 70 Readings Gillmer pages 228-232 **Videotape Information** Time= 35 minutes AVMAST# ED60
Unit 39	*Basic Naval Architecture - The Strength and Structure of Ships - 10* The midship section drawing. Section modulus calculation. Typical midship sections. Mariner, FFG-7, "Bear" class cutter, tanker, bulk carrier, RO/RO ship, SL-7 container ship. The weight estimate.	**Homework** Problems - Developed by Instructor Readings Gillmer pages 232-233 **Videotape Information** Time= 37 minutes AVMAST# ED61
Unit 40	*Basic Naval Architecture - The Ship Design Process - 1* Merchant vessel design. Mission requirements. The design spiral. Parametric design studies. Feasibility studies. Concept, preliminary, contract design phases. Deliverables. Detail design.	**Homework** Problems - Previously Unassigned Readings Gillmer pages 257-262 **Videotape Information** Time= 29 minutes AVMAST# ED62

Unit 41

Basic Naval Architecture - The Ship Design Process - 2

Concept design example.

Homework
Problems - Previously Unassigned

Readings
Gillmer pages 289-309

Videotape Information
Time= 31 minutes
AVMAST# ED63

Unit 42

Basic Naval Architecture - The Ship Design Process - 3

Steps in preliminary design. Contract design. Design margins. Naval ship design and procurement.

Homework
Problems - None

Readings
Gillmer pages 263-269

Videotape Information
Time= 29 minutes
AVMAST# ED64

Unit 43

Basic Naval Architecture - Shipbuilding Methods - 1

Use of the computer in design and manufacturing. CAD/CAM drafting, lofting, shell plate development, nesting. Scheduling and critical path analysis, production control. Work measurement and analysis, ordering and inventory control, weight management.

Homework
Problems - None

Readings
Gillmer pages 271-287

Videotape Information
Time= 31 minutes
AVMAST# ED65

Unit 44

Basic Naval Architecture - Shipbuilding Methods - 2

Steel cutting methods, cold forming and hot forming processes. Older shipbuilding methods. Modern shipbuilding methods. Design for ship production. Modules and subassemblies. Zone outfitting. Design of details for ease of construction.

Homework
Problems - None

Readings
Gillmer pages 185-203

Videotape Information
Time= 44 minutes
AVMAST# ED66

Unit 45

Basic Naval Architecture - Shipbuilding Methods - 3

Launching methods. End launching, key events. Side launching. Launch from floating drydock, graving dock, and moveable platform (Synchro-Lift type). Course closure.

Homework

Problems - None

Readings

Gillmer pages - None

Videotape Information

Time= 39 minutes

AVMAST# ED67

BASIC NAVAL ARCHITECTURE

APPENDIX

TO

PROBLEM SET

CONTENTS:

Table of Kinematic Viscosity of Water

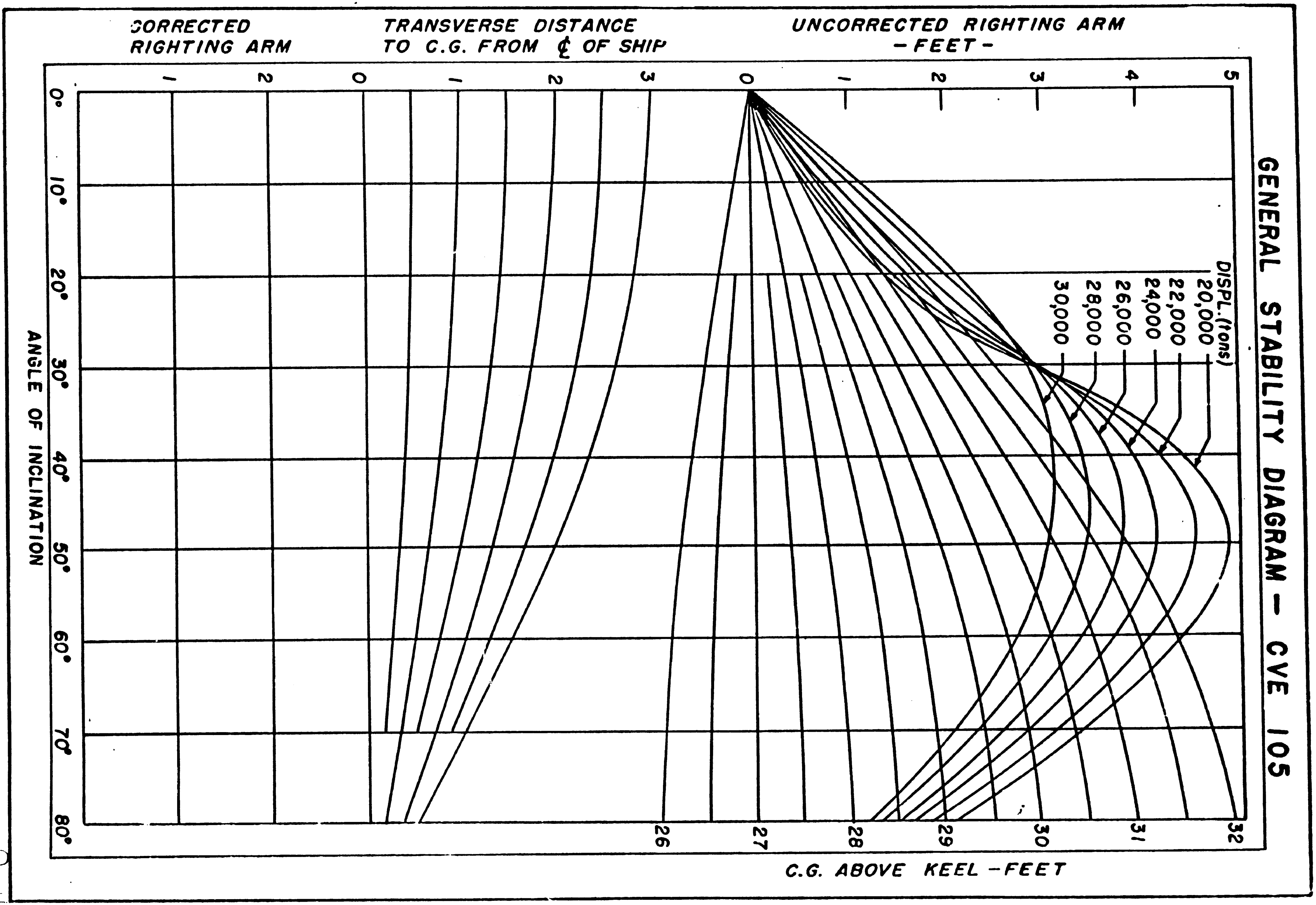
These values were adopted by the American Towing Tank Conference in 1942.
The fifth significant figures are doubtful.

Kinematic Viscosity of Fresh Water $\nu \times 10^5$ ft^2/sec	Temperature degree F	Kinematic Viscosity of Sea Water $\nu_s \times 10^5$ ft^2/sec	Kinematic Viscosity of Fresh Water $\nu \times 10^5$ ft^2/sec	Temperature degree F	Kinematic Viscosity of Sea Water $\nu_s \times 10^5$ ft^2/sec
1.9291	32		1.1937	61	1.2470
1.8922	33		1.1769	62	1.2303
1.8565	34		1.1605	63	1.2139
1.8219	35		1.1444	64	1.1979
1.7883	36		1.1287	65	1.1822
1.7558	37		1.1133	66	1.1669
1.7242	38		1.0983	67	1.1519
1.6935	39		1.0836	68	1.1372
1.6638	40		1.0692	69	1.1229
1.6349	41	1.6846	1.0552	70	1.1088
1.6068	42	1.6568	1.0414	71	1.0951
1.5795	43	1.6298	1.0279	72	1.0816
1.5530	44	1.6035	1.0147	73	1.0684
1.5272	45	1.5780	1.0018	74	1.0554
1.5021	46	1.5531	0.98918	75	1.0427
1.4776	47	1.5289	0.97680	76	1.0303
1.4538	48	1.5053	0.96466	77	1.0181
1.4306	49	1.4823	0.95276	78	1.0062
1.4080	50	1.4599	0.94111	79	0.99447
1.3860	51	1.4381	0.92969	80	0.98299
1.3646	52	1.4168	0.91850	81	0.97172
1.3437	53	1.3961	0.90752	82	0.96067
1.3233	54	1.3758	0.89676	83	0.94982
1.3034	55	1.3561	0.88621	84	0.93917
1.2840	56	1.3368	0.87586	85	0.92873
1.2651	57	1.3180	0.86570	86	0.91847
1.2466	58	1.2996			
1.2285	59	1.2817			
1.2109	60	1.2641			

Table of Density of Water

These values were adopted by the American Towing Tank Conference in 1942.
The fifth significant figures are doubtful.

Density of Fresh Water ρ lb x sec^2/ft^4	Temperature degree F	Density of Sea Water ρ_s lb x sec^2/ft^4	Density of Fresh Water ρ lb x sec^2/ft^4	Temperature degree F	Density of Sea Water ρ_s lb x sec^2/ft^4
1.9399	32	1.9947	1.9381	61	1.9901
1.9399	33	1.9946	1.9379	62	1.9898
1.9400	34	1.9946	1.9377	63	1.9895
1.9400	35	1.9945	1.9375	64	1.9893
1.9401	36	1.9944	1.9373	65	1.9890
1.9401	37	1.9943	1.9371	66	1.9888
1.9401	38	1.9942	1.9369	67	1.9885
1.9401	39	1.9941	1.9367	68	1.9882
1.9401	40	1.9940	1.9365	69	1.9879
1.9401	41	1.9939	1.9362	70	1.9876
1.9401	42	1.9937	1.9360	71	1.9873
1.9401	43	1.9936	1.9358	72	1.9870
1.9400	44	1.9934	1.9355	73	1.9867
1.9400	45	1.9933	1.9352	74	1.9864
1.9399	46	1.9931	1.9350	75	1.9861
1.9398	47	1.9930	1.9347	76	1.9858
1.9398	48	1.9928	1.9344	77	1.9854
1.9397	49	1.9926	1.9342	78	1.9851
1.9396	50	1.9924	1.9339	79	1.9848
1.9395	51	1.9923	1.9336	80	1.9844
1.9394	52	1.9921	1.9333	81	1.9841
1.9393	53	1.9919	1.9330	82	1.9837
1.9392	54	1.9917	1.9327	83	1.9834
1.9390	55	1.9914	1.9324	84	1.9830
1.9389	56	1.9912	1.9321	85	1.9827
1.9387	57	1.9910	1.9317	86	1.9823
1.9386	58	1.9908			
1.9384	59	1.9905			
1.9383	60	1.9903			



GENERAL STABILITY DIAGRAM - CVE 105
CORRECTED RIGHTING ARM
TRANSVERSE DISTANCE TO C.G. FROM ℄ OF SHIP
UNCORRECTED RIGHTING ARM -FEET-
1 2 0 1 2 3 0 1 2 3 4 5
DISPL. (tons)
20,000
22,000
24,000
26,000
28,000
30,000
0° 10° 20° 30° 40° 50° 60° 70° 80°
ANGLE OF INCLINATION
26 27 28 29 30 31 32
C.G. ABOVE KEEL -FEET

STABILITY L A 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 $\left(\frac{b^3 \times l}{12}\right)$ feet⁴	ay^2 $(b \times l \times y^2)$ feet⁴	Stbd. inclining moments (wxy) ft. tons	Port inclining moments (wxy) ft. tons
TOTALS →					X						

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 V = ____________ FT.⁴

FINAL CONDITION

DISPLACEMENT (W_1) = W ± [5] = (   ) (   ) = ____________ TONS

NET VERTICAL MOMENT = ± wxKg = [7a] − [7b] = ____________ FT. TONS

$KG_1 = \frac{(W \times KG) \pm wxkg}{W_1} = \frac{(\quad x \quad)(\quad)}{(\quad)}$ = ____________ 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

[10a] − [10b] = ____________ FT. TONS

OFF CENTER DISTANCE OF C.G. (NET INCL. ARM AT 0°) =

$\frac{\text{NET INCL. MOM.}}{W_1} = \frac{(\quad)}{(\quad)}$ = ____________ FT.

KG_1 = ____________ FT.

NET. VIR. SHIFT = ____________ FT.

VIRTUAL KG [____________ FT]

BASIC NAVAL ARCHITECTURE

Selected Tables Reprinted from

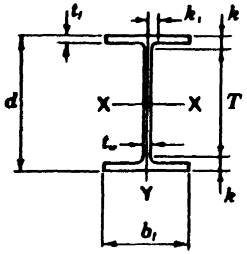
Manual of Steel Construction, Eighth Editions

Manual of Steel Construction

may be ordered directly from the publisher,

American Institute of Steel Construction, Inc.
400 North MIchigan Avenue
Chicago, Illinois 60611

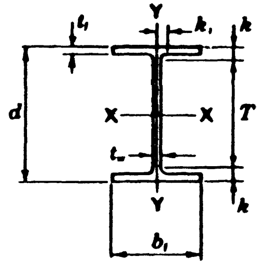
A 1



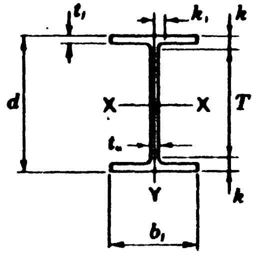
W SHAPES
Dimensions

Designation	Area A	Depth d		Web Thickness t_w		$\frac{t_w}{2}$	Flange Width b_f		Flange Thickness t_f		Distance T	k	k_1
	In.²	In.		In.		In.	In.		In.		In.	In.	In.
W 12x336	98.8	16.82	16 7/8	1.775	1 3/4	7/8	13.385	13 3/8	2.955	2 15/16	9 1/2	3 11/16	1 1/2
x305	89.6	16.32	16 3/8	1.625	1 5/8	13/16	13.235	13 1/4	2.705	2 11/16	9 1/2	3 7/16	1 7/16
x279	81.9	15.85	15 7/8	1.530	1 1/2	3/4	13.140	13 1/8	2.470	2 1/2	9 1/2	3 3/16	1 3/8
x252	74.1	15.41	15 3/8	1.395	1 3/8	11/16	13.005	13	2.250	2 1/4	9 1/2	2 15/16	1 5/16
x230	67.7	15.05	15	1.285	1 5/16	11/16	12.895	12 7/8	2.070	2 1/16	9 1/2	2 3/4	1 1/4
x210	61.8	14.71	14 3/4	1.180	1 3/16	5/8	12.790	12 3/4	1.900	1 7/8	9 1/2	2 5/8	1 1/4
x190	55.8	14.38	14 3/8	1.060	1 1/16	9/16	12.670	12 5/8	1.735	1 3/4	9 1/2	2 7/16	1 3/16
x170	50.0	14.03	14	0.960	15/16	1/2	12.570	12 5/8	1.560	1 9/16	9 1/2	2 1/4	1 1/8
x152	44.7	13.71	13 3/4	0.870	7/8	7/16	12.480	12 1/2	1.400	1 3/8	9 1/2	2 1/8	1 1/16
x136	39.9	13.41	13 3/8	0.790	13/16	7/16	12.400	12 3/8	1.250	1 1/4	9 1/2	1 15/16	1
x120	35.3	13.12	13 1/8	0.710	11/16	3/8	12.320	12 3/8	1.105	1 1/8	9 1/2	1 13/16	1
x106	31.2	12.89	12 7/8	0.610	5/8	5/16	12.220	12 1/4	0.990	1	9 1/2	1 11/16	15/16
x 96	28.2	12.71	12 3/4	0.550	9/16	5/16	12.160	12 1/8	0.900	7/8	9 1/2	1 5/8	7/8
x 87	25.6	12.53	12 1/2	0.515	1/2	1/4	12.125	12 1/8	0.810	13/16	9 1/2	1 1/2	7/8
x 79	23.2	12.38	12 3/8	0.470	1/2	1/4	12.080	12 1/8	0.735	3/4	9 1/2	1 7/16	7/8
x 72	21.1	12.25	12 1/4	0.430	7/16	1/4	12.040	12	0.670	11/16	9 1/2	1 3/8	7/8
x 65	19.1	12.12	12 1/8	0.390	3/8	3/16	12.000	12	0.605	5/8	9 1/2	1 5/16	13/16
W 12x 58	17.0	12.19	12 1/4	0.360	3/8	3/16	10.010	10	0.640	5/8	9 1/2	1 3/8	13/16
x 53	15.6	12.06	12	0.345	3/8	3/16	9.995	10	0.575	9/16	9 1/2	1 1/4	13/16
W 12x 50	14.7	12.19	12 1/4	0.370	3/8	3/16	8.080	8 1/8	0.640	5/8	9 1/2	1 3/8	13/16
x 45	13.2	12.06	12	0.335	5/16	3/16	8.045	8	0.575	9/16	9 1/2	1 1/4	13/16
x 40	11.8	11.94	12	0.295	5/16	3/16	8.005	8	0.515	1/2	9 1/2	1 1/4	3/4
W 12x 35	10.3	12.50	12 1/2	0.300	5/16	3/16	6.560	6 1/2	0.520	1/2	10 1/2	1	9/16
x 30	8.79	12.34	12 3/8	0.260	1/4	1/8	6.520	6 1/2	0.440	7/16	10 1/2	15/16	1/2
x 26	7.65	12.22	12 1/4	0.230	1/4	1/8	6.490	6 1/2	0.380	3/8	10 1/2	7/8	1/2
W 12x 22	6.48	12.31	12 1/4	0.260	1/4	1/8	4.030	4	0.425	7/16	10 1/2	7/8	1/2
x 19	5.57	12.16	12 1/8	0.235	1/4	1/8	4.005	4	0.350	3/8	10 1/2	13/16	1/2
x 16	4.71	11.99	12	0.220	1/4	1/8	3.990	4	0.265	1/4	10 1/2	3/4	1/2
x 14	4.16	11.91	11 7/8	0.200	3/16	1/8	3.970	4	0.225	1/4	10 1/2	11/16	1/2

W SHAPES
Properties



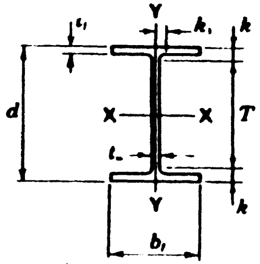
Nominal Wt. per Ft.	Compact Section Criteria $\frac{b_f}{2t_f}$	F_y'	$\frac{d}{t_w}$	F_y'''	r_T	$\frac{d}{A_f}$	Elastic Properties Axis X-X I	S	r	Axis Y-Y I	S	r	Torsional constant J	Plastic Modulus Z_x	Z_y
Lb.		Ksi		Ksi	In.		In.⁴	In.³	In.	In.⁴	In.³	In.	In.⁴	In.³	In.³
336	2.3	—	9.5	—	3.71	0.43	4060	483	6.41	1190	177	3.47	243	603	274
305	2.4	—	10.0	—	3.67	0.46	3550	435	6.29	1050	159	3.42	185	537	244
279	2.7	—	10.4	—	3.64	0.49	3110	393	6.16	937	143	3.38	143	481	220
252	2.9	—	11.0	—	3.59	0.53	2720	353	6.06	828	127	3.34	108	428	196
230	3.1	—	11.7	—	3.56	0.56	2420	321	5.97	742	115	3.31	83.8	386	177
210	3.4	—	12.5	—	3.53	0.61	2140	292	5.89	664	104	3.28	64.7	348	159
190	3.7	—	13.6	—	3.50	0.65	1890	263	5.82	589	93.0	3.25	48.8	311	143
170	4.0	—	14.6	—	3.47	0.72	1650	235	5.74	517	82.3	3.22	35.6	275	126
152	4.5	—	15.8	—	3.44	0.79	1430	209	5.66	454	72.8	3.19	25.8	243	111
136	5.0	—	17.0	—	3.41	0.87	1240	186	5.58	398	64.2	3.16	18.5	214	98.0
120	5.6	—	18.5	—	3.38	0.96	1070	163	5.51	345	56.0	3.13	12.9	186	85.4
106	6.2	—	21.1	—	3.36	1.07	933	145	5.47	301	49.3	3.11	9.13	164	75.1
96	6.8	—	23.1	—	3.34	1.16	833	131	5.44	270	44.4	3.09	6.86	147	67.5
87	7.5	—	24.3	—	3.32	1.28	740	118	5.38	241	39.7	3.07	5.10	132	60.4
79	8.2	62.6	26.3	—	3.31	1.39	662	107	5.34	216	35.8	3.05	3.84	119	54.3
72	9.0	52.3	28.5	—	3.29	1.52	597	97.4	5.31	195	32.4	3.04	2.93	108	49.2
65	9.9	43.0	31.1	—	3.28	1.67	533	87.9	5.28	174	29.1	3.02	2.18	96.8	44.1
58	7.8	—	33.9	57.6	2.72	1.90	475	78.0	5.28	107	21.4	2.51	2.10	86.4	32.5
53	8.7	55.9	35.0	54.1	2.71	2.10	425	70.6	5.23	95.8	19.2	2.48	1.58	77.9	29.1
50	6.3	—	32.9	60.9	2.17	2.36	394	64.7	5.18	56.3	13.9	1.96	1.78	72.4	21.4
45	7.0	—	36.0	51.0	2.15	2.61	350	58.1	5.15	50.0	12.4	1.94	1.31	64.7	19.0
40	7.8	—	40.5	40.3	2.14	2.90	310	51.9	5.13	44.1	11.0	1.93	0.95	57.5	16.8
35	6.3	—	41.7	38.0	1.74	3.66	285	45.6	5.25	24.5	7.47	1.54	0.74	51.2	11.5
30	7.4	—	47.5	29.3	1.73	4.30	238	38.6	5.21	20.3	6.24	1.52	0.46	43.1	9.56
26	8.5	57.9	53.1	23.4	1.72	4.95	204	33.4	5.17	17.3	5.34	1.51	0.30	37.2	8.17
22	4.7	—	47.3	29.5	1.02	7.19	156	25.4	4.91	4.66	2.31	0.847	0.29	29.3	3.66
19	5.7	—	51.7	24.7	1.00	8.67	130	21.3	4.82	3.76	1.88	0.822	0.18	24.7	2.98
16	7.5	—	54.5	22.2	0.96	11.3	103	17.1	4.67	2.82	1.41	0.773	0.10	20.1	2.26
14	8.8	54.3	59.6	18.6	0.95	13.3	88.6	14.9	4.62	2.36	1.19	0.753	0.07	17.4	1.90



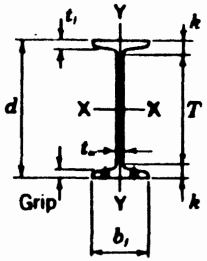
W SHAPES
Dimensions

Designation	Area A	Depth d		Web Thickness t_w		$\frac{t_w}{2}$	Flange Width b_f		Flange Thickness t_f		Distance T	Distance k	Distance k_1
	In.^{2}	In.		In.		In.	In.		In.		In.	In.	In.
W 10x112	32.9	11.36	11 3/8	0.755	3/4	3/8	10.415	10 3/8	1.250	1 1/4	7 5/8	1 7/8	15/16
x100	29.4	11.10	11 1/8	0.680	11/16	3/8	10.340	10 3/8	1.120	1 1/8	7 5/8	1 3/4	7/8
x 88	25.9	10.84	10 7/8	0.605	5/8	5/16	10.265	10 1/4	0.990	1	7 5/8	1 5/8	13/16
x 77	22.6	10.60	10 5/8	0.530	1/2	1/4	10.190	10 1/4	0.870	7/8	7 5/8	1 1/2	13/16
x 68	20.0	10.40	10 3/8	0.470	1/2	1/4	10.130	10 1/8	0.770	3/4	7 5/8	1 3/8	3/4
x 60	17.6	10.22	10 1/4	0.420	7/16	1/4	10.080	10 1/8	0.680	11/16	7 5/8	1 5/16	3/4
x 54	15.8	10.09	10 1/8	0.370	3/8	3/16	10.030	10	0.615	5/8	7 5/8	1 1/4	11/16
x 49	14.4	9.98	10	0.340	5/16	3/16	10.000	10	0.560	9/16	7 5/8	1 3/16	11/16
W 10x 45	13.3	10.10	10 1/8	0.350	3/8	3/16	8.020	8	0.620	5/8	7 5/8	1 1/4	11/16
x 39	11.5	9.92	9 7/8	0.315	5/16	3/16	7.985	8	0.530	1/2	7 5/8	1 1/8	11/16
x 33	9.71	9.73	9 3/4	0.290	5/16	3/16	7.960	8	0.435	7/16	7 5/8	1 1/16	11/16
W 10x 30	8.84	10.47	10 1/2	0.300	5/16	3/16	5.810	5 3/4	0.510	1/2	8 5/8	15/16	1/2
x 26	7.61	10.33	10 3/8	0.260	1/4	1/8	5.770	5 3/4	0.440	7/16	8 5/8	7/8	1/2
x 22	6.49	10.17	10 1/8	0.240	1/4	1/8	5.750	5 3/4	0.360	3/8	8 5/8	3/4	1/2
W 10x 19	5.62	10.24	10 1/4	0.250	1/4	1/8	4.020	4	0.395	3/8	8 5/8	13/16	1/2
x 17	4.99	10.11	10 1/8	0.240	1/4	1/8	4.010	4	0.330	5/16	8 5/8	3/4	1/2
x 15	4.41	9.99	10	0.230	1/4	1/8	4.000	4	0.270	1/4	8 5/8	11/16	7/16
x 12	3.54	9.87	9 7/8	0.190	3/16	1/8	3.960	4	0.210	3/16	8 5/8	5/8	7/16

W SHAPES
Properties

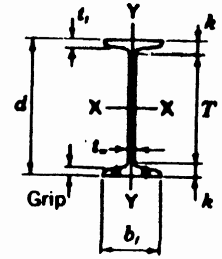


Nominal Wt. per Ft.	Compact Section Criteria $\frac{b_f}{2t_f}$	F_y'	$\frac{d}{t_w}$	F_y'''	r_T	$\frac{d}{A_f}$	Elastic Properties Axis X-X I	S	r	Axis Y-Y I	S	r	Torsional constant J	Plastic Modulus Z_x	Z_y
Lb.		Ksi		Ksi	In.		In.^{4}	In.^{3}	In.	In.^{4}	In.^{3}	In.	In.^{4}	In.^{3}	In.^{3}
112	4.2	—	15.0	—	2.88	0.87	716	126	4.66	236	45.3	2.68	15.1	147	69.2
100	4.6	—	16.3	—	2.85	0.96	623	112	4.60	207	40.0	2.65	10.9	130	61.0
88	5.2	—	17.9	—	2.83	1.07	534	98.5	4.54	179	34.8	2.63	7.53	113	53.1
77	5.9	—	20.0	—	2.80	1.20	455	85.9	4.49	154	30.1	2.60	5.11	97.6	45.9
68	6.6	—	22.1	—	2.79	1.33	394	75.7	4.44	134	26.4	2.59	3.56	85.3	40.1
60	7.4	—	24.3	—	2.77	1.49	341	66.7	4.39	116	23.0	2.57	2.48	74.6	35.0
54	8.2	63.5	27.3	—	2.75	1.64	303	60.0	4.37	103	20.6	2.56	1.82	66.6	31.3
49	8.9	53.0	29.4	—	2.74	1.78	272	54.6	4.35	93.4	18.7	2.54	1.39	60.4	28.3
45	6.5	—	28.9	—	2.18	2.03	248	49.1	4.32	53.4	13.3	2.01	1.51	54.9	20.3
39	7.5	—	31.5	—	2.16	2.34	209	42.1	4.27	45.0	11.3	1.98	0.98	46.8	17.2
33	9.1	50.5	33.6	58.7	2.14	2.81	170	35.0	4.19	36.6	9.20	1.94	0.58	38.8	14.0
30	5.7	—	34.9	54.2	1.55	3.53	170	32.4	4.38	16.7	5.75	1.37	0.62	36.6	8.84
26	6.6	—	39.7	41.8	1.54	4.07	144	27.9	4.35	14.1	4.89	1.36	0.40	31.3	7.50
22	8.0	—	42.4	36.8	1.51	4.91	118	23.2	4.27	11.4	3.97	1.33	0.24	26.0	6.10
19	5.1	—	41.0	39.4	1.03	6.45	96.3	18.8	4.14	4.29	2.14	0.874	0.23	21.6	3.35
17	6.1	—	42.1	37.2	1.01	7.64	81.9	16.2	4.05	3.56	1.78	0.844	0.16	18.7	2.80
15	7.4	—	43.4	35.0	0.99	9.25	68.9	13.8	3.95	2.89	1.45	0.810	0.10	16.0	2.30
12	9.4	47.5	51.9	24.5	0.96	11.9	53.8	10.9	3.90	2.18	1.10	0.785	0.06	12.6	1.74



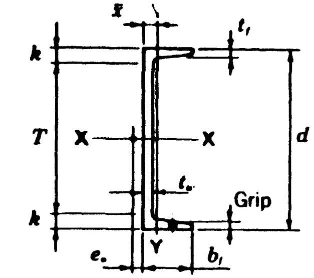
S SHAPES
Dimensions

Designation	Area A	Depth d		Web Thickness t_w		$\frac{t_w}{2}$	Flange Width b_f		Flange Thickness t_f		Distance T	Distance k	Grip	Max. Flge. Fastener
	In.²	In.		In.		In.	In.		In.		In.	In.	In.	In.
S 24x121	35.6	24.50	24½	0.800	13/16	7/16	8.050	8	1.090	1 1/16	20½	2	1⅛	1
x106	31.2	24.50	24½	0.620	5/8	5/16	7.870	7⅞	1.090	1 1/16	20½	2	1⅛	1
S 24x100	29.3	24.00	24	0.745	3/4	3/8	7.245	7¼	0.870	7/8	20½	1¾	7/8	1
x90	26.5	24.00	24	0.625	5/8	5/16	7.125	7⅛	0.870	7/8	20½	1¾	7/8	1
x80	23.5	24.00	24	0.500	1/2	1/4	7.000	7	0.870	7/8	20½	1¾	7/8	1
S 20x96	28.2	20.30	20¼	0.800	13/16	7/16	7.200	7¼	0.920	15/16	16¾	1¾	15/16	1
x86	25.3	20.30	20¼	0.660	11/16	3/8	7.060	7	0.920	15/16	16¾	1¾	15/16	1
S 20x75	22.0	20.00	20	0.635	5/8	5/16	6.385	6⅜	0.795	13/16	16¾	1⅝	13/16	7/8
x66	19.4	20.00	20	0.505	1/2	1/4	6.255	6¼	0.795	13/16	16¾	1⅝	13/16	7/8
S 18x70	20.6	18.00	18	0.711	11/16	3/8	6.251	6¼	0.691	11/16	15	1½	11/16	7/8
x54.7	16.1	18.00	18	0.461	7/16	1/4	6.001	6	0.691	11/16	15	1½	11/16	7/8
S 15x50	14.7	15.00	15	0.550	9/16	5/16	5.640	5⅝	0.622	5/8	12¼	1⅜	9/16	3/4
x42.9	12.6	15.00	15	0.411	7/16	1/4	5.501	5½	0.622	5/8	12¼	1⅜	9/16	3/4
S 12x50	14.7	12.00	12	0.687	11/16	3/8	5.477	5½	0.659	11/16	9⅛	1 7/16	11/16	3/4
x40.8	12.0	12.00	12	0.462	7/16	1/4	5.252	5¼	0.659	11/16	9⅛	1 7/16	5/8	3/4
S 12x35	10.3	12.00	12	0.428	7/16	1/4	5.078	5⅛	0.544	9/16	9⅝	1 3/16	1/2	3/4
x31.8	9.35	12.00	12	0.350	3/8	3/16	5.000	5	0.544	9/16	9⅝	1 3/16	1/2	3/4
S 10x35	10.3	10.00	10	0.594	5/8	5/16	4.944	5	0.491	1/2	7¾	1⅛	1/2	3/4
x25.4	7.46	10.00	10	0.311	5/16	3/16	4.661	4⅝	0.491	1/2	7¾	1⅛	1/2	3/4
S 8x23	6.77	8.00	8	0.441	7/16	1/4	4.171	4⅛	0.426	7/16	6	1	7/16	3/4
x18.4	5.41	8.00	8	0.271	1/4	1/8	4.001	4	0.426	7/16	6	1	7/16	3/4
S 7x20	5.88	7.00	7	0.450	7/16	1/4	3.860	3⅞	0.392	3/8	5⅛	15/16	3/8	5/8
x15.3	4.50	7.00	7	0.252	1/4	1/8	3.662	3⅝	0.392	3/8	5⅛	15/16	3/8	5/8
S 6x17.25	5.07	6.00	6	0.465	7/16	1/4	3.565	3⅝	0.359	3/8	4¼	7/8	3/8	5/8
x12.5	3.67	6.00	6	0.232	1/4	1/8	3.332	3⅜	0.359	3/8	4¼	7/8	3/8	—
S 5x14.75	4.34	5.00	5	0.494	1/2	1/4	3.284	3¼	0.326	5/16	3⅜	13/16	5/16	—
x10	2.94	5.00	5	0.214	3/16	1/8	3.004	3	0.326	5/16	3⅜	13/16	5/16	—
S 4x9.5	2.79	4.00	4	0.326	5/16	3/16	2.796	2¾	0.293	5/16	2½	3/4	5/16	—
x7.7	2.26	4.00	4	0.193	3/16	1/8	2.663	2⅝	0.293	5/16	2½	3/4	5/16	—
S 3x7.5	2.21	3.00	3	0.349	3/8	3/16	2.509	2½	0.260	1/4	1⅝	11/16	1/4	—
x5.7	1.67	3.00	3	0.170	3/16	1/8	2.330	2⅜	0.260	1/4	1⅝	11/16	1/4	—



S SHAPES
Properties

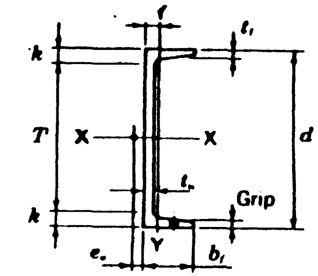
Nominal Wt. per Ft	Compact Section Criteria $\frac{b_f}{2t_f}$	F_y'	$\frac{d}{t_w}$	F_y'''	r_T	$\frac{d}{A_f}$	Elastic Properties Axis X-X I	S	r	Axis Y-Y I	S	r	Torsional constant J	Plastic Modulus Z_x	Z_y
Lb.		Ksi		Ksi	In.		In.⁴	In.³	In.	In.⁴	In.³	In.	In.⁴	In.³	In.³
121	3.7	—	30.6	—	1.86	2.79	3160	258	9.43	83.3	20.7	1.53	12.8	306	36.2
106	3.6	—	39.5	42.3	1.86	2.86	2940	240	9.71	77.1	19.6	1.57	10.1	279	33.2
100	4.2	—	32.2	63.6	1.59	3.81	2390	199	9.02	47.7	13.2	1.27	7.58	240	23.9
90	4.1	—	38.4	44.8	1.60	3.87	2250	187	9.21	44.9	12.6	1.30	6.04	222	22.3
80	4.0	—	48.0	28.7	1.61	3.94	2100	175	9.47	42.2	12.1	1.34	4.88	204	20.7
96	3.9	—	25.4	—	1.63	3.06	1670	165	7.71	50.2	13.9	1.33	8.39	198	24.9
86	3.8	—	30.8	—	1.63	3.13	1580	155	7.89	46.8	13.3	1.36	6.64	183	23.0
75	4.0	—	31.5	—	1.43	3.94	1280	128	7.62	29.8	9.32	1.16	4.59	153	16.7
66	3.9	—	39.6	42.1	1.44	4.02	1190	119	7.83	27.7	8.85	1.19	3.58	140	15.3
70	4.5	—	25.3	—	1.35	4.17	926	103	6.71	24.1	7.72	1.08	4.15	125	14.4
54.7	4.3	—	39.0	43.3	1.37	4.34	804	89.4	7.07	20.8	6.94	1.14	2.37	105	12.1
50	4.5	—	27.3	—	1.26	4.28	486	64.8	5.75	15.7	5.57	1.03	2.12	77.1	9.97
42.9	4.4	—	36.5	49.6	1.26	4.38	447	59.6	5.95	14.4	5.23	1.07	1.54	69.3	9.02
50	4.2	—	17.5	—	1.25	3.32	305	50.8	4.55	15.7	5.74	1.03	2.82	61.2	10.3
40.8	4.0	—	26.0	—	1.24	3.46	272	45.4	4.77	13.6	5.16	1.06	1.76	53.1	8.85
35	4.7	—	28.0	—	1.16	4.34	229	38.2	4.72	9.87	3.89	0.980	1.08	44.8	6.79
31.8	4.6	—	34.3	56.2	1.16	4.41	218	36.4	4.83	9.36	3.74	1.00	0.90	42.0	6.40
35	5.0	—	16.8	—	1.10	4.12	147	29.4	3.78	8.36	3.38	0.901	1.29	35.4	6.22
25.4	4.7	—	32.2	63.9	1.09	4.37	124	24.7	4.07	6.79	2.91	0.954	0.60	28.4	4.96
23	4.9	—	18.1	—	0.95	4.51	64.9	16.2	3.10	4.31	2.07	0.798	0.55	19.3	3.68
18.4	4.7	—	29.5	—	0.94	4.70	57.6	14.4	3.26	3.73	1.86	0.831	0.34	16.5	3.16
20	4.9	—	15.6	—	0.88	4.63	42.4	12.1	2.69	3.17	1.64	0.734	0.45	14.5	2.96
15.3	4.7	—	27.8	—	0.87	4.88	36.7	10.5	2.86	2.64	1.44	0.766	0.24	12.1	2.44
17.25	5.0	—	12.9	—	0.81	4.69	26.3	8.77	2.28	2.31	1.30	0.675	0.37	10.6	2.36
12.5	4.6	—	25.9	—	0.79	5.02	22.1	7.37	2.45	1.82	1.09	0.705	0.17	8.47	1.85
14.75	5.0	—	10.1	—	0.74	4.66	15.2	6.09	1.87	1.67	1.01	0.620	0.32	7.42	1.88
10	4.6	—	23.4	—	0.72	5.10	12.3	4.92	2.05	1.22	0.809	0.643	0.11	5.67	1.37
9.5	4.8	—	12.3	—	0.65	4.88	6.79	3.39	1.56	0.903	0.646	0.569	0.12	4.04	1.13
7.7	4.5	—	20.7	—	0.64	5.13	6.08	3.04	1.64	0.764	0.574	0.581	0.07	3.51	0.964
7.5	4.8	—	8.6	—	0.59	4.60	2.93	1.95	1.15	0.586	0.468	0.516	0.09	2.36	0.826
5.7	4.5	—	17.6	—	0.57	4.95	2.52	1.68	1.23	0.455	0.390	0.522	0.04	1.95	0.653



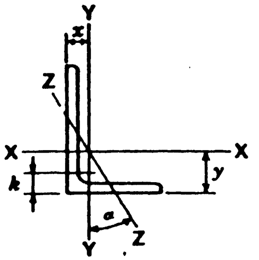
CHANNELS
AMERICAN STANDARD
Dimensions

Designation	Area A	Depth d	Web Thickness t_w		$\frac{t_w}{2}$	Flange Width b_f		Flange Average thickness t_f		Distance T	Distance k	Grip	Max. Flge. Fastener
	In.²	In.	In.		In.	In.		In.		In.	In.	In.	In.
C 15x50	14.7	15.00	0.716	11/16	3/8	3.716	3 3/4	0.650	5/8	12 1/8	1 7/16	5/8	1
x40	11.8	15.00	0.520	1/2	1/4	3.520	3 1/2	0.650	5/8	12 1/8	1 7/16	5/8	1
x33.9	9.96	15.00	0.400	3/8	3/16	3.400	3 3/8	0.650	5/8	12 1/8	1 7/16	5/8	1
C 12x30	8.82	12.00	0.510	1/2	1/4	3.170	3 1/8	0.501	1/2	9 3/4	1 1/8	1/2	7/8
x25	7.35	12.00	0.387	3/8	3/16	3.047	3	0.501	1/2	9 3/4	1 1/8	1/2	7/8
x20.7	6.09	12.00	0.282	5/16	1/8	2.942	3	0.501	1/2	9 3/4	1 1/8	1/2	7/8
C 10x30	8.82	10.00	0.673	11/16	5/16	3.033	3	0.436	7/16	8	1	7/16	3/4
x25	7.35	10.00	0.526	1/2	1/4	2.886	2 7/8	0.436	7/16	8	1	7/16	3/4
x20	5.88	10.00	0.379	3/8	3/16	2.739	2 3/4	0.436	7/16	8	1	7/16	3/4
x15.3	4.49	10.00	0.240	1/4	1/8	2.600	2 5/8	0.436	7/16	8	1	7/16	3/4
C 9x20	5.88	9.00	0.448	7/16	1/4	2.648	2 5/8	0.413	7/16	7 1/8	15/16	7/16	3/4
x15	4.41	9.00	0.285	5/16	1/8	2.485	2 1/2	0.413	7/16	7 1/8	15/16	7/16	3/4
x13.4	3.94	9.00	0.233	1/4	1/8	2.433	2 3/8	0.413	7/16	7 1/8	15/16	7/16	3/4
C 8x18.75	5.51	8.00	0.487	1/2	1/4	2.527	2 1/2	0.390	3/8	6 1/8	15/16	3/8	3/4
x13.75	4.04	8.00	0.303	5/16	1/8	2.343	2 3/8	0.390	3/8	6 1/8	15/16	3/8	3/4
x11.5	3.38	8.00	0.220	1/4	1/8	2.260	2 1/4	0.390	3/8	6 1/8	15/16	3/8	3/4
C 7x14.75	4.33	7.00	0.419	7/16	3/16	2.299	2 1/4	0.366	3/8	5 1/4	7/8	3/8	5/8
x12.25	3.60	7.00	0.314	5/16	3/16	2.194	2 1/4	0.366	3/8	5 1/4	7/8	3/8	5/8
x 9.8	2.87	7.00	0.210	3/16	1/8	2.090	2 1/8	0.366	3/8	5 1/4	7/8	3/8	5/8
C 6x13	3.83	6.00	0.437	7/16	3/16	2.157	2 1/8	0.343	5/16	4 3/8	13/16	5/16	5/8
x10.5	3.09	6.00	0.314	5/16	3/16	2.034	2	0.343	5/16	4 3/8	13/16	3/8	5/8
x 8.2	2.40	6.00	0.200	3/16	1/8	1.920	1 7/8	0.343	5/16	4 3/8	13/16	5/16	5/8
C 5x 9	2.64	5.00	0.325	5/16	3/16	1.885	1 7/8	0.320	5/16	3 1/2	3/4	5/16	5/8
x 6.7	1.97	5.00	0.190	3/16	1/8	1.750	1 3/4	0.320	5/16	3 1/2	3/4	—	—
C 4x 7.25	2.13	4.00	0.321	5/16	3/16	1.721	1 3/4	0.296	5/16	2 5/8	11/16	5/16	5/8
x 5.4	1.59	4.00	0.184	3/16	1/16	1.584	1 5/8	0.296	5/16	2 5/8	11/16	—	—
C 3x 6	1.76	3.00	0.356	3/8	3/16	1.596	1 5/8	0.273	1/4	1 5/8	11/16	—	—
x 5	1.47	3.00	0.258	1/4	1/8	1.498	1 1/2	0.273	1/4	1 5/8	11/16	—	—
x 4.1	1.21	3.00	0.170	3/16	1/16	1.410	1 3/8	0.273	1/4	1 5/8	11/16	—	—

CHANNELS
AMERICAN STANDARD
Properties



Nominal Weight per Ft.	$\bar{x}$	Shear Center Location e_o	$\frac{d}{A_f}$	Axis X-X I	Axis X-X S	Axis X-X r	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r
	In.	In.		In.⁴	In.³	In.	In.⁴	In.³	In.
50	0.798	0.583	6.21	404	53.8	5.24	11.0	3.78	0.867
40	0.777	0.767	6.56	349	46.5	5.44	9.23	3.37	0.886
33.9	0.787	0.896	6.79	315	42.0	5.62	8.13	3.11	0.904
30	0.674	0.618	7.55	162	27.0	4.29	5.14	2.06	0.763
25	0.674	0.746	7.85	144	24.1	4.43	4.47	1.88	0.780
20.7	0.698	0.870	8.13	129	21.5	4.61	3.88	1.73	0.799
30	0.649	0.369	7.55	103	20.7	3.42	3.94	1.65	0.669
25	0.617	0.494	7.94	91.2	18.2	3.52	3.36	1.48	0.676
20	0.606	0.637	8.36	78.9	15.8	3.66	2.81	1.32	0.692
15.3	0.634	0.796	8.81	67.4	13.5	3.87	2.28	1.16	0.713
20	0.583	0.515	8.22	60.9	13.5	3.22	2.42	1.17	0.642
15	0.586	0.682	8.76	51.0	11.3	3.40	1.93	1.01	0.661
13.4	0.601	0.743	8.95	47.9	10.6	3.48	1.76	0.962	0.669
18.75	0.565	0.431	8.12	44.0	11.0	2.82	1.98	1.01	0.599
13.75	0.553	0.604	8.75	36.1	9.03	2.99	1.53	0.854	0.615
11.5	0.571	0.697	9.08	32.6	8.14	3.11	1.32	0.781	0.625
14.75	0.532	0.441	8.31	27.2	7.78	2.51	1.38	0.779	0.564
12.25	0.525	0.538	8.71	24.2	6.93	2.60	1.17	0.703	0.571
9.8	0.540	0.647	9.14	21.3	6.08	2.72	0.968	0.625	0.581
13	0.514	0.380	8.10	17.4	5.80	2.13	1.05	0.642	0.525
10.5	0.499	0.486	8.59	15.2	5.06	2.22	0.866	0.564	0.529
8.2	0.511	0.599	9.10	13.1	4.38	2.34	0.693	0.492	0.537
9	0.478	0.427	8.29	8.90	3.56	1.83	0.632	0.450	0.489
6.7	0.484	0.552	8.93	7.49	3.00	1.95	0.479	0.378	0.493
7.25	0.459	0.386	7.84	4.59	2.29	1.47	0.433	0.343	0.450
5.4	0.457	0.502	8.52	3.85	1.93	1.56	0.319	0.283	0.449
6	0.455	0.322	6.87	2.07	1.38	1.08	0.305	0.268	0.416
5	0.438	0.392	7.32	1.85	1.24	1.12	0.247	0.233	0.410
4.1	0.436	0.461	7.78	1.66	1.10	1.17	0.197	0.202	0.404



ANGLES

Equal legs and unequal legs
Properties for designing

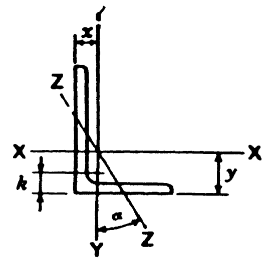
Size and Thickness	k	Weight per Foot	Area	AXIS X-X I	AXIS X-X S	AXIS X-X r	AXIS X-X y	AXIS Y-Y I	AXIS Y-Y S	AXIS Y-Y r	AXIS Y-Y x	AXIS Z-Z r	AXIS Z-Z Tan α
In.	In.	Lb.	In.²	In.⁴	In.³	In.	In.	In.⁴	In.³	In.	In.	In.	
L 9 x4 x 5/8	1 1/8	26.3	7.73	64.9	11.5	2.90	3.36	8.32	2.65	1.04	0.858	.847	0.216
9/16	1 1/16	23.8	7.00	59.1	10.4	2.91	3.33	7.63	2.41	1.04	0.834	.850	0.218
1/2	1	21.3	6.25	53.2	9.34	2.92	3.31	6.92	2.17	1.05	0.810	.854	0.220
L 8 x8 x1 1/8	1 3/4	56.9	16.7	98.0	17.5	2.42	2.41	98.0	17.5	2.42	2.41	1.56	1.000
1	1 5/8	51.0	15.0	89.0	15.8	2.44	2.37	89.0	15.8	2.44	2.37	1.56	1.000
7/8	1 1/2	45.0	13.2	79.6	14.0	2.45	2.32	79.6	14.0	2.45	2.32	1.57	1.000
3/4	1 3/8	38.9	11.4	69.7	12.2	2.47	2.28	69.7	12.2	2.47	2.28	1.58	1.000
5/8	1 1/4	32.7	9.61	59.4	10.3	2.49	2.23	59.4	10.3	2.49	2.23	1.58	1.000
9/16	1 3/16	29.6	8.68	54.1	9.34	2.50	2.21	54.1	9.34	2.50	2.21	1.59	1.000
1/2	1 1/8	26.4	7.75	48.6	8.36	2.50	2.19	48.6	8.36	2.50	2.19	1.59	1.000
L 8 x6 x1	1 1/2	44.2	13.0	80.8	15.1	2.49	2.65	38.8	8.92	1.73	1.65	1.28	0.543
7/8	1 3/8	39.1	11.5	72.3	13.4	2.51	2.61	34.9	7.94	1.74	1.61	1.28	0.547
3/4	1 1/4	33.8	9.94	63.4	11.7	2.53	2.56	30.7	6.92	1.76	1.56	1.29	0.551
5/8	1 1/8	28.5	8.36	54.1	9.87	2.54	2.52	26.3	5.88	1.77	1.52	1.29	0.554
9/16	1 1/16	25.7	7.56	49.3	8.95	2.55	2.50	24.0	5.34	1.78	1.50	[illegible]	[illegible]
1/2	1	23.0	6.75	44.3	8.02	2.56	2.47	21.7	4.79	1.79	1.47	1.30	0.558
7/16	15/16	20.2	5.93	39.2	7.07	2.57	2.45	19.3	4.23	1.80	1.45	1.31	[illegible]
L 8 x4 x1	1 1/2	37.4	11.0	69.6	14.1	2.52	3.05	11.6	3.94	1.03	1.05	0.846	0.247
3/4	1 1/4	28.7	8.44	54.9	10.9	2.55	2.95	9.36	3.07	1.05	0.953	0.852	0.258
9/16	1 1/16	21.9	6.43	42.8	8.35	2.58	2.88	7.43	2.38	1.07	0.882	0.861	0.265
1/2	1	19.6	5.75	38.5	7.49	2.59	2.86	6.74	2.15	1.08	0.859	0.865	0.267
L 7 x4 x 3/4	1 1/4	26.2	7.69	37.8	8.42	2.22	2.51	9.05	3.03	1.09	1.01	0.860	0.324
5/8	1 1/8	22.1	6.48	32.4	7.14	2.24	2.46	7.84	2.58	1.10	[illegible]	[illegible]	[illegible]
1/2	1	17.9	5.25	26.7	5.81	2.25	2.42	6.53	2.12	1.11	0.917	0.872	0.335
3/8	7/8	13.6	3.98	20.6	4.44	2.27	2.37	5.10	1.63	1.13	0.870	0.880	0.340

Angles in shaded rows may not be readily available. Availability is subject to rolling accumulation and geographical location, and should be checked with material suppliers.

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

ANGLES

Equal legs and unequal legs
Properties for designing



Size and Thickness	k	Weight per Foot	Area	AXIS X-X I	AXIS X-X S	AXIS X-X r	AXIS X-X y	AXIS Y-Y I	AXIS Y-Y S	AXIS Y-Y r	AXIS Y-Y x	AXIS Z-Z r	AXIS Z-Z Tan α
In.	In.	Lb.	In.²	In.⁴	In.³	In.	In.	In.⁴	In.³	In.	In.	In	
L 6 x6 x1	1 1/2	37.4	11.0	35.5	8.57	1.80	1.86	35.5	8.57	1.80	1.86	1.17	1.000
7/8	1 3/8	33.1	9.73	31.9	7.63	1.81	1.82	31.9	7.63	1.81	1.82	1.17	1.000
3/4	1 1/4	28.7	8.44	28.2	6.66	1.83	1.78	28.2	6.66	1.83	1.78	1.17	1.000
5/8	1 1/8	24.2	7.11	24.2	5.66	1.84	1.73	24.2	5.66	1.84	1.73	1.18	1.000
9/16	1 1/16	21.9	6.43	22.1	5.14	1.85	1.71	22.1	5.14	1.85	1.71	1.18	1.000
1/2	1	19.6	5.75	19.9	4.61	1.86	1.68	19.9	4.61	1.86	1.68	1.18	1.000
7/16	15/16	17.2	5.06	17.7	4.08	1.87	1.66	17.7	4.08	1.87	1.66	1.19	1.000
3/8	7/8	14.9	4.36	15.4	3.53	1.88	1.64	15.4	3.53	1.88	1.64	1.19	1.000
5/16	13/16	12.4	3.65	13.0	2.97	1.89	1.62	13.0	2.97	1.89	1.62	1.20	1.000
L 6 x4 x 7/8	1 3/8	27.2	7.98	27.7	7.15	1.86	2.12	9.75	3.39	1.11	1.12	0.857	0.421
3/4	1 1/4	23.6	6.94	24.5	6.25	1.88	2.08	8.68	2.97	1.12	1.08	0.860	0.428
5/8	1 1/8	20.0	5.86	21.1	5.31	1.90	2.03	7.52	2.54	1.13	1.03	0.864	0.435
9/16	1 1/16	18.1	5.31	19.3	4.83	1.90	2.01	6.91	2.31	1.14	1.01	0.866	0.438
1/2	1	16.2	4.75	17.4	4.33	1.91	1.99	6.27	2.08	1.15	0.987	0.870	0.440
7/16	15/16	14.3	4.18	15.5	3.83	1.92	1.96	5.60	1.85	1.16	0.964	0.873	0.443
3/8	7/8	12.3	3.61	13.5	3.32	1.93	1.94	4.90	1.60	1.17	0.941	0.877	0.446
5/16	13/16	10.3	3.03	11.4	2.79	1.94	1.92	4.18	1.35	1.17	0.918	0.882	0.448
L 6 x3 1/2 x 1/2	1	15.3	4.50	16.6	4.24	1.92	2.08	4.25	1.59	0.972	0.833	0.759	0.344
3/8	7/8	11.7	3.42	12.9	3.24	1.94	2.04	3.34	1.23	0.988	0.787	0.767	0.350
5/16	13/16	9.8	2.87	10.9	2.73	1.95	2.01	2.85	1.04	0.996	0.763	0.772	0.352
L 5 x5 x 7/8	1 3/8	27.2	7.98	17.8	5.17	1.49	1.57	17.8	5.17	1.49	1.57	0.973	1.000
3/4	1 1/4	23.6	6.94	15.7	4.53	1.51	1.52	15.7	4.53	1.51	1.52	0.975	1.000
5/8	1 1/8	20.0	5.86	13.6	3.86	1.52	1.48	13.6	3.86	1.52	1.48	0.978	1.000
1/2	1	16.2	4.75	11.3	3.16	1.54	1.43	11.3	3.16	1.54	1.43	0.983	1.000
7/16	15/16	14.3	4.18	10.0	2.79	1.55	1.41	10.0	2.79	1.55	1.41	0.986	1.000
3/8	7/8	12.3	3.61	8.74	2.42	1.56	1.39	8.74	2.42	1.56	1.39	0.990	1.000
5/16	13/16	10.3	3.03	7.42	2.04	1.57	1.37	7.42	2.04	1.57	1.37	0.994	1.000

Angles in shaded rows may not be readily available. Availability is subject to rolling accumulation and geographical location, and should be checked with material suppliers.

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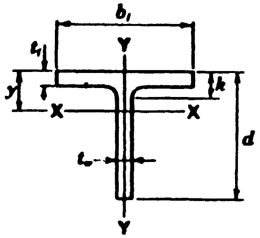
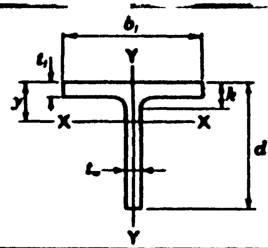
D-11



STRUCTURAL TEES
Cut from W shapes
Dimensions

Designation	Area	Depth of Tee d		Stem Thickness t_w		$\frac{t_w}{2}$	Area of Stem	Flange Width b_f		Flange Thickness t_f		Distance k
	In.^{2}	In.		In.		In.	In.^{2}	In.		In.		In.
WT 9x59.5	17.5	9.485	9 1/2	0.655	5/8	5/16	6.21	11.265	11 1/4	1.060	1 1/16	1 3/4
x53	15.6	9.365	9 3/8	0.590	9/16	5/16	5.53	11.200	11 1/4	0.940	15/16	1 5/8
x48.5	14.3	9.295	9 1/4	0.535	9/16	5/16	4.97	11.145	11 1/8	0.870	7/8	1 9/16
x43	12.7	9.195	9 1/4	0.480	1/2	1/4	4.41	11.090	11 1/8	0.770	3/4	1 7/16
x38	11.2	9.105	9 1/8	0.425	7/16	1/4	3.87	11.035	11	0.680	11/16	1 3/8
WT 9x35.5	10.4	9.235	9 1/4	0.495	1/2	1/4	4.57	7.635	7 5/8	0.810	13/16	1 1/2
x32.5	9.55	9.175	9 1/8	0.450	7/16	1/4	4.13	7.590	7 5/8	0.750	3/4	1 7/16
x30	8.82	9.120	9 1/8	0.415	7/16	1/4	3.78	7.555	7 1/2	0.695	11/16	1 3/8
x27.5	8.10	9.055	9	0.390	3/8	3/16	3.53	7.530	7 1/2	0.630	5/8	1 5/16
x25	7.33	8.995	9	0.355	3/8	3/16	3.19	7.495	7 1/2	0.570	9/16	1 1/4
WT 9x23	6.77	9.030	9	0.360	3/8	3/16	3.25	6.060	6	0.605	5/8	1 1/4
x20	5.88	8.950	9	0.315	5/16	3/16	2.82	6.015	6	0.525	1/2	1 3/16
x17.5	5.15	8.850	8 7/8	0.300	5/16	3/16	2.65	6.000	6	0.425	7/16	1 1/8
WT 8x50	14.7	8.485	8 1/2	0.585	9/16	5/16	4.96	10.425	10 3/8	0.985	1	1 11/16
x44.5	13.1	8.375	8 3/8	0.525	1/2	1/4	4.40	10.365	10 3/8	0.875	7/8	1 9/16
x38.5	11.3	8.260	8 1/4	0.455	7/16	1/4	3.76	10.295	10 1/4	0.760	3/4	1 7/16
x33.5	9.84	8.165	8 1/8	0.395	3/8	3/16	3.23	10.235	10 1/4	0.665	11/16	1 3/8
WT 8x28.5	8.38	8.215	8 1/4	0.430	7/16	1/4	3.53	7.120	7 1/8	0.715	11/16	1 3/8
x25	7.37	8.130	8 1/8	0.380	3/8	3/16	3.09	7.070	7 1/8	0.630	5/8	1 5/16
x22.5	6.63	8.065	8 1/8	0.345	3/8	3/16	2.78	7.035	7	0.565	9/16	1 1/4
x20	5.89	8.005	8	0.305	5/16	3/16	2.44	6.995	7	0.505	1/2	1 3/16
x18	5.28	7.930	7 7/8	0.295	5/16	3/16	2.34	6.985	7	0.430	7/16	1 1/8
WT 8x15.5	4.56	7.940	8	0.275	1/4	1/8	2.18	5.525	5 1/2	0.440	7/16	1 1/8
x13	3.84	7.845	7 7/8	0.250	1/4	1/8	1.96	5.500	5 1/2	0.345	3/8	1 1/16

STRUCTURAL TEES
Cut from W shapes
Properties



$$C_c' = \sqrt{\frac{2\pi^2 E}{Q_s Q_a F_y}}, \quad Q_a = 1.0$$

Nominal Weight per Ft.	$\frac{d}{t_w}$	Axis X-X I	Axis X-X S	Axis X-X r	Axis X-X y	Axis Y-Y I	Axis Y-Y S	Axis Y-Y r	F_y = 36 ksi Q_s	F_y = 36 ksi C_c'	F_y = 50 ksi Q_s	F_y = 50 ksi C_c'
Lb.		In.^{4}	In.^{3}	In.	In.	In.^{4}	In.^{3}	In.				
59.5	14.5	119	15.9	2.60	2.03	126	22.5	2.69	—	—	—	—
53	15.9	104	14.1	2.59	1.97	110	19.7	2.66	—	—	—	—
48.5	17.4	93.8	12.7	2.56	1.91	100	18.0	2.65	—	—	—	—
43	19.2	82.4	11.2	2.55	1.86	87.6	15.8	2.63	—	—	0.937	111
38	21.4	71.8	9.83	2.54	1.80	76.2	13.8	2.61	0.990	127	0.826	118
35.5	18.7	78.2	11.2	2.74	2.26	30.1	7.89	1.70	—	—	0.963	109
32.5	20.4	70.7	10.1	2.72	2.20	27.4	7.22	1.69	—	—	0.877	114
30	22.0	64.7	9.29	2.71	2.16	25.0	6.63	1.69	0.964	128	0.796	120
27.5	23.2	59.5	8.63	2.71	2.16	22.5	5.97	1.67	0.913	132	0.736	125
25	25.3	53.5	7.79	2.70	2.12	20.0	5.35	1.65	0.823	139	0.625	135
23	25.1	52.1	7.77	2.77	2.33	11.3	3.72	1.29	0.831	138	0.635	134
20	28.4	44.8	6.73	2.76	2.29	9.55	3.17	1.27	0.690	152	0.496	152
17.5	29.5	40.1	6.21	2.79	2.39	7.67	2.56	1.22	0.638	158	0.460	158
50	14.5	76.8	11.4	2.28	1.76	93.1	17.9	2.51	—	—	—	—
44.5	16.0	67.2	10.1	2.27	1.70	81.3	15.7	2.49	—	—	—	—
38.5	18.2	56.9	8.59	2.24	1.63	69.2	13.4	2.47	—	—	0.988	108
33.5	20.7	48.6	7.36	2.22	1.56	59.5	11.6	2.46	—	—	0.861	115
28.5	19.1	48.7	7.77	2.41	1.94	21.6	6.06	1.60	—	—	0.942	110
25	21.4	42.3	6.78	2.40	1.89	18.6	5.26	1.59	0.990	127	0.826	118
22.5	23.4	37.8	6.10	2.39	1.86	16.4	4.67	1.57	0.904	133	0.725	126
20	26.2	33.1	5.35	2.37	1.81	14.4	4.12	1.57	0.784	142	0.583	140
18	26.9	30.6	5.05	2.41	1.88	12.2	3.50	1.52	0.754	145	0.553	144
15.5	28.9	27.4	4.64	2.45	2.02	6.20	2.24	1.17	0.668	154	0.479	155
13	31.4	23.5	4.09	2.47	2.09	4.80	1.74	1.12	0.563	168	0.406	168

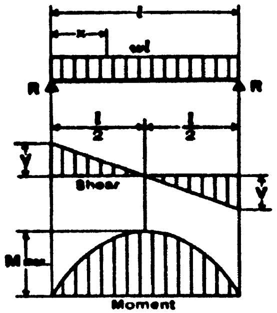
Where no value of C_c' or Q_s is shown, the Tee complies with Specification Sect. 1.9.1.2.

BEAM DIAGRAMS AND FORMULAS

For various static loading conditions

For meaning of symbols, see page 2-111.

1. SIMPLE BEAM—UNIFORMLY DISTRIBUTED LOAD



Total Equiv. Uniform Load . . . . $= wl$

$R = V$ . . . . $= \frac{wl}{2}$

V_x . . . . $= w\left(\frac{l}{2} - x\right)$

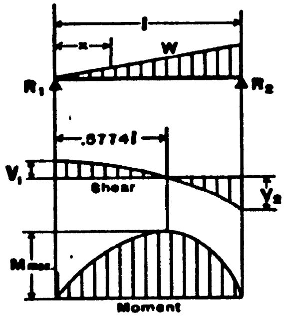
M max. (at center) . . . . $= \frac{wl^2}{8}$

M_x . . . . $= \frac{wx}{2}(l - x)$

Δmax. (at center) . . . . $= \frac{5wl^4}{384EI}$

Δ_x . . . . $= \frac{wx}{24EI}(l^3 - 2lx^2 + x^3)$

2. SIMPLE BEAM—LOAD INCREASING UNIFORMLY TO ONE END



Total Equiv. Uniform Load . . . . $= \frac{16W}{9\sqrt{3}} = 1.0264W$

$R_1 = V_1$ . . . . $= \frac{W}{3}$

$R_2 = V_2$ max. . . . . $= \frac{2W}{3}$

V_x . . . . $= \frac{W}{3} - \frac{Wx^2}{l^2}$

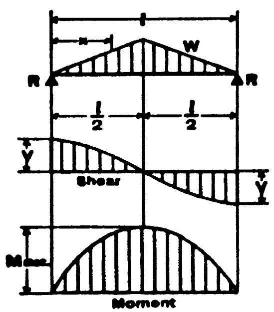
M max. $\left(\text{at } x = \frac{l}{\sqrt{3}} = .5774l\right)$ . . . $= \frac{2Wl}{9\sqrt{3}} = .1283\ Wl$

M_x . . . . $= \frac{Wx}{3l^2}(l^2 - x^2)$

Δmax. $\left(\text{at } x = l\sqrt{1 - \sqrt{\frac{8}{15}}} = .5193l\right) = .01304\,\frac{Wl^3}{EI}$

Δ_x . . . . $= \frac{Wx}{180EIl^2}(3x^4 - 10l^2x^2 + 7l^4)$

3. SIMPLE BEAM—LOAD INCREASING UNIFORMLY TO CENTER



Total Equiv. Uniform Load . . . . $= \frac{4W}{3}$

$R = V$ . . . . $= \frac{W}{2}$

V_x $\left(\text{when } x < \frac{l}{2}\right)$ . . . . $= \frac{W}{2l^2}(l^2 - 4x^2)$

M max. (at center) . . . . $= \frac{Wl}{6}$

M_x $\left(\text{when } x < \frac{l}{2}\right)$ . . . . $= Wx\left(\frac{1}{2} - \frac{2x^2}{3l^2}\right)$

Δmax. (at center) . . . . $= \frac{Wl^3}{60EI}$

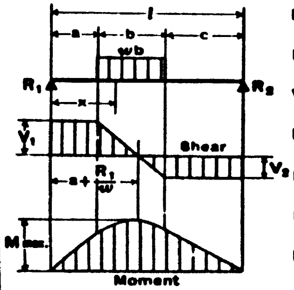
Δ_x $\left(\text{when } x < \frac{l}{2}\right)$ . . . . $= \frac{Wx}{480EIl^2}(5l^2 - 4x^2)^2$

BEAM DIAGRAMS AND FORMULAS

For various static loading conditions

For meaning of symbols, see page 2-111.

4. SIMPLE BEAM—UNIFORM LOAD PARTIALLY DISTRIBUTED



$R_1 = V_1$ (max. when $a < c$) . . . $= \frac{wb}{2l}(2c + b)$

$R_2 = V_2$ (max. when $a > c$) . . . $= \frac{wb}{2l}(2a + b)$

V_x (when $x > a$ and $< (a + b)$) . $= R_1 - w(x - a)$

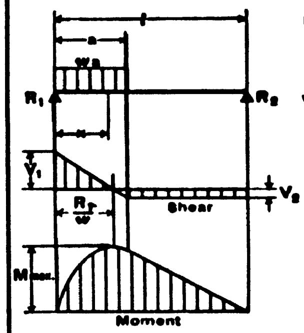
M max. $\left(\text{at } x = a + \frac{R_1}{w}\right)$ . . . . $= R_1\left(a + \frac{R_1}{2w}\right)$

M_x (when $x < a$) . . . . $= R_1x$

M_x (when $x > a$ and $< (a + b)$) . $= R_1x - \frac{w}{2}(x - a)^2$

M_x (when $x > (a + b)$) . . . . $= R_2(l - x)$

5. SIMPLE BEAM—UNIFORM LOAD PARTIALLY DISTRIBUTED AT ONE END



$R_1 = V_1$ max. . . . . $= \frac{wa}{2l}(2l - a)$

$R_2 = V_2$ . . . . $= \frac{wa^2}{2l}$

V_x (when $x < a$) . . . . $= R_1 - wx$

M max. $\left(\text{at } x = \frac{R_1}{w}\right)$ . . . . $= \frac{R_1^2}{2w}$

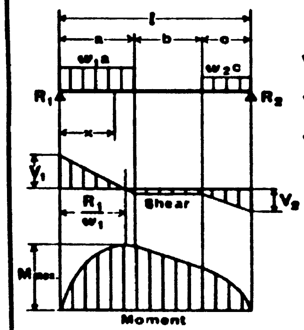
M_x (when $x < a$) . . . . $= R_1x - \frac{wx^2}{2}$

M_x (when $x > a$) . . . . $= R_2(l - x)$

Δ_x (when $x < a$) . . . . $= \frac{wx}{24EIl}\left(a^2(2l - a)^2 - 2ax^2(2l - a) + lx^3\right)$

Δ_x (when $x > a$) . . . . $= \frac{wa^2(l - x)}{24EIl}(4xl - 2x^2 - a^2)$

6. SIMPLE BEAM—UNIFORM LOAD PARTIALLY DISTRIBUTED AT EACH END



$R_1 = V_1$ . . . . $= \frac{w_1a(2l - a) + w_2c^2}{2l}$

$R_2 = V_2$ . . . . $= \frac{w_2c(2l - c) + w_1a^2}{2l}$

V_x (when $x < a$) . . . . $= R_1 - w_1x$

V_x (when $x > a$ and $< (a + b)$) . $= R_1 - w_1a$

V_x (when $x > (a + b)$) . . . . $= R_2 - w_2(l - x)$

M max. $\left(\text{at } x = \frac{R_1}{w_1} \text{ when } R_1 < w_1a\right)$. $= \frac{R_1^2}{2w_1}$

M max. $\left(\text{at } x = l - \frac{R_2}{w_2} \text{ when } R_2 < w_2c\right) = \frac{R_2^2}{2w_2}$

M_x (when $x < a$) . . . . $= R_1x - \frac{w_1x^2}{2}$

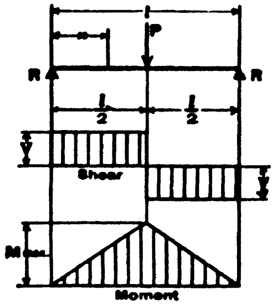
M_x (when $x > a$ and $< (a + b)$) . $= R_1x - \frac{w_1a}{2}(2x - a)$

M_x (when $x > (a + b)$) . . . . $= R_2(l - x) - \frac{w_2(l - x)^2}{2}$

BEAM DIAGRAMS AND FORMULAS
For various static loading conditions

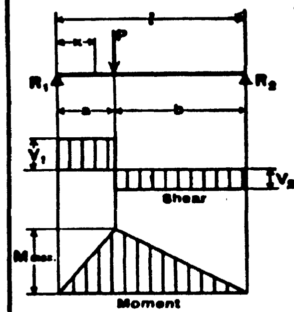
For meaning of symbols, see page 2-111.

7. SIMPLE BEAM—CONCENTRATED LOAD AT CENTER



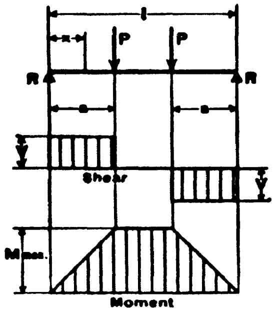
Total Equiv. Uniform Load		$= 2P$
$R = V$		$= \frac{P}{2}$
M max.	(at point of load)	$= \frac{Pl}{4}$
M_x	(when $x < \frac{l}{2}$)	$= \frac{Px}{2}$
Δmax.	(at point of load)	$= \frac{Pl^3}{48EI}$
Δ_x	(when $x < \frac{l}{2}$)	$= \frac{Px}{48EI}(3l^2 - 4x^2)$

8. SIMPLE BEAM—CONCENTRATED LOAD AT ANY POINT



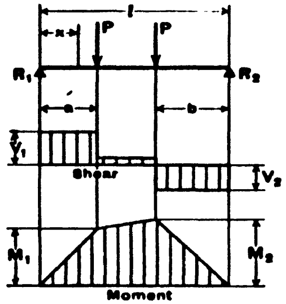
Total Equiv. Uniform Load		$= \frac{8Pab}{l^2}$
$R_1 = V_1$	(max. when $a < b$)	$= \frac{Pb}{l}$
$R_2 = V_2$	(max. when $a > b$)	$= \frac{Pa}{l}$
M max.	(at point of load)	$= \frac{Pab}{l}$
M_x	(when $x < a$)	$= \frac{Pbx}{l}$
Δmax.	(at $x = \sqrt{\frac{a(a+2b)}{3}}$ when $a > b$)	$= \frac{Pab(a+2b)\sqrt{3a(a+2b)}}{27EIl}$
Δ_a	(at point of load)	$= \frac{Pa^2b^2}{3EIl}$
Δ_x	(when $x < a$)	$= \frac{Pbx}{6EIl}(l^2 - b^2 - x^2)$

9. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS SYMMETRICALLY PLACED



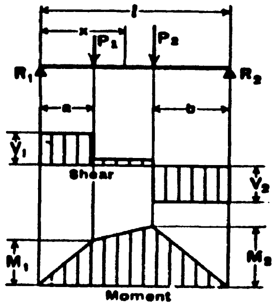
Total Equiv. Uniform Load		$= \frac{8Pa}{l}$
$R = V$		$= P$
M max.	(between loads)	$= Pa$
M_x	(when $x < a$)	$= Px$
Δmax.	(at center)	$= \frac{Pa}{24EI}(3l^2 - 4a^2)$
Δ_x	(when $x < a$)	$= \frac{Px}{6EI}(3la - 3a^2 - x^2)$
Δ_x	(when $x > a$ and $< (l - a)$)	$= \frac{Pa}{6EI}(3lx - 3x^2 - a^2)$

10. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS UNSYMMETRICALLY PLACED



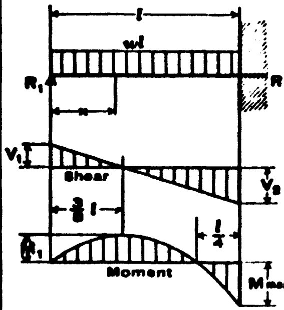
$R_1 = V_1$	(max. when $a < b$)	$= \frac{P}{l}(l - a + b)$
$R_2 = V_2$	(max. when $a > b$)	$= \frac{P}{l}(l - b + a)$
V_x	(when $x > a$ and $< (l - b)$)	$= \frac{P}{l}(b - a)$
M_1	(max. when $a > b$)	$= R_1a$
M_2	(max. when $a < b$)	$= R_2b$
M_x	(when $x < a$)	$= R_1x$
M_x	(when $x > a$ and $< (l - b)$)	$= R_1x - P(x - a)$

11. SIMPLE BEAM—TWO UNEQUAL CONCENTRATED LOADS UNSYMMETRICALLY PLACED



$R_1 = V_1$		$= \frac{P_1(l - a) + P_2b}{l}$
$R_2 = V_2$		$= \frac{P_1a + P_2(l - b)}{l}$
V_x	(when $x > a$ and $< (l - b)$)	$= R_1 - P_1$
M_1	(max. when $R_1 < P_1$)	$= R_1a$
M_2	(max. when $R_2 < P_2$)	$= R_2b$
M_x	(when $x < a$)	$= R_1x$
M_x	(when $x > a$ and $< (l - b)$)	$= R_1x - P_1(x - a)$

12. BEAM FIXED AT ONE END, SUPPORTED AT OTHER—UNIFORMLY DISTRIBUTED LOAD



Total Equiv. Uniform Load		$= wl$
$R_1 = V_1$		$= \frac{3wl}{8}$
$R_2 = V_2$ max.		$= \frac{5wl}{8}$
V_x		$= R_1 - wx$
M max.		$= \frac{wl^2}{8}$
M_1	(at $x = \frac{3}{8}l$)	$= \frac{9}{128}wl^2$
M_x		$= R_1x - \frac{wx^2}{2}$
Δmax.	(at $x = \frac{l}{16}(1 + \sqrt{33}) = .4215l$)	$= \frac{wl^4}{185EI}$
Δ_x		$= \frac{wx}{48EI}(l^3 - 3lx^2 + 2x^3)$

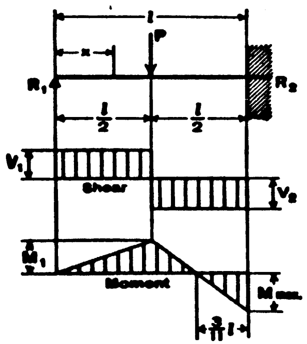
AMERICAN INSTITUTE OF STEEL CONSTRUCTION

D-5

BEAM DIAGRAMS AND FORMULAS
For various static loading conditions

For meaning of symbols, see page 2-111

13. BEAM FIXED AT ONE END, SUPPORTED AT OTHER—CONCENTRATED LOAD AT CENTER



Total Equiv. Uniform Load . . . . . $= \frac{3P}{2}$

$R_1 = V_1$ . . . . $= \frac{5P}{16}$

$R_2 = V_2$ max. . . . . $= \frac{11P}{16}$

M max. (at fixed end) . . . . . . $= \frac{3Pl}{16}$

M_1 (at point of load) . . . . . $= \frac{5Pl}{32}$

M_x (when $x < \frac{l}{2}$) . . . . . . $= \frac{5Px}{16}$

M_x (when $x > \frac{l}{2}$) . . . . . . $= P\left(\frac{l}{2} - \frac{11x}{16}\right)$

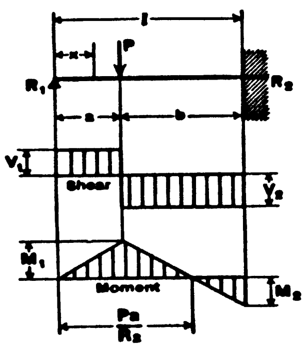
Δmax. (at $x = l\sqrt{\frac{1}{5}} = .4472l$) . . . $= \frac{Pl^3}{48EI\sqrt{5}} = .009317\frac{Pl^3}{EI}$

Δ_x (at point of load) . . . . . $= \frac{7Pl^3}{768EI}$

Δ_x (when $x < \frac{l}{2}$) . . . . . . $= \frac{Px}{96EI}(3l^2 - 5x^2)$

Δ_x (when $x > \frac{l}{2}$) . . . . . . $= \frac{P}{96EI}(x-l)^2(11x-2l)$

14. BEAM FIXED AT ONE END, SUPPORTED AT OTHER—CONCENTRATED LOAD AT ANY POINT



$R_1 = V_1$ . . . . $= \frac{Pb^2}{2l^3}(a+2l)$

$R_2 = V_2$ . . . . $= \frac{Pa}{2l^3}(3l^2 - a^2)$

M_1 (at point of load) . . . . . $= R_1a$

M_2 (at fixed end) . . . . . . $= \frac{Pab}{2l^2}(a+l)$

M_x (when $x < a$) . . . . . . $= R_1x$

M_x (when $x > a$) . . . . . . $= R_1x - P(x-a)$

Δmax. (when $a < .414l$ at $x = l\frac{l^2+a^2}{3l^2-a^2}$) $= \frac{Pa}{3EI}\frac{(l^2-a^2)^3}{(3l^2-a^2)^2}$

Δmax. (when $a > .414l$ at $x = l\sqrt{\frac{a}{2l+a}}$) $= \frac{Pab^2}{6EI}\sqrt{\frac{a}{2l+a}}$

Δ_a (at point of load) . . . . $= \frac{Pa^2b^3}{12EIl^3}(3l+a)$

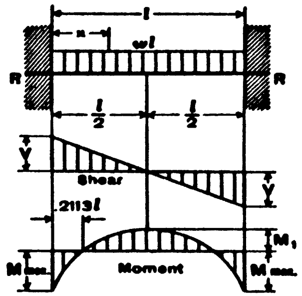
Δ_x (when $x < a$) . . . . . . $= \frac{Pb^2x}{12EIl^3}(3al^2 - 2lx^2 - ax^2)$

Δ_x (when $x > a$) . . . . . . $= \frac{Pa}{12EIl^3}(l-x)^2(3l^2x - a^2x - 2a^2l)$

BEAM DIAGRAMS AND FORMULAS
For various static loading conditions

For meaning of symbols, see page 2-111.

15. BEAM FIXED AT BOTH ENDS—UNIFORMLY DISTRIBUTED LOADS



Total Equiv. Uniform Load . . . . . $= \frac{2wl}{3}$

$R = V$ . . . . $= \frac{wl}{2}$

V_x . . . . $= w\left(\frac{l}{2} - x\right)$

M max. (at ends) . . . . $= \frac{wl^2}{12}$

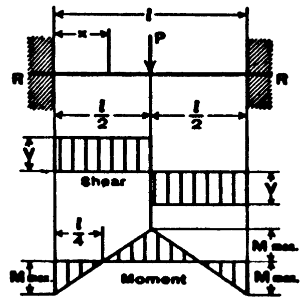
M_1 (at center) . . . . $= \frac{wl^2}{24}$

M_x . . . . $= \frac{w}{12}(6lx - l^2 - 6x^2)$

Δmax. (at center) . . . . $= \frac{wl^4}{384EI}$

Δ_x . . . . $= \frac{wx^2}{24EI}(l-x)^2$

16. BEAM FIXED AT BOTH ENDS—CONCENTRATED LOAD AT CENTER



Total Equiv. Uniform Load . . . . . $= P$

$R = V$ . . . . $= \frac{P}{2}$

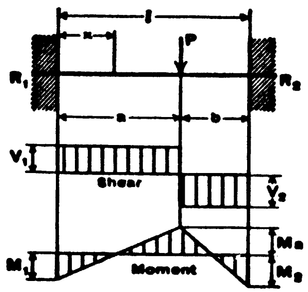
M max. (at center and ends) . . . . $= \frac{Pl}{8}$

M_x (when $x < \frac{l}{2}$) . . . . . . $= \frac{P}{8}(4x - l)$

Δmax. (at center) . . . . $= \frac{Pl^3}{192EI}$

Δ_x (when $x < \frac{l}{2}$) . . . . . . $= \frac{Px^2}{48EI}(3l - 4x)$

17. BEAM FIXED AT BOTH ENDS—CONCENTRATED LOAD AT ANY POINT



$R_1 = V_1$ (max. when $a < b$) . . . . $= \frac{Pb^2}{l^3}(3a+b)$

$R_2 = V_2$ (max. when $a > b$) . . . . $= \frac{Pa^2}{l^3}(a+3b)$

M_1 (max. when $a < b$) . . . . $= \frac{Pab^2}{l^2}$

M_2 (max. when $a > b$) . . . . $= \frac{Pa^2b}{l^2}$

M_a (at point of load) . . . . $= \frac{2Pa^2b^2}{l^3}$

M_x (when $x < a$) . . . . . . $= R_1x - \frac{Pab^2}{l^2}$

Δmax. (when $a > b$ at $x = \frac{2al}{3a+b}$) . $= \frac{2Pa^3b^2}{3EI(3a+b)^2}$

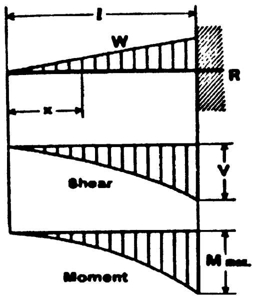
Δ_a (at point of load) . . . . $= \frac{Pa^3b^3}{3EIl^3}$

Δ_x (when $x < a$) . . . . . . $= \frac{Pb^2x^2}{6EIl^3}(3al - 3ax - bx)$

A-15

For meaning of symbols, see page 2-111.

18. CANTILEVER BEAM—LOAD INCREASING UNIFORMLY TO FIXED END



Total Equiv. Uniform Load . . . . . $= \frac{8}{3}W$

R = V . . . . $= W$

V_x . . . . $= W\frac{x^2}{l^2}$

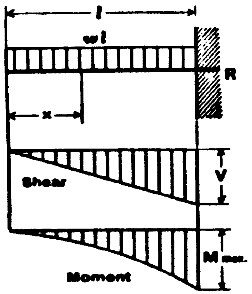
M max. (at fixed end) . . . . . . $= \frac{Wl}{3}$

M_x . . . . $= \frac{Wx^3}{3l^2}$

Δmax. (at free end) . . . . . . $= \frac{Wl^3}{15EI}$

Δx . . . . $= \frac{W}{60EIl^2}(x^5 - 5l^4x + 4l^5)$

19. CANTILEVER BEAM—UNIFORMLY DISTRIBUTED LOAD



Total Equiv. Uniform Load . . . . . $= 4wl$

R = V . . . . $= wl$

V_x . . . . $= wx$

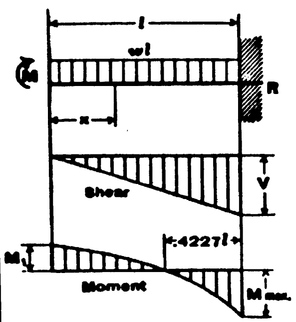
M max. (at fixed end) . . . . . . $= \frac{wl^2}{2}$

M_x . . . . $= \frac{wx^2}{2}$

Δmax. (at free end) . . . . . . $= \frac{wl^4}{8EI}$

Δx . . . . $= \frac{w}{24EI}(x^4 - 4l^3x + 3l^4)$

20. BEAM FIXED AT ONE END, FREE TO DEFLECT VERTICALLY BUT NOT ROTATE AT OTHER—UNIFORMLY DISTRIBUTED LOAD



Total Equiv. Uniform Load . . . . . $= \frac{8}{3}wl$

R = V . . . . $= wl$

V_x . . . . $= wx$

M max. (at fixed end) . . . . . . $= \frac{wl^2}{3}$

M_1 (at deflected end) . . . . . $= \frac{wl^2}{6}$

M_x . . . . $= \frac{w}{6}(l^2 - 3x^2)$

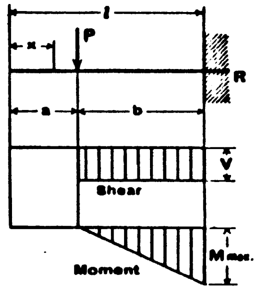
Δmax. (at deflected end) . . . . . $= \frac{wl^4}{24EI}$

Δx . . . . $= \frac{w(l^2 - x^2)^2}{24EI}$

BEAM DIAGRAMS AND FORMULAS
For various static loading conditions

For meaning of symbols, see page 2-111.

21. CANTILEVER BEAM—CONCENTRATED LOAD AT ANY POINT



Total Equiv. Uniform Load . . . . . $= \frac{8Pb}{l}$

R = V . . . . $= P$

M max. (at fixed end) . . . . . . $= Pb$

M_x (when x > a) . . . . . . $= P(x - a)$

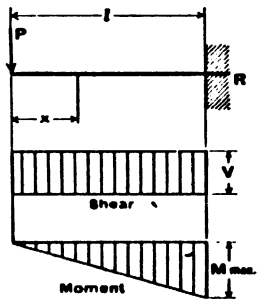
Δmax. (at free end) . . . . . . $= \frac{Pb^2}{6EI}(3l - b)$

Δa (at point of load) . . . . . $= \frac{Pb^3}{3EI}$

Δx (when x < a) . . . . . . $= \frac{Pb^2}{6EI}(3l - 3x - b)$

Δx (when x > a) . . . . . . $= \frac{P(l - x)^2}{6EI}(3b - l + x)$

22. CANTILEVER BEAM—CONCENTRATED LOAD AT FREE END



Total Equiv. Uniform Load . . . . . $= 8P$

R = V . . . . $= P$

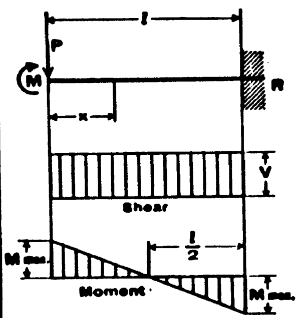
M max. (at fixed end) . . . . . . $= Pl$

M_x . . . . $= Px$

Δmax. (at free end) . . . . . . $= \frac{Pl^3}{3EI}$

Δx . . . . $= \frac{P}{6EI}(2l^3 - 3l^2x + x^3)$

23. BEAM FIXED AT ONE END, FREE TO DEFLECT VERTICALLY BUT NOT ROTATE AT OTHER—CONCENTRATED LOAD AT DEFLECTED END



Total Equiv. Uniform Load . . . . . $= 4P$

R = V . . . . $= P$

M max. (at both ends) . . . . . . $= \frac{Pl}{2}$

M_x . . . . $= P\left(\frac{l}{2} - x\right)$

Δmax. (at deflected end) . . . . . $= \frac{Pl^3}{12EI}$

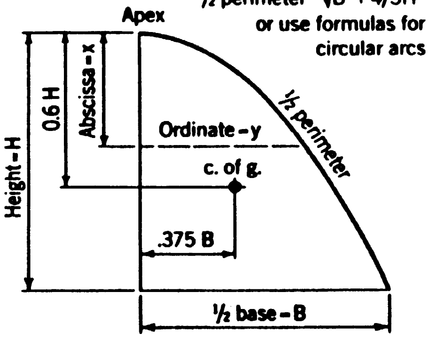
Δx . . . . $= \frac{P(l - x)^2}{12EI}(l + 2x)$

AMERICAN INSTITUTE OF STEEL CONSTRUCTION

PROPERTIES OF PARABOLA AND ELLIPSE

PARABOLA

When $H \div B = 0.1$ or less, approximate $\frac{1}{2}$ perimeter $= \sqrt{B^2 + 4/3H^2}$ or use formulas for circular arcs

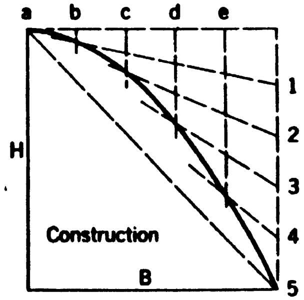


Parameter $P = B^2 \div H$

$x = y^2 \div P$

$y = \sqrt{xP}$

Area $= \frac{2}{3}$ HB



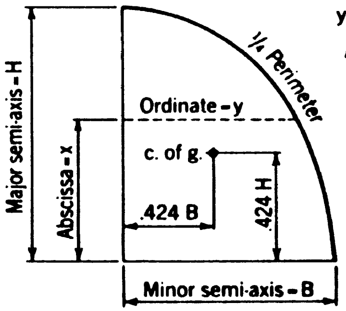
ELLIPSE

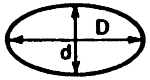
$(x^2 \div H^2) + (y^2 \div B^2) = 1$

$x = (H \div B)\sqrt{B^2 - y^2}$

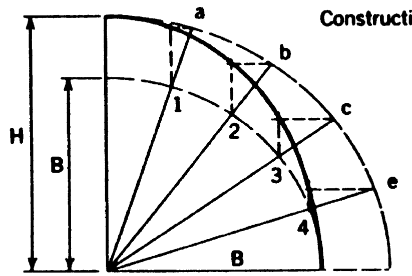
$y = (B \div H)\sqrt{H^2 - x^2}$

Approximate ¼ perimeter $= \frac{\pi}{4}\sqrt{2(H^2 + B^2)}$



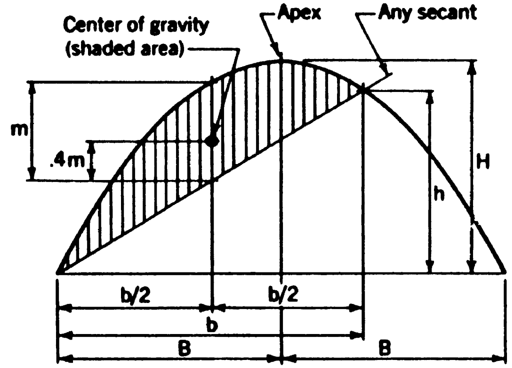


Area = .7854 Dd



Construction

AREA BETWEEN PARABOLIC CURVE AND SECANT



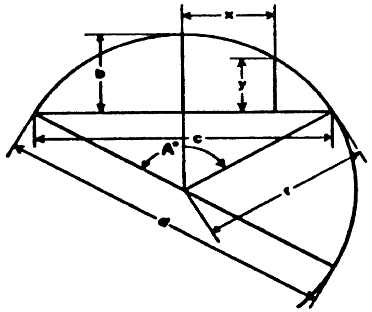
$h = \frac{Hb(2B - b)}{B^2}$

$m = \frac{Hb^2}{4B^2}$

Shaded area $= \frac{2}{3}$ bm $= \frac{Hb^3}{6B^2}$

Length b may vary from 0 to 2B

PROPERTIES OF THE CIRCLE



Circumference $= 6.28318\ r = 3.14159\ d$

Diameter $= 0.31831$ circumference

Area $= 3.14159\ r^2$

Arc $a = \frac{\pi r A°}{180°} = 0.017453\ r A°$

Angle $A° = \frac{180° a}{\pi r} = 57.29578 \frac{a}{r}$

Radius $r = \frac{4 b^2 + c^2}{8 b}$

Chord $c = 2\sqrt{2 br - b^2} = 2 r \sin \frac{A}{2}$

Rise $b = r - \frac{1}{2}\sqrt{4 r^2 - c^2} = \frac{c}{2} \tan \frac{A}{4}$

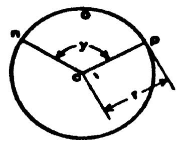
$= 2 r \sin^2 \frac{A}{4} = r + y - \sqrt{r^2 - x^2}$

$y = b - r + \sqrt{r^2 - x^2}$

$x = \sqrt{r^2 - (r + y - b)^2}$

Diameter of circle of equal periphery as square = 1.27324 side of square
Side of square of equal periphery as circle = 0.78540 diameter of circle
Diameter of circle circumscribed about square = 1.41421 side of square
Side of square inscribed in circle = 0.70711 diameter of circle

CIRCULAR SECTOR



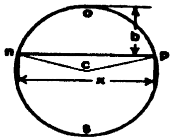
r = radius of circle   y = angle ncp in degrees

Area of Sector ncpo = ½ (length of arc nop × r)

$=$ Area of Circle $\times \frac{y}{360}$

$= 0.0087266 \times r^2 \times y$

CIRCULAR SEGMENT



r = radius of circle   x = chord   b = rise

Area of Segment nop = Area of Sector ncpo − Area of triangle ncp

$= \frac{(\text{Length of arc nop} \times r) - x(r - b)}{2}$

Area of Segment nsp = Area of Circle − Area of Segment nop

VALUES FOR FUNCTIONS OF π

$\pi = 3.14159265359$,   log = 0.4971499

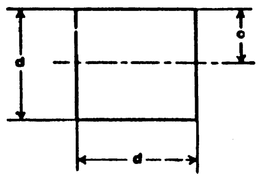
$\pi^2 = 9.8696044$, log = 0.9942997	$\frac{1}{\pi} = 0.3183099$, log = $\overline{1}.5028501$	$\sqrt{\frac{1}{\pi}} = 0.5641896$, log = $\overline{1}.7514251$
$\pi^3 = 31.0062767$, log = 1.4914496	$\frac{1}{\pi^2} = 0.1013212$, log = $\overline{1}.0057003$	$\frac{\pi}{180} = 0.0174533$, log = $\overline{2}.2418774$
$\sqrt{\pi} = 1.7724539$, log = 0.2485749	$\frac{1}{\pi^3} = 0.0322515$, log = $\overline{2}.5085504$	$\frac{180}{\pi} = 57.2957795$, log = 1.7581226

Note: Logs of fractions such as $\overline{1}.5028501$ and $\overline{2}.5085500$ may also be written 9.5028501 − 10 and 8.5085500 − 10 respectively.

PROPERTIES OF GEOMETRIC SECTIONS

SQUARE

Axis of moments through center



$A = d^2$

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

$I = \frac{d^4}{12}$

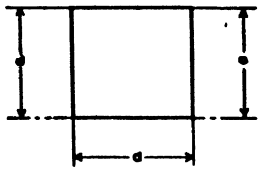
$S = \frac{d^3}{6}$

$r = \frac{d}{\sqrt{12}} = .288675\ d$

$Z = \frac{d^3}{4}$

SQUARE

Axis of moments on base



$A = d^2$

$c = d$

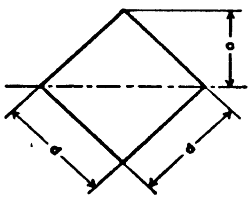
$I = \frac{d^4}{3}$

$S = \frac{d^3}{3}$

$r = \frac{d}{\sqrt{3}} = .577350\ d$

SQUARE

Axis of moments on diagonal



$A = d^2$

$c = \frac{d}{\sqrt{2}} = .707107\ d$

$I = \frac{d^4}{12}$

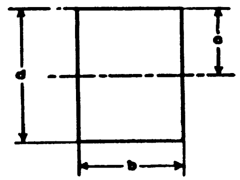
$S = \frac{d^3}{6\sqrt{2}} = .117851\ d^3$

$r = \frac{d}{\sqrt{12}} = .288675\ d$

$Z = \frac{2c^3}{3} = \frac{d^3}{3\sqrt{2}} = .235702 d^3$

RECTANGLE

Axis of moments through center



$A = bd$

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

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

$S = \frac{bd^2}{6}$

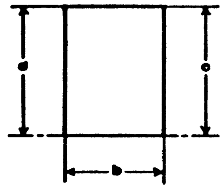
$r = \frac{d}{\sqrt{12}} = .288675\ d$

$Z = \frac{bd^2}{4}$

PROPERTIES OF GEOMETRIC SECTIONS

RECTANGLE

Axis of moments on base



$A = bd$

$c = d$

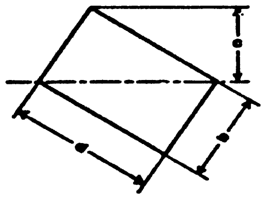
$I = \frac{bd^3}{3}$

$S = \frac{bd^2}{3}$

$r = \frac{d}{\sqrt{3}} = .577350\ d$

RECTANGLE

Axis of moments on diagonal



$A = bd$

$c = \frac{bd}{\sqrt{b^2 + d^2}}$

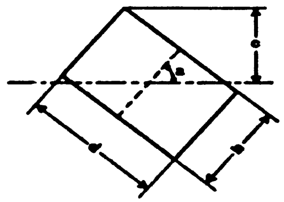
$I = \frac{b^3d^3}{6\,(b^2 + d^2)}$

$S = \frac{b^2d^2}{6\sqrt{b^2 + d^2}}$

$= \frac{bd}{\sqrt{6\,(b^2 + d^2)}}$

RECTANGLE

Axis of moments any line through center of gravity



$A = bd$

$c = \frac{b \sin a + d \cos a}{2}$

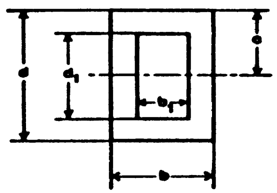
$I = \frac{bd\,(b^2 \sin^2 a + d^2 \cos^2 a)}{12}$

$S = \frac{bd\,(b^2 \sin^2 a + d^2 \cos^2 a)}{6\,(b \sin a + d \cos a)}$

$r = \sqrt{\frac{b^2 \sin^2 a + d^2 \cos^2 a}{12}}$

HOLLOW RECTANGLE

Axis of moments through center



$A = bd - b_1d_1$

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

$I = \frac{bd^3 - b_1d_1^3}{12}$

$S = \frac{bd^3 - b_1d_1^3}{6d}$

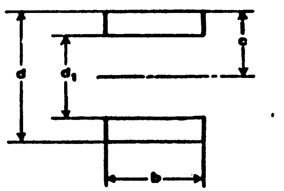
$r = \sqrt{\frac{bd^3 - b_1d_1^3}{12\ A}}$

$Z = \frac{bd^2}{4} - \frac{b_1d_1^2}{4}$

PROPERTIES OF GEOMETRIC SECTIONS

EQUAL RECTANGLES

Axis of moments through center of gravity



$A = b(d - d_1)$

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

$I = \frac{b(d^3 - d_1^3)}{12}$

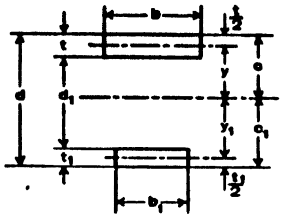
$S = \frac{b(d^3 - d_1^3)}{6d}$

$r = \sqrt{\frac{d^3 - d_1^3}{12(d - d_1)}}$

$Z = \frac{b}{4}(d^2 - d_1^2)$

UNEQUAL RECTANGLES

Axis of moments through center of gravity



$A = bt + b_1t_1$

$c = \frac{\frac{1}{2}bt^2 + b_1t_1(d - \frac{1}{2}t_1)}{A}$

$I = \frac{bt^3}{12} + bty^2 + \frac{b_1t_1^3}{12} + b_1t_1y_1^2$

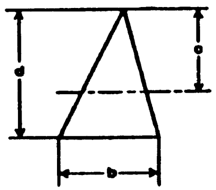
$S = \frac{I}{c} \qquad S_1 = \frac{I}{c_1}$

$r = \sqrt{\frac{I}{A}}$

$Z = \frac{A}{2}\left[d - \left(\frac{t + t_1}{2}\right)\right]$

TRIANGLE

Axis of moments through center of gravity



$A = \frac{bd}{2}$

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

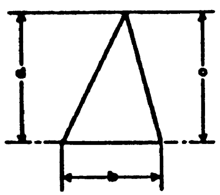
$I = \frac{bd^3}{36}$

$S = \frac{bd^2}{24}$

$r = \frac{d}{\sqrt{18}} = .235702\ d$

TRIANGLE

Axis of moments on base



$A = \frac{bd}{2}$

$c = d$

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

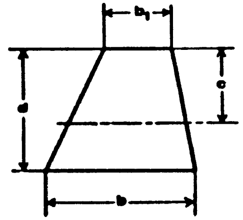
$S = \frac{bd^2}{12}$

$r = \frac{d}{\sqrt{6}} = .408248\ d$

PROPERTIES OF GEOMETRIC SECTIONS

TRAPEZOID

Axis of moments through center of gravity



$A = \frac{d(b + b_1)}{2}$

$c = \frac{d(2b + b_1)}{3(b + b_1)}$

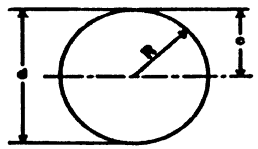
$I = \frac{d^3(b^2 + 4bb_1 + b_1^2)}{36(b + b_1)}$

$S = \frac{d^2(b^2 + 4bb_1 + b_1^2)}{12(2b + b_1)}$

$r = \frac{d}{6(b + b_1)}\sqrt{2(b^2 + 4bb_1 + b_1^2)}$

CIRCLE

Axis of moments through center



$A = \frac{\pi d^2}{4} = \pi R^2 = .785398\ d^2 = 3.141593\ R^2$

$c = \frac{d}{2} = R$

$I = \frac{\pi d^4}{64} = \frac{\pi R^4}{4} = .049087\ d^4 = .785398\ R^4$

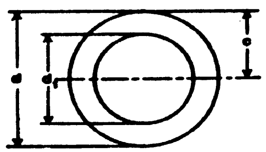
$S = \frac{\pi d^3}{32} = \frac{\pi R^3}{4} = .098175\ d^3 = .785398\ R^3$

$r = \frac{d}{4} = \frac{R}{2}$

$Z = \frac{d^3}{6}$

HOLLOW CIRCLE

Axis of moments through center



$A = \frac{\pi(d^2 - d_1^2)}{4} = .785398(d^2 - d_1^2)$

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

$I = \frac{\pi(d^4 - d_1^4)}{64} = .049087(d^4 - d_1^4)$

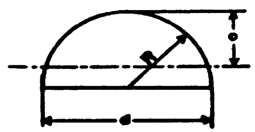
$S = \frac{\pi(d^4 - d_1^4)}{32d} = .098175\frac{d^4 - d_1^4}{d}$

$r = \frac{\sqrt{d^2 + d_1^2}}{4}$

$Z = \frac{d^3}{6} - \frac{d_1^3}{6}$

HALF CIRCLE

Axis of moments through center of gravity



$A = \frac{\pi R^2}{2} = 1.570796\ R^2$

$c = R\left(1 - \frac{4}{3\pi}\right) = .575587\ R$

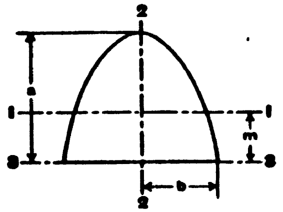
$I = R^4\left(\frac{\pi}{8} - \frac{8}{9\pi}\right) = .109757\ R^4$

$S = \frac{R^3}{24}\frac{(9\pi^2 - 64)}{(3\pi - 4)} = .190687\ R^3$

$r = R\frac{\sqrt{9\pi^2 - 64}}{6\pi} = .264336\ R$

PROPERTIES OF GEOMETRIC SECTIONS

PARABOLA



$A = \frac{4}{3}ab$

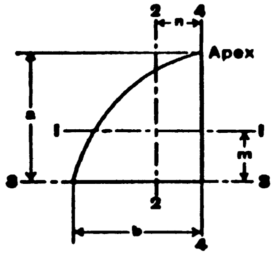
$m = \frac{2}{5}a$

$I_1 = \frac{16}{175}a^3b$

$I_2 = \frac{4}{15}ab^3$

$I_3 = \frac{32}{105}a^3b$

HALF PARABOLA



$A = \frac{2}{3}ab$

$m = \frac{2}{5}a$

$n = \frac{3}{8}b$

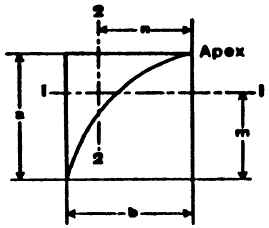
$I_1 = \frac{8}{175}a^3b$

$I_2 = \frac{19}{480}ab^3$

$I_3 = \frac{16}{105}a^3b$

$I_4 = \frac{2}{15}ab^3$

COMPLEMENT OF HALF PARABOLA



$A = \frac{1}{3}ab$

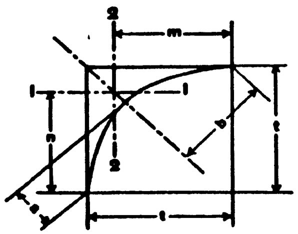
$m = \frac{7}{10}a$

$n = \frac{3}{4}b$

$I_1 = \frac{37}{2100}a^3b$

$I_2 = \frac{1}{80}ab^3$

PARABOLIC FILLET IN RIGHT ANGLE



$a = \frac{t}{2\sqrt{2}}$

$b = \frac{t}{\sqrt{2}}$

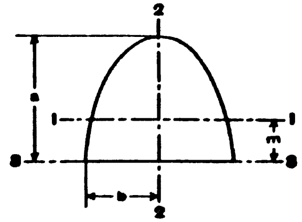
$A = \frac{1}{6}t^2$

$m = n = \frac{4}{5}t$

$I_1 = I_2 = \frac{11}{2100}t^4$

PROPERTIES OF GEOMETRIC SECTIONS

* HALF ELLIPSE



$A = \frac{1}{2}\pi ab$

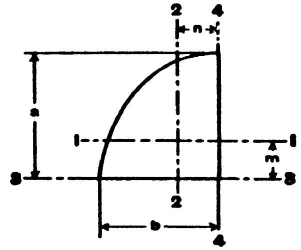
$m = \frac{4a}{3\pi}$

$I_1 = a^3b\left(\frac{\pi}{8} - \frac{8}{9\pi}\right)$

$I_2 = \frac{1}{8}\pi ab^3$

$I_3 = \frac{1}{8}\pi a^3b$

* QUARTER ELLIPSE



$A = \frac{1}{4}\pi ab$

$m = \frac{4a}{3\pi}$

$n = \frac{4b}{3\pi}$

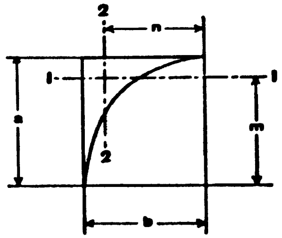
$I_1 = a^3b\left(\frac{\pi}{16} - \frac{4}{9\pi}\right)$

$I_2 = ab^3\left(\frac{\pi}{16} - \frac{4}{9\pi}\right)$

$I_3 = \frac{1}{16}\pi a^3b$

$I_4 = \frac{1}{16}\pi ab^3$

* ELLIPTIC COMPLEMENT



$A = ab\left(1 - \frac{\pi}{4}\right)$

$m = \frac{a}{6\left(1 - \frac{\pi}{4}\right)}$

$n = \frac{b}{6\left(1 - \frac{\pi}{4}\right)}$

$I_1 = a^3b\left(\frac{1}{3} - \frac{\pi}{16} - \frac{1}{36\left(1 - \frac{\pi}{4}\right)}\right)$

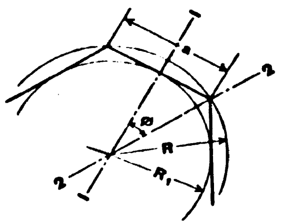
$I_2 = ab^3\left(\frac{1}{3} - \frac{\pi}{16} - \frac{1}{36\left(1 - \frac{\pi}{4}\right)}\right)$

* To obtain properties of half circle, quarter circle and circular complement substitute $a = b = R$.

PROPERTIES OF GEOMETRIC SECTIONS AND STRUCTURAL SHAPES

REGULAR POLYGON

Axis of moments through center



n = Number of sides

$\phi = \dfrac{180°}{n}$

$a = 2\sqrt{R^2 - R_1^2}$

$R = \dfrac{a}{2\sin\phi}$

$R_1 = \dfrac{a}{2\tan\phi}$

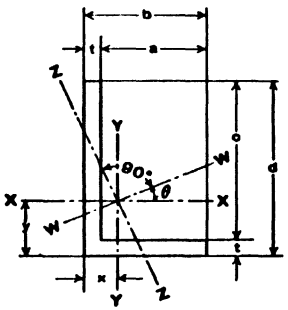
$A = \frac{1}{4}na^2\cot\phi = \frac{1}{2}nR^2\sin 2\phi = nR_1^2\tan\phi$

$I_1 = I_2 = \dfrac{A(6R^2 - a^2)}{24} = \dfrac{A(12R_1^2 + a^2)}{48}$

$r_1 = r_2 = \sqrt{\dfrac{6R^2 - a^2}{24}} = \sqrt{\dfrac{12R_1^2 + a^2}{48}}$

ANGLE

Axis of moments through center of gravity



Z-Z is axis of minimum I

$\tan 2\theta = \dfrac{2K}{I_y - I_x}$

$A = t(b + c) \quad x = \dfrac{b^2 + ct}{2(b + c)} \quad y = \dfrac{d^2 + at}{2(b + c)}$

K = Product of Inertia about X-X & Y-Y

$= \pm \dfrac{abcdt}{4(b + c)}$

$I_x = \frac{1}{3}\left(t(d - y)^3 + by^3 - a(y - t)^3\right)$

$I_y = \frac{1}{3}\left(t(b - x)^3 + dx^3 - c(x - t)^3\right)$

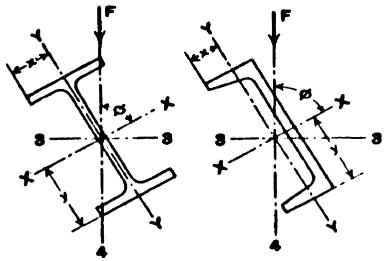
$I_z = I_x\sin^2\theta + I_y\cos^2\theta + K\sin 2\theta$

$I_w = I_x\cos^2\theta + I_y\sin^2\theta - K\sin 2\theta$

K is negative when heel of angle, with respect to c. g., is in 1st or 3rd quadrant, positive when in 2nd or 4th quadrant.

BEAMS AND CHANNELS

Transverse force oblique through center of gravity



$I_3 = I_x\sin^2\phi + I_y\cos^2\phi$

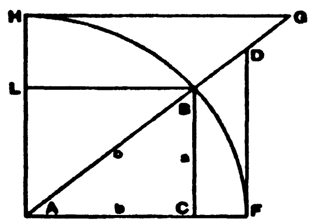
$I_4 = I_x\cos^2\phi + I_y\sin^2\phi$

$f_b = M\left(\dfrac{y}{I_x}\sin\phi + \dfrac{x}{I_y}\cos\phi\right)$

where M is bending moment due to force F.

TRIGONOMETRIC FORMULAS

TRIGONOMETRIC FUNCTIONS



Radius AF $= 1$
$= \sin^2 A + \cos^2 A = \sin A \operatorname{cosec} A$
$= \cos A \sec A = \tan A \cot A$

Sine A $= \dfrac{\cos A}{\cot A} = \dfrac{1}{\operatorname{cosec} A} = \cos A \tan A = \sqrt{1 - \cos^2 A} = BC$

Cosine A $= \dfrac{\sin A}{\tan A} = \dfrac{1}{\sec A} = \sin A \cot A = \sqrt{1 - \sin^2 A} = AC$

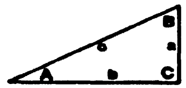
Tangent A $= \dfrac{\sin A}{\cos A} = \dfrac{1}{\cot A} = \sin A \sec A \quad = FD$

Cotangent A $= \dfrac{\cos A}{\sin A} = \dfrac{1}{\tan A} = \cos A \operatorname{cosec} A \quad = HG$

Secant A $= \dfrac{\tan A}{\sin A} = \dfrac{1}{\cos A} \quad = AD$

Cosecant A $= \dfrac{\cot A}{\cos A} = \dfrac{1}{\sin A} \quad = AG$

RIGHT ANGLED TRIANGLES



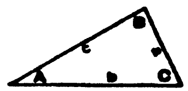
$a^2 = c^2 - b^2$

$b^2 = c^2 - a^2$

$c^2 = a^2 + b^2$

Known	Required: A	B	a	b	c	Area
a, b	$\tan A = \frac{a}{b}$	$\tan B = \frac{b}{a}$			$\sqrt{a^2 + b^2}$	$\frac{ab}{2}$
a, c	$\sin A = \frac{a}{c}$	$\cos B = \frac{a}{c}$		$\sqrt{c^2 - a^2}$		$\frac{a\sqrt{c^2 - a^2}}{2}$
A, a		$90° - A$		$a \cot A$	$\frac{a}{\sin A}$	$\frac{a^2 \cot A}{2}$
A, b		$90° - A$	$b \tan A$		$\frac{b}{\cos A}$	$\frac{b^2 \tan A}{2}$
A, c		$90° - A$	$c \sin A$	$c \cos A$		$\frac{c^2 \sin 2A}{4}$

OBLIQUE ANGLED TRIANGLES



$s = \dfrac{a + b + c}{2}$

$K = \sqrt{\dfrac{(s - a)(s - b)(s - c)}{s}}$

$a^2 = b^2 + c^2 - 2bc\cos A$

$b^2 = a^2 + c^2 - 2ac\cos B$

$c^2 = a^2 + b^2 - 2ab\cos C$

Known	Required: A	B	C	b	c	Area
a, b, c	$\tan\frac{1}{2}A = \frac{K}{s - a}$	$\tan\frac{1}{2}B = \frac{K}{s - b}$	$\tan\frac{1}{2}C = \frac{K}{s - c}$			$\sqrt{s(s-a)(s-b)(s-c)}$
a, A, B			$180° - (A + B)$	$\frac{a\sin B}{\sin A}$	$\frac{a\sin C}{\sin A}$	
a, b, A		$\sin B = \frac{b\sin A}{a}$			$\frac{b\sin C}{\sin B}$	
a, b, C	$\tan A = \frac{a\sin C}{b - a\cos C}$				$\sqrt{a^2 + b^2 - 2ab\cos C}$	$\frac{ab\sin C}{2}$

DECIMALS OF AN INCH

For each 64th of an inch

With Millimeter Equivalents

Fraction	1/64ths	Decimal	Millimeters (Approx.)	Fraction	1/64ths	Decimal	Millimeters (Approx.)
...	1	.015625	0.397	...	33	.515625	13.097
1/32	2	.03125	0.794	17/32	34	.53125	13.494
...	3	.046875	1.191	...	35	.546875	13.891
1/16	4	.0625	1.588	9/16	36	.5625	14.288
...	5	.078125	1.984	...	37	.578125	14.684
3/32	6	.09375	2.381	19/32	38	.59375	15.081
...	7	.109375	2.778	...	39	.609375	15.478
1/8	8	.125	3.175	5/8	40	.625	15.875
...	9	.140625	3.572	...	41	.640625	16.272
5/32	10	.15625	3.969	21/32	42	.65625	16.669
...	11	.171875	4.366	...	43	.671875	17.066
3/16	12	.1875	4.763	11/16	44	.6875	17.463
...	13	.203125	5.159	...	45	.703125	17.859
7/32	14	.21875	5.556	23/32	46	.71875	18.256
...	15	.234375	5.953	...	47	.734375	18.653
1/4	16	.250	6.350	3/4	48	.750	19.050
...	17	.265625	6.747	...	49	.765625	19.447
9/32	18	.28125	7.144	25/32	50	.78125	19.844
...	19	.296875	7.541	...	51	.796875	20.241
5/16	20	.3125	7.938	13/16	52	.8125	20.638
...	21	.328125	8.334	...	53	.828125	21.034
11/32	22	.34375	8.731	27/32	54	.84375	21.431
...	23	.359375	9.128	...	55	.859375	21.828
3/8	24	.375	9.525	7/8	56	.875	22.225
...	25	.390625	9.922	...	57	.890625	22.622
13/32	26	.40625	10.319	29/32	58	.90625	23.019
...	27	.421875	10.716	...	59	.921875	23.416
7/16	28	.4375	11.113	15/16	60	.9375	23.813
...	29	.453125	11.509	...	61	.953125	24.209
15/32	30	.46875	11.906	31/32	62	.96875	24.606
...	31	.484375	12.303	...	63	.984375	25.003
1/2	32	.500	12.700	1	64	1.000	25.400

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DECIMALS OF A FOOT
For each 32nd of an inch

Inch	0	1	2	3	4	5
0	0	.0833	.1667	.2500	.3333	.4167
1/32	.0026	.0859	.1693	.2526	.3359	.4193
1/16	.0052	.0885	.1719	.2552	.3385	.4219
3/32	.0078	.0911	.1745	.2578	.3411	.4245
1/8	.0104	.0938	.1771	.2604	.3438	.4271
5/32	.0130	.0964	.1797	.2630	.3464	.4297
3/16	.0156	.0990	.1823	.2656	.3490	.4323
7/32	.0182	.1016	.1849	.2682	.3516	.4349
1/4	.0208	.1042	.1875	.2708	.3542	.4375
9/32	.0234	.1068	.1901	.2734	.3568	.4401
5/16	.0260	.1094	.1927	.2760	.3594	.4427
11/32	.0286	.1120	.1953	.2786	.3620	.4453
3/8	.0313	.1146	.1979	.2812	.3646	.4479
13/32	.0339	.1172	.2005	.2839	.3672	.4505
7/16	.0365	.1198	.2031	.2865	.3698	.4531
15/32	.0391	.1224	.2057	.2891	.3724	.4557
1/2	.0417	.1250	.2083	.2917	.3750	.4583
17/32	.0443	.1276	.2109	.2943	.3776	.4609
9/16	.0469	.1302	.2135	.2969	.3802	.4635
19/32	.0495	.1328	.2161	.2995	.3828	.4661
5/8	.0521	.1354	.2188	.3021	.3854	.4688
21/32	.0547	.1380	.2214	.3047	.3880	.4714
11/16	.0573	.1406	.2240	.3073	.3906	.4740
23/32	.0599	.1432	.2266	.3099	.3932	.4766
3/4	.0625	.1458	.2292	.3125	.3958	.4792
25/32	.0651	.1484	.2318	.3151	.3984	.4818
13/16	.0677	.1510	.2344	.3177	.4010	.4844
27/32	.0703	.1536	.2370	.3203	.4036	.4870
7/8	.0729	.1563	.2396	.3229	.4063	.4896
29/32	.0755	.1589	.2422	.3255	.4089	.4922
15/16	.0781	.1615	.2448	.3281	.4115	.4948
31/32	.0807	.1641	.2474	.3307	.4141	.4974

DECIMALS OF A FOOT
For each 32nd of an inch

Inch	6	7	8	9	10	11
0	.5000	.5833	.6667	.7500	.8333	.9167
1/32	.5026	.5859	.6693	.7526	.8359	.9193
1/16	.5052	.5885	.6719	.7552	.8385	.9219
3/32	.5078	.5911	.6745	.7578	.8411	.9245
1/8	.5104	.5938	.6771	.7604	.8438	.9271
5/32	.5130	.5964	.6797	.7630	.8464	.9297
3/16	.5156	.5990	.6823	.7656	.8490	.9323
7/32	.5182	.6016	.6849	.7682	.8516	.9349
1/4	.5208	.6042	.6875	.7708	.8542	.9375
9/32	.5234	.6068	.6901	.7734	.8568	.9401
5/16	.5260	.6094	.6927	.7760	.8594	.9427
11/32	.5286	.6120	.6953	.7786	.8620	.9453
3/8	.5313	.6146	.6979	.7813	.8646	.9479
13/32	.5339	.6172	.7005	.7839	.8672	.9505
7/16	.5365	.6198	.7031	.7865	.8698	.9531
15/32	.5391	.6224	.7057	.7891	.8724	.9557
1/2	.5417	.6250	.7083	.7917	.8750	.9583
17/32	.5443	.6276	.7109	.7943	.8776	.9609
9/16	.5469	.6302	.7135	.7969	.8802	.9635
19/32	.5495	.6328	.7161	.7995	.8828	.9661
5/8	.5521	.6354	.7188	.8021	.8854	.9688
21/32	.5547	.6380	.7214	.8047	.8880	.9714
11/16	.5573	.6406	.7240	.8073	.8906	.9740
23/32	.5599	.6432	.7266	.8099	.8932	.9766
3/4	.5625	.6458	.7292	.8125	.8958	.9792
25/32	.5651	.6484	.7318	.8151	.8984	.9818
13/16	.5677	.6510	.7344	.8177	.9010	.9844
27/32	.5703	.6536	.7370	.8203	.9036	.9870
7/8	.5729	.6563	.7396	.8229	.9063	.9896
29/32	.5755	.6589	.7422	.8255	.9089	.9922
15/16	.5781	.6615	.7448	.8281	.9115	.9948
31/32	.5807	.6641	.7474	.8307	.9141	.9974

BASIC NAVAL ARCHITECTURE

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A-24

SECTION 11

Pillars and Deck Girders

11.1 General

All tiers of beams are supported by pillars or by means which are not less effective. 'Tween-deck pillars are to be arranged directly above those in the holds, or effective means are to be provided for transmitting their loads to the supports below. Wide-spaced pillars are to be fitted in line with a keelson or intercostal double-bottom girder, or as close thereto as practicable; the seating under them is to be of ample strength and is to provide effective distribution of the load; lightening holes are to be omitted in floors and girders directly under wide-spaced hold pillars of large size. Special support is to be arranged at the ends and corners of deckhouses, in machinery spaces, at ends of partial superstructures and under heavy concentrated weights. For forecastle decks see also 17.9.

11.3 Stanchions and Pillars

11.3.1 Permissible Load

The permissible load W_a of a pillar or strut is to be obtained from the following equation which will, in all cases, be equal to or greater than the calculated load W as determined elsewhere in the Rules.

Metric Tons — *Long Tons*

$$W_a = (1.232 - 0.00452l/r)A \qquad W_a = (7.83 - 0.345l/r)A$$

l = unsupported span of the strut or pillar in cm or ft
r = least radius of gyration in cm or in.
A = area of strut or pillar in cm^2 or $in.^2$

11.3.2 Length

The length l for use in the equation is to be measured from the top of the inner bottom, deck or other structure on which the pillars are based to the under side of the beam or girder supported.

11.3.3 Calculated Load

The calculated load W for a specific pillar is to be obtained from the following equation.

Metric Tons — *Long Tons*

$$W = 0.715bhs \qquad W = 0.02bhs$$

b = mean breadth of the area supported, in m or ft
h = height above the area supported as defined below, in m or ft
s = mean length of the area supported, in m or ft

For pillars spaced not more than two frame spaces the height h is to be taken as the distance from the deck supported to a point 3.80 m (12.5 ft) above the freeboard deck.

For wide-spaced pillars, the height h is to be taken as the distance from the deck supported to a point 2.44 m (8 ft) above the freeboard deck, except in the case of such pillars immediately below the freeboard deck in which case the value of h is not to be less than given in Table 10.1, Column a; in measuring the distance from the deck supported to the specified height above the freeboard deck, the height for any 'tween decks devoted to passenger or crew accommodation may be taken as the height given in 10.3 for bridge-deck beams.

The height h for any pillar under the first superstructure above the freeboard deck is not to be less than 2.44 m (8 ft). The height h for any pillar is not to be less than the height given in 10.3 for the beams at the top of the pillar plus the sum of the heights given in the same paragraph for the beams of all complete decks and one-half the heights given for all partial superstructures above.

The height h for pillars under bulkhead recesses or the tops of tunnels is not to be less than the distance from the recess or tunnel top to the bulkhead deck at the centerline.

11.3.4 Special Pillars

Special pillars which are not directly in line with those above, or which are not on the lines of the girders, but which support the loads from above or the deck girders through a system of supplementary fore and aft or transverse girders, such as at hatch ends where the pillars are fitted only on the centerline, are to have the load W for use with the equation proportionate to the actual loads transmitted to the pillars through the system of girders with modifications to the design value of h as described in 1.3.3.

11.3.5 Pillars under the Tops of Deep Tanks

Pillars under the tops of deep tanks are not to be less than required by the foregoing. They are to be of solid sections and to have not less area than $1.015W$ cm^2 or $0.16W$ $in.^2$, where W is obtained from the following equation.

$$W = 107bhs \text{ metric tons} \qquad W = 0.03bhs \text{ long tons}$$

b = breadth of the area of the top of the tank supported by the pillar, in m or ft
s = length of the area of the top of the tank supported by the pillar, in m or ft
h = height as required by Section 10 for the beams of the top of the tank, in m or ft

11.3.6 Bulkhead Stiffening
Bulkheads which support girders, or pillars and longitudinal bulkheads which are fitted in lieu of girders, are to be specially stiffened in such manner as to provide supports not less effective than required for stanchions or pillars.

11.3.7 Attachments
Wide-spaced tubular or solid pillars are to bear solidly at head and heel and are to be attached by welding, properly proportioned on the size of the pillar. The attachments of stanchions or pillars under bulkhead recesses, tunnel tops or deep-tank tops which may be subjected to tension loads are to be specially developed to provide sufficient welding to withstand the tension load.

11.5 Deck Girders

Girders of the sizes required by 11.7, 11.9, and 11.11 are to be fitted elsewhere as required to support the beams; in way of bulkhead recesses and the tops of tanks they are to be arranged so that the unsupported spans of the beams do not exceed 4.57 m (15 ft). Additional girders are to be fitted as required under masts, king posts, deck machinery or other heavy concentrated loads. In way of deck girders or special deep beams the deck plating is to be of sufficient thickness and suitably stiffened to provide an effective part of the girder.

11.7 Deck Girders and Transverses Clear of Tanks

11.7.1 Deck Girders Clear of Tanks
Each deck girder clear of tanks, similar to that shown in Figure 11.1, is to have a section modulus *SM* as obtained from the following equation.

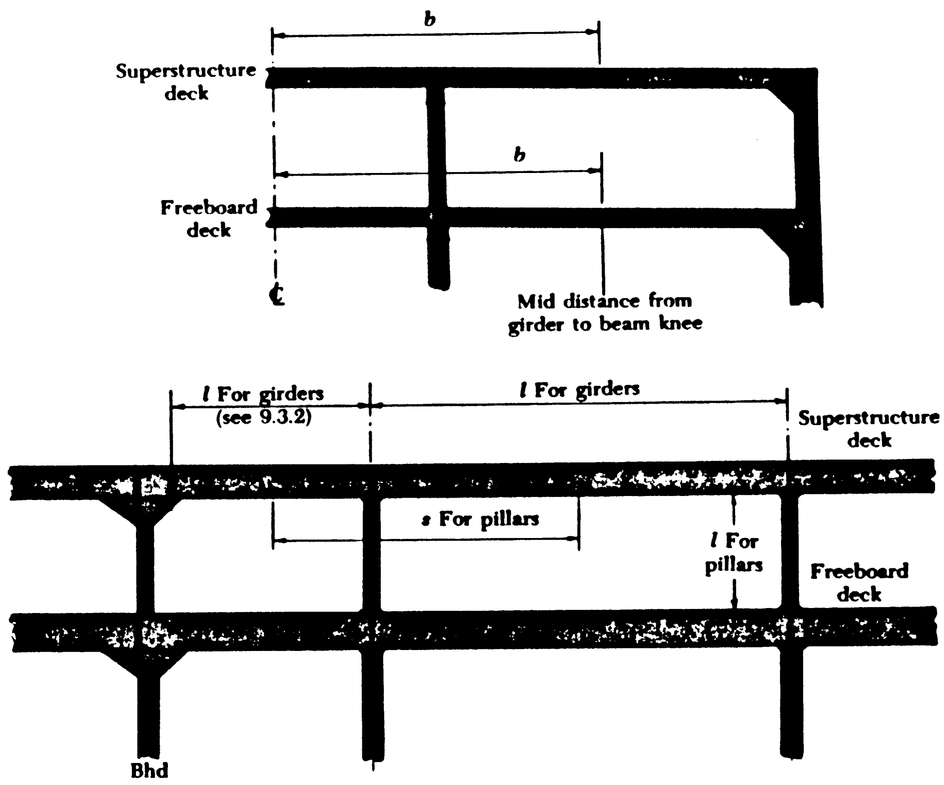
$$SM = 4.74cbhl^2 \text{ cm}^3 \qquad SM = 0.0025cbhl^2 \text{ in.}^3$$

c = 1.0
b = mean breadth of the area of deck supported in m or ft
h = height as required by Section 10 for the beams supported, in m or ft
l = span between centers of supporting pillars, or between pillar and bulkhead, in m or ft. Where an effective bracket in accordance with 9.3.3 is fitted at the bulkhead, the length l may be modified.

11.7.2 Deck Transverses Clear of Tanks
Each deck transverse supporting a longitudinal deck beam is to have a section modulus *SM* as obtained from the equations in 11.7.1 where

c = 1.0
b = spacing of deck transverses in m or ft

FIGURE 11.1
Deck Girders and Pillars



h = height as required by Section 10 for the beams supported, in m or ft

l = span between supporting girders or bulkheads, or between girder and side frame, in m or ft. Where an effective bracket is fitted at the side frame, the length l may be modified. See 9.3.3.

11.7.3 Proportions
Girders are to have a depth of not less than $0.0583l$ (0.7 in. per ft of span l), the thickness is not to be less than 1 mm per 100 mm (.01 in. per in.) of depth plus 4 mm (0.16 in.), but is not to be less than 8.5 mm (0.34 in.) where the face area is 38 cm^2 (6 $in.^2$), 10 mm with 63 cm^2 (0.40 in. with 10 $in.^2$), 12.5 mm with 127 cm^2 (0.50 in. with 20 $in.^2$) and 15 mm with 190 cm^2 (0.60 in. with 30 $in.^2$).

11.7.4 Tripping Brackets
Tripping brackets arranged to support the flanges are to be fitted at every third frame where the breadth of the flanges on either side of the web exceeds 200 mm (8 in.), at every second frame where it exceeds 400 mm (16 in.) and at every frame where it exceeds 600 mm (24 in.).

11.7.5 End Attachments
End attachments of deck girders are to be effectively attached by welding.

11.9 Deck Girders and Transverses in Tanks

Deck girders and transverses in tanks are to be obtained in the same manner as given in 11.7.1 above, except the value of c is to be equal to 1.50 and the minimum depth of the girder is to be $0.0833l$ (1 in. per ft of span l). The minimum thickness and the sizes and arrangements of the stiffeners, tripping brackets and end connections are to be the same as given in 11.7.3, 11.7.4, and 11.7.5.

11.11 Hatch Side Girders

Scantlings for hatch side girders supporting athwartship shifting beams or supporting hatch covers are to be obtained in the same manner as deck girders (11.7 and 11.9). Such girders along lower deck hatches under trunks in which covers are omitted are to be increased in proportion to the extra load which may be required to be carried due to the loading up into the trunks. The structure on which the hatch covers are seated is to be effectively supported. Where deep coamings are fitted above decks, such as at weather decks, the girder below deck may be modified so as to obtain a section modulus in cm^3 or $in.^3$, when taken in conjunction with the coaming up to and including the horizontal coaming stiffener, of not less than 35% more than the required girder value as derived from 11.7.1. Where hatch side girders are not continuous under deck beyond the hatchways to the bulkheads, brackets extending for at least two frame spaces beyond the ends of the hatchways are to be fitted. Where hatch side girders are continuous beyond the hatchways, care is to be taken in proportioning their scantlings beyond the hatchway. Gusset plates are to be fitted at hatchway corners arranged so as to tie effectively the flanges of the side coamings and extension pieces or continuous girders and the hatch-end beam flanges both beyond and in the hatchway.

11.13 Hatch-end Beams

11.13.1 Hatch-end Beam Supports
Each hatch-end beam, similar to that shown in Figure 11.2, which is supported by a centerline pillar without a pillar at the corner of the hatchway, is to have a section modulus SM not less than obtained from the following equations.

a ***Where Deck Hatch-side Girders are Fitted Fore and Aft Beyond the Hatchways***

$SM = K(AB + CD)hl$ cm^2 $\qquad$ $SM = 0.000527K(AB + CD)hl$ cm^3

b ***Where Girders are not Fitted on the Line of the Hatch Side Beyond the Hatchway***

$SM = KABhl$ cm^3 $\qquad$ $SM = 0.000527KABhl$ $in.^3$

A = length of the hatchway, in m or ft

B = distance from the centerline to the midpoint between the hatch side and the line of the toes of the beam knees, in m or ft

C = distance from a point midway between the centerline and the line of the hatch side to the midpoint between the hatch side and the line of the toes of the beam knees, in m or ft; where no girder is fitted on the centerline beyond the hatchway C is equal to B

D = distance from the hatch-end beam to the adjacent hold bulkhead, in m or ft

h = height for the beams of the deck under consideration as given in Section 10, in m or ft

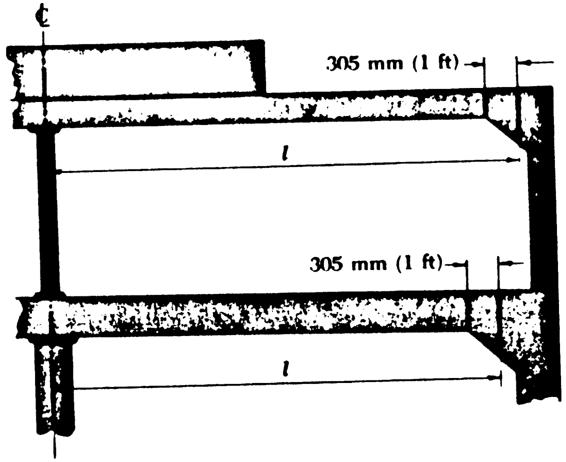
l = distance from the toe of the beam knee to the centerline plus 0.305 m (1 ft), in m or ft

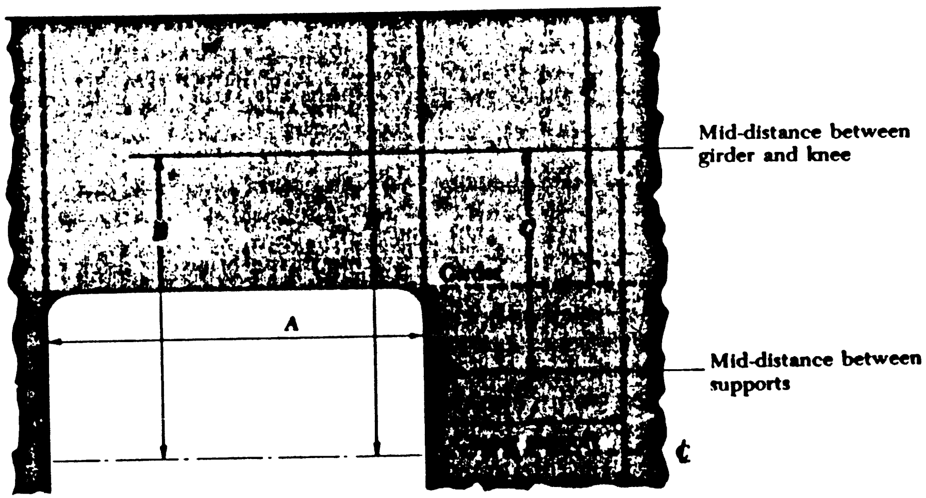
$K = 2.20 + 1.29(F/N)$ when $F/N \leq 0.6$
$\quad = 4.28 - 2.17(F/N)$ when $F/N > 0.6$

N = one-half the breadth of the vessel in way of the hatch-end beam

F = distance from the side of the vessel to the hatch side girder

FIGURE 11.2
Hatch-end Beams





11.13.2 Weather-deck Hatch-end Beams
Weather-deck hatch-end beams which have deep coamings above deck for the width of the hatch may have the flange area reduced from a point well within the line of the hatch side girder to approximately 50% of the required area at the centerline; in such cases it is recommended that athwartship brackets be fitted above deck at the ends of the hatch-end coaming.

11.13.3 Depth and Thickness
The depth and thickness of hatch-end beams are to be similar to those required for deck girders by 11.7.3.

11.13.4 Tripping Brackets
Tripping brackets arranged to support the flanges are to be located at intervals of about 3 m (10 ft).

11.13.5 Brackets
Brackets at the ends of hatch-end beams are to be generally as described in 9.3.3. Where brackets are not fitted, the length *l* is to be measured to the side of the vessel and the face plates or flanges on the beams are to be attached to the shell by heavy horizontal brackets extending to the adjacent frame.

11.14 Container Loading

Where it is intended to carry containers, the structure is to comply with 10.10.

11.15 Higher-strength Materials

11.15.1 General
In general, applications of higher-strength materials for deck girders and deck transverses are to meet the requirements of this section, but may be modified as permitted by the following paragraphs. Calculations are to be submitted to show adequate provision to resist buckling. Longitudinal members are to be of essentially the same material as the plating they support.

11.15.2 Girders and Deck Transverses
Each girder and deck transverse of higher-strength material, in association with the higher-strength plating to which they are attached, are generally to comply with the requirements of the appropriate preceding paragraphs of this section and is to have a section modulus SM_{hts} not less than obtained from the following equation.

$$SM_{hts} = SM(Q)$$

SM = required section modulus in ordinary-strength material as determined elsewhere in this section
Q = as defined in 6.13.3

A-28

BASIC NAVAL ARCHITECTURE

Unit Number: 1

Title: Introduction

Tape Running Time: 44^M 45^S

Reading Assignment: None

Additional References: None

Scope:

In this unit the course is introduced to the students with a presentation of the specific objectives of the course as applied to this particular class. The text is introduced. Required student background is discussed. Reactions to the video diagnostic test are solicited. Required materials are described.

Key Points to Emphasize:

1. Identify instructor's name and times and place where he will be available for consultation.

2. Introduce title of course, the time and place for classes, and specific objectives of the course as applied to this particular class.

3. Play the Unit 1 video tape.

4. Announce how and where the course text, Modern Ship Design, may be obtained. If the student is to purchase his own text note that the price has increased over that announced in the video.

5. Discuss the diagnostic test given in the video.

6. Distribute the handout "Engineering Calculations". (A good time to go into a discussion of engineering calculation procedures and formats will be at the end of Unit 6 or Unit 7 before assigning home problems.)

Suggested Problem Assignment: None

INTRODUCTION

EXAMPLE NO. 1

A CONTAINER SHIP IS RESPOTTING CONTAINERS ON DECK. THE SHIP IS INITIALLY UPRIGHT. TEN LOADED CONTAINERS WEIGHING 20 TONS EACH ARE SHIFTED TRANSVERSELY A DISTANCE OF 50.0 FEET. THE SHIP'S DISPLACEMENT IS 28,000 LONG TONS AND ITS METACENTRIC HEIGHT, GM = 3.40 FEET.

FIND THE RESULTING ANGLE OF LIST.

EXAMPLE NO. 1 (CON'T)

THE FORMULA IS:

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

WE HAVE BEEN GIVEN:

$$w = 10 \text{ CONT'R} \times 20 \frac{\text{LT}}{\text{CONT'R}} = 200 \text{ LT}$$

$$t = 50.0 \text{ FT}$$

$$\Delta = 28{,}000 \text{ LT}$$

$$GM = 3.40 \text{ FT}$$

WE WISH TO FIND θ .

EXAMPLE NO. 1 (CON'T)

SOLUTION:

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

$$\tan\theta = \frac{(1200\ \cancel{LT})(50.0\ \cancel{FT})}{(3.40\ \cancel{FT})(28{,}000\ \cancel{LT})}$$

$$\tan\theta = .1050$$

$$\theta = \tan^{-1}(.1050)$$

$$\theta = 6.0^\circ$$

THE INCLINATION WILL BE 6.0°

INTRODUCTION

EXAMPLE NO. 2

FIND THE FRICTIONAL RESISTANCE OF A 600-FT (LWL) SHIP TRAVELING AT 10 KNOTS IN SALT WATER (TEMPERATURE = 59°F). THE SHIP HAS A WETTED SURFACE OF 2.0×10^6 FT^2 .

THE APPLICABLE FORMULAE ARE:

FRICTIONAL RESISTANCE = $R_f = C_f \frac{\rho}{2} S v^2$

FRICTIONAL COEFFICIENT = $C_f = \frac{.075}{(\log R_e - 2)^2}$

REYNOLDS NUMBER = $R_e = \frac{vL}{\nu}$

INTRODUCTION

EXAMPLE NO. 2 (CON'T)

V = VELOCITY IN FT/SEC

$V = 10 \text{ ~~KNOTS~~} \times 1.688 \frac{\text{FT/SEC}}{\text{~~KT~~}} = 16.88 \text{ FT/SEC}$

$L = 600 \text{ FT}$ (GIVEN)

ν = KINEMATIC VISCOSITY OF SEA WATER AT 59°F

$\nu = 1.2791 \times 10^{-5} \frac{\text{FT}^2}{\text{SEC}}$ (FROM TABLES)

ρ = DENSITY OF SEA WATER AT 59°F

$\rho = 1.9905 \frac{\text{LB SEC}^2}{\text{FT}^4}$ (FROM TABLES)

S = WETTED SURFACE IN FT^2

$S = 2.0 \times 10^6 \text{ FT}^2$ (GIVEN)

EXAMPLE NO. 2 (CON'T)

SOLUTION:

1. **REYNOLDS NUMBER,**

$$Re = \frac{VL}{\nu} = \frac{(16.88\ \text{ft/sec})(600\ \text{ft})}{(1.2791 \times 10^{-5}\ \text{ft}^2/\text{sec})}$$

$$Re = 7918.1 \times 10^{5}$$

$$Re = 7.9181 \times 10^{8}$$

2. **FRICTION COEFFICIENT,**

$$C_f = \frac{.075}{(\log Re - 2)^2}$$

$$= \frac{.075}{(\log(7.918 \times 10^{8}) - 2)^2}$$

$$= \frac{.075}{(8.8986 - 2)^2}$$

$$= \frac{.075}{(6.8986)^2}$$

$$= .001576$$

$$C_f = 1.576 \times 10^{-3}$$

INTRODUCTION

EXAMPLE NO. 2 (CON'T)

3. FRICTIONAL RESISTANCE:

$$R_f = C_f \frac{\rho}{2} S v^2$$

$$= (1.2791 \times 10^{-5})\left(\frac{1.9905}{2} \frac{LB\ SEC^2}{FT^4}\right)(2.0 \times 10^6\ FT^2)\left(16.88\ \frac{FT}{SEC}\right)^2$$

$$= 725.5 \times 10\ LB$$

$$R_f = 7255\ LB$$

FRICTIONAL RESISTANCE: $R_f = 7255\ LB$

ENGINEERING CALCULATIONS

Engineering calculations are the heart of any engineering design job. Calculations represent the application of basic engineering principles and engineering codes to a particular project. The calculations should be clear, concise and easily checked by a supervisor or checker. The calculations also have legal force and may be used in the event of a dispute in future years to demonstrate that good engineering practice was followed in performing the engineering work on the projects.

In this course, the student should practice good engineering calculation procedure in working the problems. The outline that follows is pointed toward engineering in practice, but can be applied equally well to solving the practice problems in this course.

OUTLINE OF ENGINEERING CALCULATION PROCEDURES

1. Use of a quadrille or cross-section paper is recommended. This facilitates preparation of sketches, tabular calculation formats, and neat calculations. Many companies have preprinted calculation sheets, often with a non-reproducible grid background.

2. The company name, project number, title of the project and subject of the calculations and your name or initials should appear on every page. The date the work is done should also appear on every page. Each page should be numbered, for example, "Page 12 of 18", and a Table of Contents should be included for long calculations.

3. All calculations should be printed legibly.

4. The formulas used in the calculation should be shown clearly and the source of these formulas should be cited as a reference.

5. The approach to the problem should be explained clearly. Any steps taken in the solution that are not completely obvious should be explained. Assume that another person, unfamiliar with the job, will be reviewing your calculations years from now. Write your calculations up so that this imaginary reviewer will be able to understand clearly what you did.

6. Key results should be underlined or enclosed in a box so that they stand out clearly.

7. Whenever possible calculations should be performed in a tabular format. Experience has shown that tabular formats are more compact, can be checked more easily, and that errors tend to be more conspicuous.

   It is preferable to arrange summations in vertical columns rather than horizontal lines. For example,

$$\begin{array}{rl} 16{,}148.0 & ft^2 \\ 247.6 & ft^2 \\ \underline{5{,}912.2} & ft^2 \\ 22{,}307.8 & ft^2 \end{array}$$

is preferable to

$$16{,}148.0\ ft^2 + 247.6\ ft^2 + 5{,}912.2\ ft^2 = 22{,}307.8\ ft^2.$$

8. Be sure to include units. Note that there is often confusion between long tons (LT), short tons (ST) and metric tons (MT or TONNES).

9. Be consistent with the number of decimal places and the number of significant places carried in the calculation. For example, the area of a circle 35 ½" in diameter is:

   Area = 35.50 x 3.141592654 = 111.5265392.

   In this case, everything past the second decimal place has no significance. Also, the number of decimal places carried should be consistent. There is a difference in meaning between:

   35 ½"
   35.5"
   35.50"
   35.500"

   In this example, 35 ½" means 35 ½ inches exactly, or to the tolerance specified on the drawing. 35.5" means between 35.45 inches and 35.54 inches. 35.50" means between 35.495 inches and 35.504 inches, etc. The number of places carried should be consistent with the measurement accuracy and the tolerances desired.

BASIC NAVAL ARCHITECTURE

Unit Number: 2

Title: Ship types and ship systems - 1

Tape Running Time: 34^M 0^S

Reading Assignment: Modern Ship Design (MSD), pp 3-10

Additional References: Ship Design and Construction (SDC), pp 1-13

Recent articles on ship types taken from trade magazines

Scope:

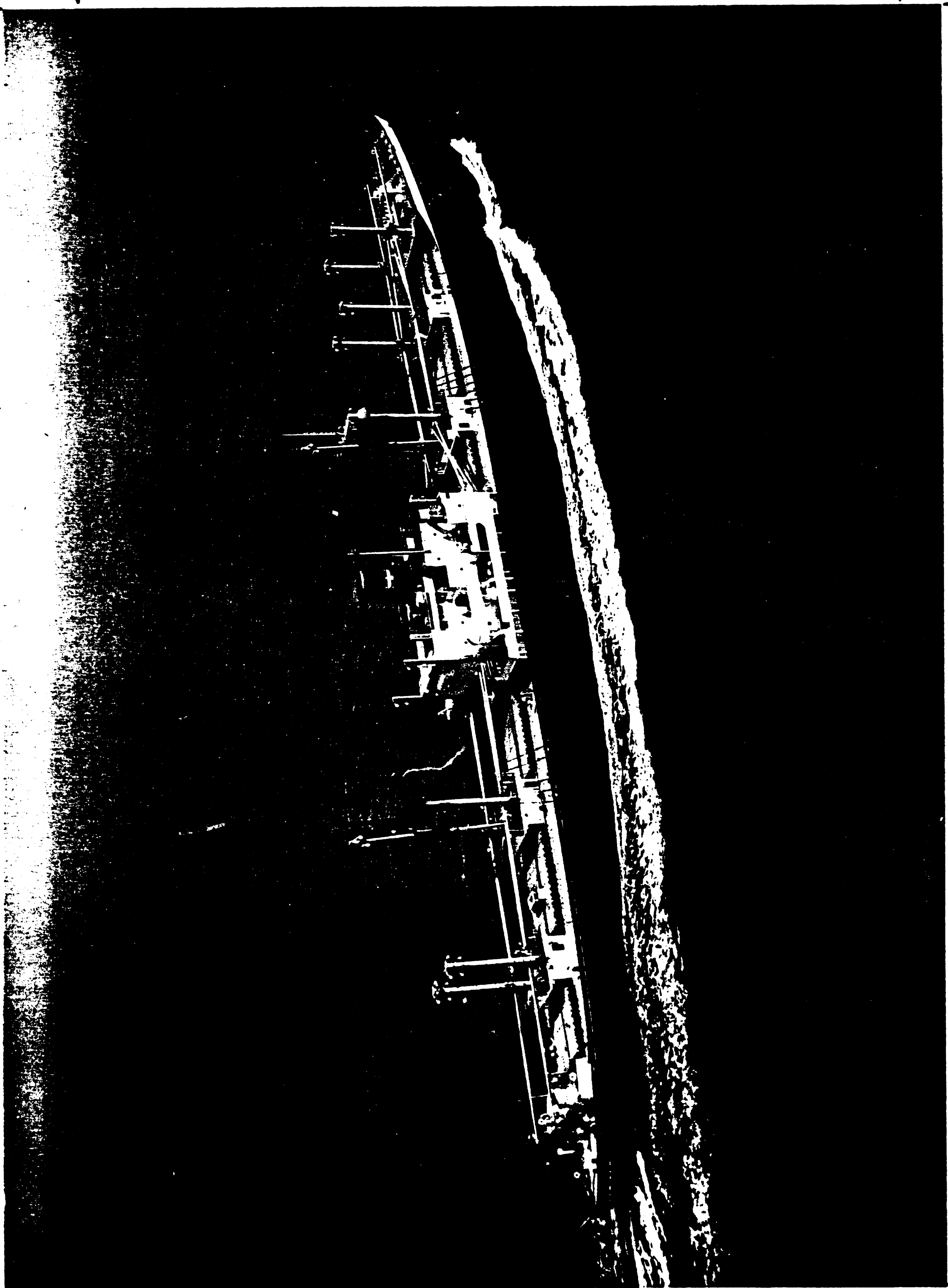
The objectives of Units 2 and 3 are to introduce the student to various types of ships and craft in commercial and military services and the trends in ship design and propulsion which have developed in recent years.

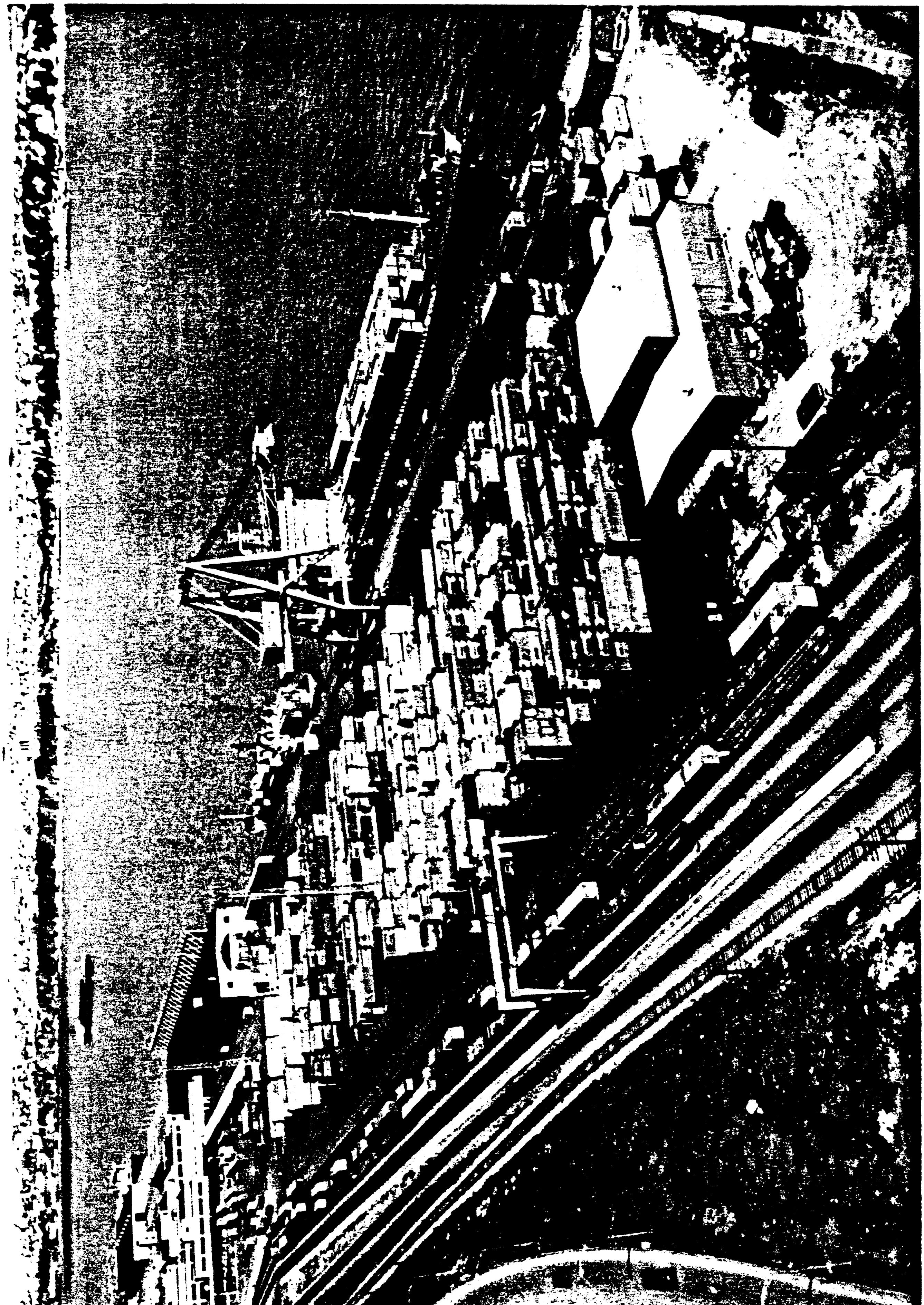
Key Points to Emphasize:

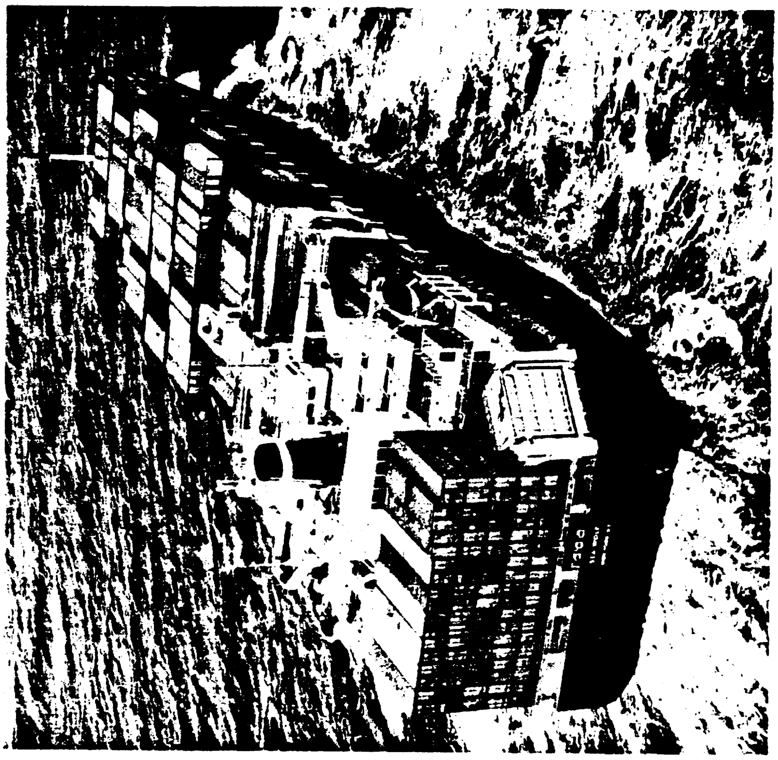
The instructor should use class time to supplement pictures shown in the video with additional slides or transparencies. Acceptable transparencies can be made from photos in trade magazines. Transparencies should be selected to emphasize trends or ship features.

Suggested Problem Assignment: None

(The instructor may wish to require students to read assigned articles in trade magazines.)







Odense built – trio for U S Lines charter

An innovative design of RoRo/LoLo containership inspired by the trading requirements of US-based Delta Line, has been delivered by Odense's Lindo yard in Denmark. 'Sea Wolf' is the first of three 24,180dwt vessels for which, due to a subsequent chartering deal by Delta's San Francisco-based parent, Crowley Maritime Corporation, the versatility of the series operating in other services may well be tested.

Conceived for serving ports on Latin American routes having, as yet, limited handling facilities, and totally equipped for their cargo access by MacGregor-Navire (MGN), the design specified two rail-mounted 40 tonne gantry cranes of a new 'CCB' type from Liebherr. These units can traverse the holds over three layers of containers; a fourth layer can also be stacked.

The 10 cellular holds, all forward of the superstructure, and the garage deck aft respectively, offer capacity for 1,936TEU and 27 x 40ft trailers. Provision for both containers and trailers reflects the operator's RoRo experience in US West Coast/Alaskan as well as Caribbean services.

The MGN supply for the trio was detailed in *MacGregor-Navire News 102*, so we shall only briefly recap here. RoRo access to the garage area, which runs full beam from aft under the accommodation into No. 10 hold, is via an MGN stern ramp/door angled at 45 degrees on the starboard side. In three sections, it provides an 18.0m long x 6.25m wide driveway and, as a watertight door, closes a clear opening 6.25m wide x 5.55m high in the transom stern. Its total weight is 52 tonnes and a maximum load of 100 tonnes can be sustained: this allows for certain types of tractor and US standard road trailers.

The normal maximum operating slope is ± 1:7 (or 8.1 degrees of arc) but the ramp can also be lowered to water level at a slope of −19 degrees.

Holds Nos 1 to 9 are each accessed by three hatches, with two only on No. 10 because its central space is taken up by a CO^2 room. MGN's supply is therefore 29 hatch covers per ship, all being one-piece weathertight pontoon (lift away) type panels with a combined area of 3,374m².

Clear opening sizes are:
Hatches 1 to 9, centre - 12.445m long x 10.492m wide; hatches 2 to 10 p & sb - 12.445m long x 7.959m wide; hatch No. 1 p & sb - 12.445m long x 5.290m wide.

The maximum weight of one centre panel is 28 tonnes; the combined weight of all the covers is about 618 tonnes.

Each cover is designed for a UDL of 1.75 tonnes/m², equivalent to containers stacked three-tiers high weighing 60 tonnes/20ft or 90 tonnes/40ft.

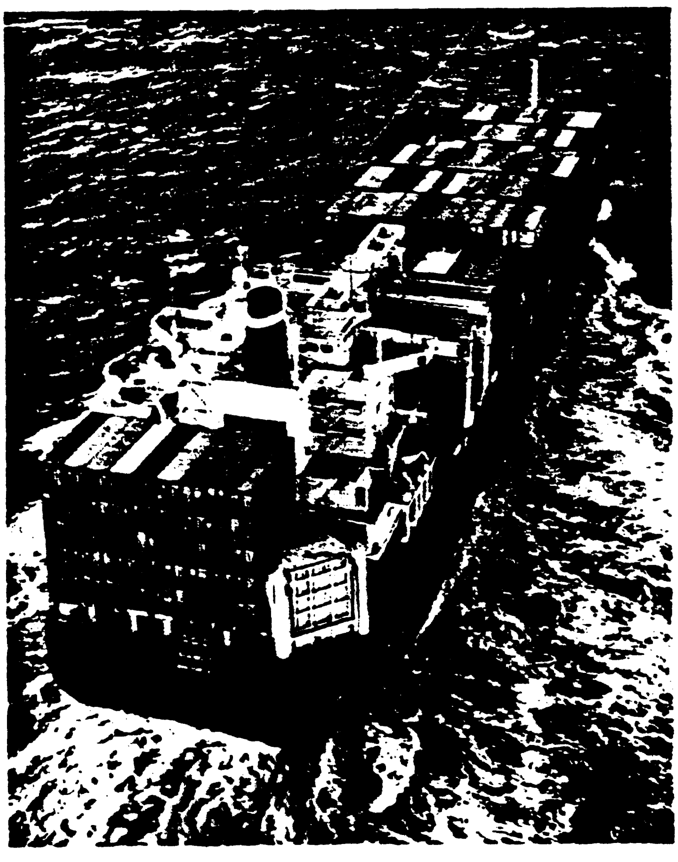
Sea Wolf was delivered last December only 14 months after the contract signing; her sisters are scheduled to follow this year. Not long before the handing over, however, Crowley Maritime agreed to bareboat charter the new trio to United States Lines which also acquire outright 11 other Delta vessels. The agreement, subject to MARAD approval, could see the ships serving the round-the-world feeder network of their new operator.

For Odense, this new class is yet another design reference for an experienced Danish yard whose abilities were recently recognised by the award of Lloyd's Register of Shipping's prized 'Quality Assurance Certificate': the first for a European yard and only the seventh for a shipbuilder anywhere.

PRINCIPAL PARTICULARS
'Sea Wolf'

Length (o.a.)	198.80m
Length (b.p.)	186.40m
Breadth	32.20m
Depth	20.45m
Draught	9.15m
Deadweight	24,180 tonnes
Containers	1,936TEU
Trailers	27 x 40ft
Propulsion	Sulzer 7RTA76
Output	23,030 bhp
Speed	17.80 knots

A container-laden Sea Wolf *caught by the aerial camera as she transited the English Channel*



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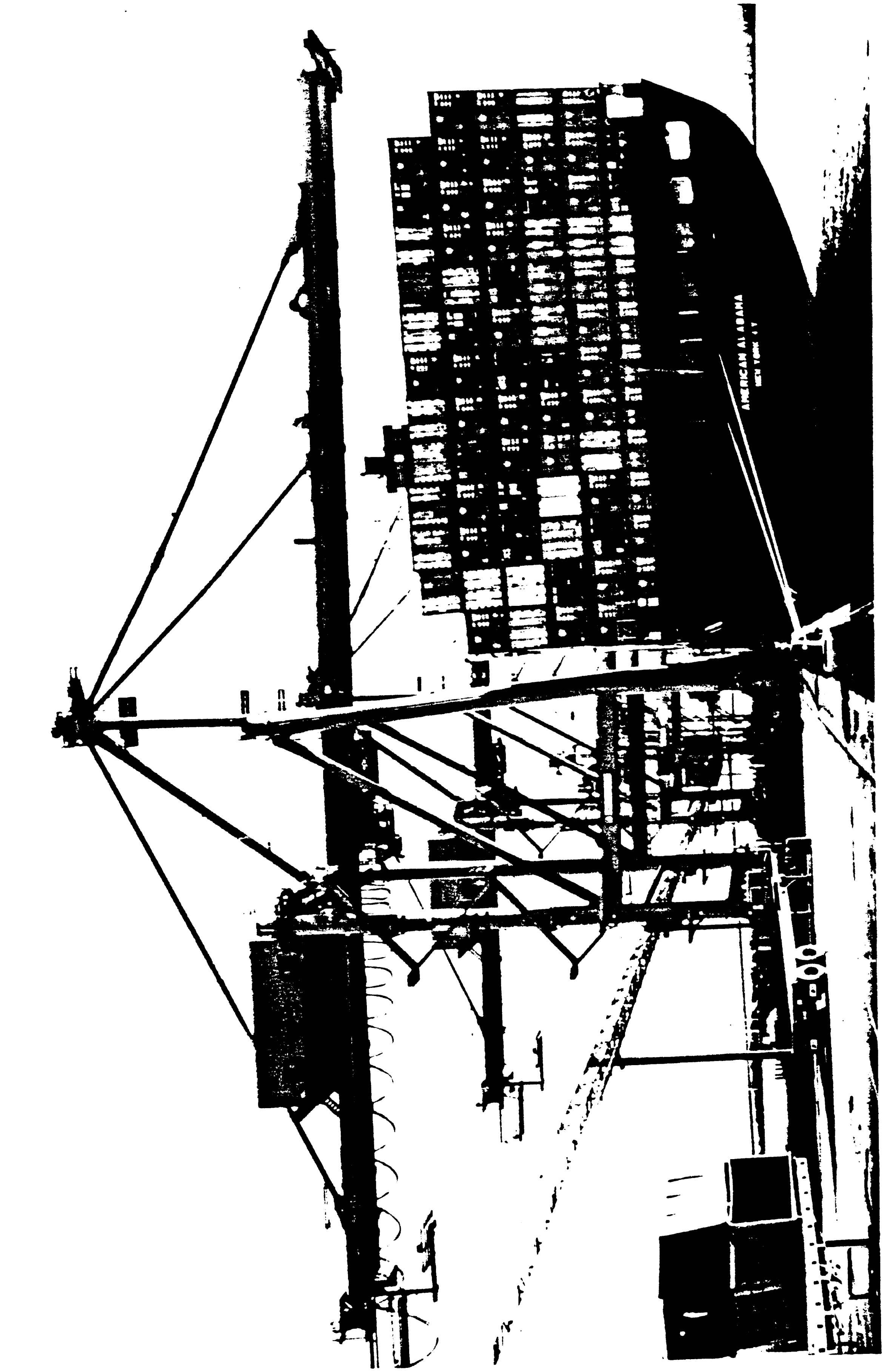

AMERICAN ALABAMA
NEW YORK NY

FULL FRAME (A) 48/10 P. 37

ME/L
FEB 87

2 PACECO "NEW GEN"
(P) PORTAINER CRANES REC.

50
7

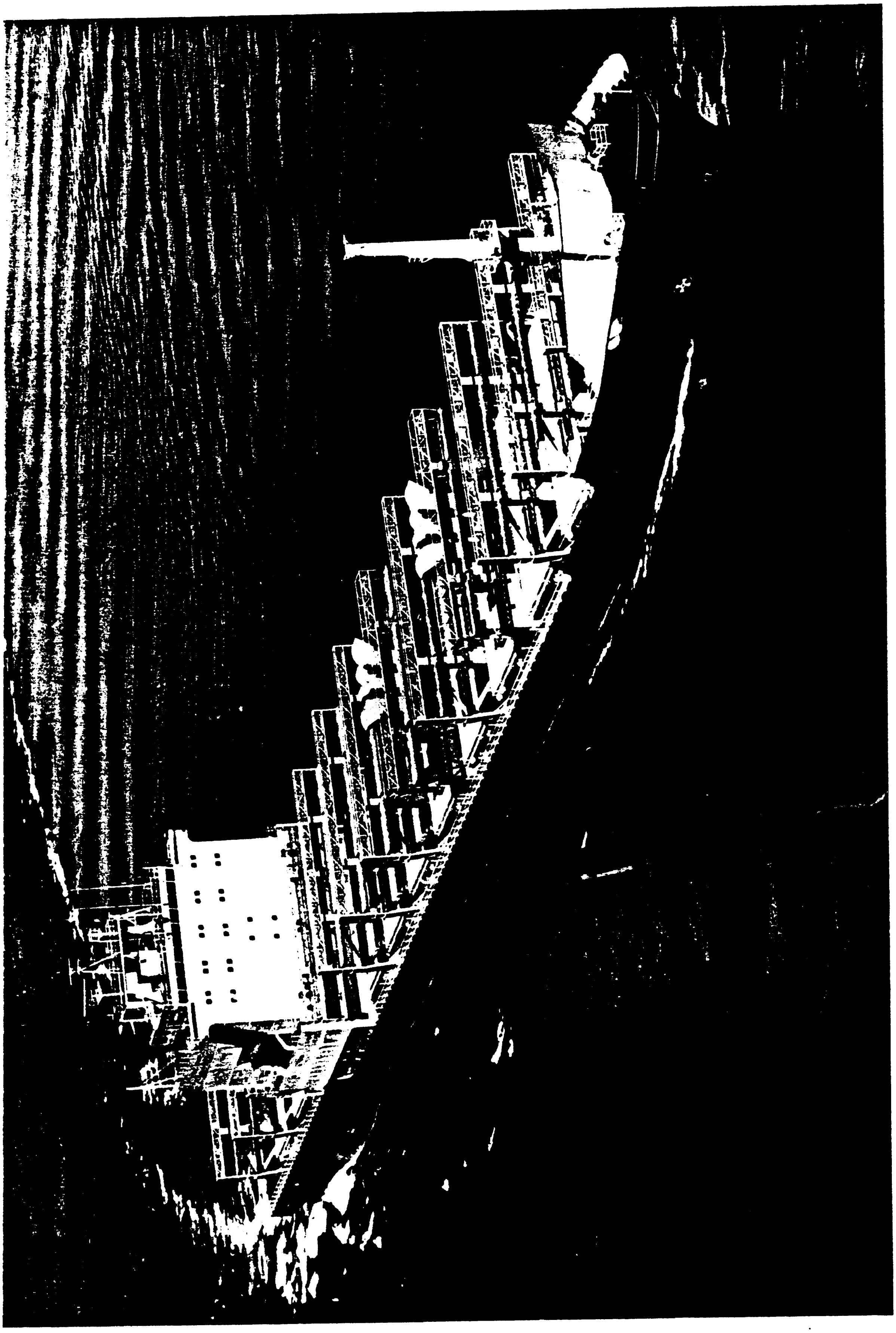
INSTALLED AT HOWLAND

13
135

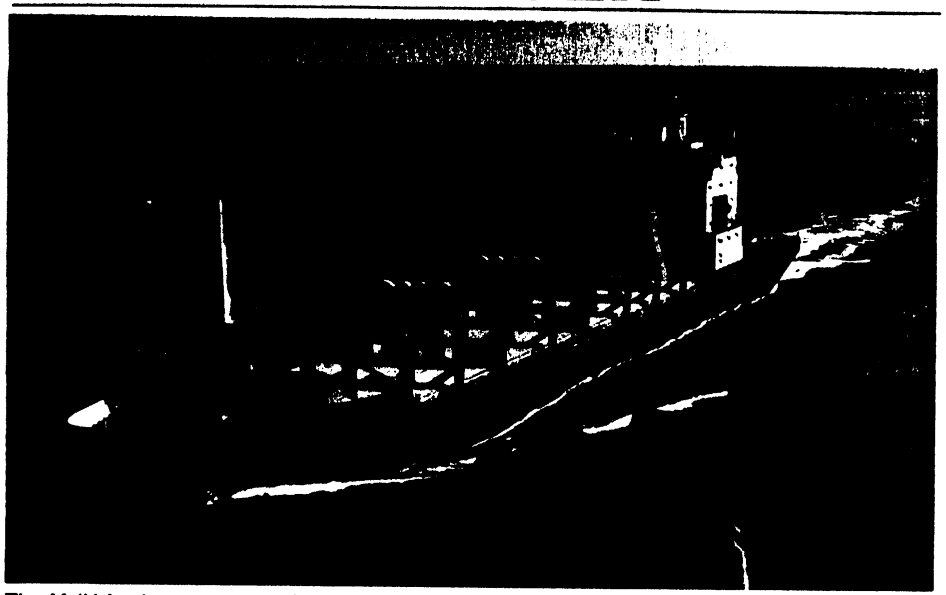
HOOK - STATEN ISLAND,
ALSO CAPABLE OF HANDLING
"BEYOND PANAMAX" SHIPS
(135' OUT REACH

(P 37)

(SINGLE GIRDER BOOM)



ON THE COVER



The M/V Anchorage, recently delivered by Bay Shipbuilding Corp. of Sturgeon Bay, Wis., is powered by a B&W/Mitsui 7 L70MC diesel engine.

Bay Shipbuilding Delivers First Of Three Containerships To Sea-Land

'Anchorage' To Serve Pacific Northwest

Bay Shipbuilding Corp. of Sturgeon Bay, Wis. recently delivered the M/V Sea-Land Anchorage, which is the first in a series of three containerships being built for Sea-land Service, Inc. The other two ships, Bay Shipbuilding Hulls 736 and 737, are also scheduled for delivery this year.

The keel for the Sea-Land Anchorage, Bay Shipbuilding's Hull No. 735, took place in Bay's 1,158-foot-long graving dock on August 14, 1985. On May 31, 1986, Hull 735 was floated out of the graving dock and berthed at one of the company's outfitting piers for completion.

The ship has an overall length of 710 feet, a beam of 78 feet and a design draft of 30 feet. A controllable pitch propeller is driven by a single slow speed 7 L70MC B&W diesel engine supplied by Mitsui Engineering and Shipbuilding Company, Ltd. The fuel efficient seven-cyclinder diesel engine is capable of developing over 22,000 bhp.

The ship's propulsion plant is designed to operate unattended ACCU, and all plant functions are monitored by Siemens computer automation equipment. Electrical power to the ship is provided through two Wartsila main AC diesel generators, each rated at 2,000 kw and two Wartsila auxillary diesel generators rated at 1,000 kw each. An emergency diesel generator is also provided by Caterpillar.

The Sea-Land Anchorage will be capable of carrying over 700 FEU containers of cargo. The ship, which has seven cargo holds, also has the capacity to carry a variety of refrigerated containers in specially equipped cargo holds and at designated areas above deck. The ship is capable of carrying 20-, 35-or 40-foot containers. To facilitate the storage and securing of containers above deck, the ship is equipped with stacking towers and hydraulically operated hinged frames which rotate from a vertical to horizontal position, securely locking in each layer of containers quickly.

The ship is specially strengthened to serve in Alaska's severe weather. The forecastle has a substantial breakwater built to protect the forward containers. Deck machinery is enclosed from the weather at the bow and at stern, providing a weathertight closure for the mooring of the ship. The ship is also equipped with Omnithruster bow and stern thrusters which greatly enhance its maneuverability.

Sea-Land Service, Inc., a subsidiary of Sea-Land Corporation, will use the three diesel-powered 700 FEU D-7 containerships to replace four smaller, steam-powered vessels currently operating between the Pacific Northwest and Alaska. Sea-Land Corporation is a world leader in ocean and overland containerized intermodal freight transportation and trade services. Its subsidiary, Sea-Land Service, Inc., is one of the largest U.S.-flag carriers of containerized ocean cargo.

As part of the building program, Bay Shipbuilding Corp. established an affiliation with three other prominent companies to assist in the design and expedite the supply of equipment for the containership. These companies are R.A. Stearn, Inc., of Sturgeon Bay, Wis., which supported Bay Shipbuilding's Engineering Department in the design and engineering of the forebody and deckhouse; Burmeister and Wain

Main engine	B&W/Mitsui
Main & anxilliary generators	Wartsila
Emergency generator	Caterpillar
Boilers	Aalborg Vaerft
Bow & stern thrusters	Omnithruster
Automation	Siemens
Propeller & shaft	Kawasaki
Stern tube bearings & seal	Kobe Steel
Steering gear	AEG/Mitsui
Navigation equipment	ITT/Mackay
Gyrocompass	Sperry
F/O pumps	Taiko Kikai
Purifiers	Alfa Laval
F/O heaters	Gadelius
Seawater pumps	Shinkoh Kinzoku
Tank gauging	Metritape
Fans	Buffalo Forge
HVAC & refrigeration	Bassett
Hatch cover & towers	Manitowoc Ship
Deck covering	Masse
Stores crane & davit	Schat Davit
Winches & windlass	IHI
Marine growth prevention system	Engelhard
Survival craft	Watercraft America
Pilothouse windows	Singer-Kearfott
Deckhouse windows	Winel of America
Fire detection system	Hiller
Foam system	National Foam
Galley & pantry	Kiefer
Sewage treatment unit	Sasakura Kikai
Ballast crete	Genstar Stone

2-10

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Bay Shipbuilding Corp., a subsidiary of The Manitowoc Company, Inc., is one of this nation's most modern shipyards and is the largest shipyard on America's "North Coast," the Great Lakes. Bay Shipbuilding is a full service shipyard with complete in-house capabilities to design, build, repair, convert, repower, retrofit, and jumboize any type of vessel.

For free color literature on the shipbuilding and ship-repairing facilities and services available from Bay Shipbuilding,

Circle 31 on Reader Service Card

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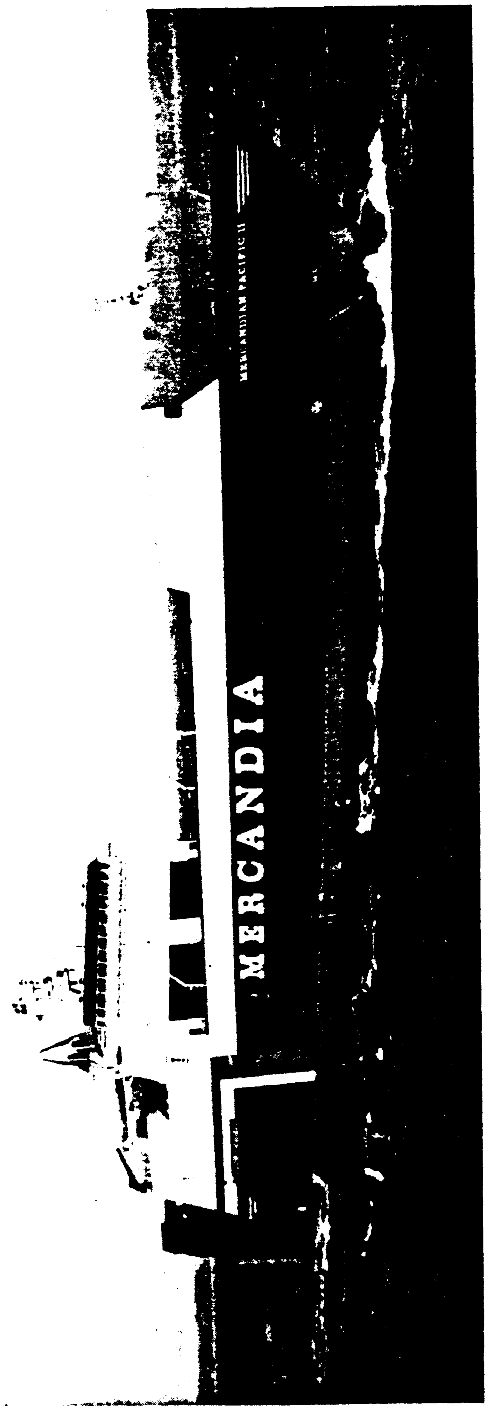
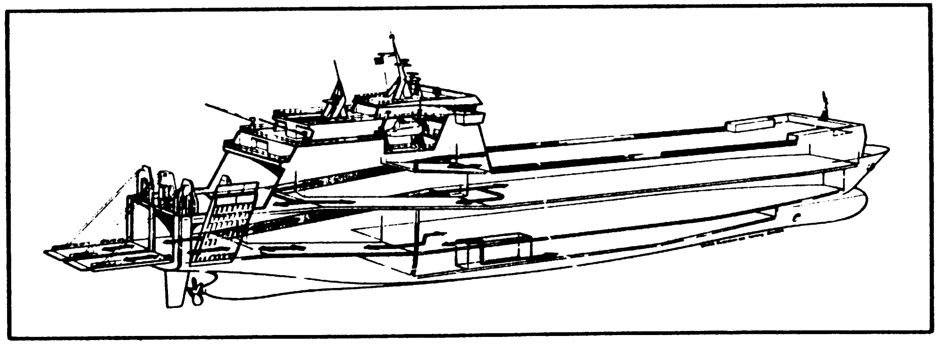

MERCANDIA

Caracas: Largest RO/RO from Danyard

Frederikshavn delivers the first of four of a new series of 14,000 dwt ships to the Mercandia Shipping Group

BUILT in two parts that were then joined after launching, the *Caracas* is the largest ship yet built by the Frederikshavn Vaerft facility of Denmark's Danyard A/S and the largest vessel in the Mercandia Group fleet. She is currently chartered to Vencaribe of Caracas, Venezuela, and received her present name just before delivery, having been originally christened *Mercandian Pacific II*.

Caracas is the first in a series of four ships that the Frederikshavn yard is building for Mercandia and her design—the FV2800—is the result of a long standing cooperation between yard and owner. The aim has been to achieve maximum operational flexibility and economy. Built to Det norske Veritas class +1A1, the ship carries the notations "General Cargo/Container/Car Carrier, RO/RO, EO."



Cargo handling flow of FV 2800, largest RO/RO built by Frederikshavn Vaerft

Main dimensions are as follows:

Length, OA	163.80 m
Length, BP	148.60 m
Breadth, molded	23.5 m
Depth, molded to upper deck	20.75 m
Scantling draft	8.80 m

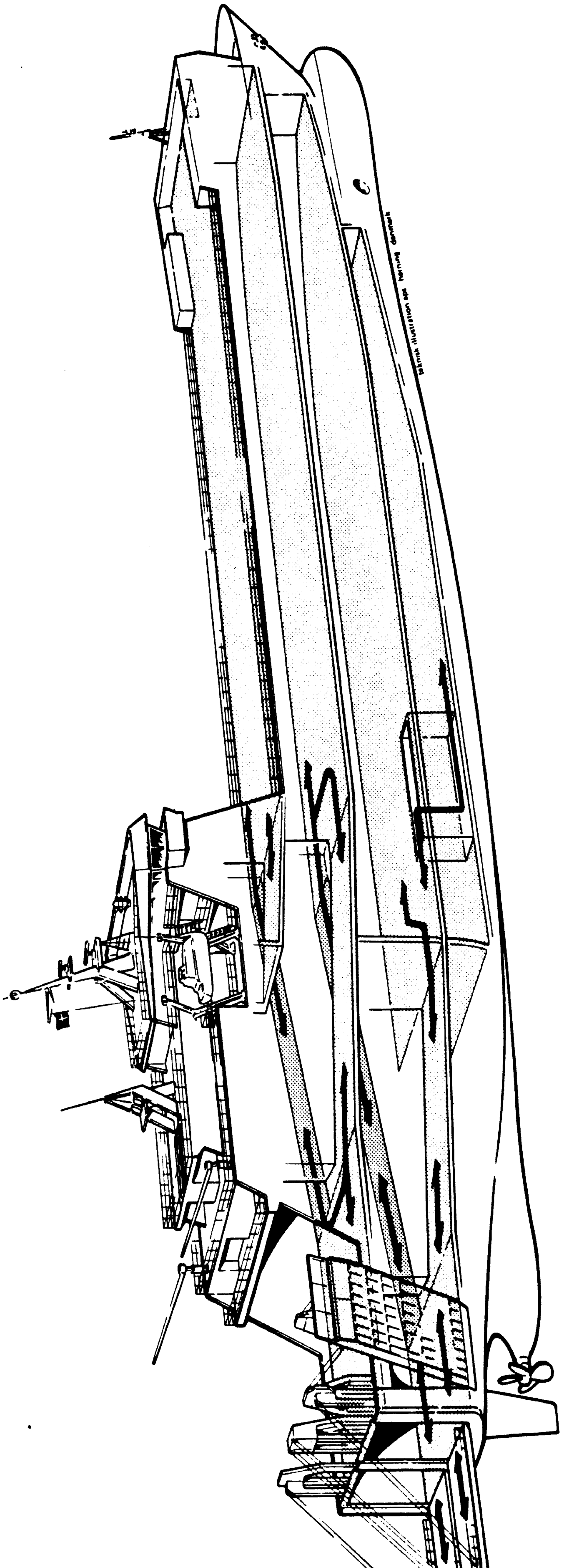
The ship offers a total trailer lane length of 2,800 m and a container capacity of 725 TEU. There are 72 reefer box plugs. Three external ramps—twin stern ramps and a quarter ramp, each 7.3 m wide—give access to three 7 m wide fixed internal ramps leading to the cargo decks. One of these, the weather deck, is partially enclosed by the bridge superstructure. The two others are totally enclosed. There is additional cargo space in the lower hold, served by an elevator from the second deck. If required, two intermediate car decks can be installed, bringing total lane length to 6,500 m.

HEAVY FUEL OPERATION

The machinery is approved for unattended operation. Main propulsion power is provided by an MaK 6M 601 diesel developing 9,000 bhp at 428 rpm and driving a Lips C.P. propeller via a 3.4583:1 Reintjes reduction gear. The engine is arranged for operation on heavy fuel and also drives a shaft generator that meets all the ship's at-sea power requirements. The auxiliary machinery consists of two MaK/Reliance alternator sets.

The ship is fitted with Lips thrusters at bow and stern, giving good shiphandling characteristics without the need for tug assistance. **ME/LOG**

2-13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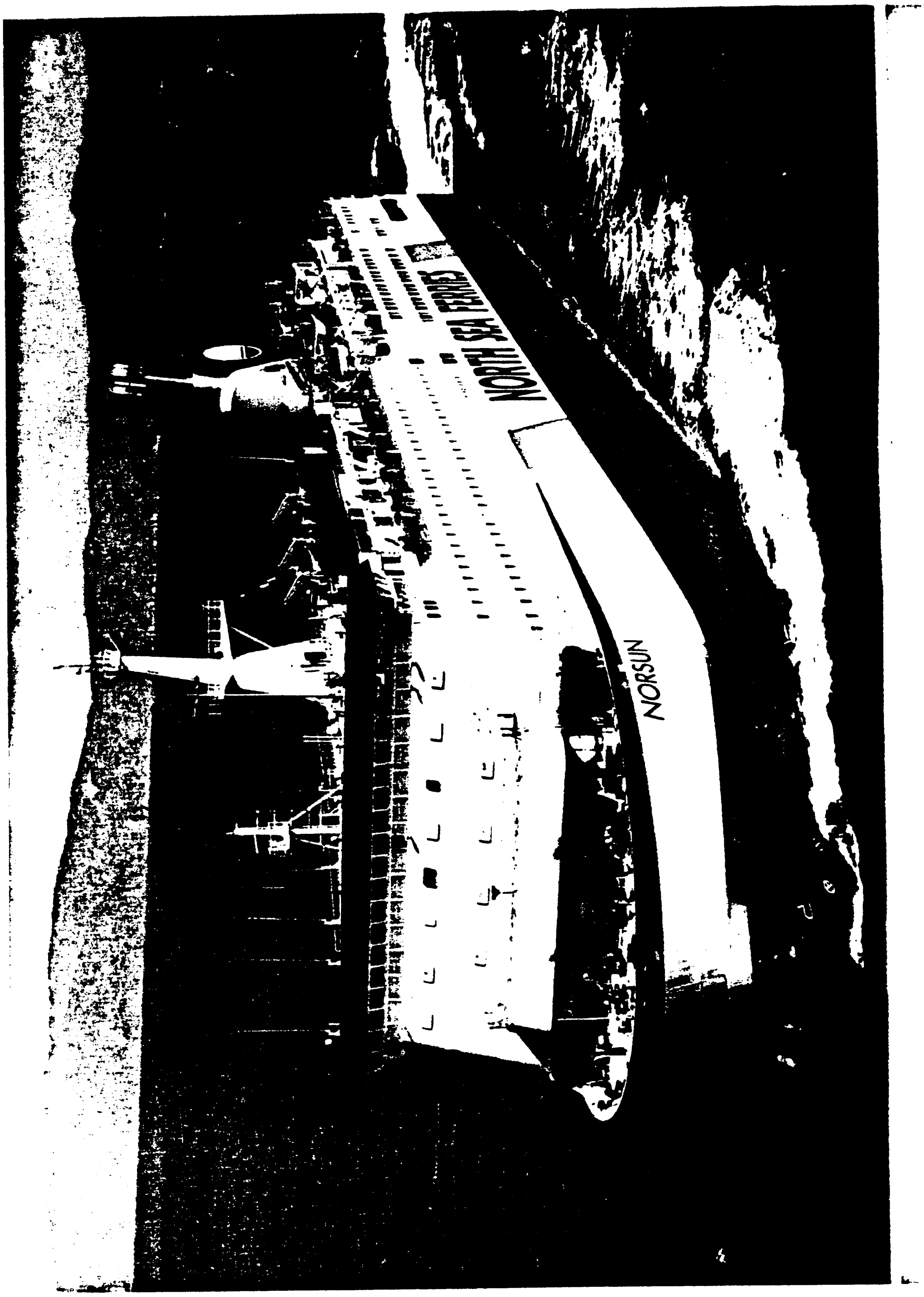
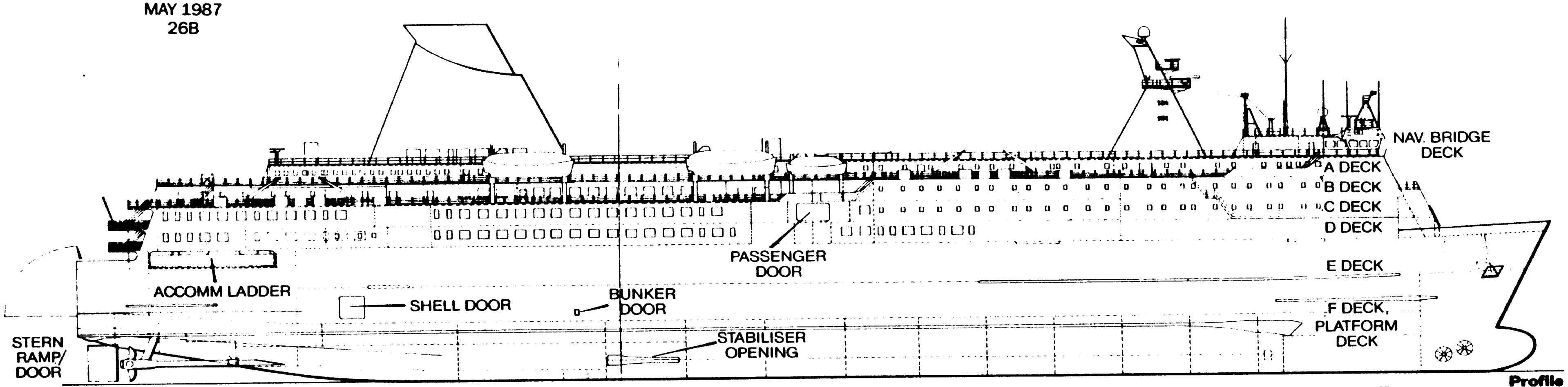

NORTH SEA FERRIES
NORSUN

THE MOTOR SHIP

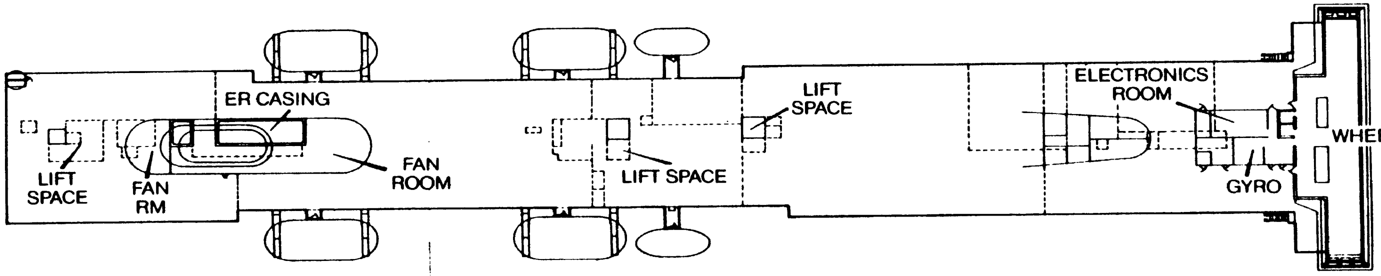
MAY 1987
26B

PROFILE AND GENERAL ARRANGEMENT PLANS OF THE 31 000 GRT NORTH SEA FERRIES

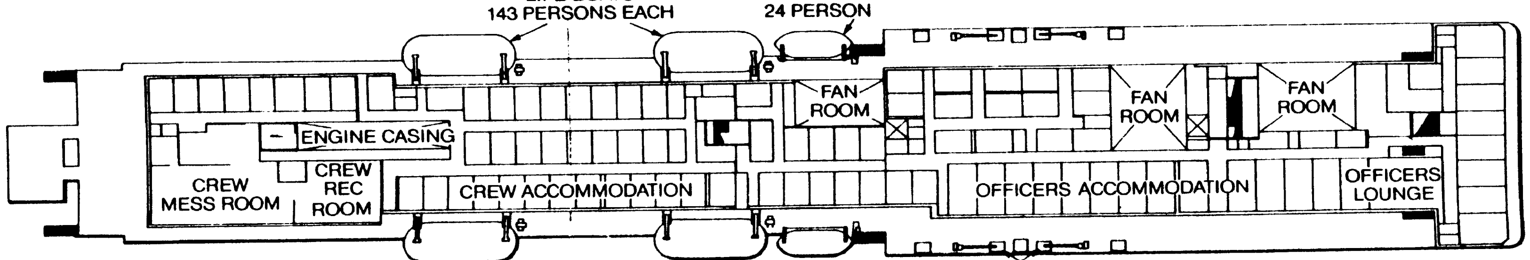
NORSEA & NORSUN



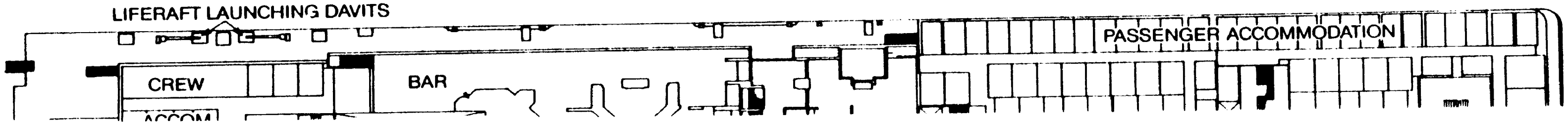
Profile

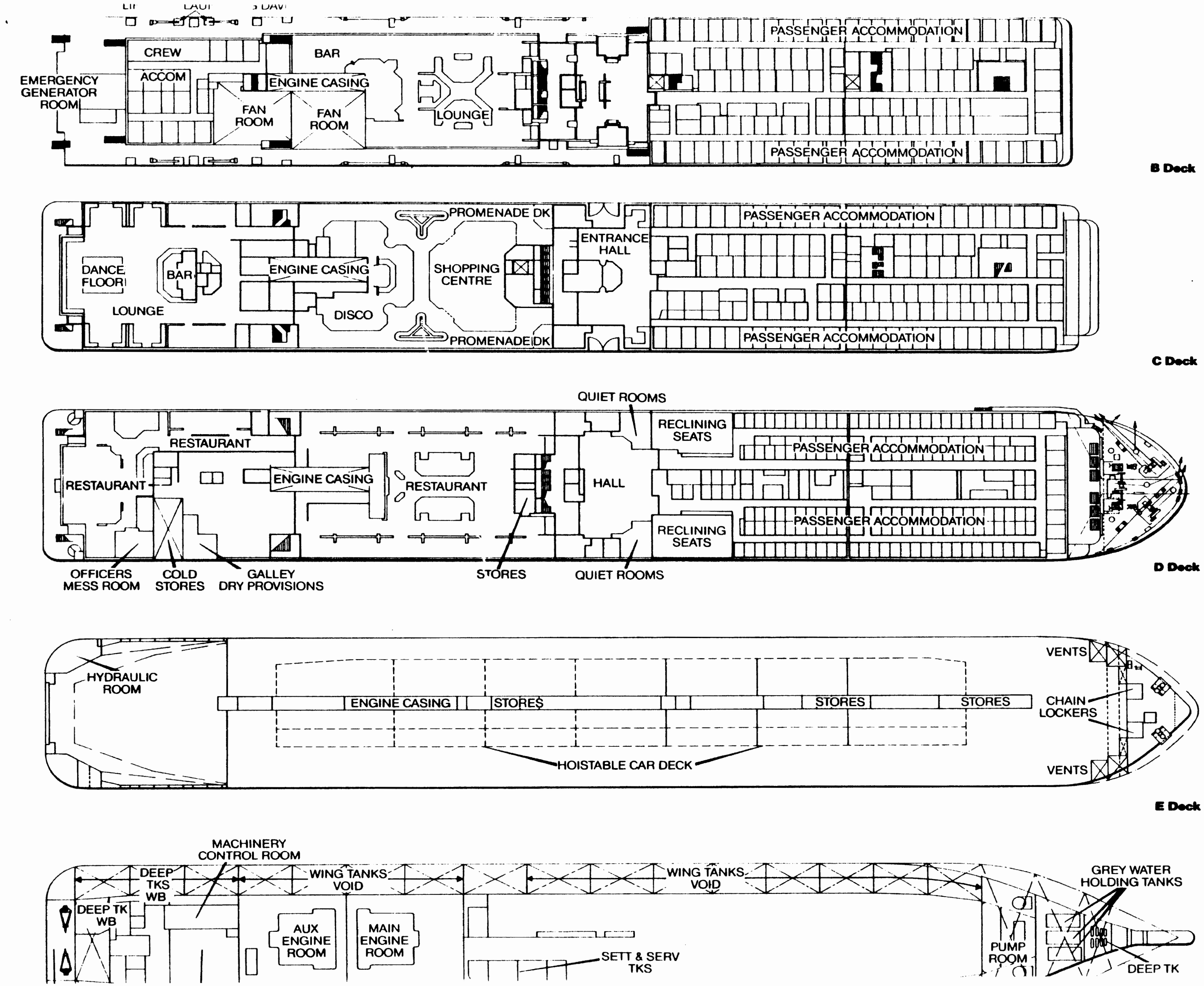


Bridge Deck

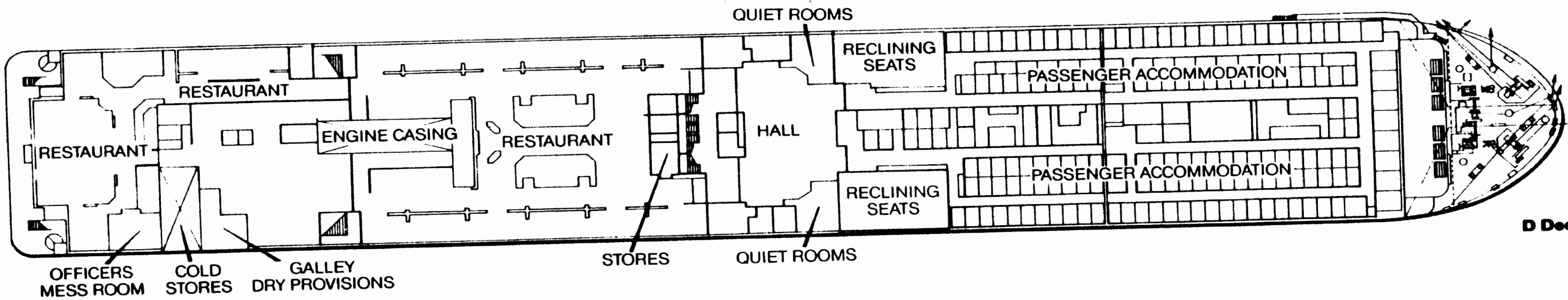


A Deck

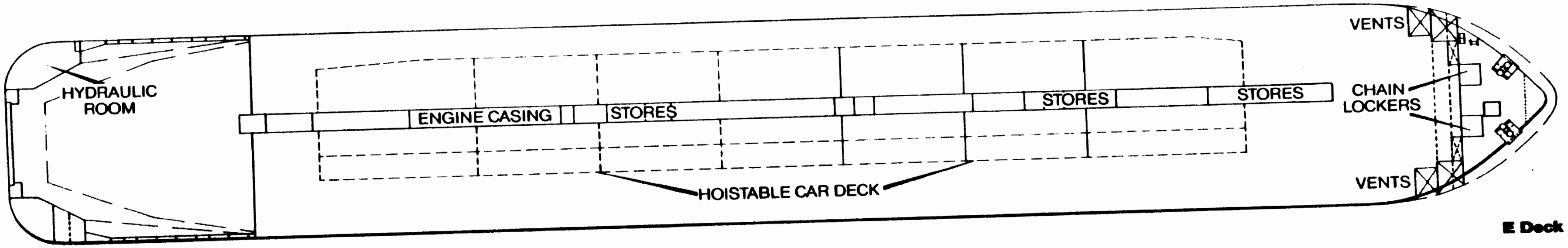




CREW
ACCOM
EMERGENCY GENERATOR ROOM
BAR
ENGINE CASING
FAN ROOM
FAN ROOM
LOUNGE
PASSENGER ACCOMMODATION
PASSENGER ACCOMMODATION
B Deck
DANCE FLOOR
BAR
LOUNGE
ENGINE CASING
DISCO
PROMENADE DK
SHOPPING CENTRE
PROMENADE DK
ENTRANCE HALL
PASSENGER ACCOMMODATION
PASSENGER ACCOMMODATION
C Deck
RESTAURANT
RESTAURANT
ENGINE CASING
RESTAURANT
HALL
QUIET ROOMS
RECLINING SEATS
PASSENGER ACCOMMODATION
PASSENGER ACCOMMODATION
RECLINING SEATS
OFFICERS MESS ROOM
COLD STORES
GALLEY DRY PROVISIONS
STORES
QUIET ROOMS
D Deck
HYDRAULIC ROOM
ENGINE CASING
STORES
STORES
STORES
VENTS
CHAIN LOCKERS
VENTS
HOISTABLE CAR DECK
E Deck
MACHINERY CONTROL ROOM
DEEP TKS WB
DEEP TK WB
WING TANKS VOID
AUX ENGINE ROOM
MAIN ENGINE ROOM
WING TANKS VOID
SETT & SERV TKS
PUMP ROOM
GREY WATER HOLDING TANKS
DEEP TK



D Deck



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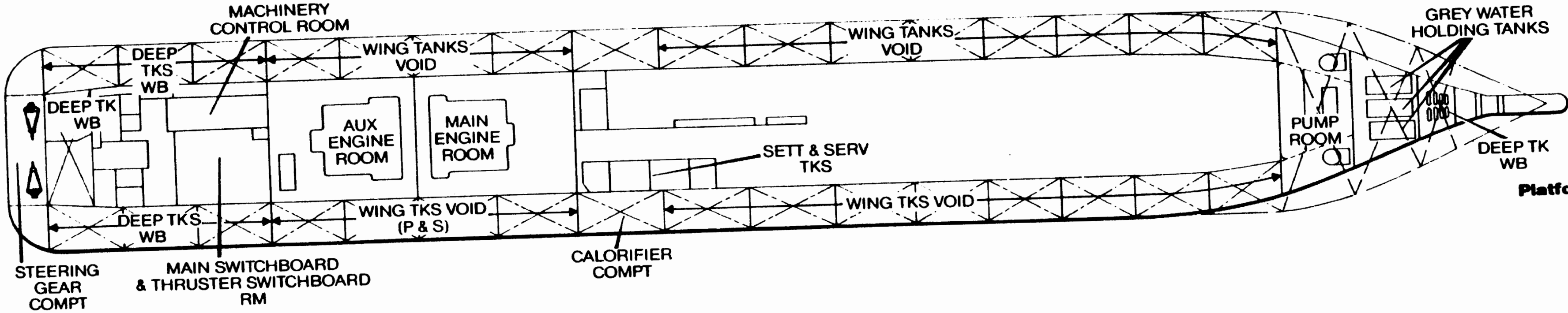
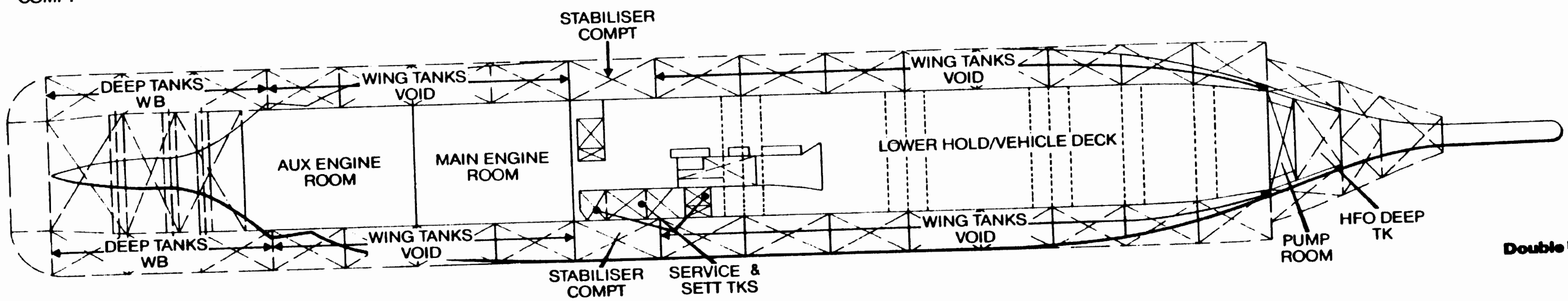


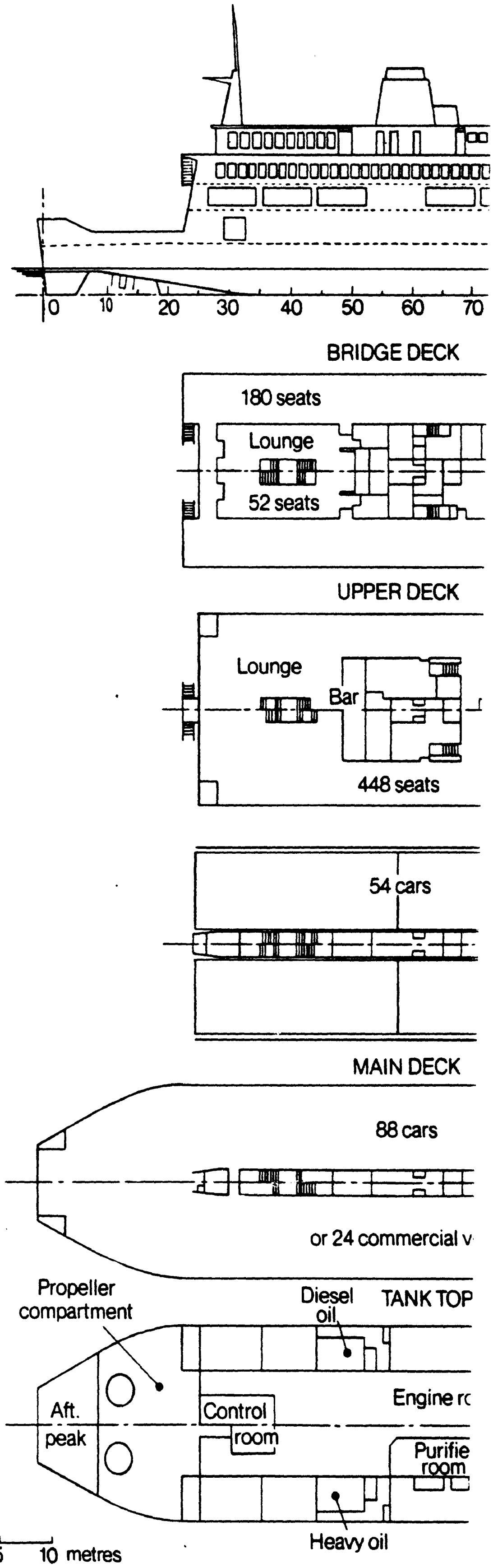
Platform Deck



Double Bottom

PRINCIPAL PARTICULARS	
NORSEA & NORSUN	
Length, oa	178.9m
Length, bp	169.8m
Breadth, extreme	25.4m
Depth, mld (to F dk)	7.85m
Draught, max	C1: 6.13m C2: 6.08m
Draught, scantling	6.23m
Deadweight	6 340 tonne
Gross register (approx)	31 600 ton
Service speeds	16.5 & 18.5 knots
Engines	2 × Wärtsilä-Sulzer 9ZAL40 2 × Wärtsilä-Sulzer 6ZAL40
Total MCR	19 200kW (26 100 bhp)
Passengers	1 250
Cabins	446/452
Crew	107
Cargo space	2 250 lane m
Cargo capacity	180 trailers, 850 cars, or a mixture of both
No of decks	8
Classification	Lloyds ✠ 100A1 Ferry ✠ LMC & UMS SOLAS Short International Voyage

PRINCIPAL EQUIPMENT	NORSEA		NORSUN	
..n engines	Wärtsilä-Sulzer		Wärtsilä-Sulzer	220
..arboxes	F Tacke		F Tacke	221
..rs	Woodward		Woodward	222
..rators	Wärtsilä-Vasa		Wärtsilä-Vasa	223
..pellers & bowthrusters	KaMeWa		KaMeWa	224
..nators & thruster ..tors	Siemens	225	Taiyo	226
..gency generator	Finning	227	Caterpillar Mitsubishi	228
..ifiers	Westfalia		Westfalia	229
..access equipment	Kvaerner	230	MacGregor Far East	231
..machinery	Sunderland Forge	232	Fukushima	233
..itchboard & control ..consoles	Siemens	234	Terasaki	235
..rtight doors	Winel	236	MacGregor Far East	237
..nditioning	Flakt	238	Novenco	239
..dders	Becker		Becker	240
..ilisers	Ross Industrie		Ross Industrie	241
..ring gear	Hastie	242	MHI	243
..ermal oil system	Saarloos		Saarloss	244
..re systems	Wormald	245	Van Rijn	246
..ring equipment	Electrolux Marine		Electrolux Marine	247
..boat davits	Schat	248	Davit Co	249
..ferafts	RFD	250	Beaufort	251
..iors	Byers	252	HCG	253
..boats	Welin Lambie	254	Mulder & Rijke	255
..eeling pump system	Frank Mohn		Frank Mohn	256
..fts	Otis Elevator	257	de Reus	258
..age system	Evac		Evac	259
..overing	Signal Marine	260	Taihei Kogyo	261
..eilings	Dampa		Dampa	262
..munications	Ericsson		Ericsson	263
.., autopilot	Anschütz		Anschütz	264
..arpets	Hugh Mackay	265	Weston	266
			KVT	267
..e oil filters	Boll & Kirch		Boll & Kirch	268



THE MOTOR SHIP

PROFILE AND G
PLANS OF T

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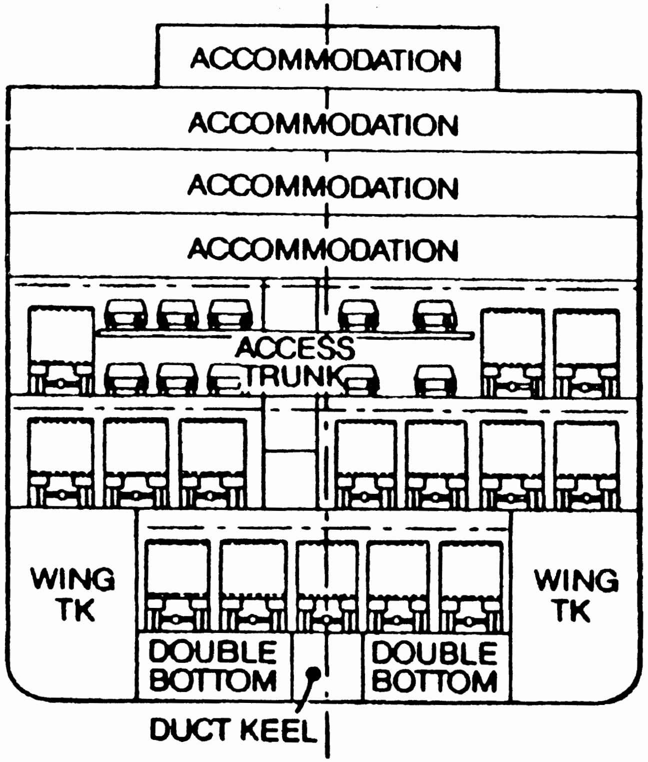
ACCOMMODATION
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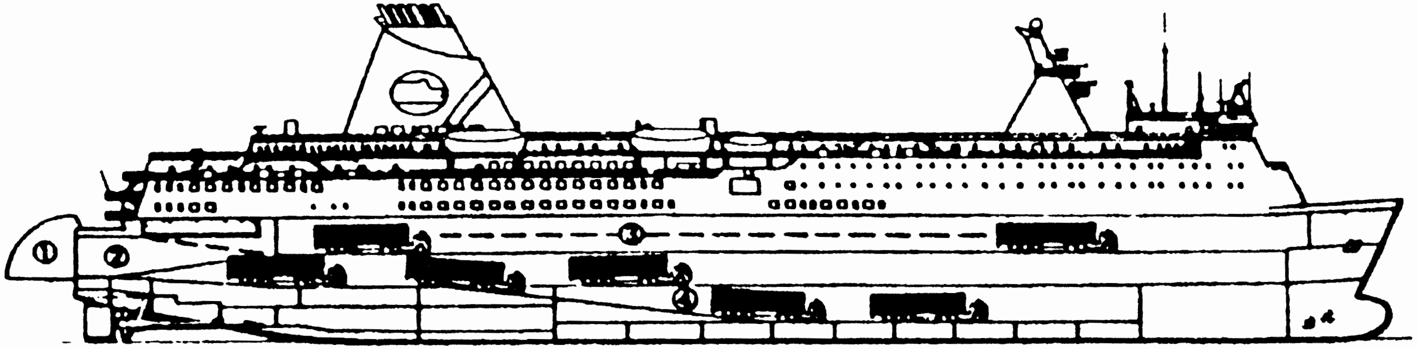
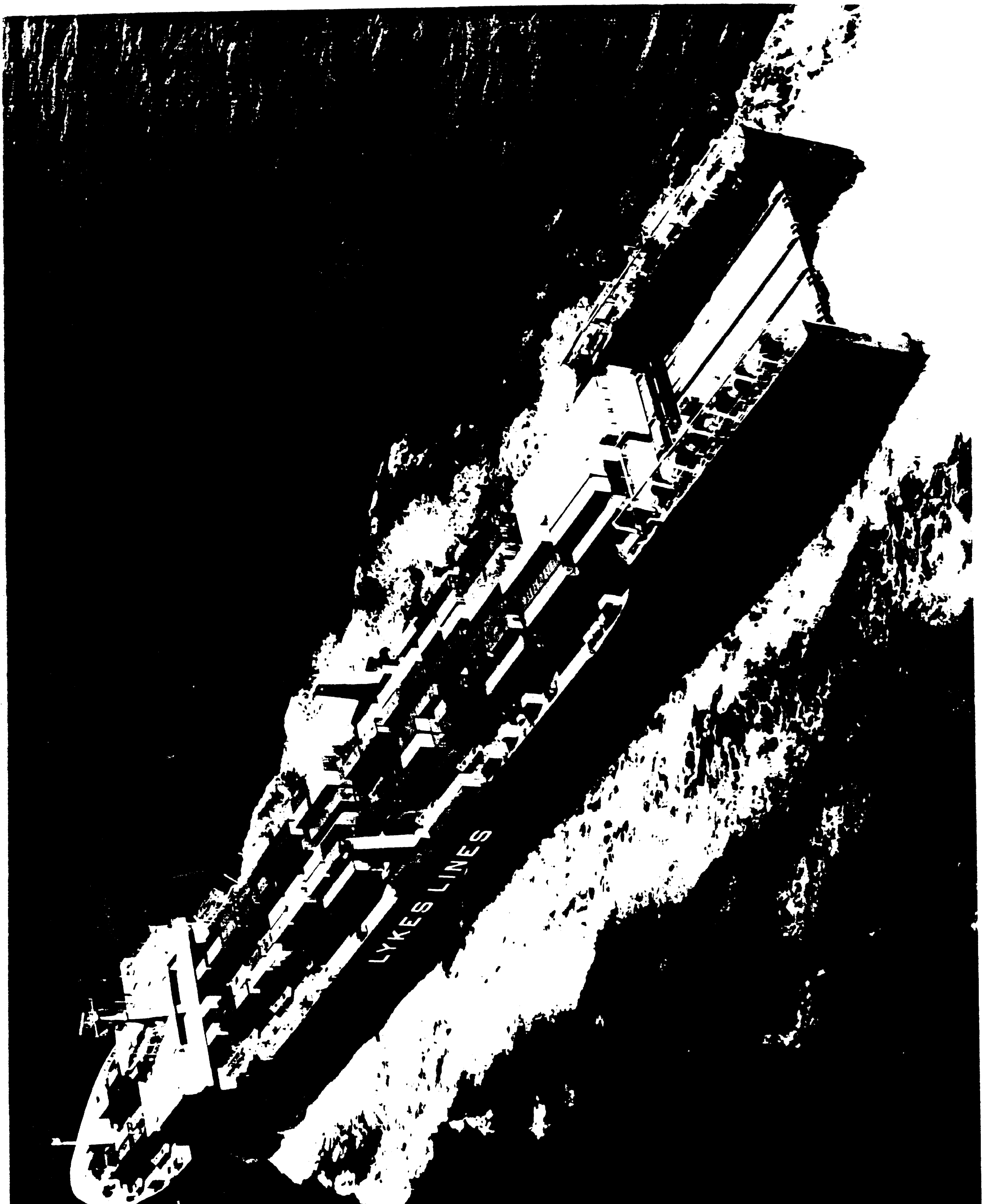
DUCT KEEL



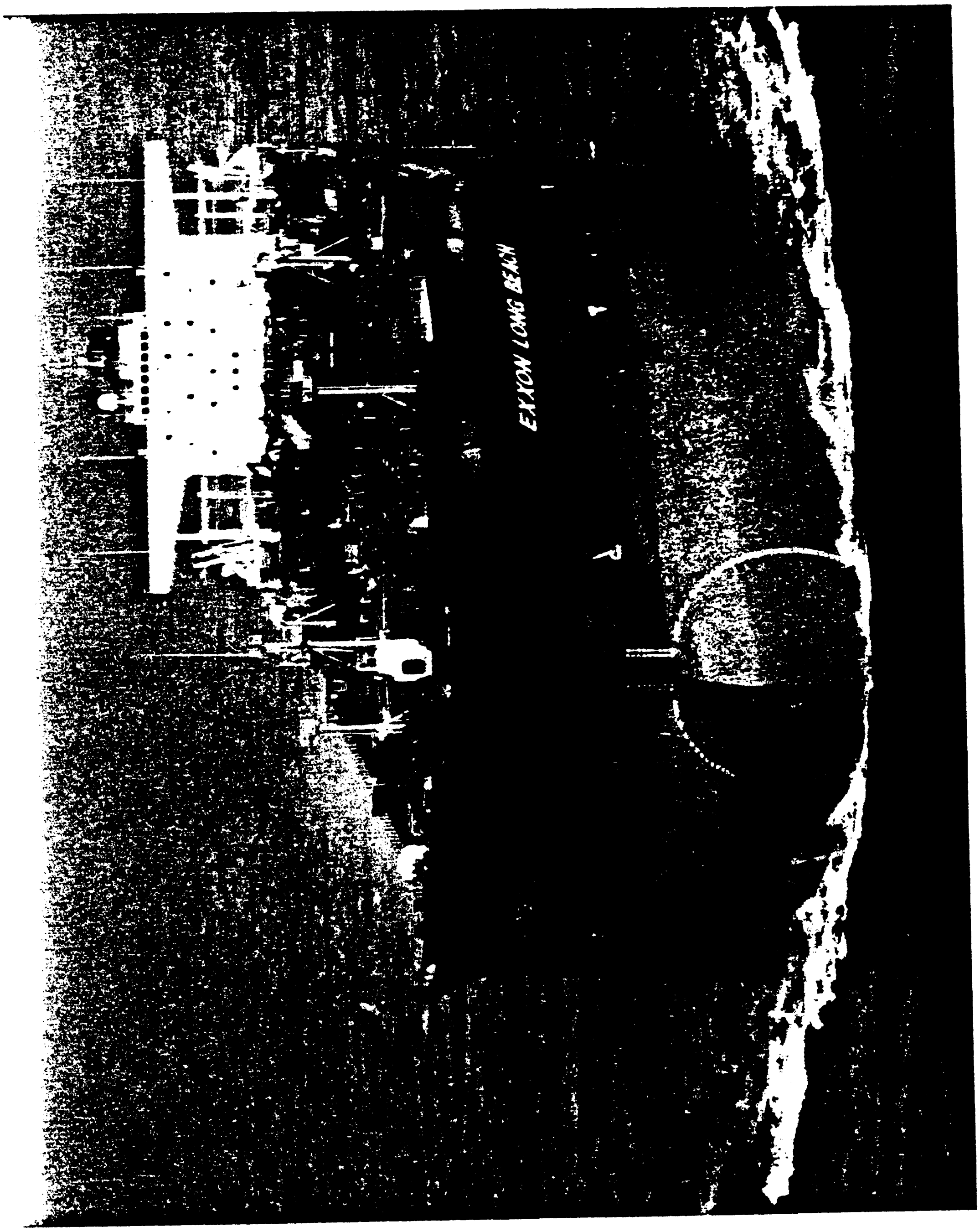

LYKES LINES

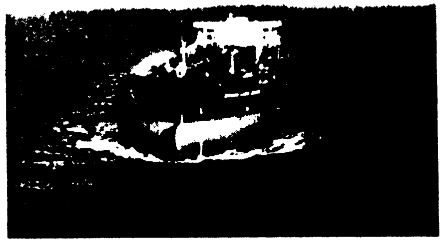
INFORMATIONAL CUTLINES

This is the SEABEE Class Tillie Lykes, one of the most unique and versatile cargo ships afloat today. She is one of three such ships in the 41-vessel fleet of Lykes Bros. Steamship Co., Inc., which operates the only such ships in the world. Built at a cost of $33 million, the Tillie Lykes is a combination barge and container carrier with a 2,000-ton submersible hydraulic elevator at its stern used to load and discharge two fully-loaded barges simultaneously. The ship is 875 feet long.

-30-

2.22


EXXON LONG BEACH



Front cover photo features VLCC Exxon Long Beach. Recently delivered by NASSCO, she'll serve in Alaskan trades. More tumultuous international tanker market is discussed on *p.18.*

2.24


BRITISH STEEL

One of a new generation

The newbuilding market for very large bulk carriers (VLBCs) is dominated by Asian yards. Japanese builders, in particular, have developed designs which offer the operational economy demanded by the contemporary trading climate. Slower service speeds and more efficient diesel propulsion plants than earlier generations of VLBC have substantially reduced fuel costs, and smaller crews are required to man the latest deliveries.

Keeping the European flag flying in this sector is Belfast shipbuilder Harland and Wolff, which last September delivered *British Steel* – the largest bulk carrier built in Europe – and soon after secured a contract for a sistership.

The 173,000dwt *British Steel*, ordered by Lombard North Central for charter to the British Steel Corporation (BSC), is designed mainly for carrying iron ore but can be arranged for coal and grain cargoes. Her maiden voyage brought 153,000 tonnes of Brazilian iron ore to BSC's deepwater terminal at Redcar; she will also be able to discharge at other UK terminals – Hunterston, Immingham and Port Talbot.

The efficiency of the main propulsion plant and aft hull design is such that fuel consumption is reportedly around 45 tonnes/day – a figure that would flatter much smaller Panamax bulkers of a decade ago. But a concern for cargo handling performance is also apparent in the selection of MacGregor-Navire (MGN) hatch covers for the vessel's nine holds. The shipset, detailed in *MacGregor News 100*, is based on the two-panel, rack and pinion-driven, side rolling cover design.

Clear opening sizes of the covers are 14.4m long x 23.3m wide for No.1 hatch, and 14.85m long x 23.3m wide for No.2 hatch. The remaining hatches, Nos 3-9, each offer 14.25m x 23.3 openings. The covers are of open construction, designed to accept a uniformly distributed load of 1.75 tonnes/m^2 and to operate at lists up to 5 degrees and trims up to 2 degrees. Four 0.6m diameter ventilators are fitted to each cover.

Each of the pair of panels forming the cover may be opened or closed independently of the other by a separate hydraulic motor. A cost effective hydraulic cleating system features only 14 cylinder-operated locking bolts per cover, achieving the same cleating effect as about 60 of the manual, quick acting type. Self-engaging locking pins secure automatic cleating at the cross joints.

The panels are lifted to the rolling position by hydraulic lifting jacks, and driven by the pinion engaged with a centrally located rack on the panel's underside. Stowage for all covers is one panel port, the other starboard, but by linking the panels, hatch Nos 1, 3, 5, 7 and 9 can be stowed both panels on one side, thus leaving only half the hatch exposed.

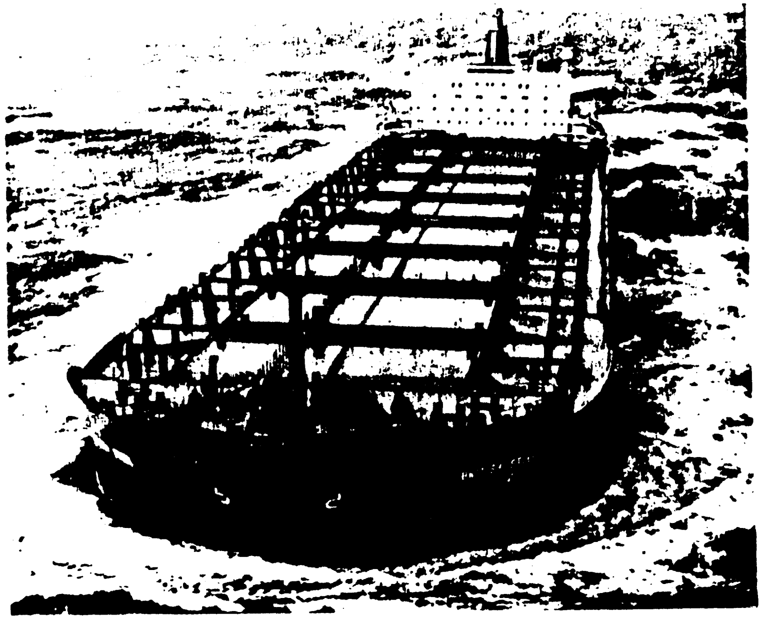
The announcement last December of a follow up order to *British Steel* extended the links between Harland and Wolff and BSC to five large bulkers aggregating 700,000dwt in the past seven years. The 30 million pound sterling sistership, due for delivery at end 1986, will be financed by Lloyd's Equipment Leasing Ltd for bareboat charter to the steel corporation. She will exploit improvements in the main engine specification, a revised aft end hull form and propeller design to yield an expected 10 per cent fuel saving over her economical predecessor.

Yard chairman, John Parker, is confident that the new generation of economy VLBCs will accelerate the replacement demand for older, less efficient large bulkers in service, and that Harland and Wolff's experience will make it a competitive challenger for such business.

PRINCIPAL PARTICULARS
'British Steel'

Length (o.a.)	286.90m
Length (b.p.)	275.00m
Breadth (mld)	47.00m
Depth (to upper deck)	24.00m
Draught (mld)	17.80m
Deadweight	173,000 tonnes
Hold volume	194,254m^3
Main engine	H&W-MAN-B&W 5L90GBE
Speed (service)	13.6 knots

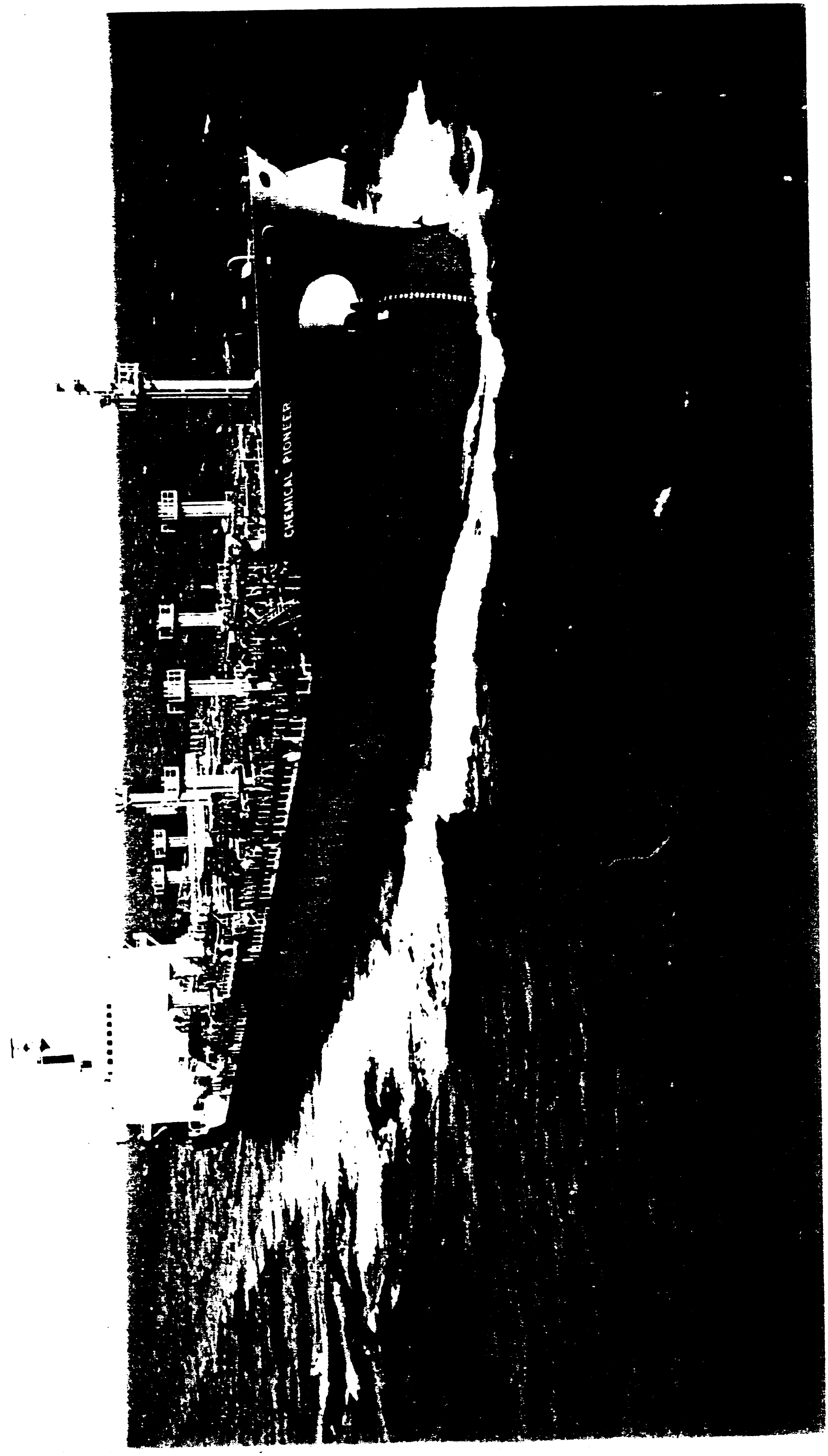
Well down in the water, the ore-laden British Steel *ploughs through the English Channel*



Repeat equipment order for MGN

We learn, as we go to press, that MacGregor-Navire has won the hatch cover order for *British Steel's* sistership. The covers for the second ship, though of the same type and dimensionally identical to those supplied for the lead vessel, do incorporate technical improvements recently introduced by MGN plus a new installation regimen that will ensure savings being made on installation time. This latter contributed to the 'common pot' of savings that Harland and Wolff were able to include in their tender – a fact which helped in the winning of the order by the N. Irish yard. Delivery is scheduled for end 1986.

2.26



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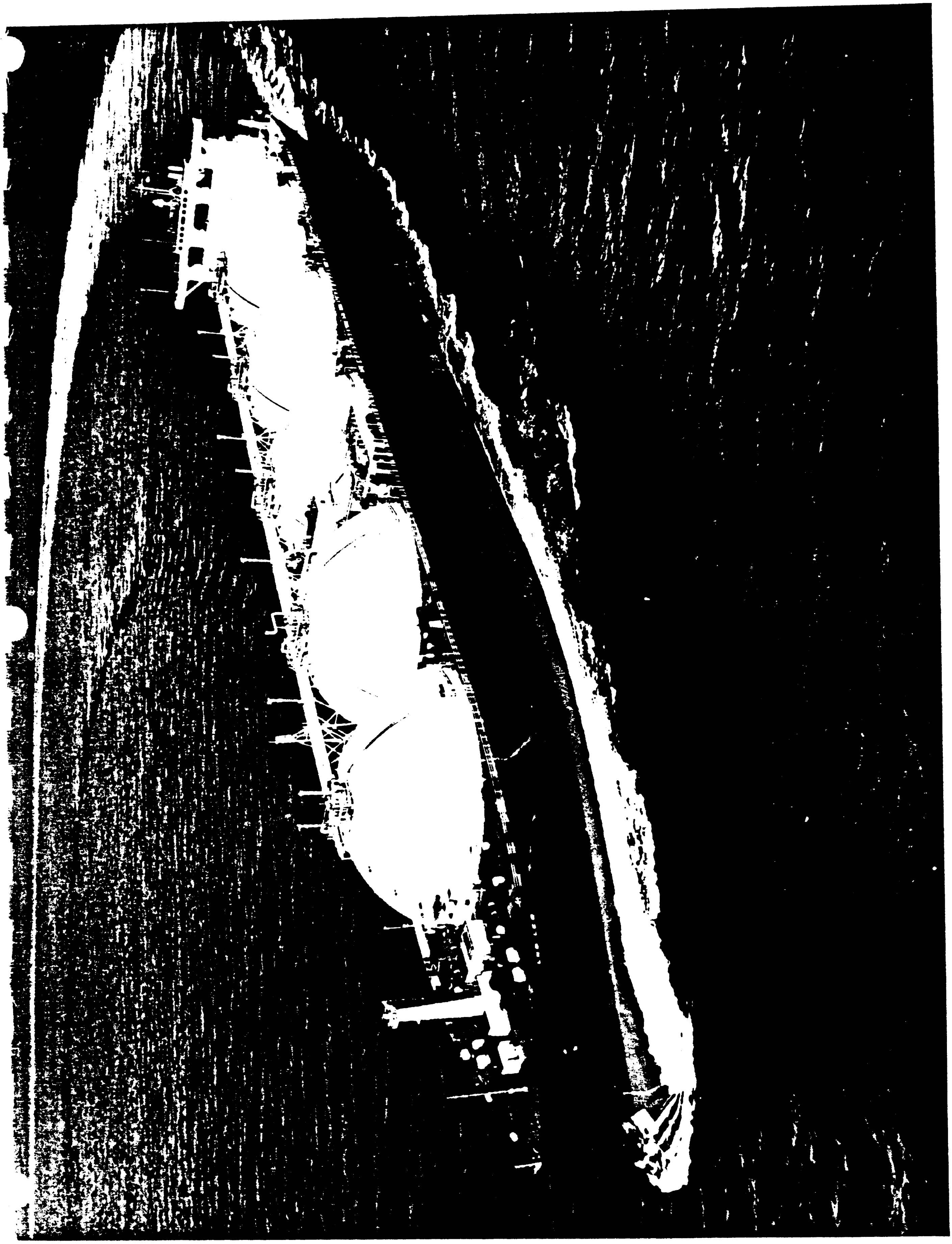

GENERAL DYNAMICS **PHOTO**

NEW LNG CARRIER -- LNG LEO, newest liquefied natural gas tanker to be built at General Dynamics' Quincy Shipbuilding Division, returns following completion of successful sea trials in the Atlantic. Naming ceremonies for the 936-foot, 125,000-cubic-meter tanker were held today (Dec. 2) and she will join her sister ships early next year in transporting LNG between Indonesia and Japan.

######

12/2/78

For further information
GENERAL DYNAMICS CORPORATION
QUINCY SHIPBUILDING DIVISION, 97 EAST HOWARD STREET, QUINCY, MASSACHUSETTS 02169 617 471-4200

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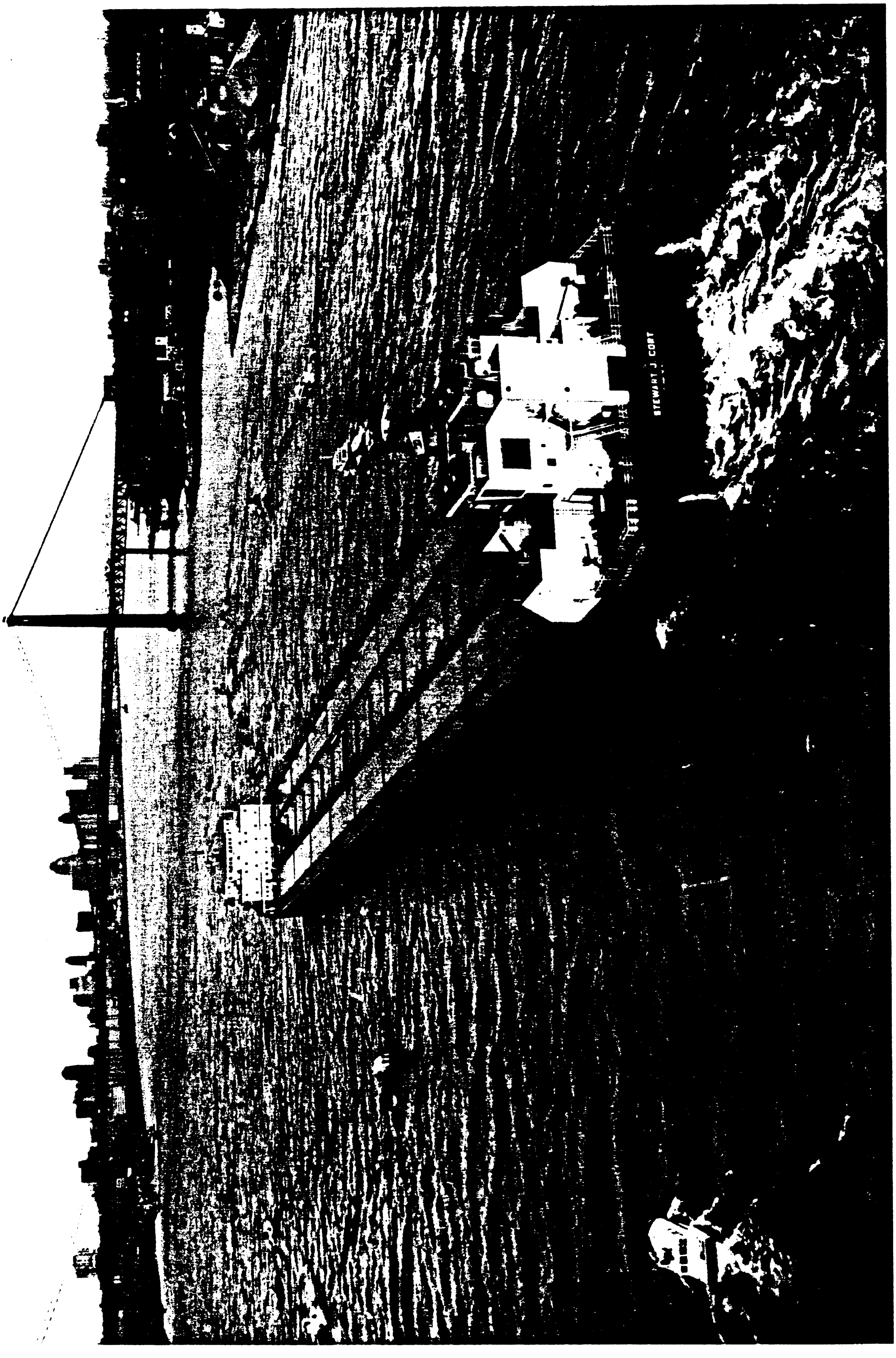
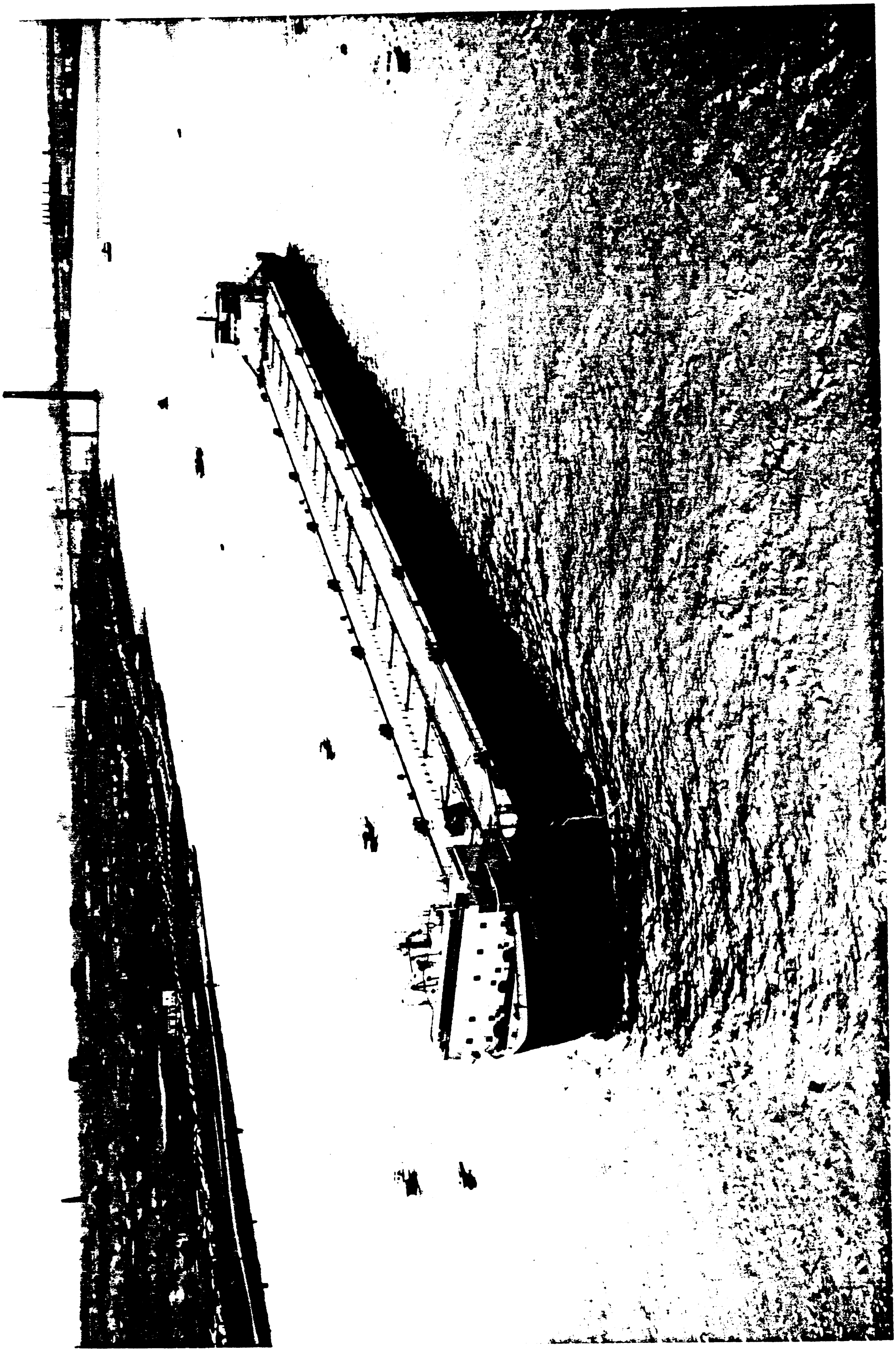

STEWART J. CORT



Powerful currents drive the Queen

The new electrical system for Queen Elizabeth 2 has an installed capacity of over 90MW, enough to drive the vessel at a service speed of 28.5 knots and supply all the passenger services with capacity to spare.

The nine diesel engine driven AC generators for the refit were designed and manufactured by the Generator Division of GEC Turbine Generators Ltd, Stafford, UK.

Each machine is rated 10.5MW at 400 rev/min and generates 10kV at a frequency of 60Hz. The generators provide power for the two 44MW electric propulsion motors and for the hotel load.

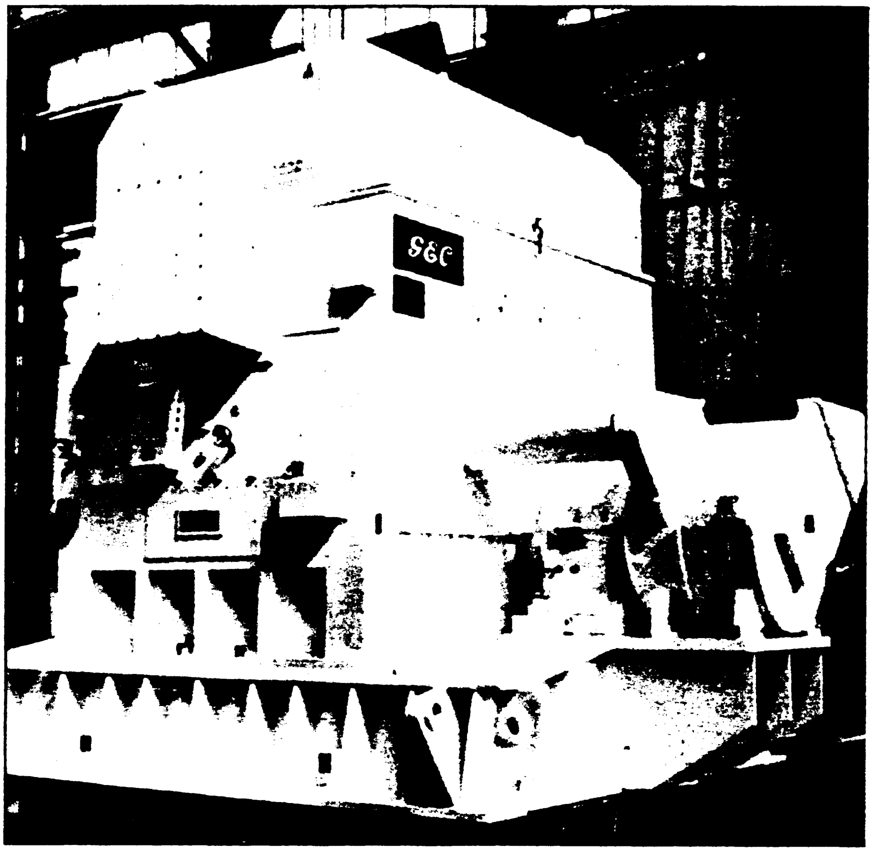
The electrical propulsion system was designed and supplied by GEC Electrical Projects Ltd, Marine & Offshore Division, as subcontractors to MAN B&W. It is the world's first in many respects, the most important aspect being the use of synchro-convertors.

In some AC propulsion systems the propulsion motor runs at a fixed speed corresponding to 50/60Hz, a constant frequency being necessary if the propulsion bus is used to supply the ship's auxiliary load. Alternatively, the propulsion motor can run at variable speeds with a variable frequency supply, but under these circumstances the propulsion busbar could not be used to supply the ship's auxiliaries.

However, the use of synchro-convertors provides a variable frequency supply for speed control of the AC propulsion motors. In addition they can be used to give a soft start facility to enable the propulsion motor to be synchronised with the propulsion busbar.

Thus, the propulsion motors can be speed controlled as they would be with a conventional thyristor fed DC motor. Alternatively, they can be run synchronised onto the propulsion busbar system. The use of one system or the other is directed by the sailing mode.

The 18-pole generators are of the salient pole type and are directly driven by the diesel engines. A brushless excitation system is used to avoid problems associated with carbon brush dust and current collection that can occur with conventional DC exciters or static excitation. The brushless design incorporates a permanent magnet pilot exciter to supply the field of the main exciter via the automatic voltage regulator. With this design the excitation scheme is independent of any external sources of supply.

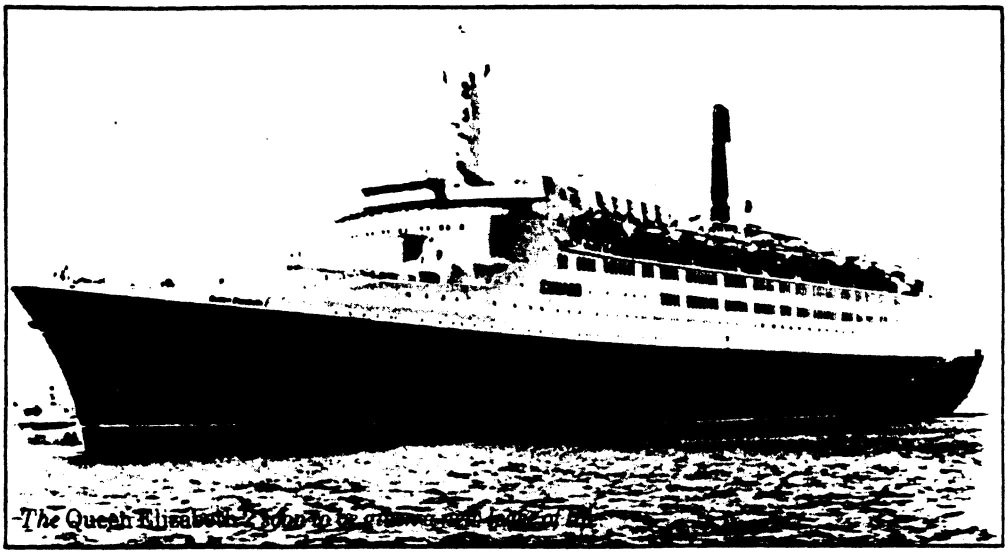


The 18-pole generators are rated at 10.5MW at 400 rev/min; the field is provided by a brushless excitation system, using a permanent magnet exciter, seen on the right of the photograph.

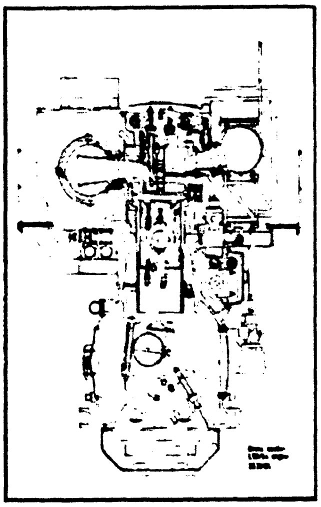
A conventional two-bearing arrangement was selected for the generators with the stator frame and bearing pedestals mounted on a fabricated bedplate; on board the bedplate is securely bolted to the floor of the engineroom.

The generator bearings are self-lubricated by an assembly of oil discs and scrapers. Both bearings are provided with cooling tubes immersed in the oil bath contained in the pedestal sump, and a continuous supply of water to these cooling tubes removes the heat generated at the bearing surfaces. The generators are coupled to the diesel engines by Vulcan flexible couplings; hence there is the possibility of some axial movement of the generator rotor arising from the pitch and roll of the ship in rough seas. To overcome this problem thrust pads are incorporated in the front end bearing to accommodate the resulting axial loads.

The machines are ventilated by a closed air-circuit water-cooled system where air is recirculated through heat exchangers mounted on top of the stator frame. Air is drawn by fans mounted at each end of the rotor, and flows through the stator windings and then in parallel paths through the air



The Queen Elizabeth 2 soon to be [illegible]



Cross section of the 58/64 engine showing the monobloc frame and the underslung crankshaft.

Diesel-electric power chosen for *Queen Elizabeth 2*

Cunard, the UK shipping line, has opted for a diesel-electric configuration to replace the existing turbines on boards its liner *Queen Elizabeth 2*. Nine 9-cylinder MAN-B&W 58/64 series engines producing a total of 94 500kW (130 000 bhp) will be installed in the vessel. MAN-B&W are also responsible for the technical layout and delivery of the complete production package which also involves GEC and Harland and Wolff.

The cost of re-engining the *QE2* will be DM90 million (US$34 million).

The new plant is expected to make a daily saving of 250 tonne of fuel oil at a service speed of 28.5 knots although a top speed of 32.2 knots will be attainable.

The West German shipyard Lloyd Werft, Bremerhaven will begin work on the DM300 million (US$114 million) refit in October 1986 with the vessel spending 179 days at the berth, to be returned to Cunard in April 1987. Cunard has already planned its cruise programme for 1987 and heavy penalty clauses are included in the contract.

MAN-B&W's L58/64 engine series (*The Motor Ship special supplement*, March 1985) has been developed for a power range between 5 884 and 11 033kW (8 000 and 15 000 bhp), to provide an overall cost effectiveness for a large bore, four-stroke engine. The characteristics of this engines fuel consumption, lube oil consumption, exhaust energy recovery, heavy fuel operation and maintenance are summarised thus:

Fuel consumption. A consumption of 123 g/hph at 85 per cent ECR was achieved on the testbed with a 3L58/64 experimental engine and figures of 120 to 121 g/hph are foreseen.

Lube oil consumption. Rates of less than 1 g/hph have been achieved.

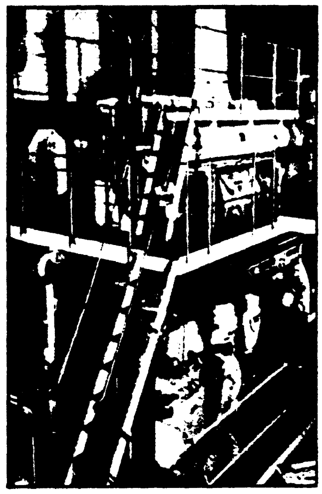
Exhaust gas recovery. Between 350 and 700kW of electrical energy can be gained from the exhaust gas, thus providing 50 per cent more exhaust energy than current two stroke engines.

Heavy fuel operation. The 58/64 engine series has been run on significantly lower grade heavy fuel than is currently available on the market, says the company, and has been operated on fuel of 1 720 cST (7 000 sec Redwood 1) from the outset. A simple means of adjusting ignition timing is incorporated with which the combustion process can be adapted to operating and ambient conditions, such as the varying quality of the fuel.

Maintenance. A high power output developed on a small number of cylinders means low maintenance costs, say MAN-B&W. With just four variants from six to nine cylinders the 58/64 series covers a 7 000kW power range. Short removal and installation times are claimed for the engine together with a long service life of the major components.

In addition to the machinery which will require some structural modifications to the ship, extensive alterations in the accommodation are also planned to provide more luxury for passengers. Extra deluxe and 1st class cabins will be added together with new communial areas with integrated shopping arcades, bars and a conference centre. A squash court and entertainment centre will also be added.

Over the bridge an all-weather observation lounge will be built for passengers. Other attractions will include a swimming pool with adjustable floor, making it possible to raise it to a safe height for children or change it to a dance floor. Galley spaces are to be rebuilt in one central location and a new hospital and doctors surgery are to be built. Crews mess and recreation areas will also be improved. A new automatic telephone exchange will be installed to make it possible for all cabins to be linked via Satcom to make international calls. □



The three-cylinder prototype 58/64 on which development tests were carried out.

Cp propeller and Grim wheel of the type to be fitted to the QE2. *The operation of the Grim Wheel was discussed in* The Motor Ship, *February 1984.*

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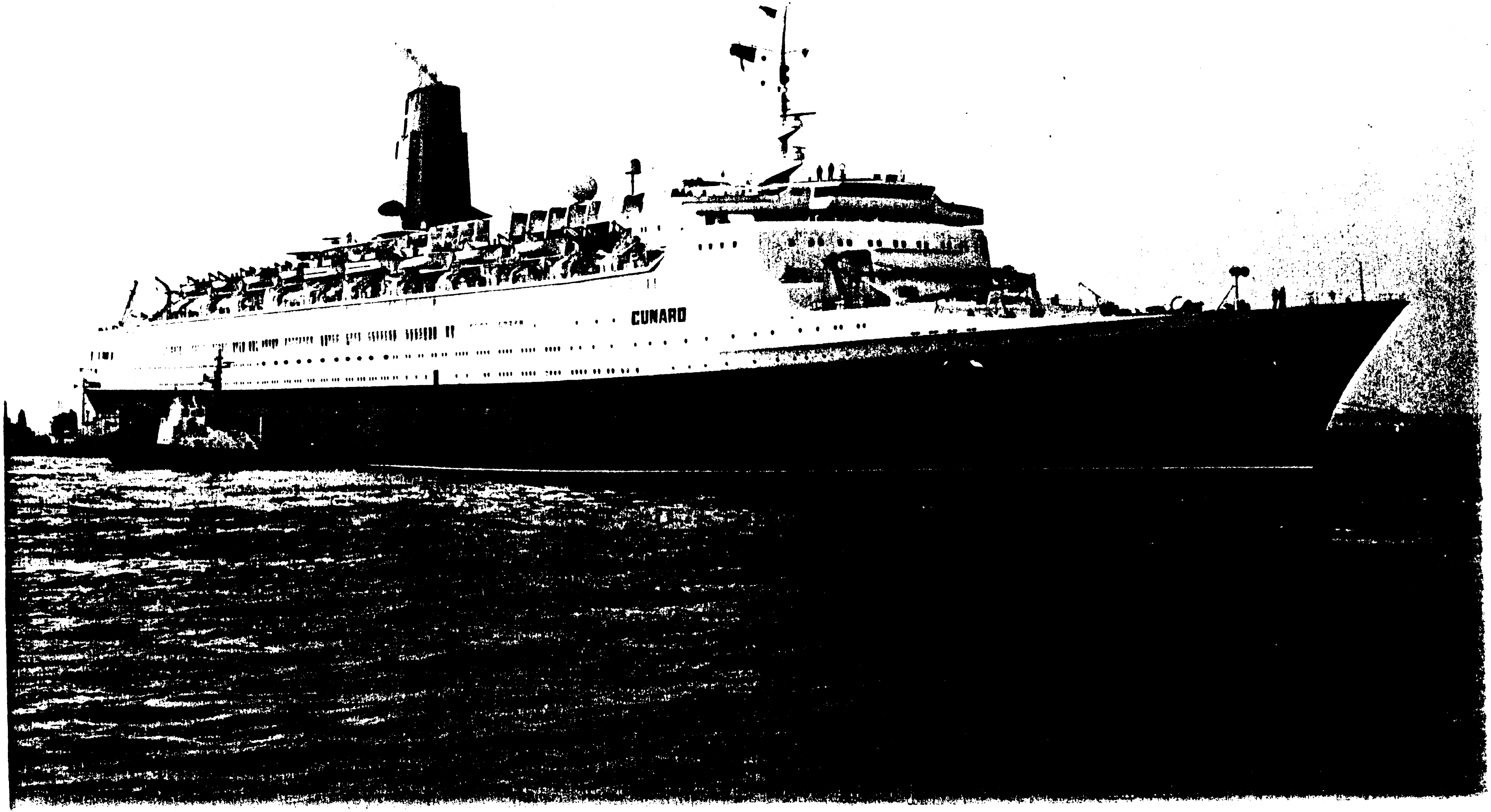


gap where it exhausts outwards through ducts in the stator core. The hot air is directed upwards through openings in the top of the frame to the heat exchanger. The recooled air is then drawn back to the rotor fans to complete the circuit. The brushless exciter is ventilated by air from the generator air circuit via overhead ducts from the stator endshields.

The heat exchanger is contained in a steel housing mounted on top of the stator frame. It utilises a double tube, double tubeplate design. With this arrangement any water leakage in the event of a tube failure is contained within the outer tube and is channelled into the space between the double tubeplates. This space is drained into a cooler leakage tank fitted to the side of the stator frame. A liquid level detector provides a warning of any leakage from a cooler.

The overall length of the machines had to be limited because of space constraints, and modifications were introduced into the exciter design to shorten its length. One such change involved the rotating diode carrier which was redesigned and mounted underneath the armature winding overhang of the main exciter.

In the event of a major failure of one of the generators, the machines are designed such that all of the poles and the top two-thirds of the stator winding can be removed without having to withdraw the rotor or remove the exciter and bearing pedestals.

To reduce the erection time at the shipyard, the machines were delivered fully erected on their bedplates. To facilitate transport with the rotor secured in the core of the stator, a new design of endshield was developed.

The stator frames are waterproofed up to the underside of the shaft to meet Lloyd's requirements.

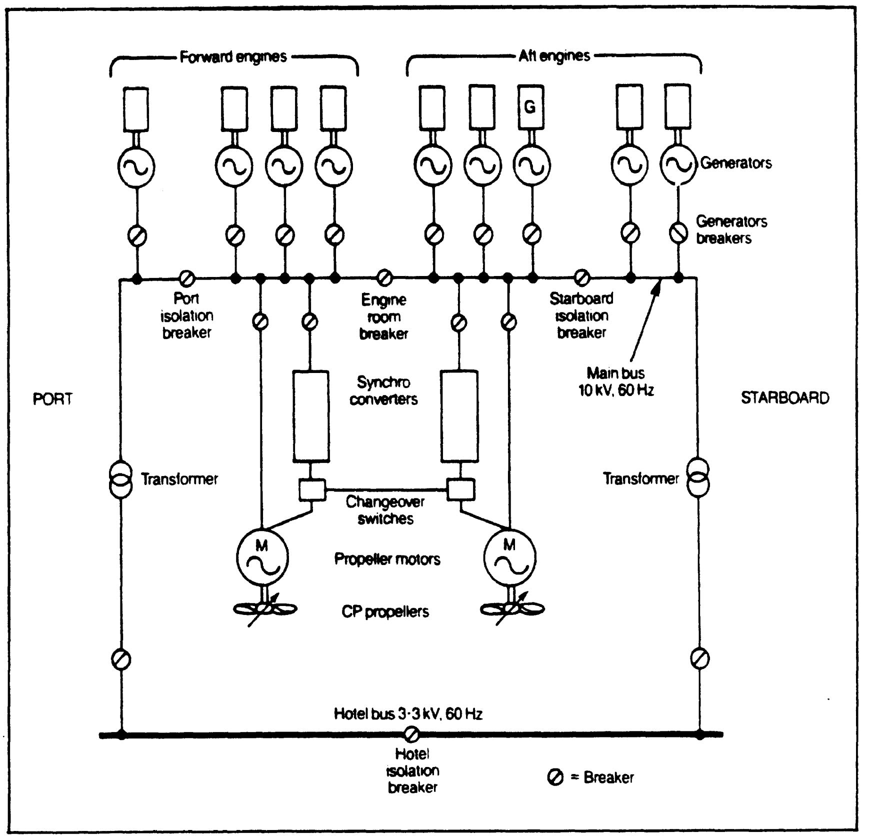
The order for the generators was received at the end of December 1985, and manufacture of all nine machines was completed by the end of September 1986.

Motors

The motors were designed and manufactured by GEC Large Machines Ltd in Rugby. The order was received in December 1985 and the motors were completed, tested and despatched to Bremerhaven in August/September 1986.

These are believed to be the largest single unit propulsion motors in commercial service.

The machines are 9m long and 8½m in diameter. The 900mm diameter shaft is 5.7m long and carries a rotor of 6m diameter, the complete shaft and rotor weighting 105 tonne. The complete motor weighs approx 300 tonne. The shaft carries a rated torque of 2.92 × 10^6Nm, nearly 12 times that of each generator.



Electrical power for propulsion and for the hotel requirements of the ship are supplied from any combination of the nine generators. The synchroconverters are used for shaft revolutions up to 72 rev/min; above that speed the shafts are driven at 144 rev/min, corresponding to the ship's frequency of 60Hz.

The machines had to be designed both mechanically and electrically to meet the stringent conflicting demands of very limited space and performance within established criteria. Because of the large physical size, the production constraints, transport and assembly at the dockside, and practicability of on-board maintenance strongly influenced the design.

The stator frame was split into two sections of about 75 tonne each to facilitate transport. When reassembled with their endplates they form an extremely rigid box structure, which is designed to be watertight up to the underside of the shaft. This was tested in the factory, prior to core and winding assembly, by filling the lower half with 50 000 litres of water.

Similarly the rotor was split into two half rim/disc units of 35 tonne, and a shaft (28 tonne). The design was arranged to minimise production time on final assembly. Factory tests included an electrically coupled run with one machine as a generator. After tests the component parts were shipped to Bremerhaven where they were reassembled under GEC supervision before being lifted complete into the ship.

The motor enclosure is arranged for closed air-circuit water cooling. Air is circulated through four frame-mounted heat exchangers by eight motor-driven fans, the re-cooled air being returned to each end of the motor. A double tube, double tubeplate design is used to provide the same high integrity cooler as on the generators. The particular air circuit arrangement was necessary because of the severe space restrictions and the need to achieve uniform ventilation.

The motor shaft is supported in two pedestal-mounted sleeve bearings. These were specially designed for the duty and are self lubricated and water-cooled in a similar manner to the generator bearings. In addition they incorporate high pressure jacking oil. This is used to ensure proper lubrication and minimise wear at start and under low speed conditions. It is also an essential factor to assist maintenance and barring operations. The motor is solid coupled to the 70m-long propellor shaft, which is inclined 1.5 deg to the horizontal. The thrust block immediately adjacent to the motor, provides axial location.

Both stator and rotor windings have full Class F insulation but operate at Class B temperature rises (82°C rise in the stator, 90°C rise in the rotor, both based on cooling water at 38°C).

(Continued on page xxii)

The stator coils were designed to facilitate removal and replacement for shipping and reassembly at the stator joints. This feature also allows in-situ removal and replacement, should this ever be required. Similarly the rotor pole and field coil are designed as an integral assembly to facilitate in situ removal. The poles can be removed through access covers in the end plates.

The motors have inboard sliprings designed for static excitation from remote mounted equipment, arrangements are made to prevent carbon dust entering the motor.

The variable frequency starting scheme avoids the high power which would be required to start the motors direct from the generators. This accelerates the motors to synchronous speed, or runs the motors at subsynchronous speed for manoeuvering purposes. The power restriction in this mode is 11MW at 144 rev/min on each motor. Thereafter the motors are synchronised on to the main generator supply where full power of 44MW can be achieved by adjustment of the variable pitch propellers.

Frequency controls

Two identical frequency convertors are provided to enable the motors to be accelerated up to speed for synchronising and to enable them to be controlled at variable speed as required.

These so-called Syncdrive convertors were manufactured and supplied by GEC Industrial Controls and they are each rated to provide the following:

5.5MW at 72 rev/min
11.0MW at 144 rev/min

with a constant torque characteristic between these speeds.

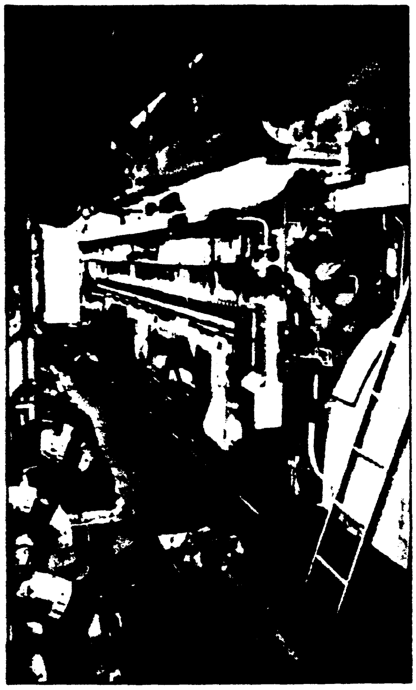
The Syncdrive is a DC link type convertor system where the power from the AC propulsion busbar is first converted into DC using a naturally commutated thyristor convertor, known as the supply convertor. An identical machine convertor changes the DC power into AC of the appropriate frequency for the motor. This convertor always works in synchronism with the rotation of the motor and it relies on the presence of sinusoidal generated voltages from the motor for its operation. The convertor directs the circuit current into the appropriate motor windings so that the optimum torque is generated at all times; it is impossible for the motor to fall out of step with the convertor.

With the normal working range the convertors are naturally commutated using the supply and motor-generated voltages to assist in the switching of the thyristors. At low speeds, however, the motor generated voltage is insufficient for this purpose and hence the supply convertor is used to assist the switching of the machine convertor from standstill up to approximately 7 rev/min.

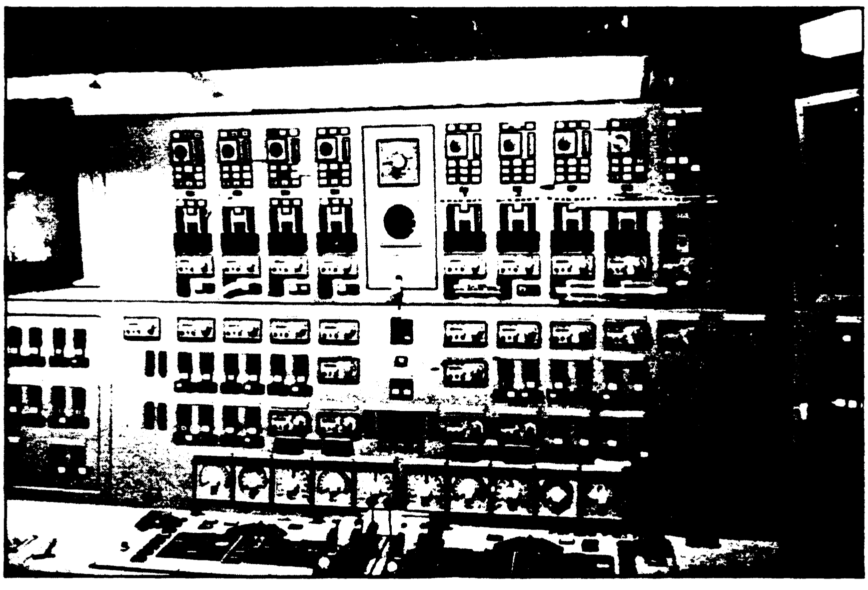
The two identical Syncdrives each consist of a suite of cubicles housing the thyristors and all the necessary control and protection apparatus. The thyristors are air-cooled and they are mounted on separate thyristor modules which can be removed and replaced quickly if necessary.

All the electronics for the drive is housed in a separate section of the suite along with the necessary sequencing relays and alarm annunciation.

The AC line reactors and the DC link reactor are installed in a room immediately below the convertors. They are air-cored and air-cooled. The AC line reactors limit the level of fault current which can flow in the circuit and also provide a measure of decoupling between the port and starboard convertors. The DC reactor provides for smoothing of the DC link current and serves to prevent interaction between the operation of the supply and machine convertors. They also limit the rate of rise of fault current and allow the convertors to be fully protected against all fault conditions by static means.



One of the five MAN B&W diesel engines in the aft engineroom; the other four are in the forward engineroom.



The engine control console has a mimic diagram of the complete generation, distribution and electric propulsion system. Note how the division of the five and four engines is replicated on the board. An uninterruptible power supply provided by Aval-Lindberg ensures that the monitoring system will continue to function irrespective of mains power failures.

Switchboard

The main 10kV switchboard, designed and built by Field & Grant Birmingham, is divided into two sections which are mounted in port and starboard switchboard rooms.

Four of the diesel generator sets are connected to the port switchboard together with the port propulsion motor and synchro-convertor and port ship service transformer. The other five units are connected to the starboard section along with the starboard propulsion motor and starboard ship service transformer.

During normal operation the number of generators on line, are selected to suit the operating conditions. The two sections of the board are synchronised and connected together through the bus tie circuit-breakers and the busbar bridge.

The two outer bus section circuit-breakers allow the propulsion and ship service supplies to be separated and

(Continued on page xxv)

operated as two independent systems. This arrangement allows for two possible operating conditions that could cause difficulties in the ship's distribution system. The first condition is frequency disturbances caused by cyclically varying propulsion load in a heavy sea, whilst the second is voltage distortion caused by the synchro-convertors.

The motor synchronising equipment is provided with a synchro-phasing feature in addition to its normal synchronising capability whereby the two propeller shafts are synchronised to the supply with a particular phase relationship. The purpose of synchrophasing is to permit the optimum blade angle for the propellers to be used minimise vibration.

There is a cross-connecting option for the convertors so that either convertor can feed either motor and using this arrangement it is possible to start the two shafts in sequence should there be a fault in one of the convertors.

Control of propulsion system

The propulsion system can be operated either automatically or manually with manual control being exercised either at the engineroom console or at the 10kV switchboard. Manual control is at two levels.

In automatic control a propulsion motor is started and runs in response to signals produced by the mode switch on the Lips control panel and changes from one mode to another are made automatically.

In manual control the operator has to start and stop the equipment auxiliaries and close or open the circuit-breakers using the controls provided on the engine-room console or at the switchboard.

However, whatever the method of control, all essential sequencing is carried out by relays in the engineroom console or in the synchronising panels of the two switchboard sections, with some interlocking for a shaft startup being carried out at the reserve excitation panel. In principle the sequencing is simple, but it is complicated in practice the convertor changeover.

In the engineroom the controls are arranged on the basis that it is possible for the starboard convertor to be used with the port motor and vice versa.

The lowest level of control is at the main 10kV switchboard; in this (manual) mode all the generators, motors, convertors, transformers can be switched and controlled from the switchboard using controls mounted on the front panel of the various sections. Effectively it is necessary for the operator to actuate the elements in the correct sequence, although there are interlocks and inhibits to ensure that all necessary operations are completed at each stage of the sequence.

The second form of manual control is at the console in the engine control room. This provides essentially the same functions as those at the switchboard.

Automatic control

The fully automatic system is based on input signals from the Lips propeller control equipment. There are four operating modes:

- harbour mode;
- ready-to-sail mode;
- combinator mode; and
- free sailing.

In **harbour** mode the propulsion system is effectively shut down and the only generators in use are those necessary to supply the demands of the ship services distribution system. In practice this means that one diesel generator set will be running while a second will be on standby.

In **ready-to-sail** mode all the essential propulsion system auxiliaries are energised and in a healthy state. For the propulsion motors this means:

- ventilating fans running;
- bearing jacking oil pumps running; and
- excitation equipment selected and healthy.

For the convertors it is necessary that:

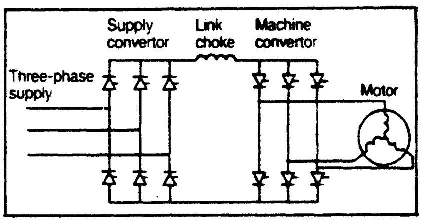
- the appropriate convertor is selected for the propulsion motor;
- the convertor auxiliary supplies are on and convertor control circuits are healthy and selected to remote control; and
- the convertor fans are running.

For the shaft system it is necessary for:

- the propeller to be in zero pitch; and
- the shaft brake and barring gear to be disengaged.

The generators running and connected to the busbar system must obviously be adequate to meet the power demands of the ship service load and

One of the main propulsion motors. Each is rated at 44MW at 144 rev/min and weighs 290 tonne. Up to 72 rev/min they operate under control of the synchroconverters; see below.



Circuit diagram for a synchroconverter and propulsion motor. Two such systems with a total rating of 22.8MW are installed.

the propulsion load.

In **combinator** mode the propulsion motors are supplied, at variable frequency, by the synchro-convertors and are running at a speed set by either the Lips propeller system or by speed setting switches on the engineroom console or the switchboard.

When running under the control of the Lips system the propeller pitch is automatically controlled to ensure that there are no overloads on the convertor system.

The convertor/motor combination is effectively a constant torque drive since the maximum torque it can develop is essentially independent of speed and is determined by the product of convertor current (which is motor stator current) and motor field current. The system behaves as a DC motor and obeys the same fundamental torque law, that is:

Motor torque = KI_aI_f
K = motor torque constant
I_a = armature current
I_f = field current

The motor is started with the propeller set to zero pitch and it remains at this setting until the speed has reached 72 rev/min.

With the motor running at 72 rev/min the propeller pitch can be increased up to the full setting and in this condition the motor will be developing 5.5MW. To increase the power it is necessary to raise the speed of the propeller but the pitch must then be reduced, otherwise there will be an overload on the motor-convertor equipment.

However should the shaft speed be increased with too high a value of pitch on the propeller then the torque imposed on the motor, by the propeller, will increase until it reaches the rated torque condition for synchro-convertor supply, that is, 730 kNm. This is the maximum torque which the motor can develop in this mode and when it is reached there will be no further increase in motor speed but the motor will continue to operate safely. An increase in speed will be possible only if the propeller pitch is reduced.

Safety features

In normal automatic operation the Lips propeller control system will reduce the propeller pitch at the same time as it calls for an increase in shaft speed and there should be no danger of torque limit operation.

The motor field current can be controlled while in the combinator mode, either to maximise the torque produced for a given value of converter current or to provide constant volts/cycle operation of the motor.

In constant volts/cycle mode the field current is controlled so that the voltage measured at the motor terminals varies linearly with speed and has a value of 10kV at 144 rev/min or 5.5kV at 72 rev/min.

In this installation the motor is operated with the maximum possible field current at 72 rev/min and at speeds up to approximately 120 rev/min when a constant volts/cycle control is introduced.

Safety

When the drive is operating in the combinator mode it is possible to take advantage of the rapid control possible with convertors to provide some safety features. For example, by monitoring the frequency of the AC supply to the convertor it is possible to detect a diesel engine overload condition since this will result in a loss of speed and hence system frequency. By arranging for the convertor load to be reduced if the frequency falls below a preset level it is possible to avoid blackout conditions, provided that the connected diesel generators can supply the other loads remaining after the convertor load has been shed.

Another overload protection feature a reduction in the overall current should any generator be subjected to an excessive current, caused possibly by an excess lagging load. This feature will avoid tripping a generator on overcurrent.

When the motor is operating at maximum power in combinator mode it has to be synchronised to the supply to obtain any higher powers.

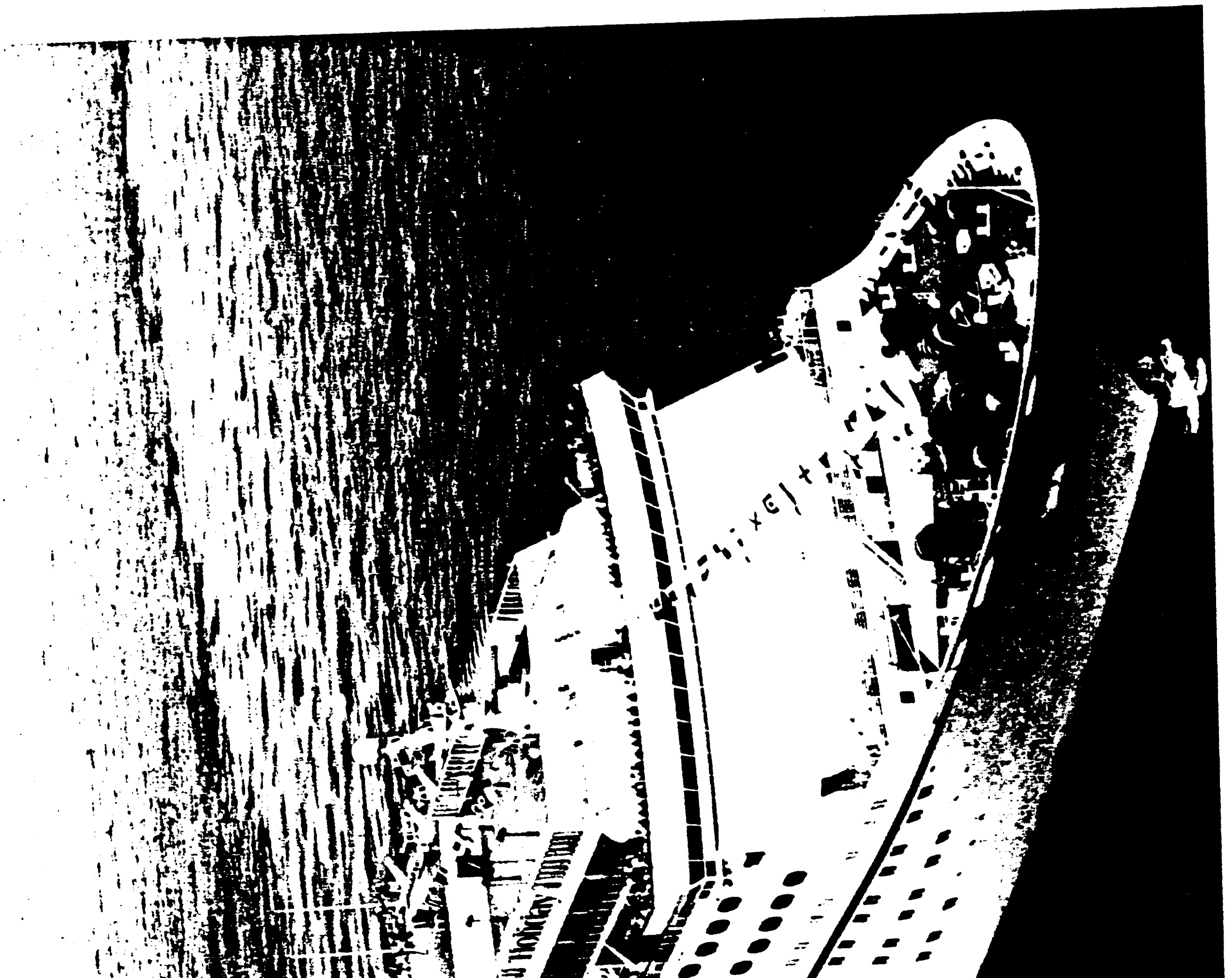
In **free sailing** mode the motor is synchronised to the busbars and operates at powers up to 44MW per shaft, the actual level being dependent on the generators connected to the busbars.

Since in free sailing mode the motors operate at a constant speed which is dictated by the supply frequency, and at 60Hz the motor speed is 144 rev/min, the power developed by the motor is determined by the propeller pitch. The pitch has therefore to be controlled so that there are no overloads on the propulsion machines, that is neither on the motors nor on any of the supply generators.

The only control function that is available at the motor during synchronous running is motor field current and this is arranged so that the motor is operated at unity power factor. This reduces the machine losses, at powers below full load, compared with the alternative strategy of operating with the field current set to the level required for unity power factor at full load. □

2-29

2.4C



PRINCIPAL PARTICULARS
HOLIDAY

Length, oa	221·56m
Length, bp	183·00m
Breadth, mld	28·00m
Draught, scantling	7·75m
Draught, design, mld	7·50m
Depth, mld to deck No 3 (bulkhead deck)	9·50m
Depth, mld to upper deck	21·05m
Deadweight, design draught	6 050 tonne
Gross register	46 052 ton
Service speed	19·50 knots
Main engine	2 × Sulzer 7RLB66
Output	11 760kW (15 990 bhp) at 140 rev/min
Class	LRS ✠ 100A1, ✠ LMC, UMS, passenger ship
Capacities	
Passengers	1 794
Crew	646
HFO	2 450m³
LO	250m³
DO	195m³
Potable freshwater	2 520m³
Sanitary freshwater	590m³
Ballast	2 520m³

PRINCIPAL SUPPLIERS
HOLIDAY

Air conditioning/ventilation	Semco
Alternators	Siemens
Antifouling	Elinca
Auxiliary engines	Wärtsilä Vasa
Boilers	Aalborg Boilers
Catering Equipment	C W Robbins
Centrifuges	Westfalia
Circuit breakers	Merlin Gerin
Compensators	Bredan Kompensatorfabrik
Compressors & oil pumps	Hamworthy Hydraulic
Davits	Davit Co
Deck machinery	Bergens Mek Verksteder
Diffusors	Netavent
Emergency alternators	Vensyssel Diesel Electric
Engine alarm & datalogging system	Siemens
External communications system	Sailor
Feeder-booster modules & heat exchangers	Alfa-Laval Zeta
Fire alarms & sprinklers	Semco
Fire fighting equipment	Wormald
Fin stabilizers	HDW
Freshwater generator	Atlas
Gear boxes	Lohman & Stolterfoht
Governors	S T Lyngsø
Hospital equipment	Metos Marine
Hydraulic equipment	A/S Cylinderservice
Level indicators	Kockumation
Lifeboats	Harding
Liferafts	Nordisk Gummibadsfabrik
Lifts	Dan-Elevator
Machinery control system	Enri
Main engines	Sulzer
Mooring & anchor handling equipment	Norwinch
PA & TV system	Philips
Paint	International Farvefabrik
Refrigerating compressors	McQuay
Steering gear	Frydenbö Mek Verksted
Switchboards	LK
Thrusters	KaMeWa
Propellers	KaMeWa
Viscotherm plant	APB Tecnic
Water pumps	Maskinfabriken Iron
Watertight doors	H A Schröder

2·42

BASIC NAVAL ARCHITECTURE

Unit Number: 3

Title: Ship types and ship systems - 2

Tape Running Time: $33^M\ 50^S$

Reading Assignment: MSD pp 11-12

Additional References: Recent articles on ship types taken from trade magazines

Scope:

(same as Unit 2)

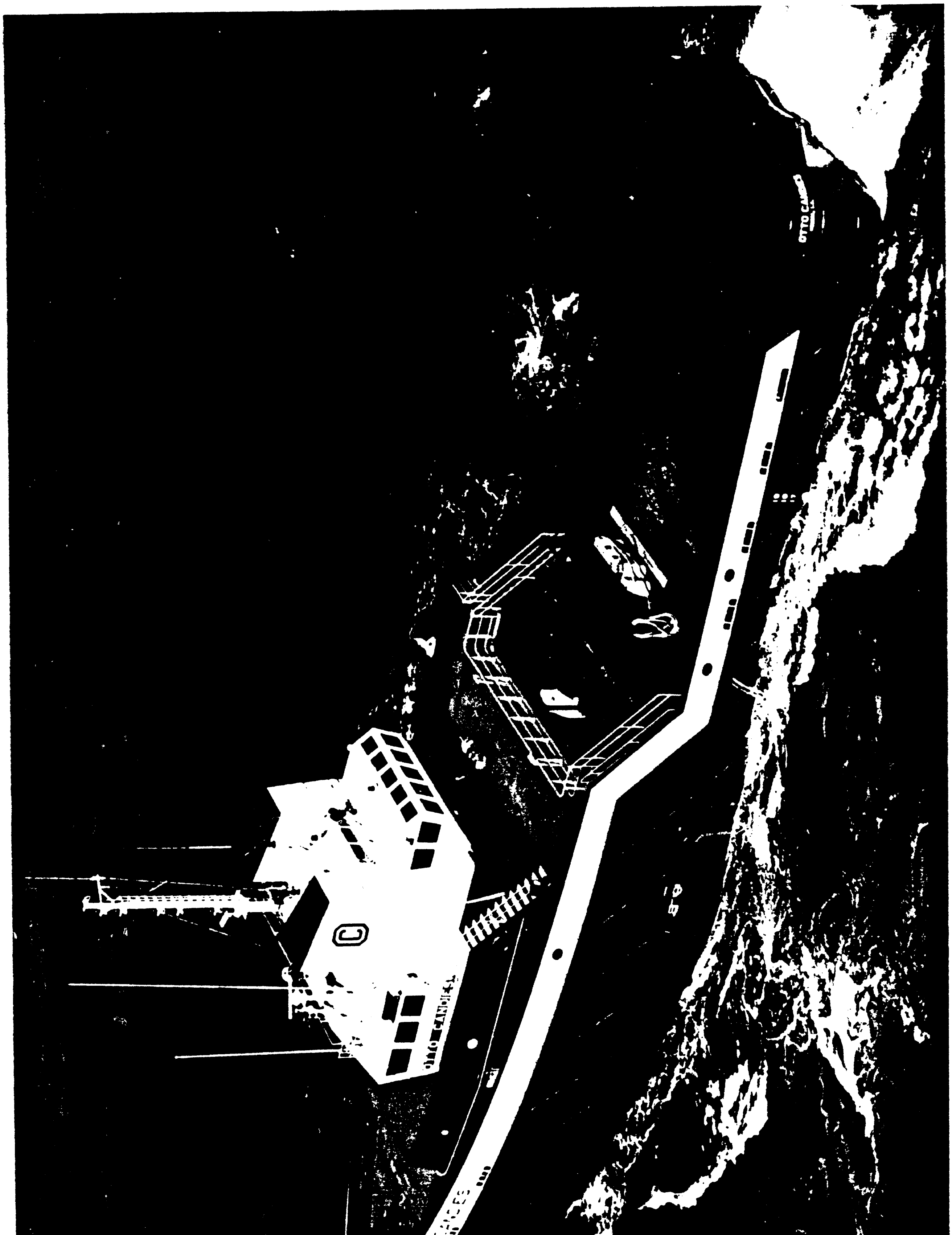
Key Points to Emphasize:

(same as Unit 2)

Suggested Problem Assignment: None

(The instructor may wish to require students to read assigned articles in trade magazines.)


INDEPENDENT LIFE
Southern Bell
Atlantic Bank
BROOKS K. McALLISTER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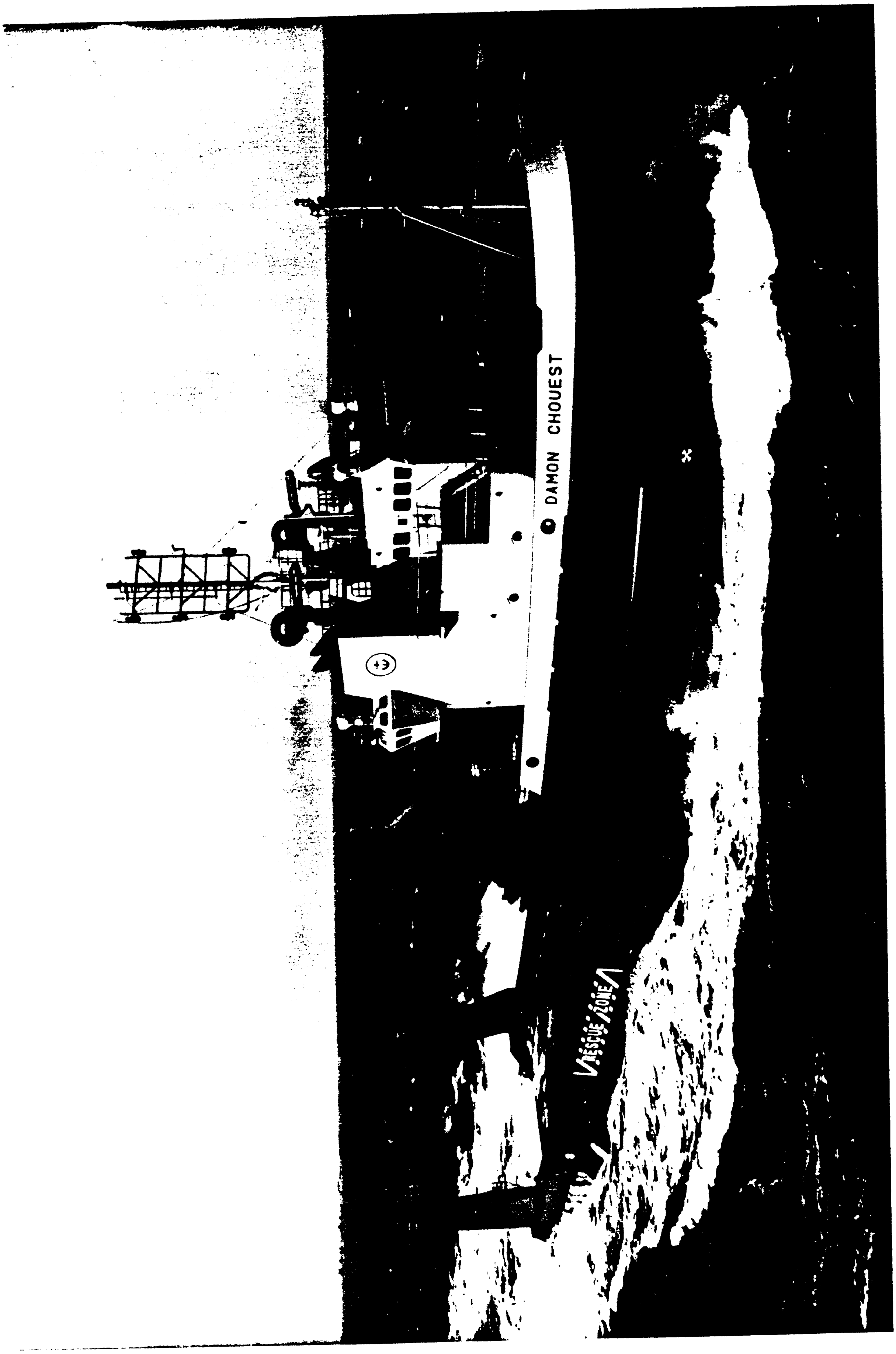
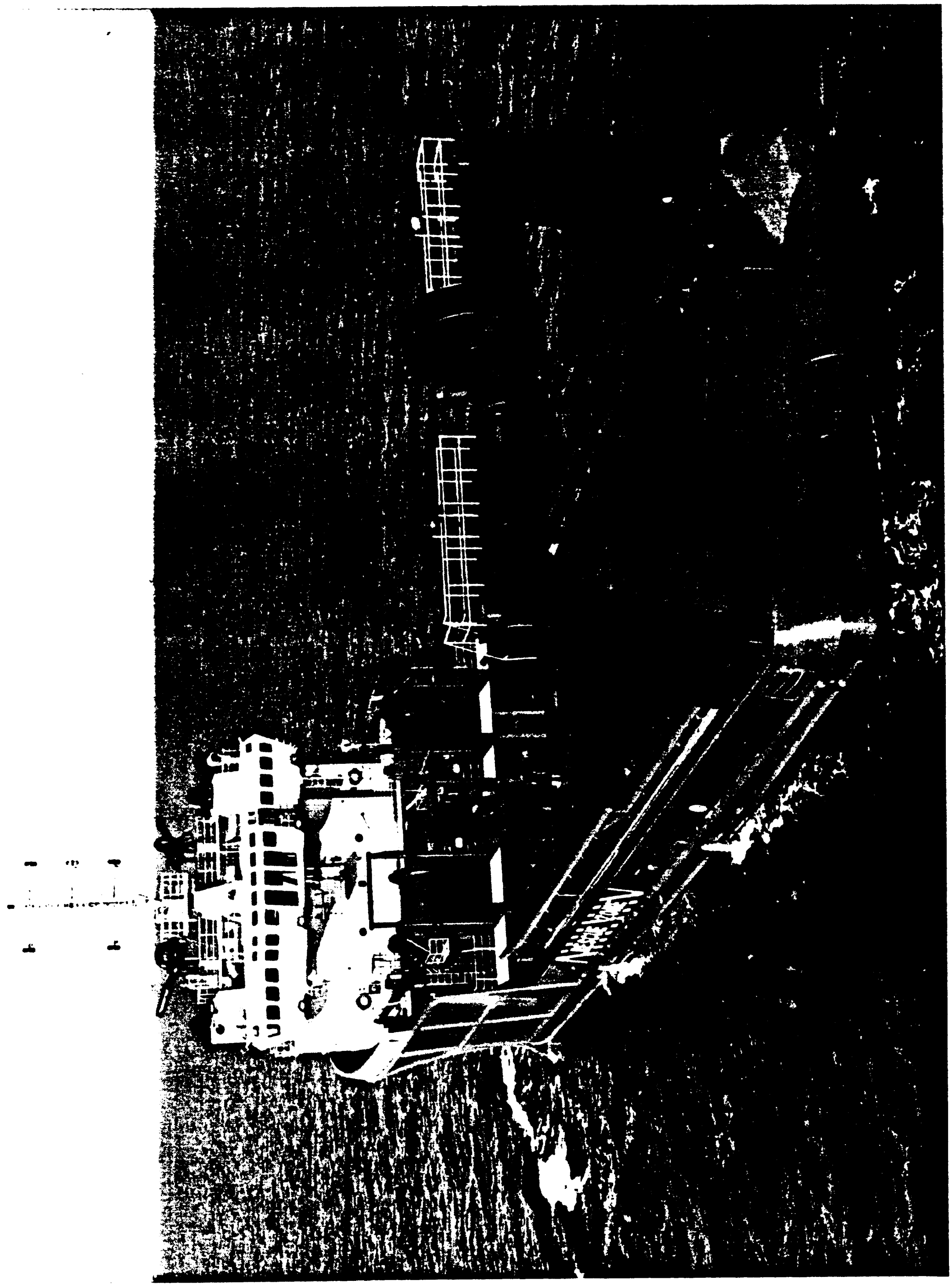
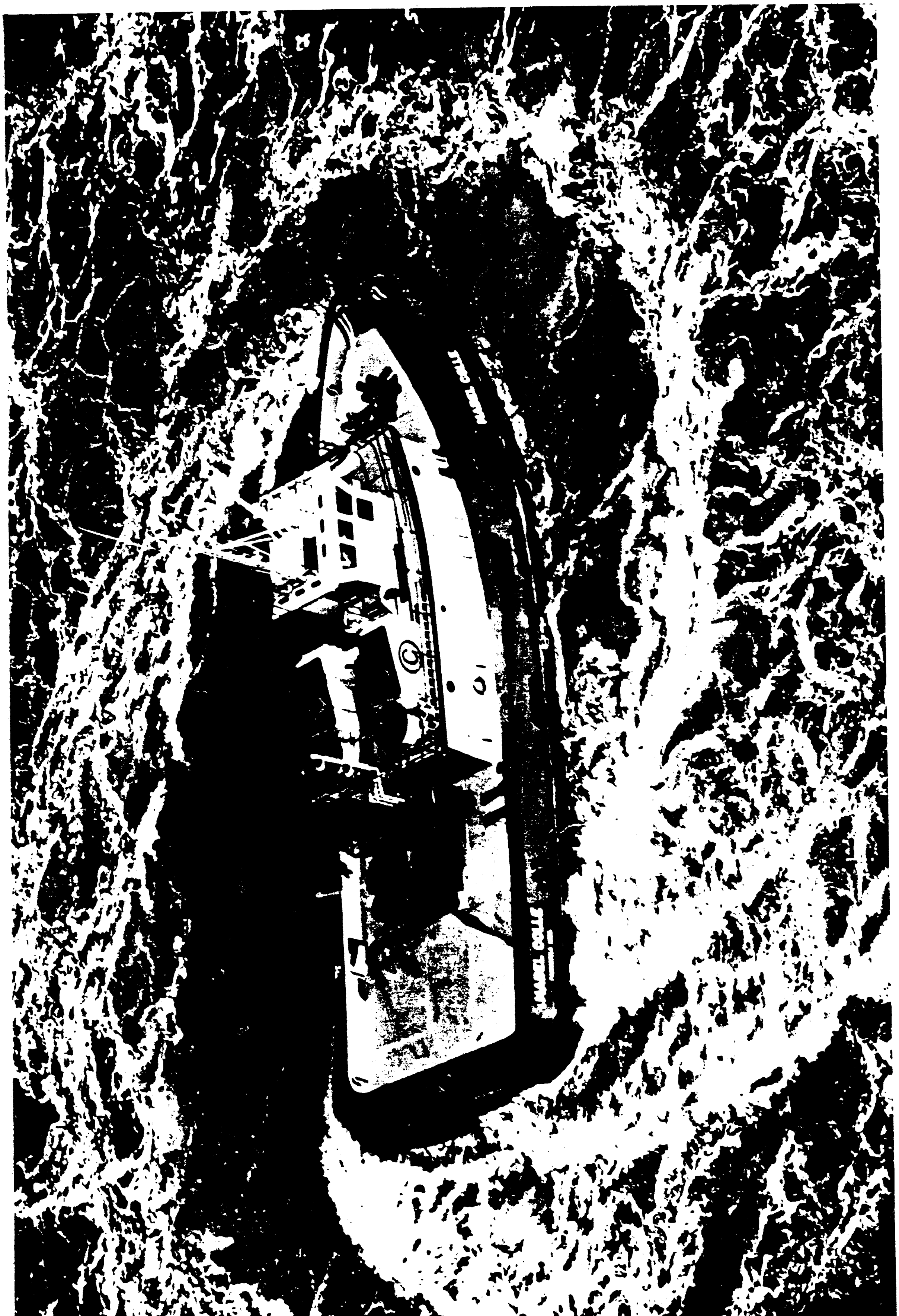
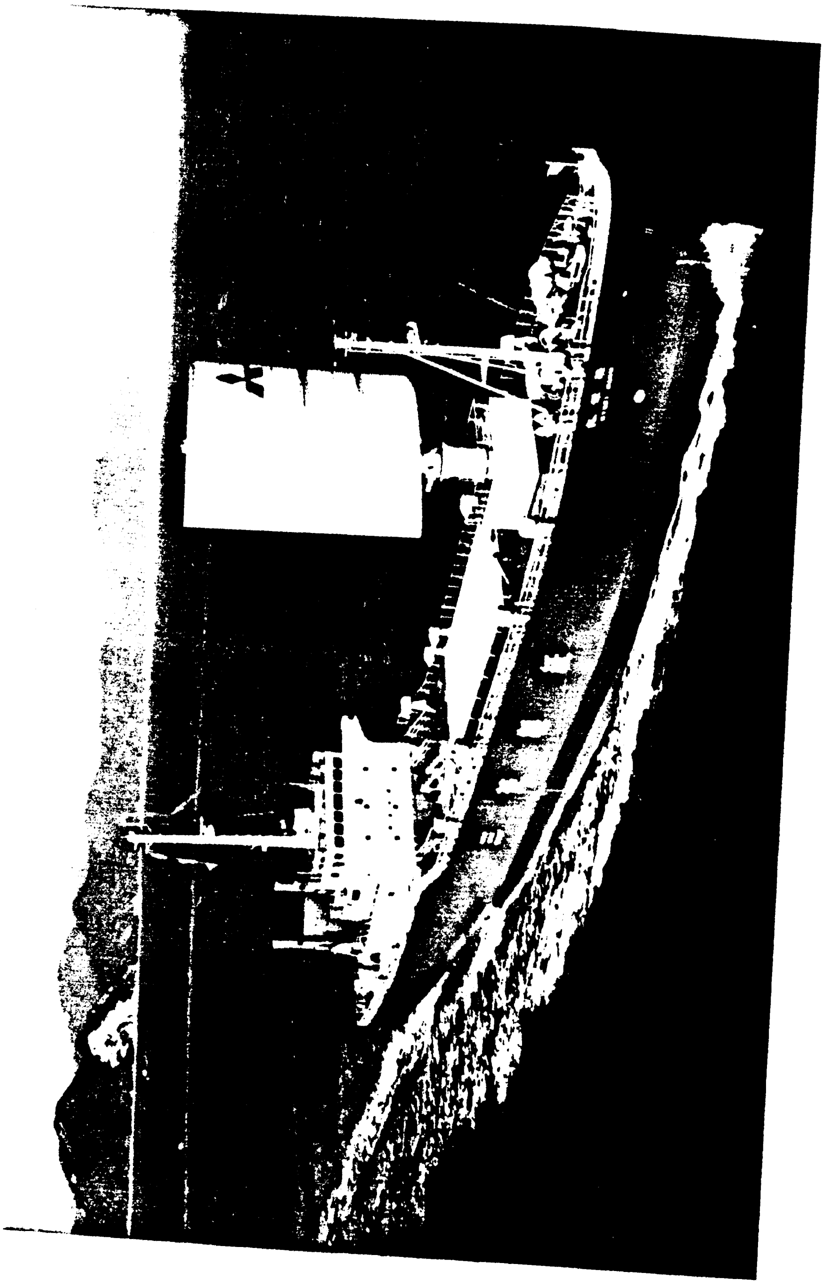
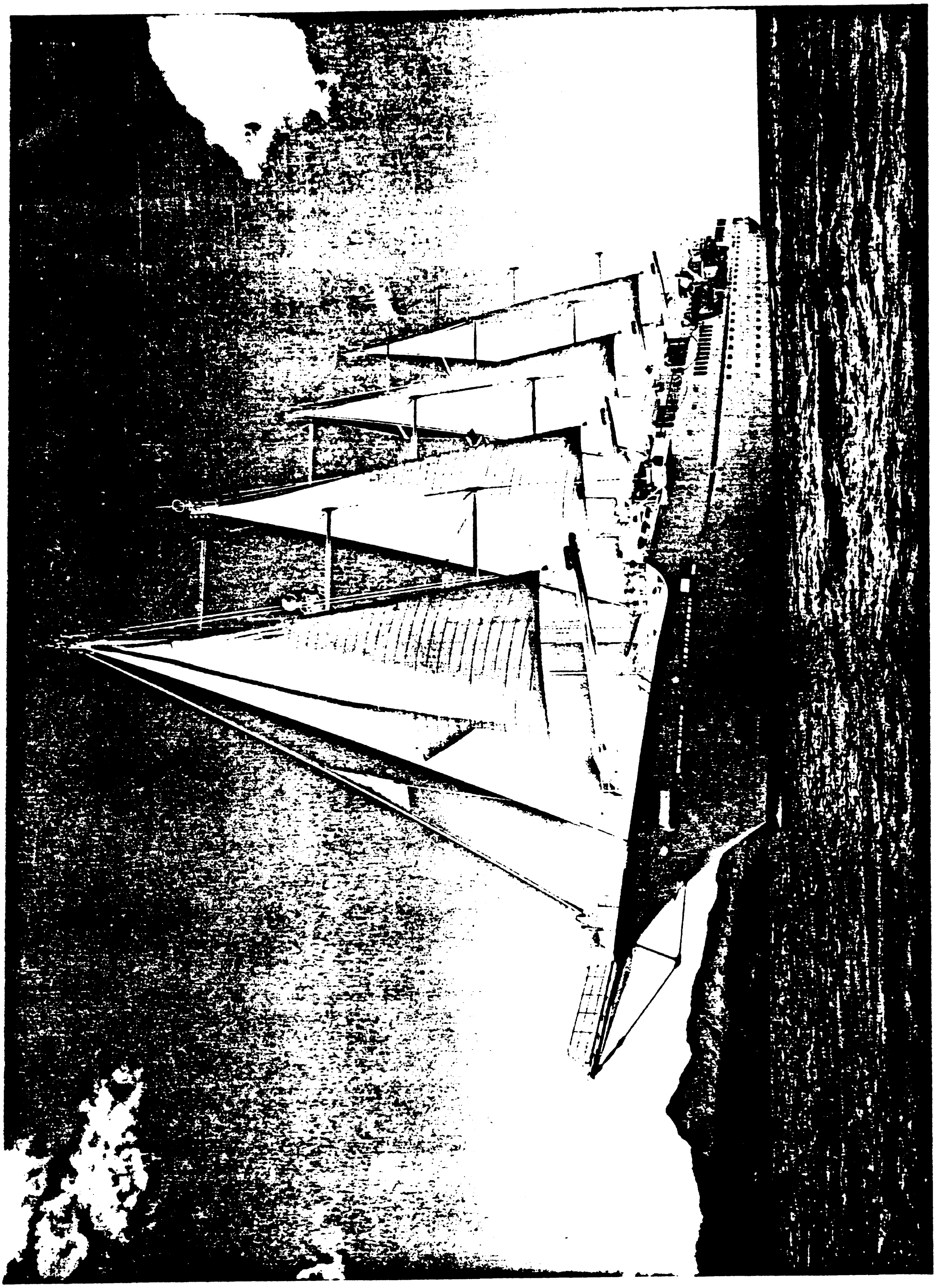
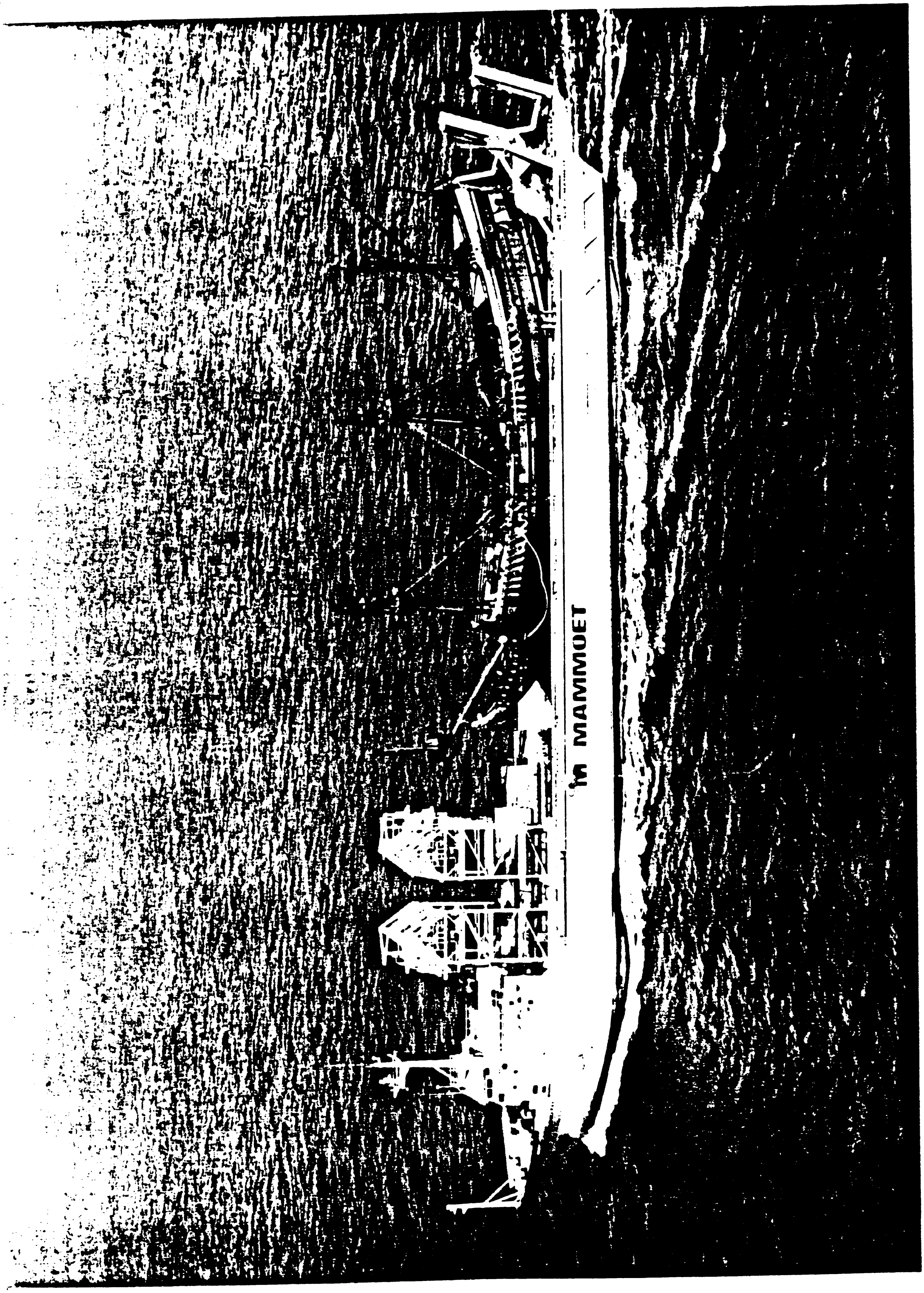

DAMON CHOUEST
RESCUE ZONE







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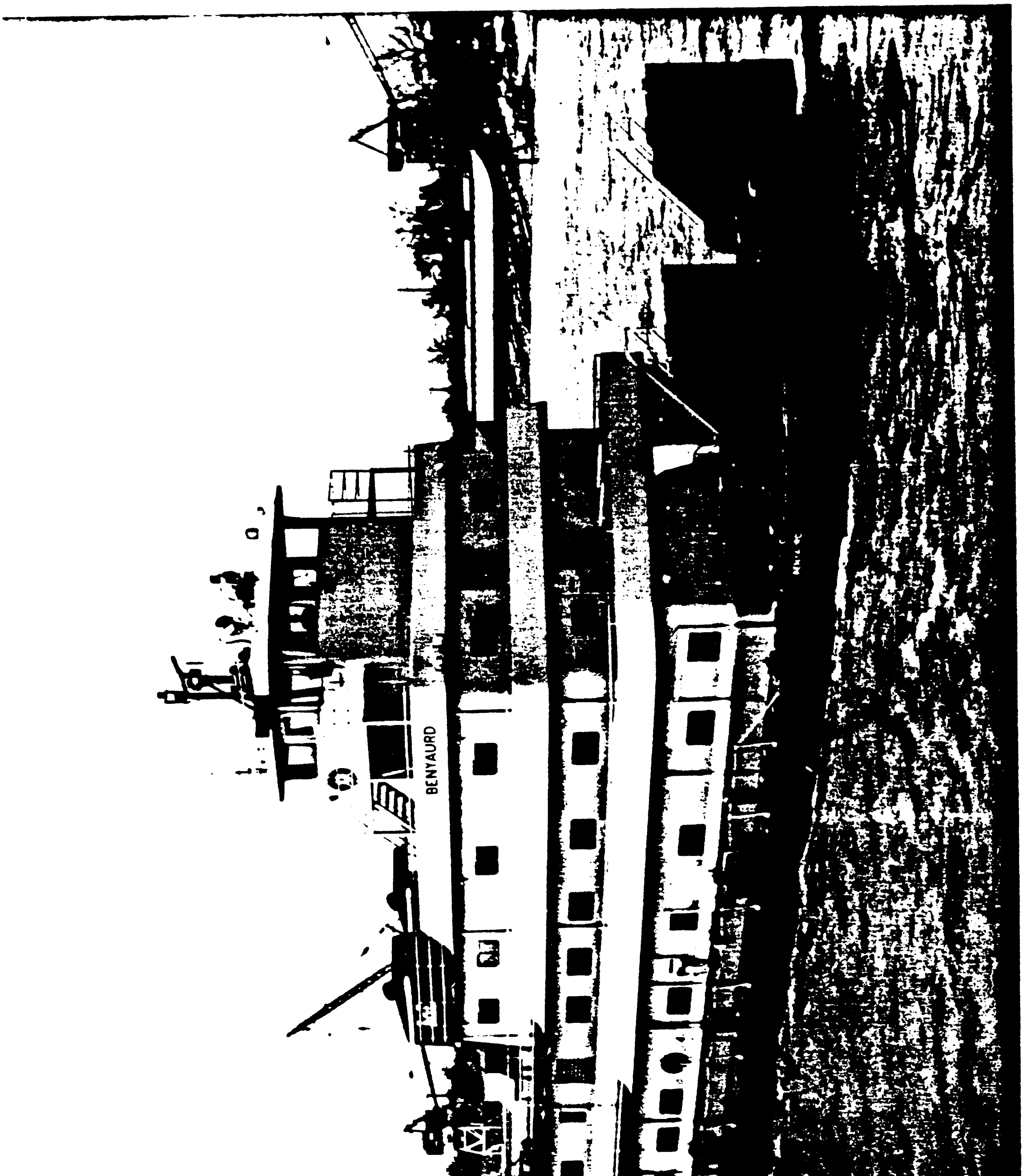
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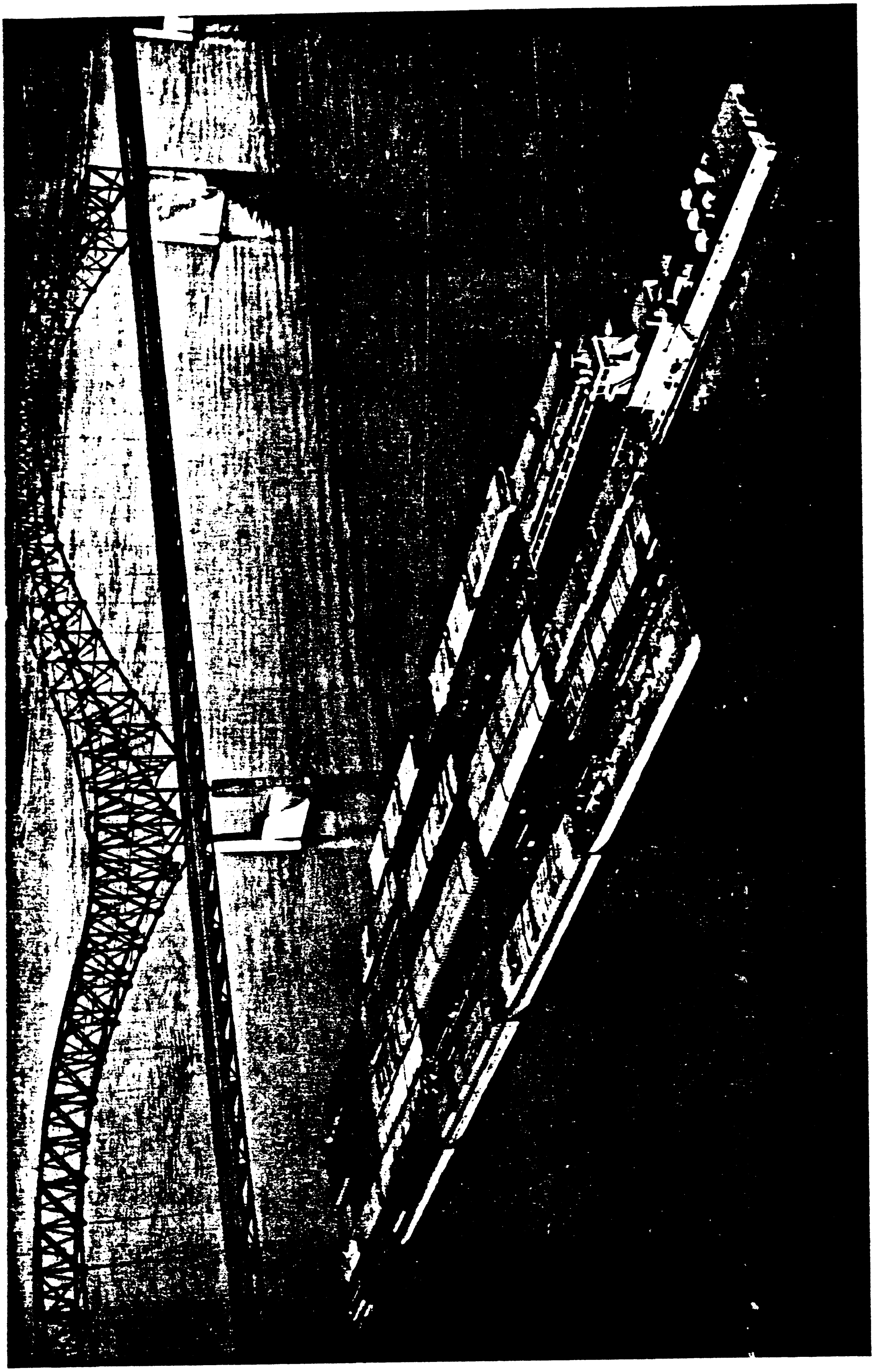

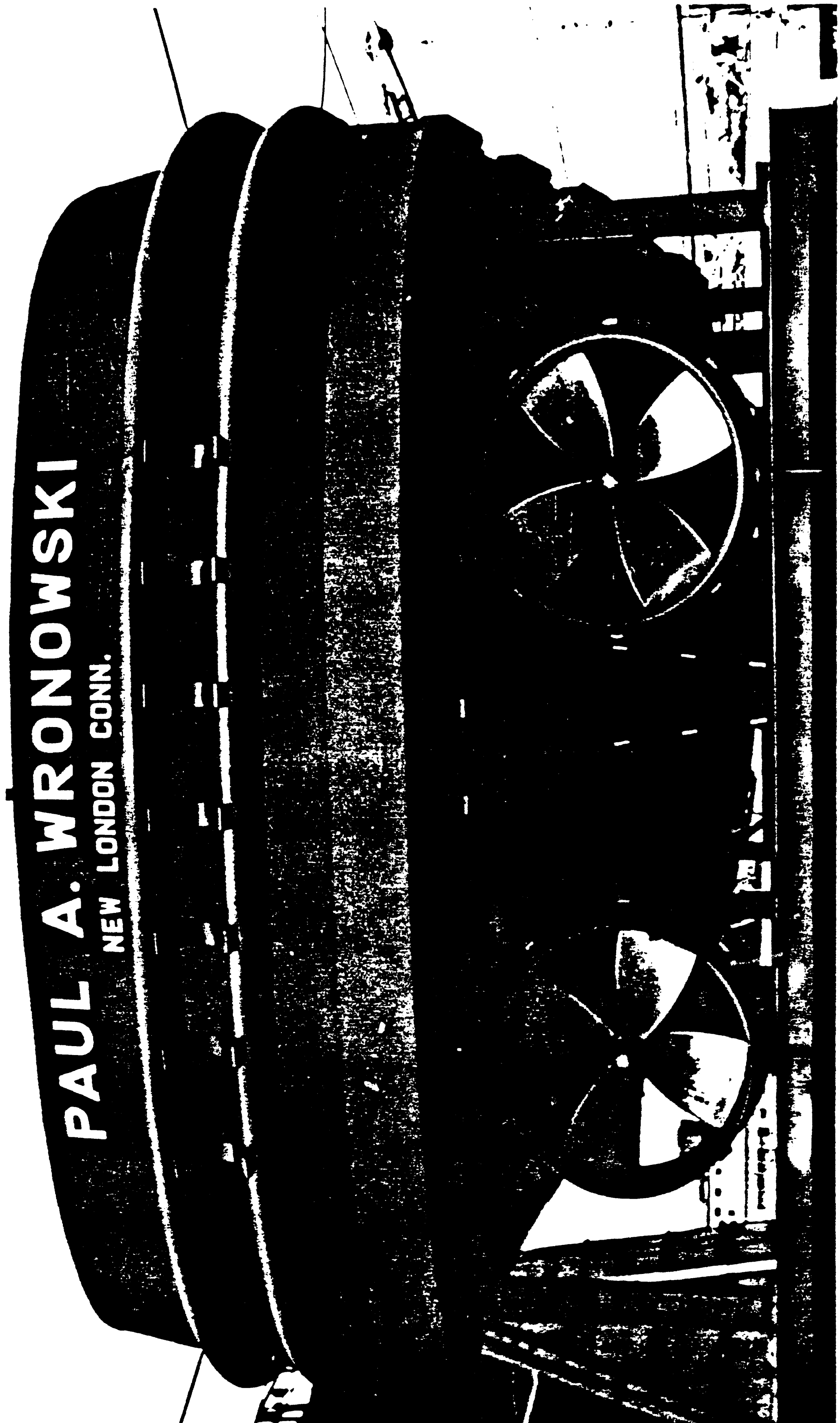

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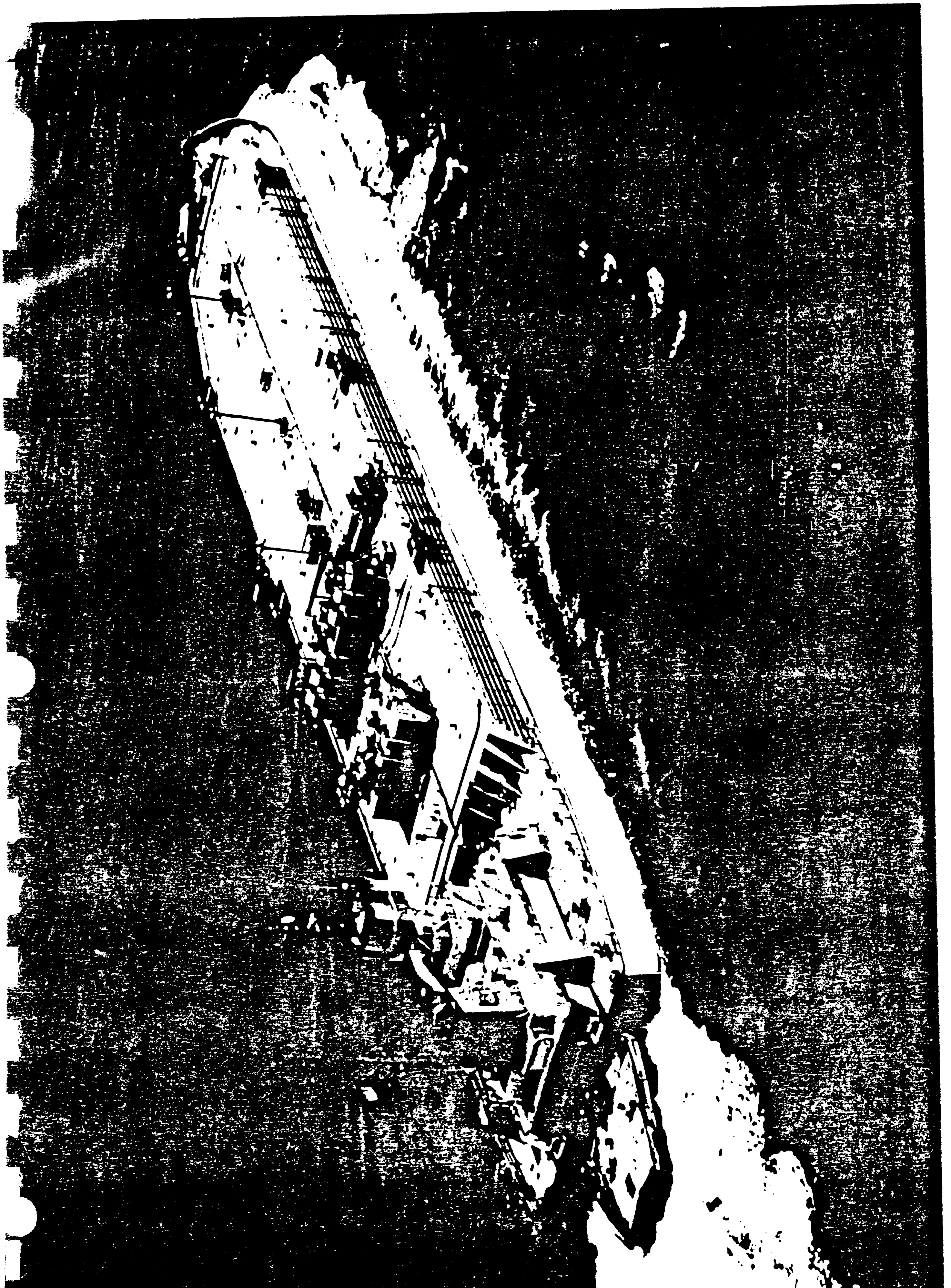

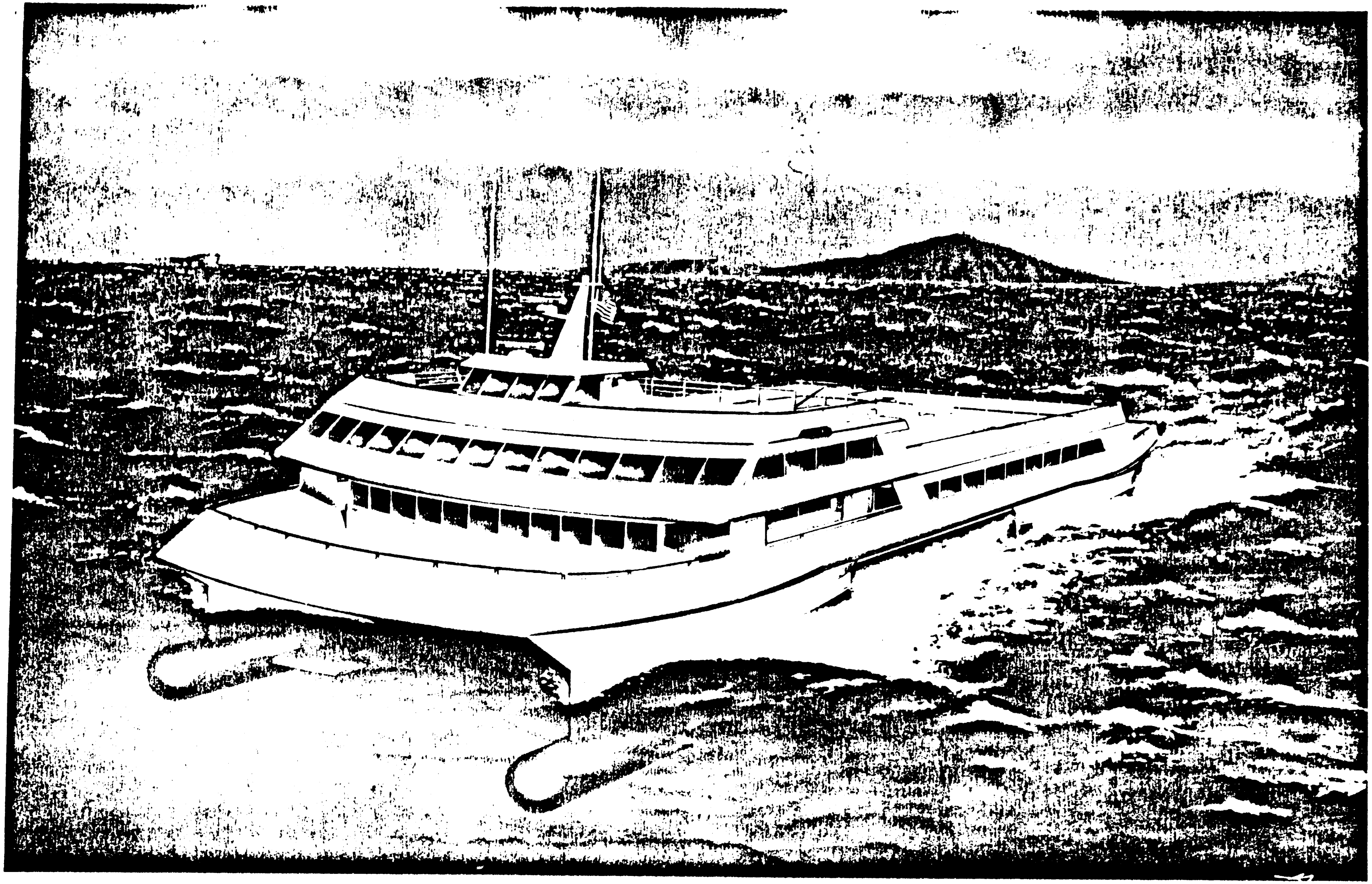

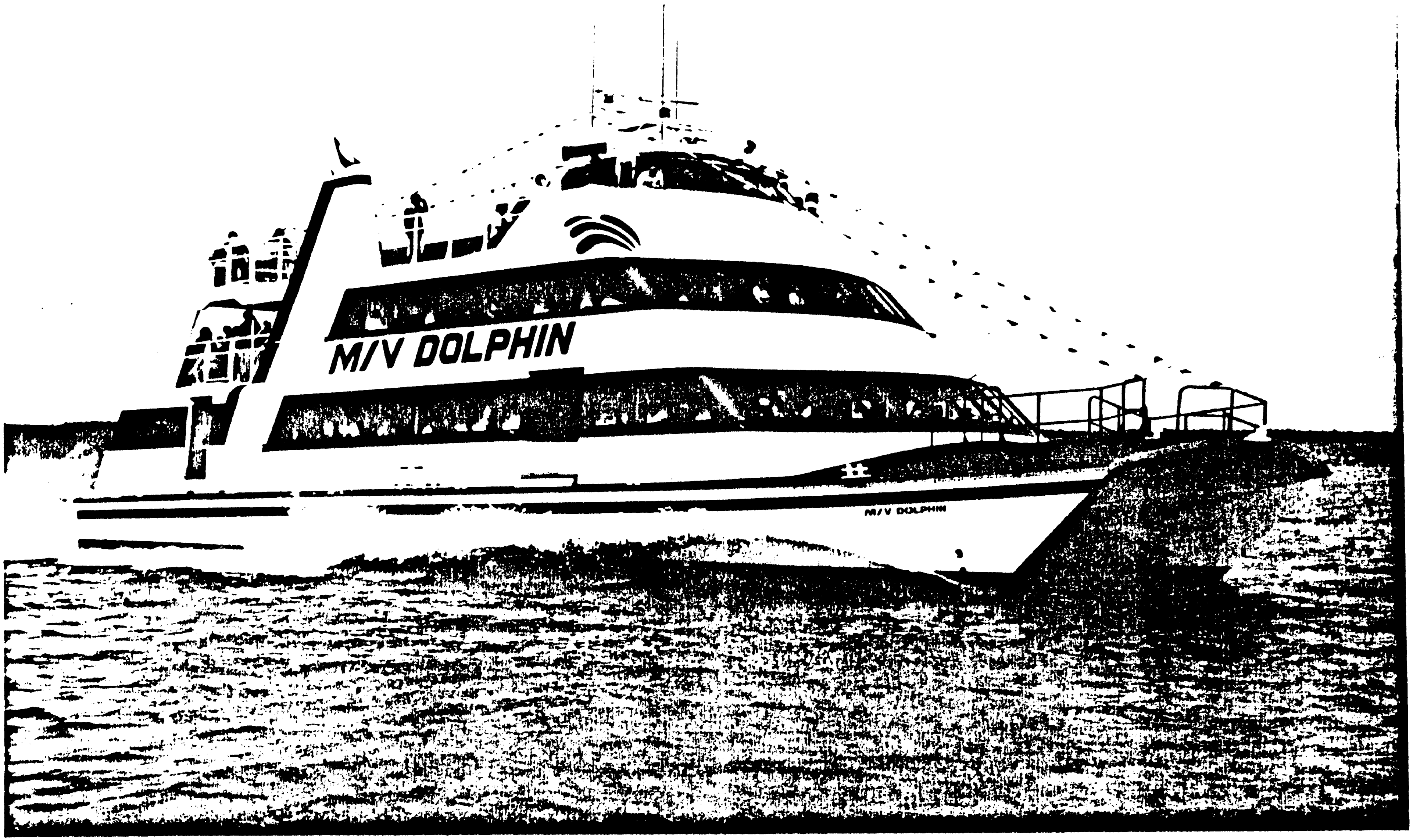
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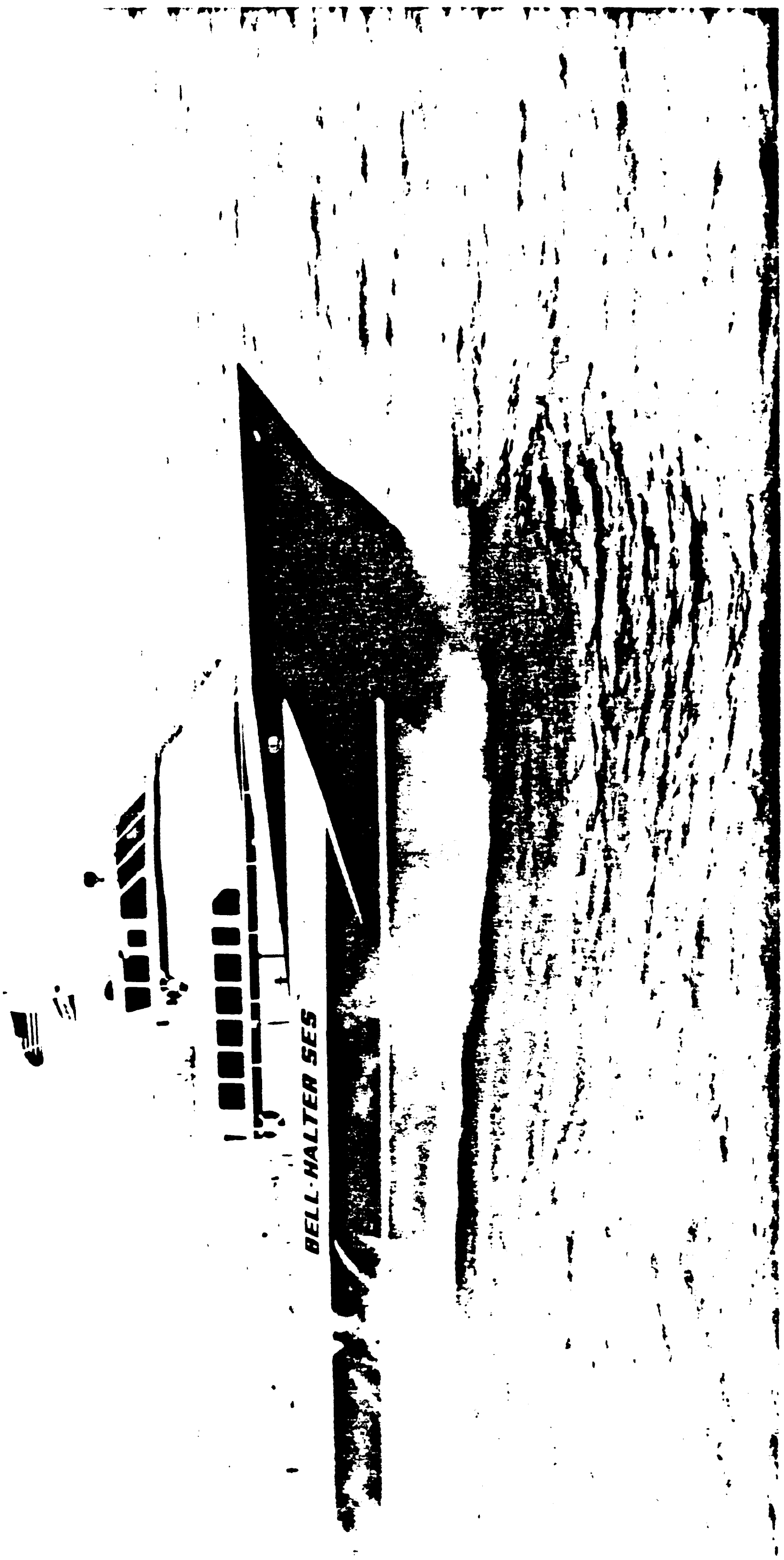
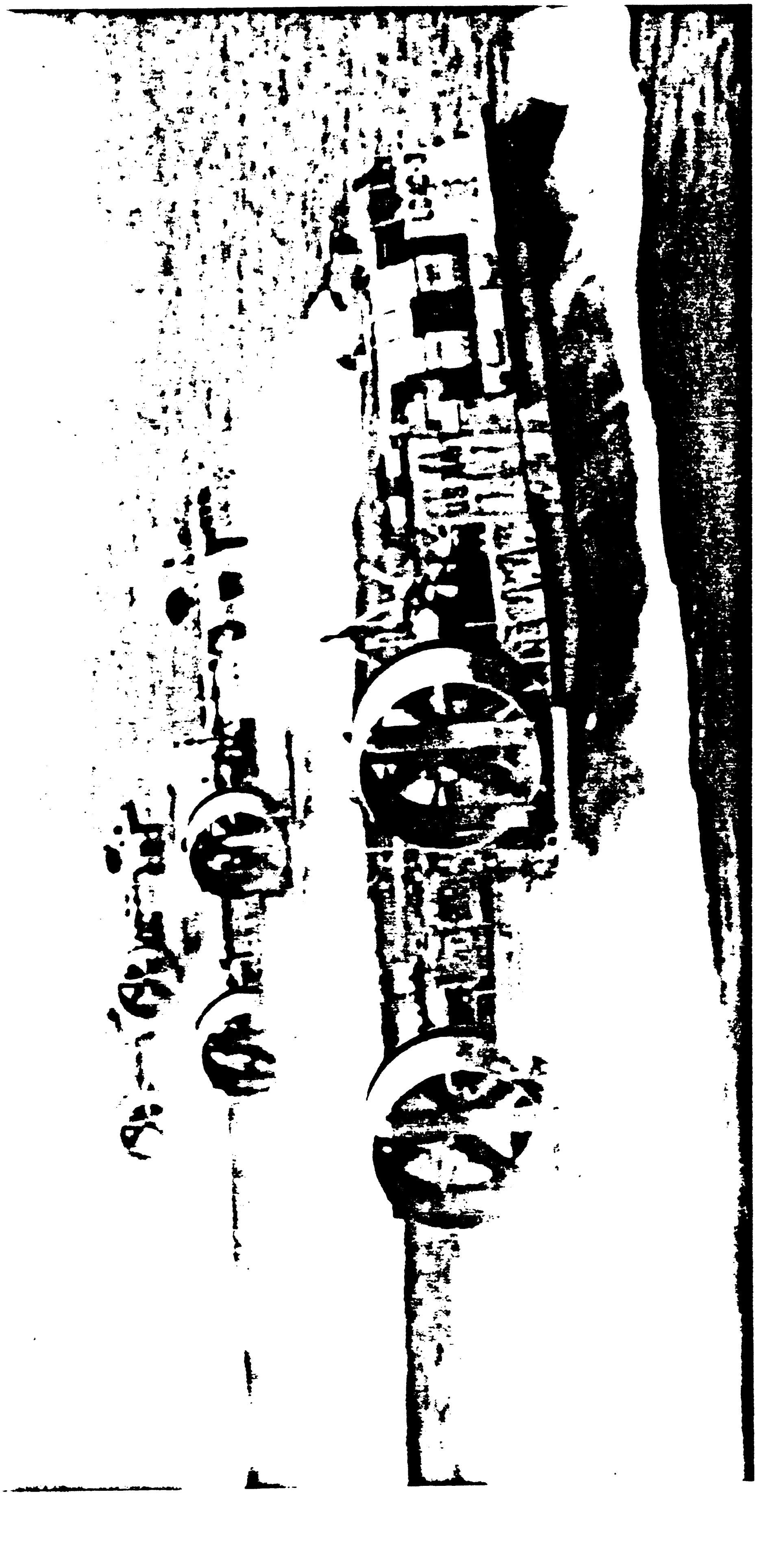
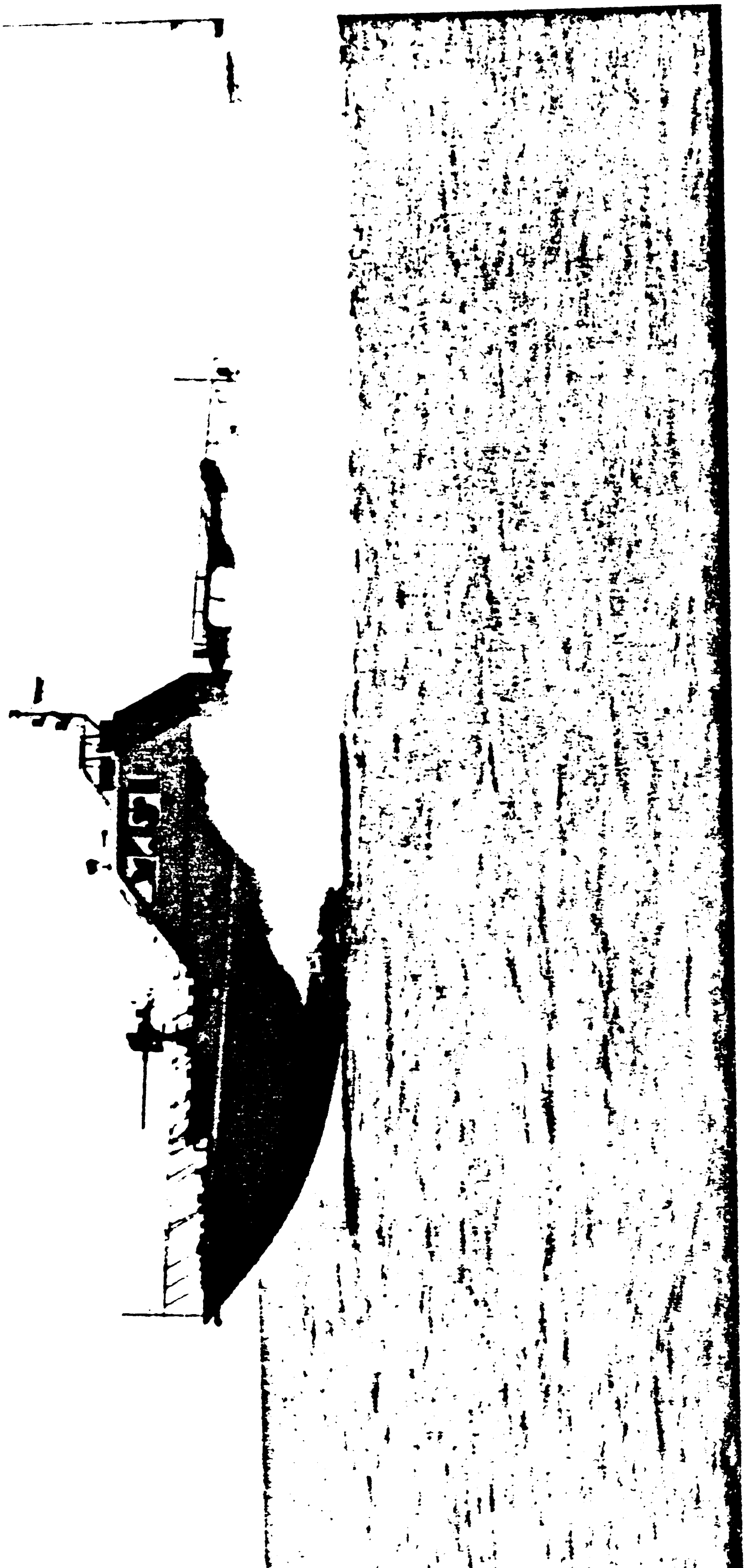
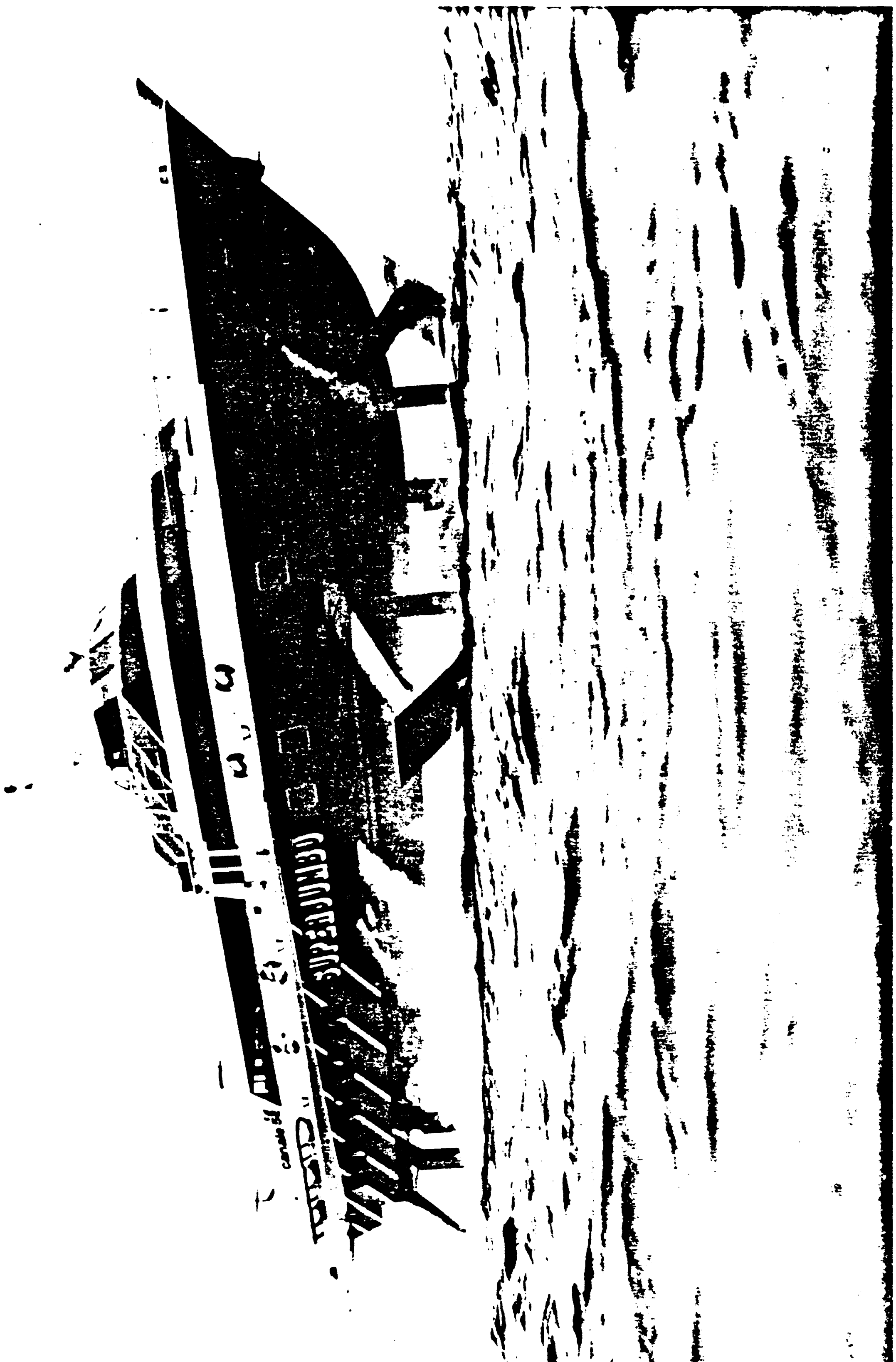
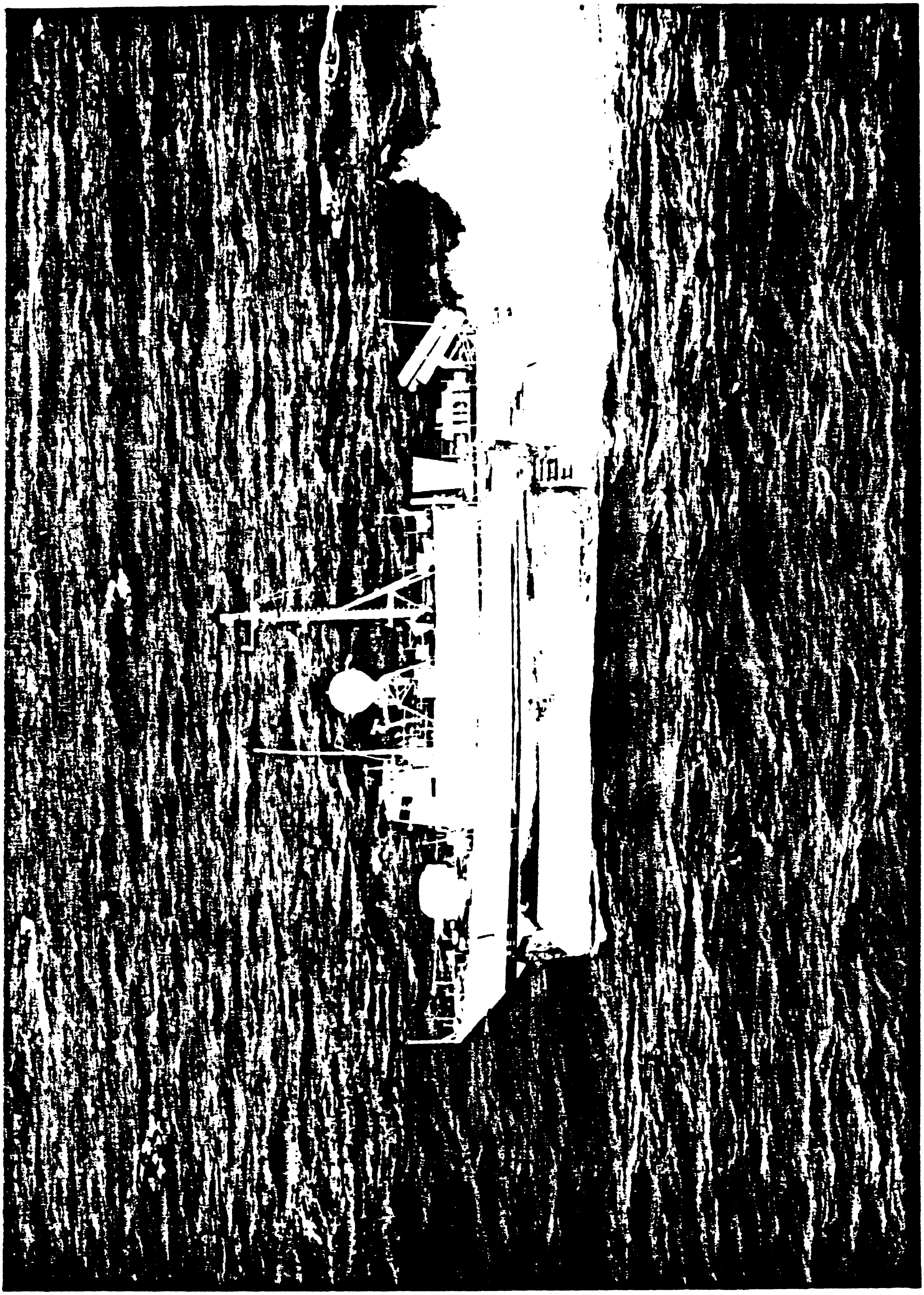
M/V DOLPHIN


BELL·HALTER SES



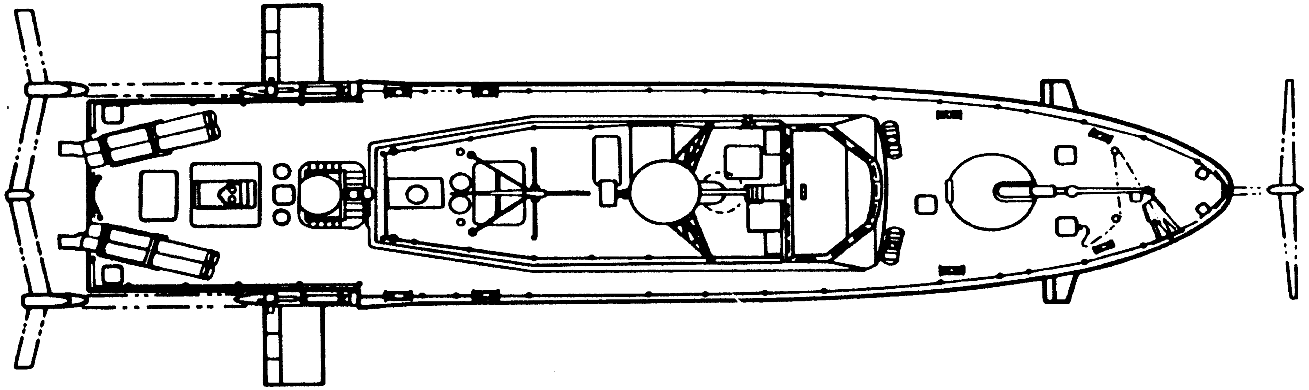




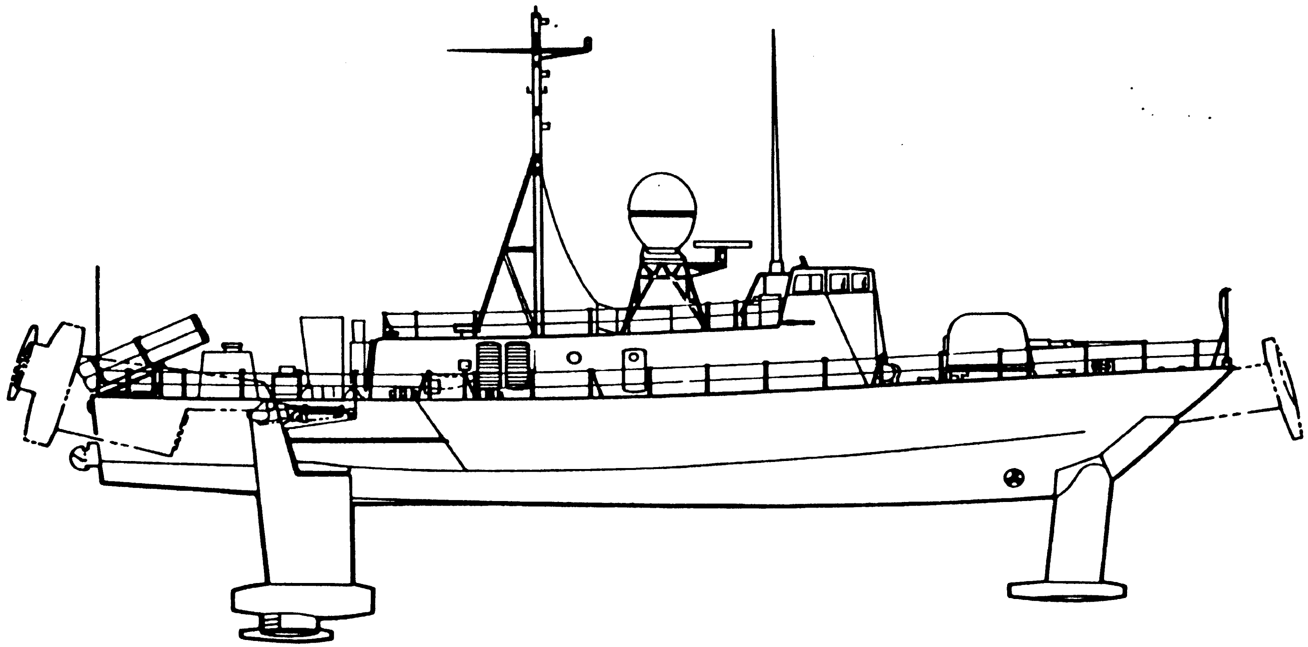


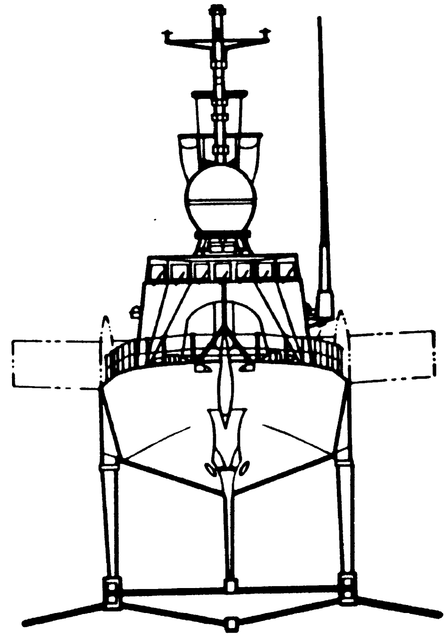
3·21

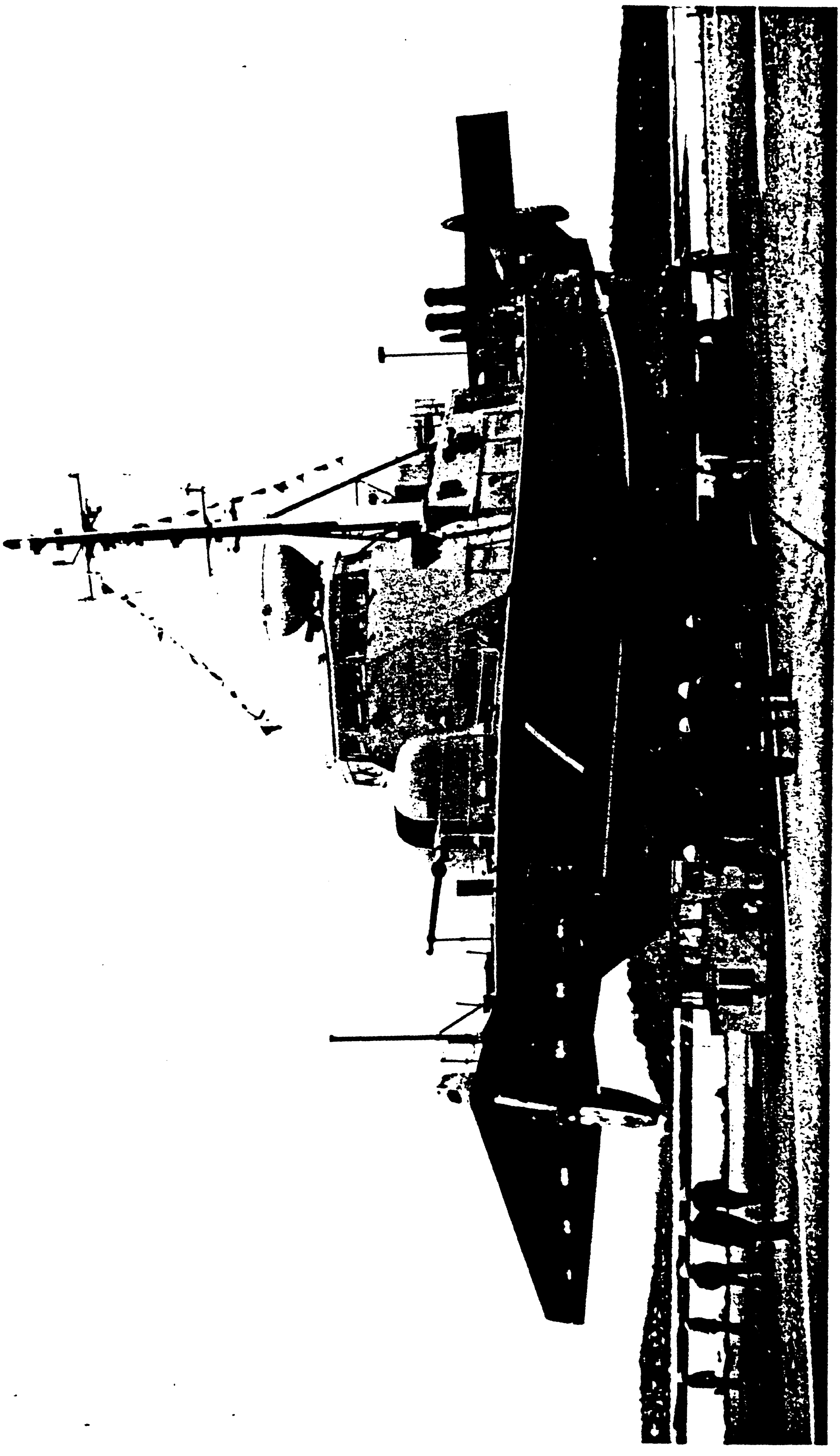
BOEING NATO Patrol Missile Hydrofoil (PHM)

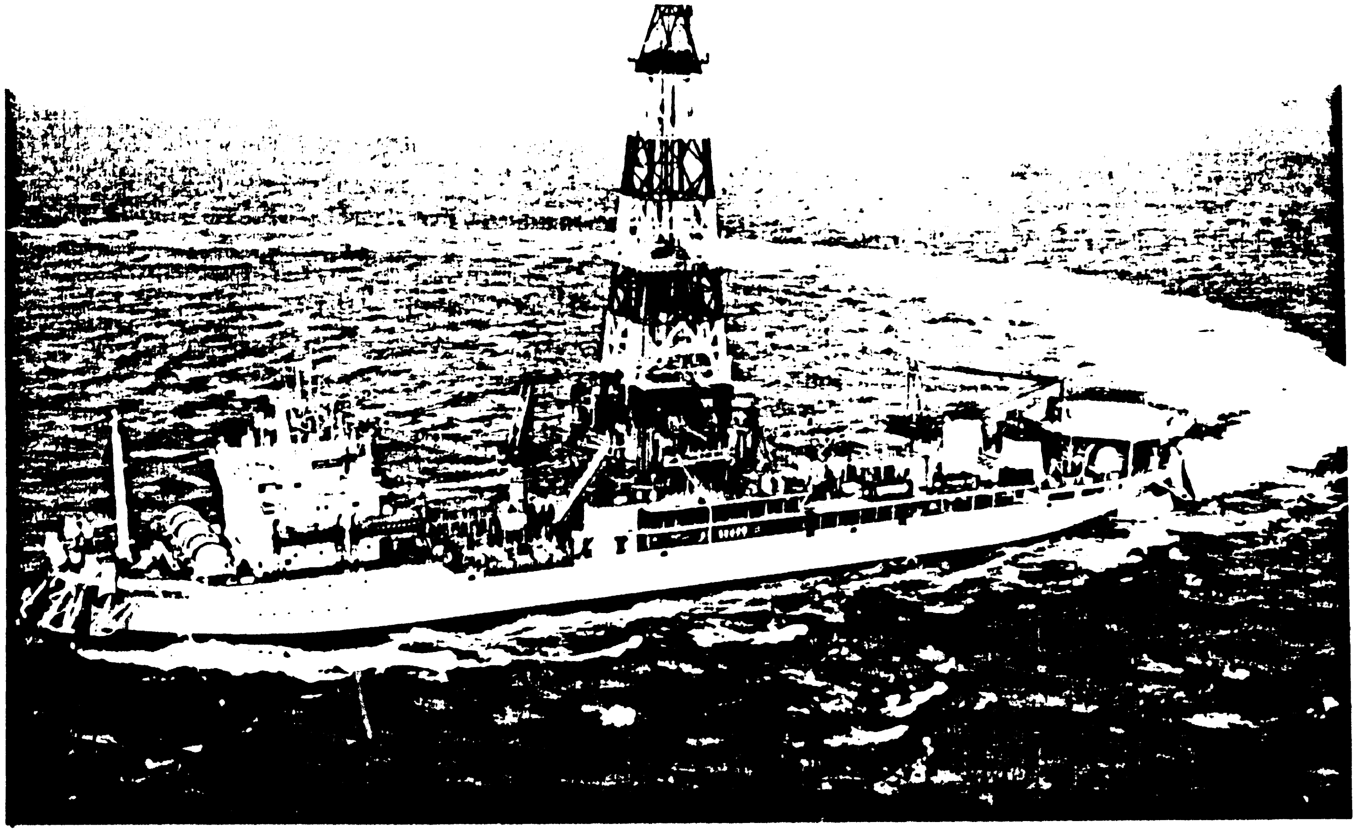


Length	131 2 feet	40 0 m
Beam	28 2 feet	8 6 m
Draft		
Hullborne (foils retracted)	6 2 feet	1 9 m
Hullborne (foils extended)	23 2 feet	7 1 m
Foilborne (nominal)	8 8 feet	2 7 m
Displacement	231 long tons	235 metric tons
Speed		
Hullborne	12 knots	
Foilborne	In excess of 40 knots	
Propulsion		
Hullborne	2 diesels with 2 waterjets	
Foilborne	1 gas turbine with waterjet	
Crew	21	









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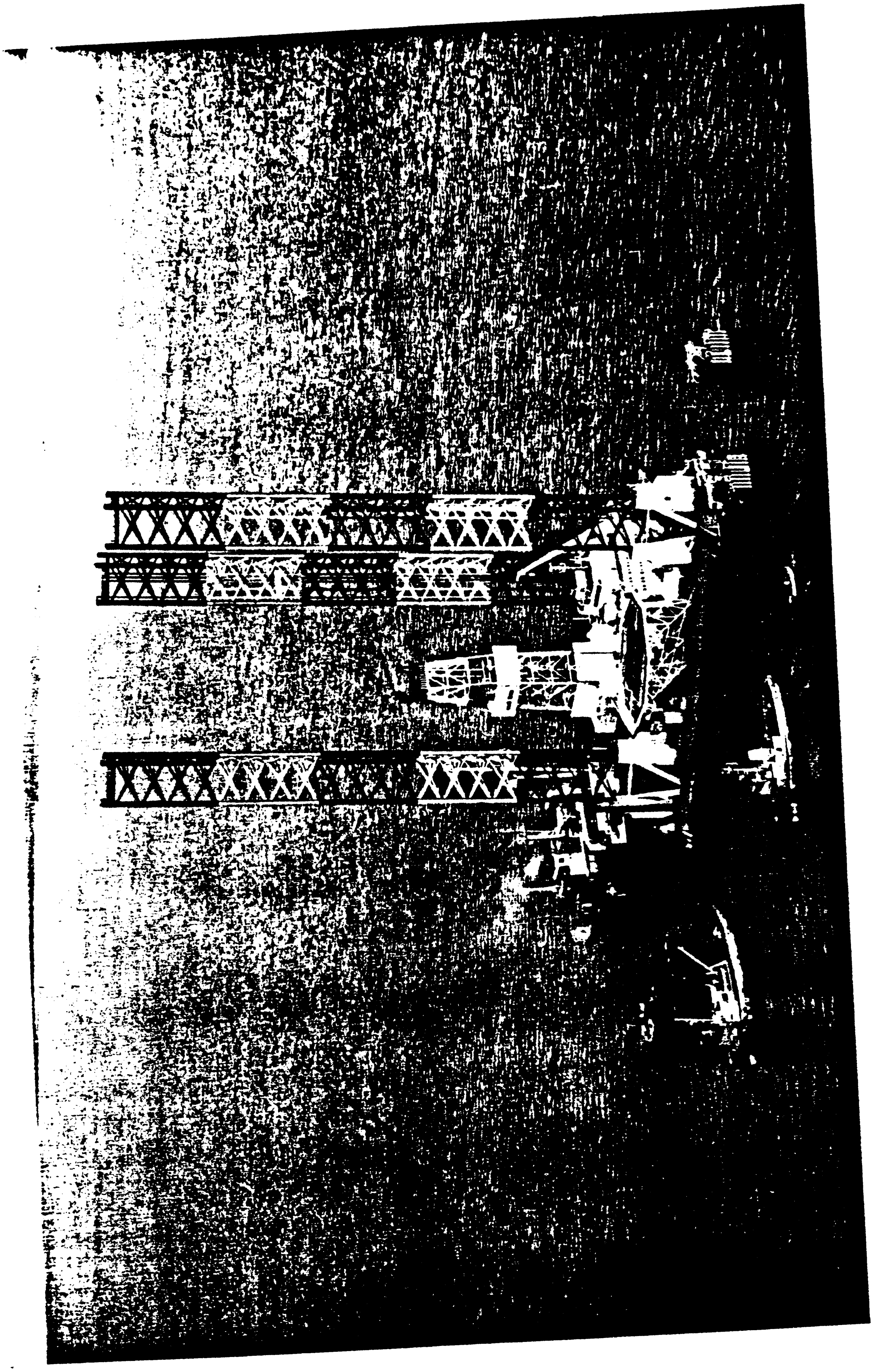

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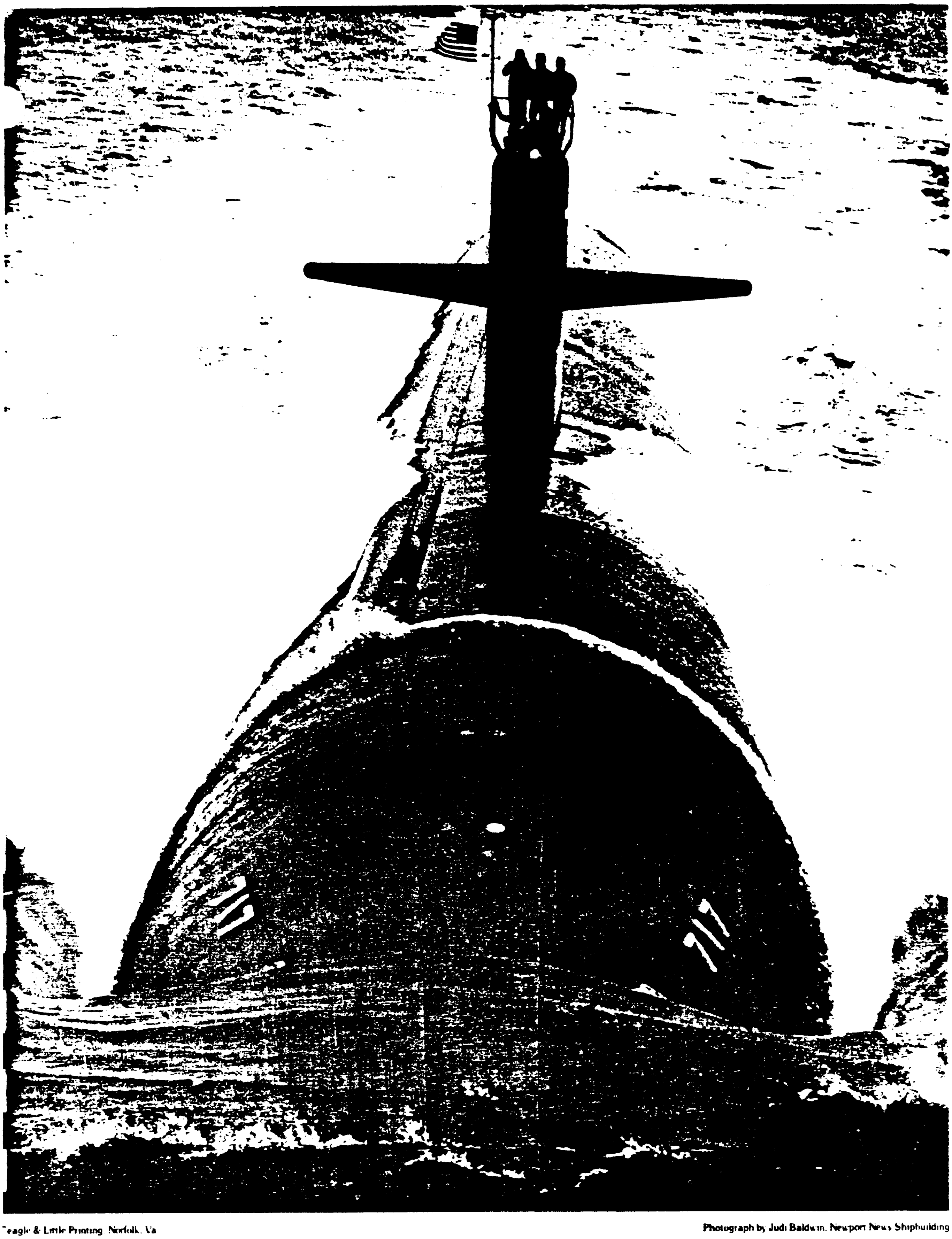


Teagle & Little Printing, Norfolk, Va

Photograph by Judi Baldwin, Newport News Shipbuilding

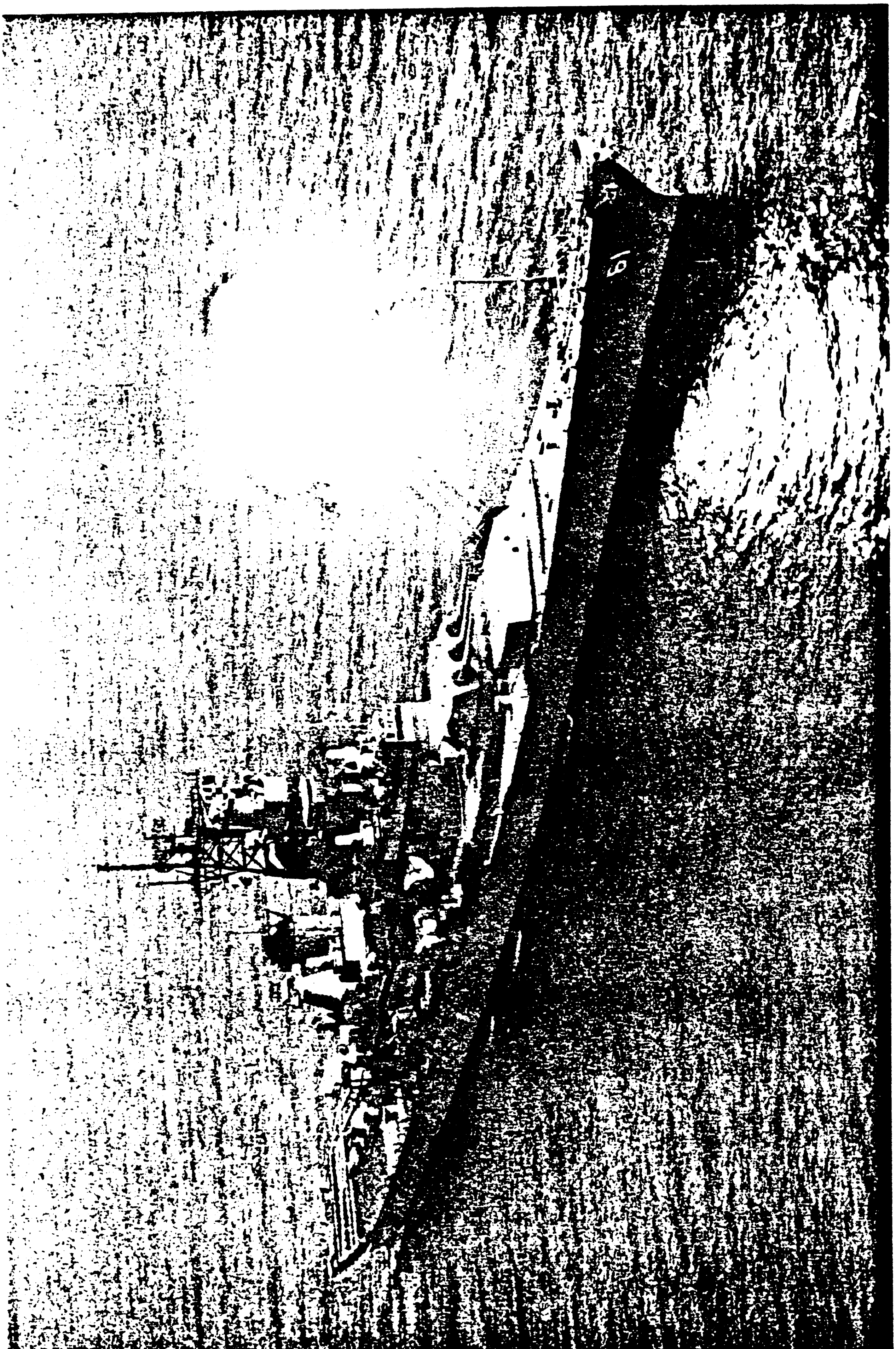
U.S.S. OLYMPIA (SSN 717)

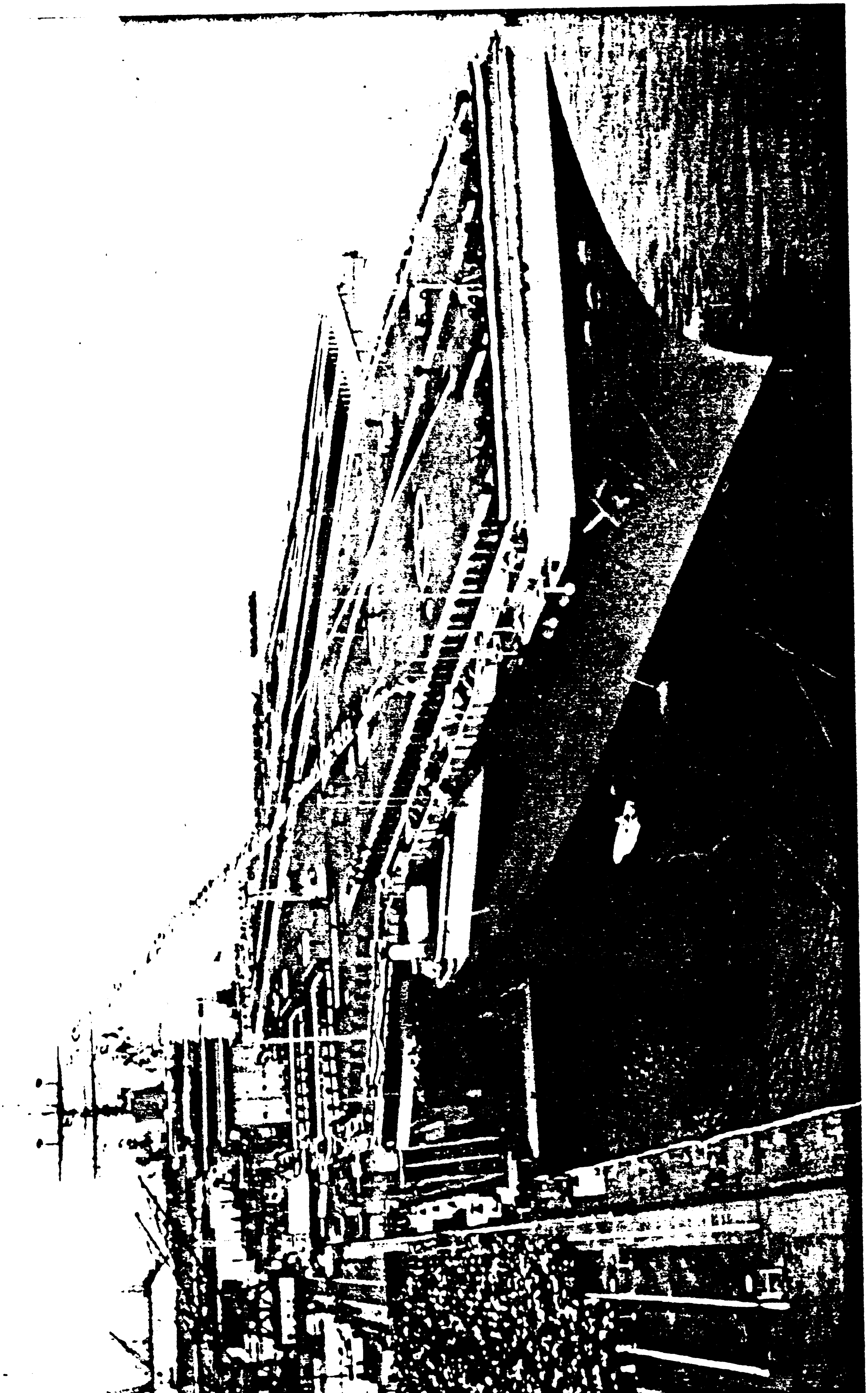
Los Angeles-Class Attack Submarine

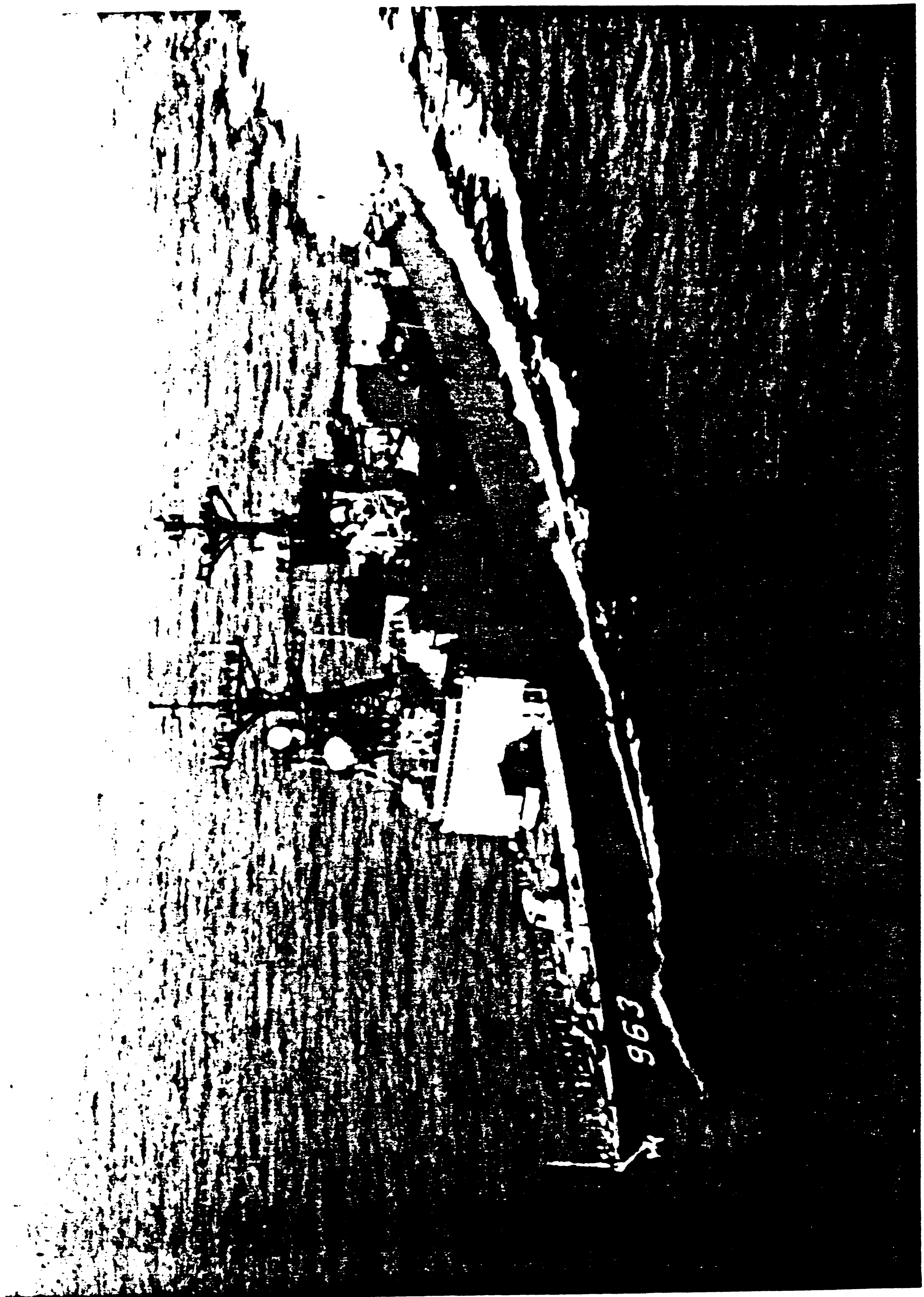
Newport News Shipbuilding

A Tenneco Company

3-26



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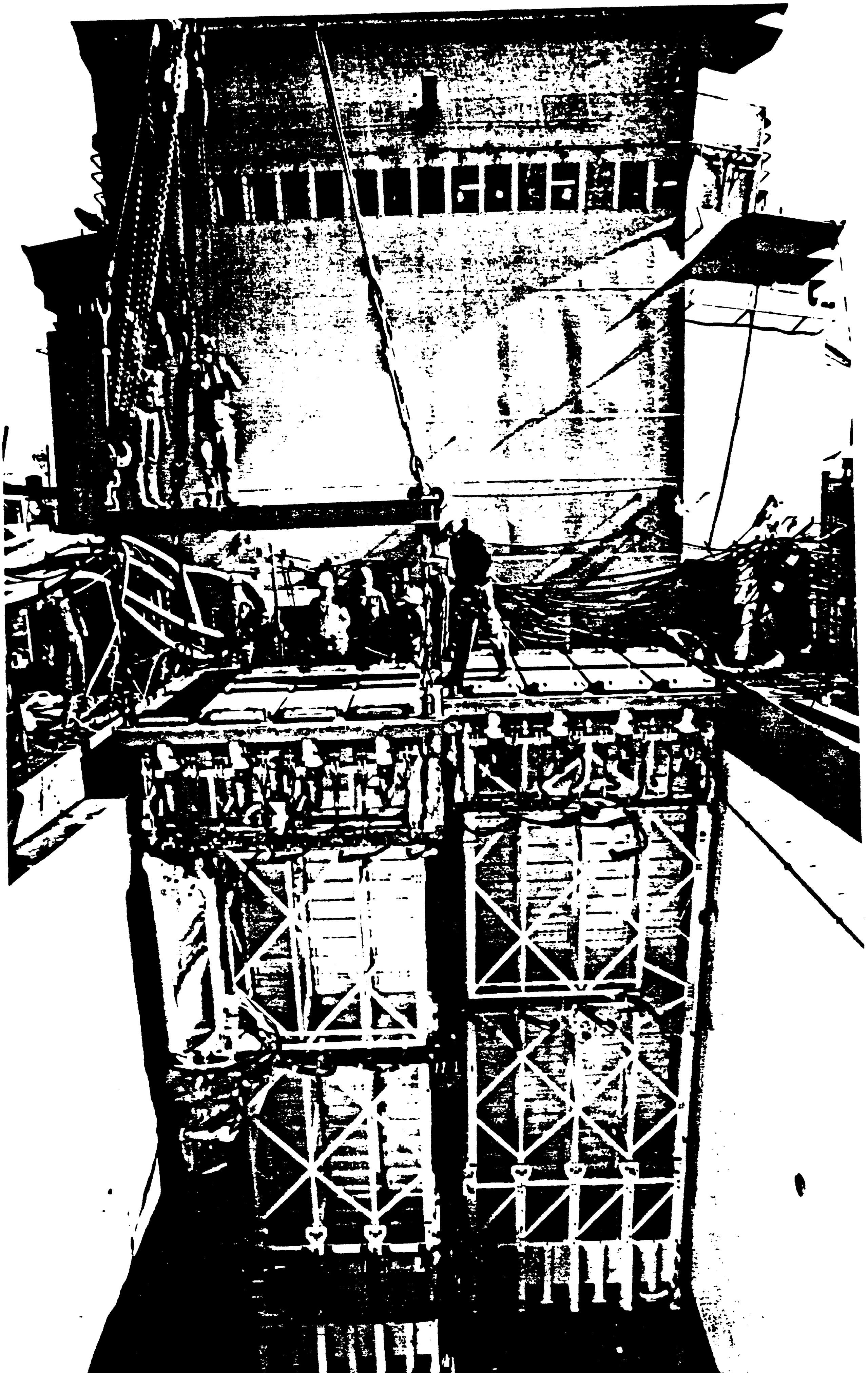

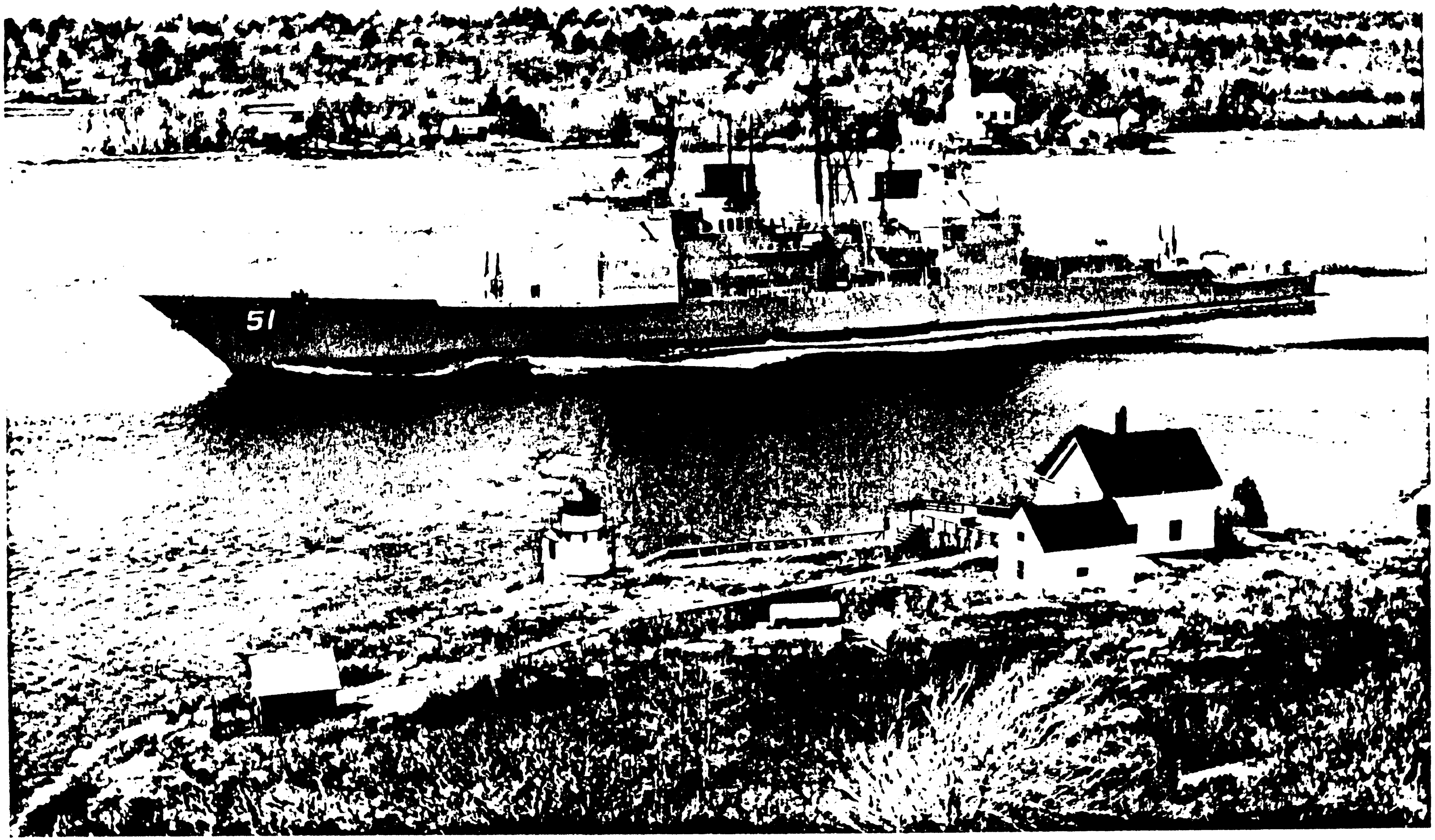
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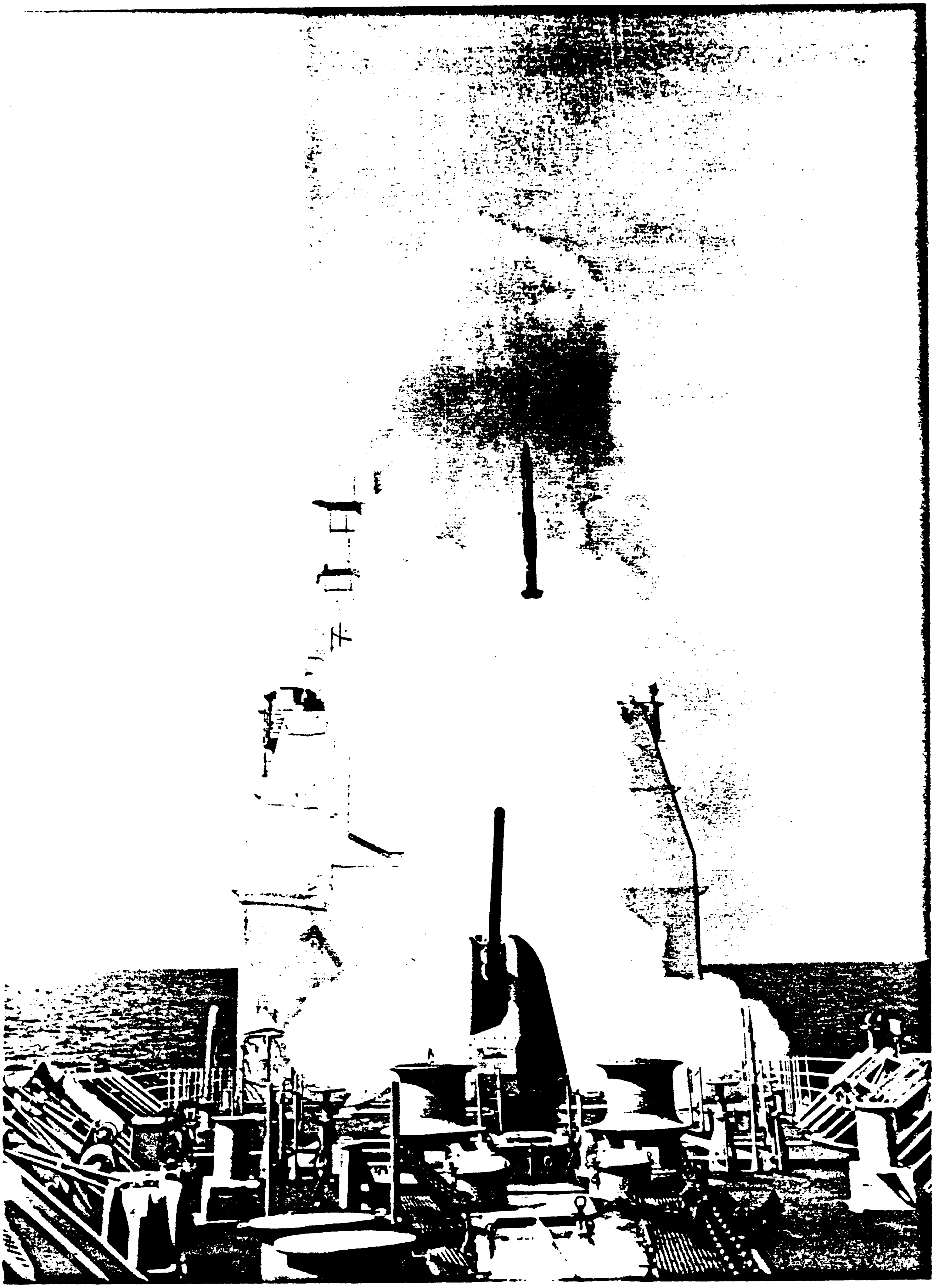

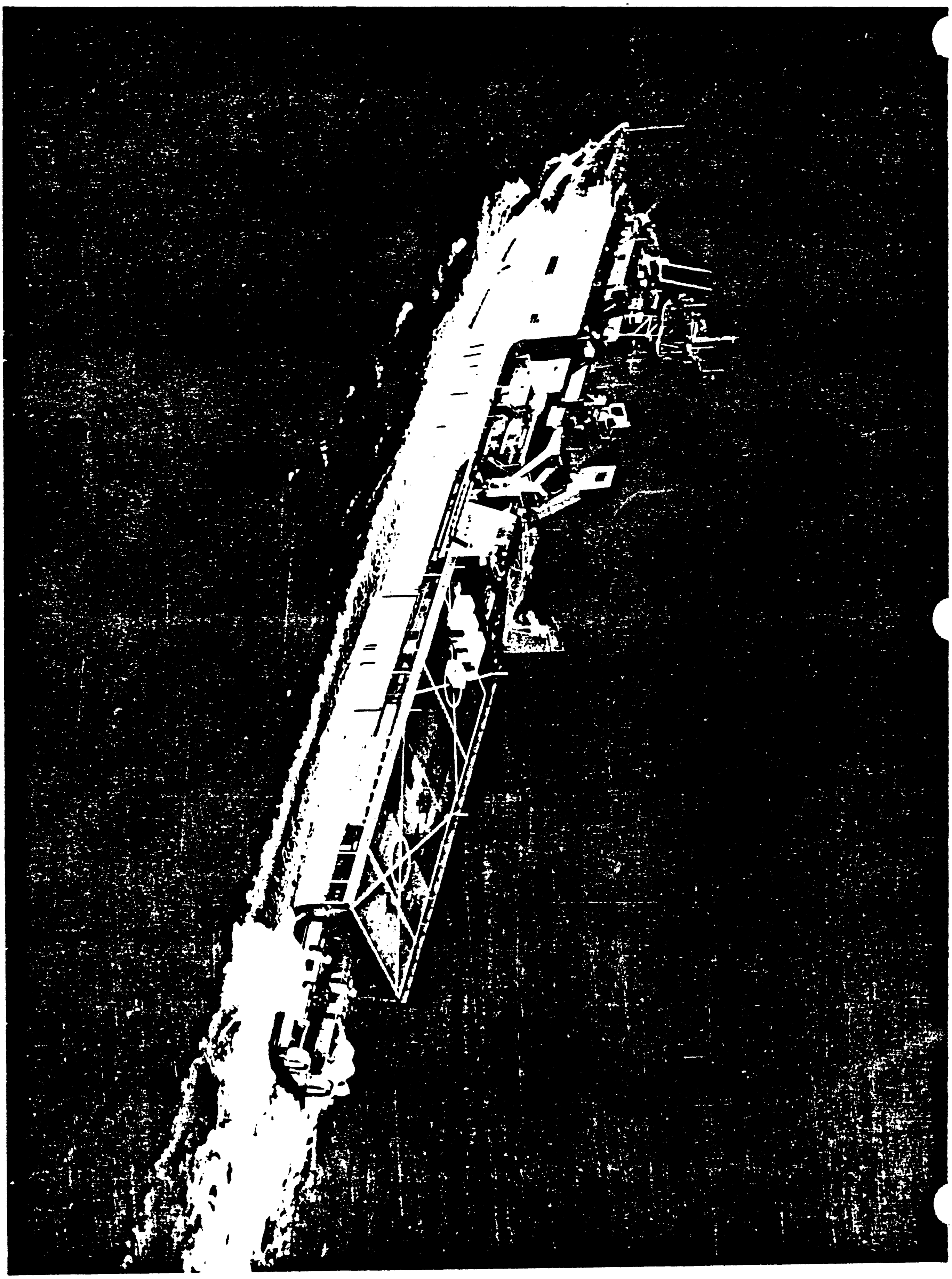

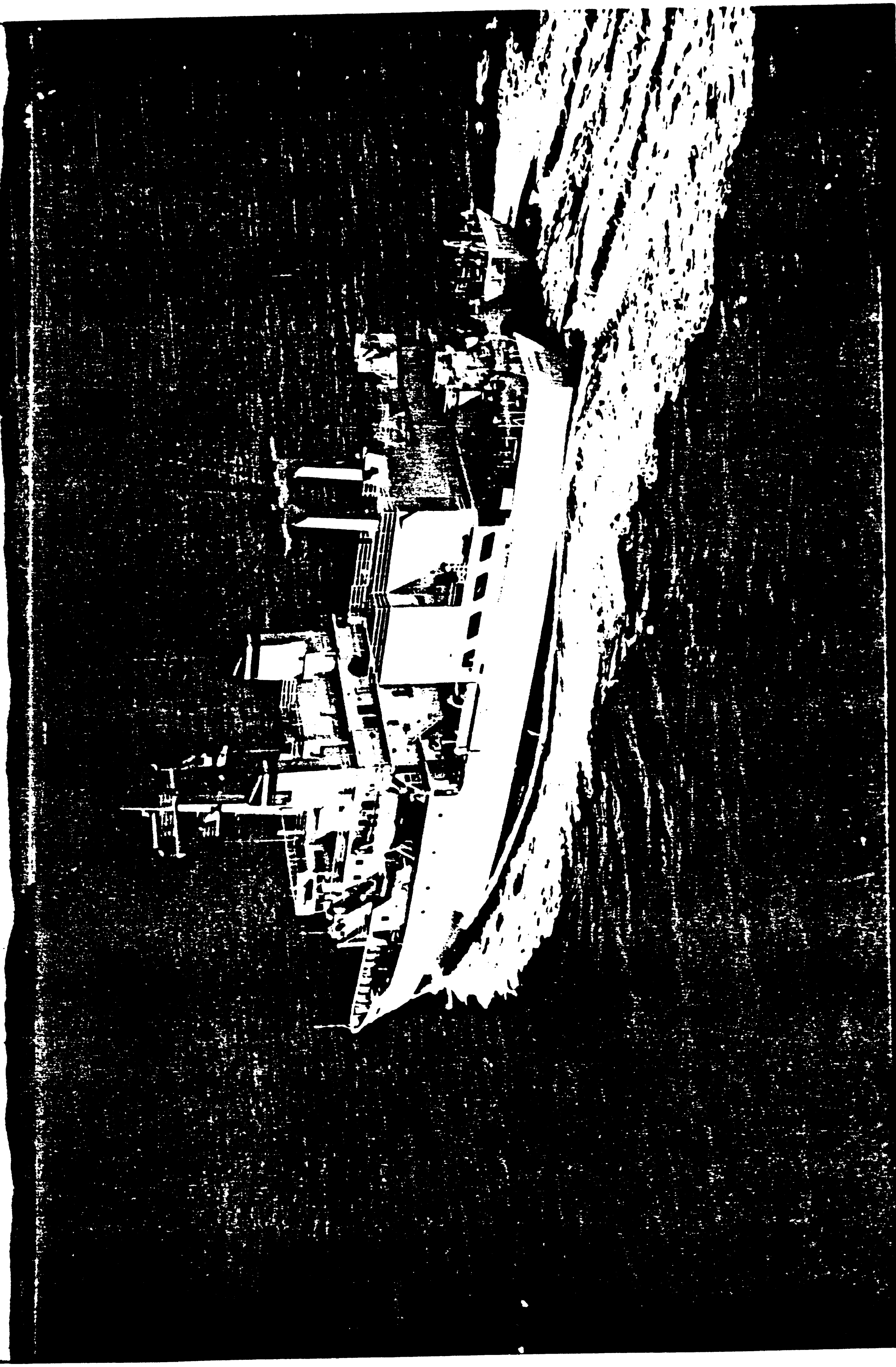

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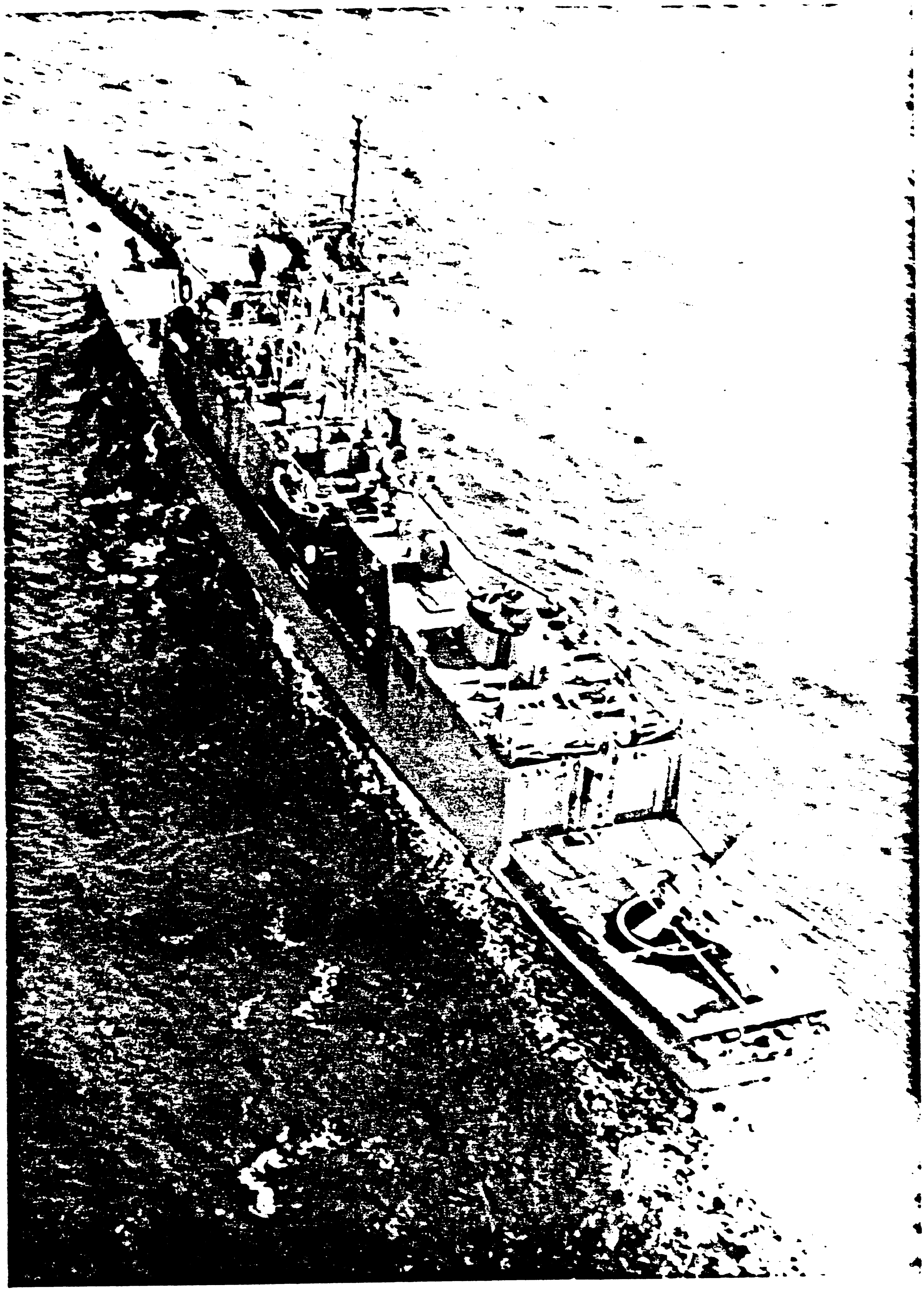

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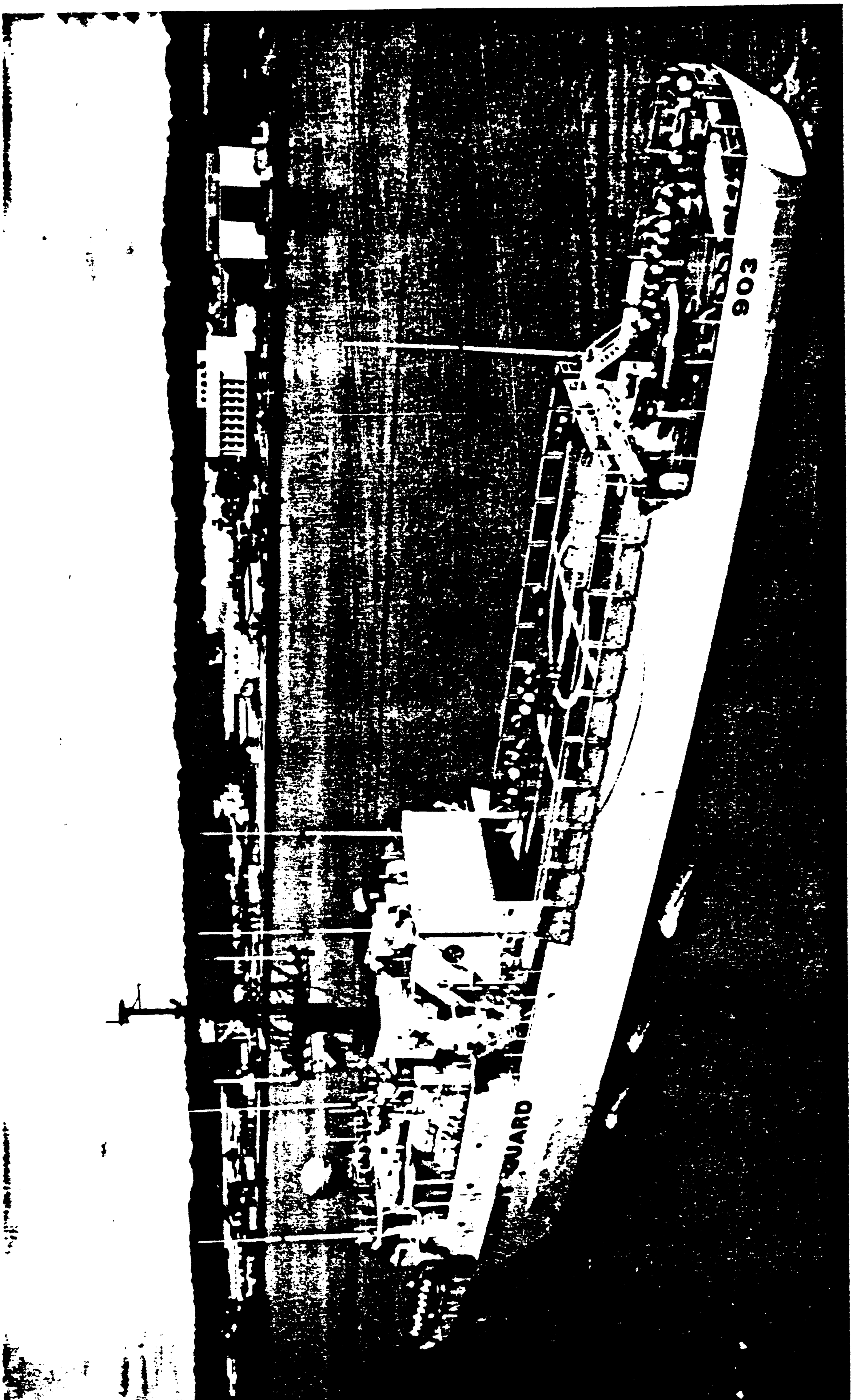
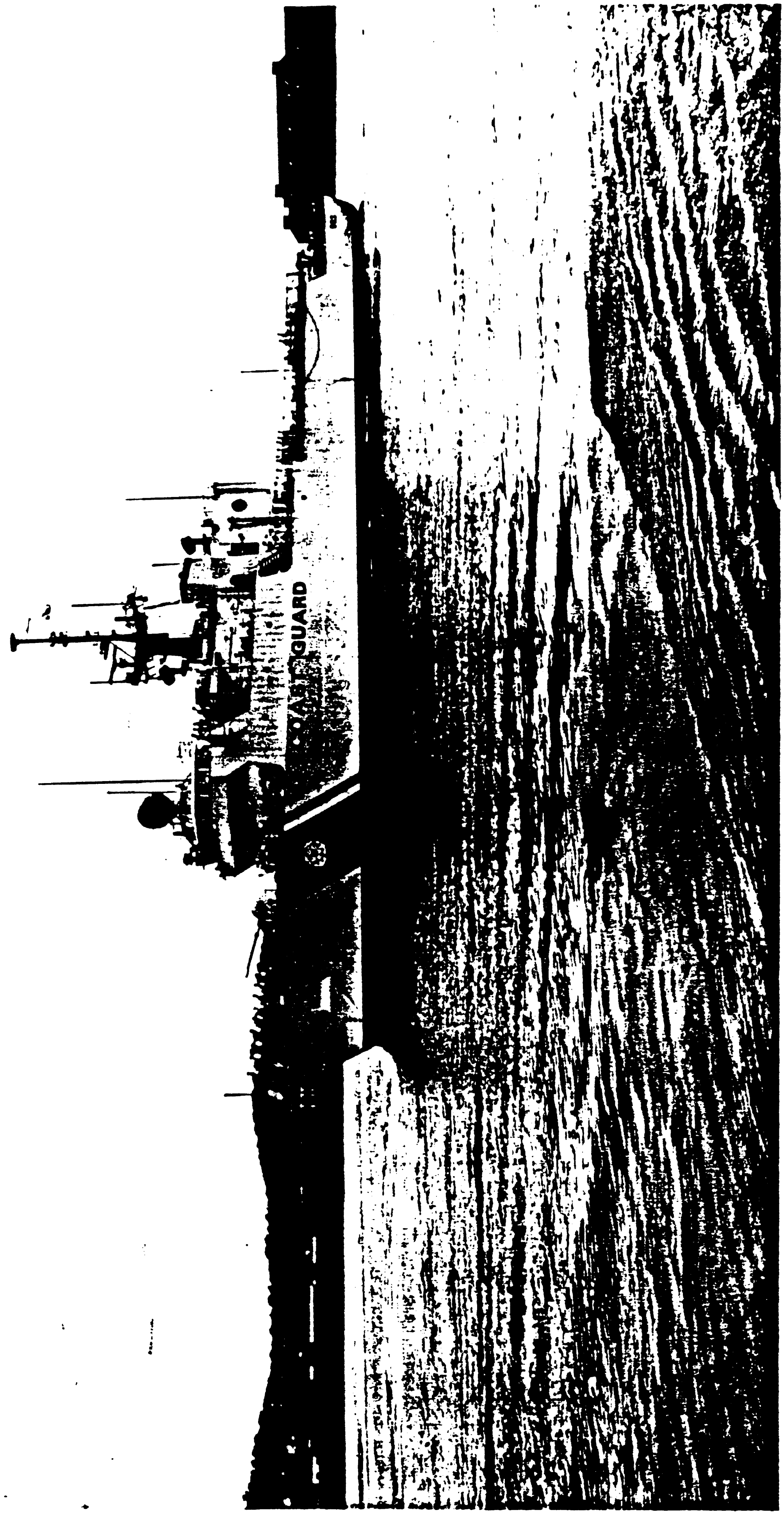

903
GUARD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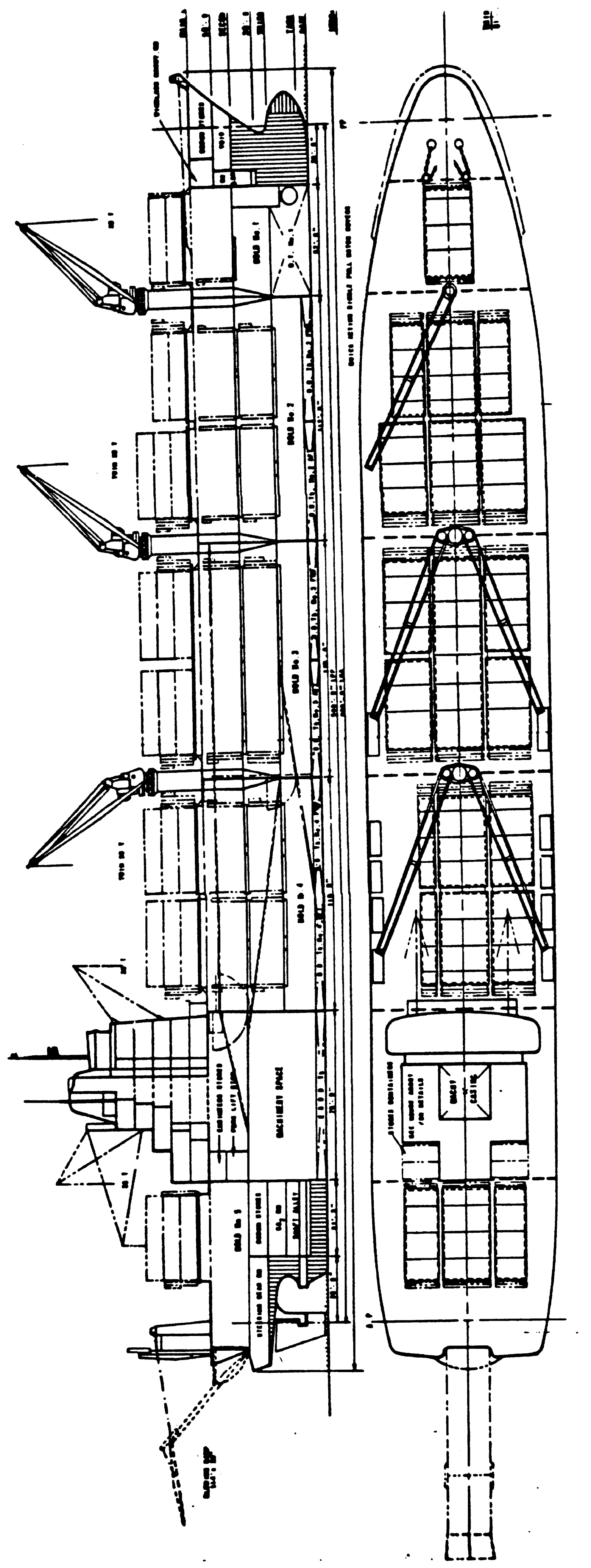


3-40.

Unit Number: 4

Title: Ship types and ship systems - 3
Nomenclature - 1

Tape Running Time: $36^M\ 39^S$

Reading Assignment: MSD, pp 13-15

Additional References: None

Scope:

The treatment of ship types and ship systems is concluded by a classification of types of commercial and naval ships by the cargoes they carry, the missions they perform, and the type of support they receive (hydrostatic, hydrodynamic, aerostatic). The first of three units on nautical nomenclature begins in the last half of this unit with a discussion of units used in the course, directions on board ship, dimensions and markings.

Key Points to Emphasize:

1. Review the units used in the course.

2. Review ship dimensions - L_{PP}, L_{WL}, L_{OA}, midships symbol, beam, depth, draft, displacement.

3. Discuss weight, displacement and tonnage.

4. Review load line marks and draft marks.

5. Review bale capacity and grain capacity.

Suggested Problem Assignment:

(A "NOMENCLATURE CHECK-OFF LIST" is included just ahead of this page. The instructor may wish to use this for his own guidance in covering nomenclature items, or may even wish to distribute to students for their use.)

BASIC NAVAL ARCHITECTURE

NOMENCLATURE CHECK-OFF LIST

UNIT 4

long ton
tonne
nautical mile
knot
-----
ship, vessel, boat
-----
port, starboard
forward, aft
outboard, inboard
athwartships
abaft
-----
midships symbol
-----
fore perpendicular
aft perpendicular
(merchant and navy)
L_{pp}
L_{WL}
L_{oa}
-----
beam
depth
draft
-----
anchor's aweigh
displacement
deadweight
tonnage

Plimsall Mark
American Bureau of Shipping
winter load line
-----
draft marks
-----
bale capacity
grain capacity

UNIT 5

forecastle
jackstaff
union jack
stem
main deck
scuppers
freeing port
bulwark
superstructure
deck house
truk - **(check)**
gaff
ensign
flagstaff
bilge keel
poop deck
weather deck
-----
main deck
second deck
partial deck
platform
forecastle
superstructure deck
fantail
-----
bulkheads
WT bulkheads
NT bulkheads
OT bulkheads
forepeak bulkhead
collision bulkhead
afterpeak bulkhead
strength bulkhead
non-structural bulkhead
-----
forepeak tank
inner bottom
tank top
flat
afterpeak tank
Navy deck numbering system
01 deck
02 deck, etc.

WT door
weathertight door
NT door
joiner doors
access hatches
cargo hatches

scuttle
manhole
-----
dog
quick acting door
quick acting scuttle
coaming
-----
compartment
hold
passageway
overhead
ceiling
-----
galley
gangway
quarterdeck
ladder
stairwell
companionway
-----
booby hatch
boot top
sea chest
'tween deck
head
-----
port
deadlight
deadwood
skeg
-----
ground tackle
anchoring
mooring
quay
hawsepipe
chain pipe
chain locker
bitter end
-----
old fashioned anchor
palm
fluke
bill
pea
stock
throat
stockless anchor
mushroom anchor
Danforth anchor
-----
shot of chain
fathom

bending shackle
pelican hook
chain stopper
-----
windlass
capstan
wildcat
-----
bitt
chock
bullnose
devil's claw
-----
cleat
open chock
closed chock
roller chock
bollard
padeye

UNIT 6

radial davit
falls
monkey lines
-----
crescent davit
Welin gravity davit
-----
accommodation ladder
Jacob's ladder
-----
kingpost
-----
burtoning system
yard-and-stay rig
-----
hatch boom
yard boom
topping lift
yard whip
hatch whip
outboard guy
midship guy
lazy guy
vang
gooseneck
gypsy
cathead
-----
gantry
spreader
-----

stuckenmast system
-----
dunnage
sparring
IWQ
battens
ceiling
scantlings
garboard strake
sheer strake
"B" strake
flat plate keel
center vertical keel
riderplate
-----
girder
hatch-side girder
CVK
FPK
beam
-----
longitudinal
stringer
stringer plate
margin plate
-----
floor
solid floor
open floor
$
lightening hole
flat bar stiffener
side girder
strut
reverse frame
-----
transverse framing system
longitudinal framing system
deep web frame
hold bracket
frame bracket
keelson
stanchion, pillar
intercostal member
limber hole
-----
stem
rolled plate stem
rabbet
breasthook
-----
stern frame
shoe
sternpost

pintles
gudgeons

SHIP TYPES AND SHIP SYSTEMS

MERCHANT SHIP TYPES BY TRADE

1. DRY BULK TRADES

   - IRON ORE CARRIERS
   - COAL CARRIERS
   - GRAIN CARRIERS
   - BAUXITE AND PHOSPHATES CARRIERS
   - FOREST PRODUCTS CARRIERS
   - STEEL PRODUCTS CARRIERS
   - OTHER TYPES: MANGANESE, IRON PYRITES, SALT, SULPHUR, GYPSUM, ETC.

2. LIQUID BULK TRADES

   - CRUDE OIL TANKERS
   - LIQUID PETROLEUM PRODUCT CARRIERS
   - LIQUIFIED NATURAL GAS AND PROPANE GAS CARRIERS
   - LIQUIFIED CHEMICAL PRODUCT CARRIERS

3. COMBINATION TYPES

   - ORE/BULK/OIL (OBO) SHIPS

MERCHANT SHIP TYPES BY TRADE (CON'T)

4. BREAK-BULK GENERAL CARGO SHIPS

MANY MANUFACTURED GOODS AND SEMI-FINISHED GOODS ARE STILL TRANSPORTED IN "BREAK-BULK" FORM; THAT IS EACH ITEM IS INDIVIDUALLY PACKAGED IN A CARTON, CRATE OR BALE AND MUST BE HANDLED SEPARATELY AS IT IS LOADED INTO THE SHIP, STOWED IN ITS HOLD, THEN OFF-LOADED AND DISCHARGED AT ITS DESTINATION.

BREAK-BULK CARGOES TEND TO BE HIGH-VALUE CARGOES AND COMMAND HIGHER FREIGHT RATES. ALTHOUGH THE SLOW CARGO HANDLING RATE MAKES THIS TYPE OF SHIP INEFFICIENT COMPARED TO A CONTAINER SHIP, GENERAL CARGO SHIPS STILL PERFORM A USEFUL SERVICE IN TRANSPORTING DIVERSE TYPES OF CARGO TO PORTS NOT SERVED BY THE LARGER CONTAINER SHIPS.

MERCHANT SHIP TYPES BY TRADE (CON'T)

5. UNITIZED CARGO CARRIERS INCLUDE CONTAINER SHIPS, RO/RO VESSELS AND BARGE CARRIERS. UNITIZED CARGO CARRIERS REDUCE MUCH OF THE CARGO HANDLING TIME AND PROBLEMS ASSOCIATED WITH BREAK-BULK GENERAL CARGO SHIPS AND HAVE REPLACED BREAK-BULK CARRIERS IN LINER SERVICE TO MAJOR PORTS.

   CONTAINER SHIPS HAVE BECOME COMMON SINCE THE ADVENT OF STANDARD SIZED CONTAINERS WHICH CAN BE UTILIZED INTERNATIONALLY. THE LARGER FASTER CONTAINER SHIPS TEND TO SERVICE LARGER PORTS WITH ELABORATE PIERSIDE CONTAINER CRANES WHICH CAN LOAD AND OFF-LOAD CONTAINERS RELATIVELY QUICKLY. CONTAINERS ARE STOWED IN THE HOLDS IN COLUMNS OR "CELLS" SUPPORTED BY VERTICAL STEEL CELL GUIDES. ADDITIONAL CONTAINERS CAN BE STOWED ON DECK ON TOP OF THE HATCHES.

SHIP TYPES AND SHIP SYSTEMS

LINER AND TRAMP TRADES

CARGO LINERS ARE GENERAL CARGO SHIPS TRADING BETWEEN SPECIFIC PORTS AND ON REGULAR SCHEDULES. THE MIX OF TYPES AND QUANTITY OF CARGOES IS FAIRLY WELL ESTABLISHED AND THE DESIGN PARAMETERS CAN BE WELL DEFINED.

A TRAMP (MORE POLITELY CALLED A GENERAL PURPOSE CARGO SHIP) IS A GENERAL BREAKBULK CARGO SHIP THAT HAS NO SET TRADE ROUTE, PORTS-OF-CALL OR SCHEDULE .

THE TRAMP SEEKS CARGOS OF OPPORTUNITY TO SERVICE PORTS NOT NORMALLY SERVICED BY CARGO LINERS.

SHIP TYPES AND SHIP SYSTEMS

NAVAL SHIP SYSTEMS

IN DEVELOPING MODERN NAVAL WARFARE SYSTEMS CONSIDERATION MUST BE GIVEN TO THE TOTAL SYSTEM -- NOT JUST AN INDIVIDUAL SHIP TYPE. THE TOTAL SYSTEM INCLUDES NOT ONLY THE COMBAT CAPABILITIES OF SHIPS, AIRCRAFT, AMPHIBIOUS VEHICLES AND POSSIBLY SUBMARINES OPERATING TOGETHER, BUT ALSO THE AT-SEA AND SHORE-BASED SUPPORT SERVICES.

THE MISSIONS WHICH EACH SHIP TYPE WILL BE REQUIRED TO PERFORM ARE CAREFULLY DEFINED IN A DOCUMENT CALLED THE TOP LEVEL REQUIREMENTS.

SHIP TYPES AND SHIP SYSTEMS

NAVAL SHIP SYSTEMS (CON'T)

INDIVIDUAL SHIPS, FOR EXAMPLE, DESTROYERS AND FRIGATES, MAY BE REQUIRED TO OPERATE ON SINGLE-SHIP MISSIONS IN WHICH CASE THEY MUST BE SELF-SUSTAINING FOR PERIODS UP TO 30 DAYS OR THEY MAY BE REQUIRED TO PROVIDE ANTI-SUBMARINE, ANTI-AIRCRAFT AND MISSILE DEFENSE SERVICES TO A BATTLE GROUP INCLUDING A MIX OF CRUISERS, AIRCRAFT CARRIERS AND BATTLESHIPS.

AIRCRAFT CARRIERS AND BATTLESHIPS CAN OPERATE FOR EXTENDED PERIODS WITHOUT RE-SUPPLY AND CAN PROVIDE LIMITED RE-SUPPLY SUPPORT TO SMALLER SHIPS IN THEIR COMPANY. AIRCRAFT CARRIERS AND BATTLESHIPS ALMOST NEVER TRAVEL ALONE BUT ARE ACCOMPANIED BY DESTROYER AND/OR FRIGATE ESCORT SHIPS.

NAVAL SHIP SYSTEMS (CON'T)

AN IMPORTANT PART OF NAVAL SHIP DESIGN AND PROCUREMENT ARE RELIABILITY, MAINTAINABILITY AND AVAILABILITY (RMA) STUDIES WHICH IDENTIFIES THE NUMBER AND TYPES OF SPARE PARTS AND THE MAINTENANCE INTERVALS FOR ALL THE VARIOUS TYPES OF EQUIPMENT AND WEAPONS INSTALLED ON THE SHIP. A "CRADLE-TO-GRAVE" INTEGRATED LOGISTIC SUPPORT (ILS) PLAN OUTLINES THE PROVISIONING AND MAINTENANCE PLAN FOR THE LIFE CYCLE OF EACH SHIP.

SHIP TYPES AND SHIP SYSTEMS

NAVAL SHIP SYSTEMS (CON'T)

AT-SEA SUPPORT REQUIREMENTS FOR NAVAL COMBATANTS ARE MET BY AUXILIARY SHIPS -- OILERS, SUPPLY SHIPS, AND AMMUNITION SHIPS. SHORE-BASED SUPPORT REQUIREMENTS ARE MET BY ADVANCED BASES AND SUPPLY DEPOTS, HOME-PORT SUPPORT FACILITIES, SUPPLY AND AMMUNITION DEPOTS, AND BY NAVAL AND CIVILIAN SHIPYARDS.

ALL NAVAL COMBATANTS MUST HAVE THE EQUIPMENT AND THE OPERATIONAL CAPABILITY FOR UNDERWAY REPLENISHMENT-AT-SEA (UNREP) WHICH IS A ROUTINE RE-SUPPLY EVOLUTION.

SHIP TYPES AND SHIP SYSTEMS

SHIP TYPES CLASSIFIED BY TYPE OF SUPPORT

HYDROSTATIC SUPPORT

THE BUOYANT SUPPORT THAT A FLOATING BODY EXPERIENCES IS EQUAL TO THE WEIGHT OF THE WATER IT DISPLACES (ARCHIMEDES PRINCIPLE).

THIS TYPE OF SUPPORT IS KNOWN AS HYDROSTATIC SUPPORT. THE VAST MAJORITY OF SURFACE SHIPS FALL IN THIS CATEGORY.

SHIP TYPES AND SHIP SYSTEMS

SHIP TYPES CLASSIFIED BY TYPE OF SUPPORT

HYDRODYNAMIC SUPPORT

AN AIRPLANE WING (AIRFOIL) TRAVELING THROUGH THE AIR GENERATES AERODYNAMIC LIFT ON BOTH THE UPPER AND LOWER SURFACES OF THE WING.

EXACTLY THE SAME PRINCIPLES APPLY IN THE CASE OF A HYDROFOIL TRAVELING THROUGH WATER. THIS TYPE OF SUPPORT IS CALLED HYDRODYNAMIC SUPPORT. HYDROFOIL CRAFT TRAVELING AT LOW SPEEDS ARE SUPPORTED BY HYDROSTATIC SUPPORT. AS THE CRAFT SPEED INCREASES THE HYDRODYNAMIC LIFT INCREASES, THE CRAFT LIFTS OFF THE SURFACE AND IS SUPPORTED ENTIRELY BY THE HYDRODYNAMIC LIFT ON THE HYDROFOILS.

TYPICALLY, THE HYDROFOIL CRAFT WILL LIFT OFF AT SPEEDS OF 10 TO 15 KNOTS AND WILL ATTAIN 35 TO 45 KNOTS.

SHIP TYPES AND SHIP SYSTEMS

SHIP TYPES CLASSIFIED BY TYPE OF SUPPORT

HYDRODYNAMIC SUPPORT (CON'T)

PLANING BOATS OPERATE ON A SIMILAR PRINCIPLE, EXCEPT THAT ONLY THE LOWER SURFACE -- THE BOTTOM OF THE PLANING BOAT -- GENERATES LIFT.

PLANING BOATS PASS THROUGH A HUMP SPEED AT WHICH POINT MOST OF THE BOAT'S WEIGHT BECOMES SUPPORTED BY HYDRODYNAMIC LIFT, BUT A DECREASING AMOUNT OF HYDROSTATIC SUPPORT REMAINS AS SPEED INCREASES.

PLANING BOATS OPERATE OVER A WIDE SPEED RANGE BUT SELDOM EXCEED 45 KNOTS.

SHIP TYPES AND SHIP SYSTEMS

SHIP TYPES CLASSIFIED BY TYPE OF SUPPORT

AEROSTATIC SUPPORT

AIR CUSHION VEHICLES (ACV's) AND SURFACE EFFECT SHIPS (SES's) ARE SUPPORTED BY A CUSHION OF AIR MAINTAINED UNDER PRESSURE UNDER THE CRAFT.

ACV's HAVE INFLATABLE "SKIRTS" WHICH TRAP THE AIR BENEATH THE VEHICLE. ACV's HAVE A LIMITED AMPHIBIOUS CAPABILITY.

SES's HAVE RIGID SIDE WALLS. THE AIR CUSHION IS MAINTAINED BY BOW AND STERN SEALS BETWEEN THE SIDE WALLS.

SHIP TYPES AND SHIP SYSTEMS

SHIP TYPES CLASSIFIED BY TYPE OF SUPPORT

A VARIETY OF "HYBRID" CONCEPTS HAVE BEEN PROPOSED AND SOME HAVE BEEN INVESTIGATED. THESE CONCEPTS REPRESENT COMBINATIONS OF THE THREE TYPES OF SUPPORT -- HYDROSTATIC, HYDRODYNAMIC, AND AEROSTATIC.

HYDROSTATIC SUPPORT -- BUOYANCY -- IS THE LEAST EXPENSIVE. AS DESIGNS INTRODUCE HYDRODYNAMIC OR AEROSTATIC SUPPORT THEY MAY BE ABLE TO ACHIEVE HIGH PERFORMANCE, BUT OVER A MUCH NARROWER RANGE OF APPLICATION, AND AT HIGHER INITIAL AND OPERATING COSTS.

NOMENCLATURE

UNITS

THE UNITED STATES USES THE ENGLISH SYSTEM OF UNITS (BUT ENGLAND HAS GONE TO THE METRIC SYSTEM). HERE ARE SOME OF THE UNITS WE WILL USE IN THIS COURSE:

FORCE, WEIGHT:	POUNDS, LONG TONS 1 LONG TON = 2240 POUNDS
TIME:	SECONDS, MINUTES, HOURS
DISTANCE:	FEET 1 NAUTICAL MILE = 6080 FEET 1 NAUTICAL MILE = 1.152 STATUTE MILES
VELOCITY:	FEET/SEC OR KNOTS 1 KNOT = 1 NAUTICAL MILE/HR 1 KNOT = 1.688 FT/SEC.

NOMENCLATURE

SHIPS, VESSELS AND BOATS

IT IS COMMON USAGE TO REFER TO SHIPS AS "VESSELS",

BUT,

THE U.S. NAVY HAS TAKEN EXCEPTION TO THIS PRACTICE AND DISCOURAGES THE USE OF THE PHRASE "NAVAL VESSELS", THUS THERE ARE **NAVAL SHIPS** AND **MERCHANT VESSELS**.

THERE IS NOT A CLEAR DISTINCTION BETWEEN "BOATS" AND "SHIPS", EXCEPT THAT, IN GENERAL, A BOAT MAY BE CARRIED ON A SHIP. THERE ARE A NUMBER OF EXCEPTIONS, E.G. SUBMARINES.

NOMENCLATURE

DIRECTIONS ON BOARD SHIP

PORT - LEFT HAND SIDE OF SHIP WHEN FACING FORWARD

STARBOARD - RIGHT HAND SIDE OF SHIP WHEN FACING FORWARD

FORWARD - IN THE DIRECTION OF THE BOW

AFT - IN THE DIRECTION OF THE STERN

OUTBOARD - IN THE DIRECTION FROM THE CENTERLINE TOWARD EITHER SIDE

INBOARD - IN THE DIRECTION FROM EITHER SIDE TOWARD THE CENTERLINE

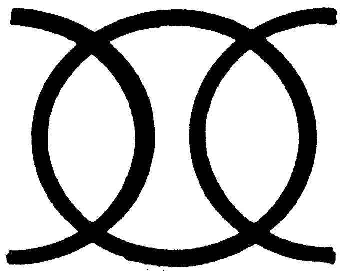
ATHWARTSHIPS - IN THE TRANSVERSE DIRECTION 90° TO THE CENTERLINE

ABAFT - AS IN "ABAFT THE BEAM". REFERS TO OBJECTS OUTSIDE THE SHIP

NOMENCLATURE

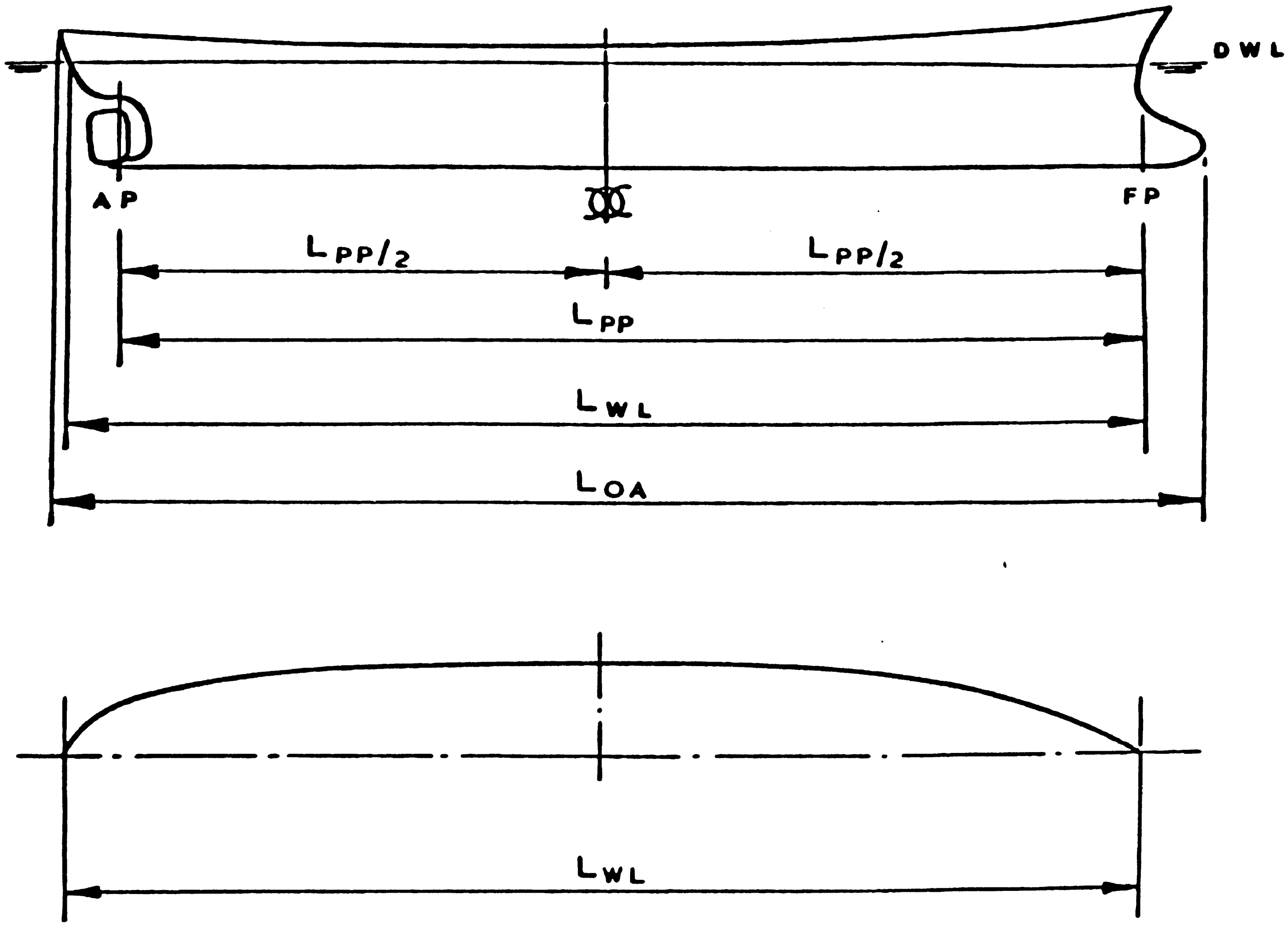
MIDSHIPS SYMBOL

THE MIDSHIPS SYMBOL APPEARS ON SHIP DRAWINGS TO MARK AMIDSHIPS, HALFWAY BETWEEN THE FORE PERPENDICULAR AND AFT PERPENDICULAR.



NOMENCLATURE

SHIP DIMENSIONS - LENGTH



NOMENCLATURE

SHIP DIMENSIONS - BEAM, DEPTH, DRAFT

BEAM - THE MAXIMUM BREADTH OF THE SHIP.

DEPTH - THE DISTANCE FROM THE BASELINE OF THE SHIP TO THE FREEBOARD DECK AT THE SIDE.

DRAFT - THE DEPTH OF THE SHIP BELOW THE WATERLINE TO THE BASELINE, OR TO PARTS OF THE SHIP EXTENDING BELOW THE BASELINE.

NOTE: MORE PRECISE DEFINITIONS WILL BE GIVEN IN UNIT 7.

NOMENCLATURE

WEIGHT, DISPLACEMENT AND TONNAGE

ANCHOR'S AWEIGH MEANS THE ANCHOR CHAIN IS VERTICAL AND THE ANCHOR HAS JUST CLEARED THE BOTTOM.

WHEN A SHIP IS GETTING UNDERWAY IT WEIGHS ITS ANCHOR, BUT IT DISPLACES A WEIGHT OF WATER JUST EQUAL TO THE WEIGHT OF THE SHIP. THIS IS KNOWN AS THE DISPLACEMENT, NOT THE WEIGHT, OF THE SHIP.

DEADWEIGHT IS THE CARGO CARRYING CAPACITY OF THE SHIP INCLUDING CARGO, FUEL, WATER, STORES, CREW AND THEIR EFFECTS.

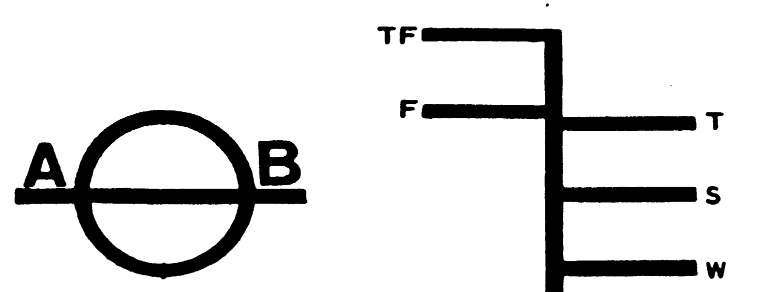
TONNAGE IS A MEASURE OF THE INTERNAL VOLUME OF A SHIP. DISPLACEMENT SHOULD NEVER BE REFERRED TO AS "TONNAGE".

NOMENCLATURE

LOAD LINE MARKS

THE LIMITING DRAFT WHICH CAN NOT BE EXCEEDED FOR A GIVEN LOCATION AND SEASON OF THE YEAR IS PRESCRIBED BY LAW AND CALCULATED BY THE AMERICAN BUREAU OF SHIPPING ON BEHALF OF THE U.S. COAST GUARD.

THE MARK IS KNOWN AS THE "PLIMSOLL MARK" AFTER AN ENGLISH LEGISLATOR WHO WAS VERY ACTIVE IN INTRODUCING LOAD LINE RESTRICTIONS.



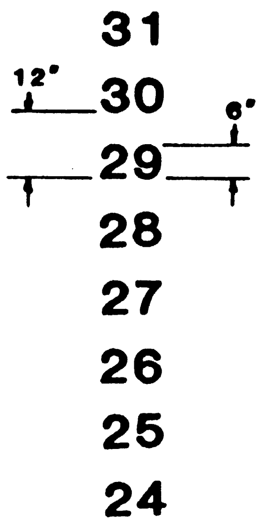
KEY WORDS: PLIMSOLL MARK

NOMENCLATURE

DRAFT MARKS

DRAFT MARKS ARE FOUND AT THE BOW AND STERN OF MERCHANT VESSELS, AS NEAR AS PRACTICAL TO THE FORE PERPENDICULAR AND THE AFT PERPENDICULAR. THE BOTTOM OF THE MARK INDICATES THE DRAFT IN FEET TO THE BOTTOM OF THE KEEL (KEEL DRAFT).

NAVY SHIPS HAVE DRAFT MARKS FORWARD, AFT, AND AMIDSHIPS.



NOMENCLATURE

BALE CAPACITY AND GRAIN CAPACITY

BALE CAPACITY IS THE CAPACITY OF A CARGO HOLD IN CUBIC FEET MEASURED TO THE INSIDE OF THE FRAMES OR CARGO BATTENS.

GRAIN CAPACITY IS THE CAPACITY OF A CARGO HOLD IN CUBIC FEET MEASURED TO THE SHELL PLATING RATHER THAN TO THE INSIDE OF THE FRAMES OR CARGO BATTENS AS IN BALE CAPACITY.

BASIC NAVAL ARCHITECTURE

Unit Number: 5

Title: Nomenclature - 2

Tape Running Time: 38^M 38^S

Reading Assignment: None

Additional References: The Bluejackets' Manual (BJM), B. Beardon and B. Wedertz, Ed., U.S. Naval Institute, 1978, pp 199-219

Seamanship, Fundamentals for the Deck Officer (SFDO), R.O. Dodge and S.E. Kyriss, Naval Institute Press, 1981, pp 125-132, 140-150, 170-177, 182-191, 258-263, 266-271, 360-362, 425-439

SDC, pp 373-418, 717-728

Scope:

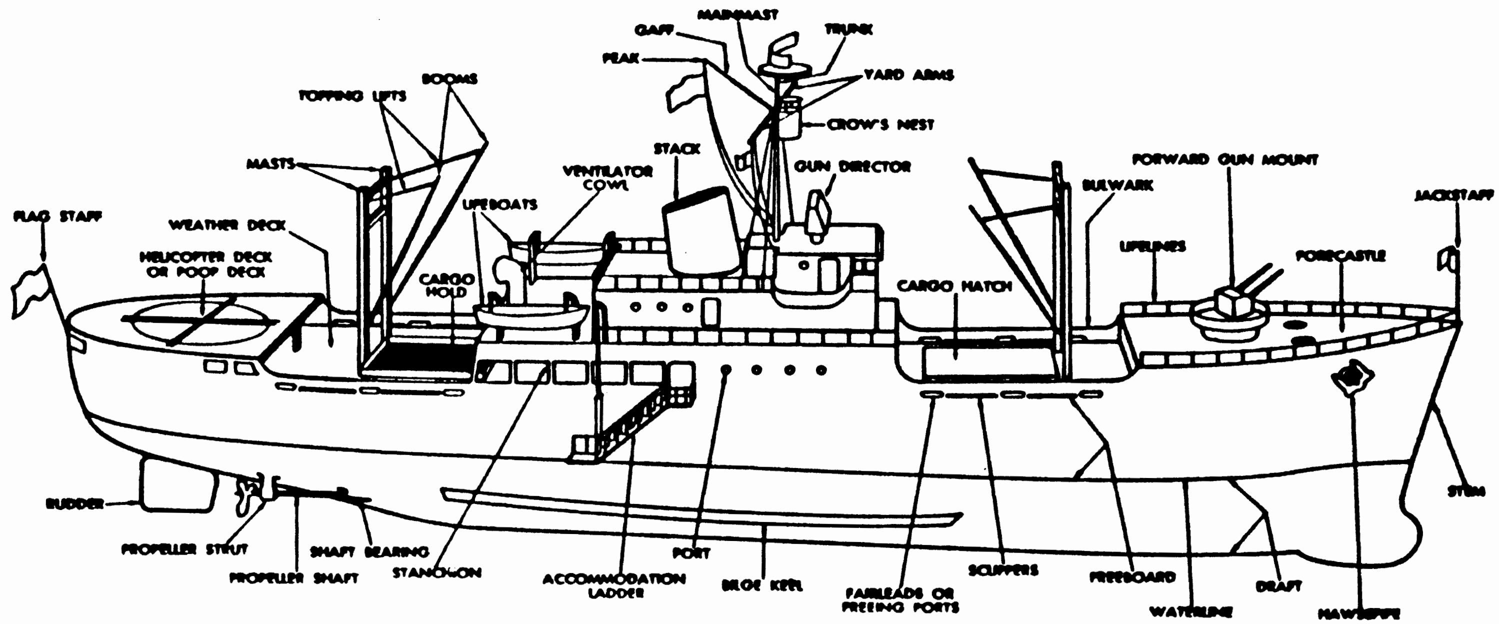
Key Points to Emphasize:

1. Review graphics on video tape as necessary to provide clarity.
2. Glossaries in SFDO and SDC are helpful.
3. Add additional items as desired.

Suggested Problem Assignment: None

NOMENCLATURE

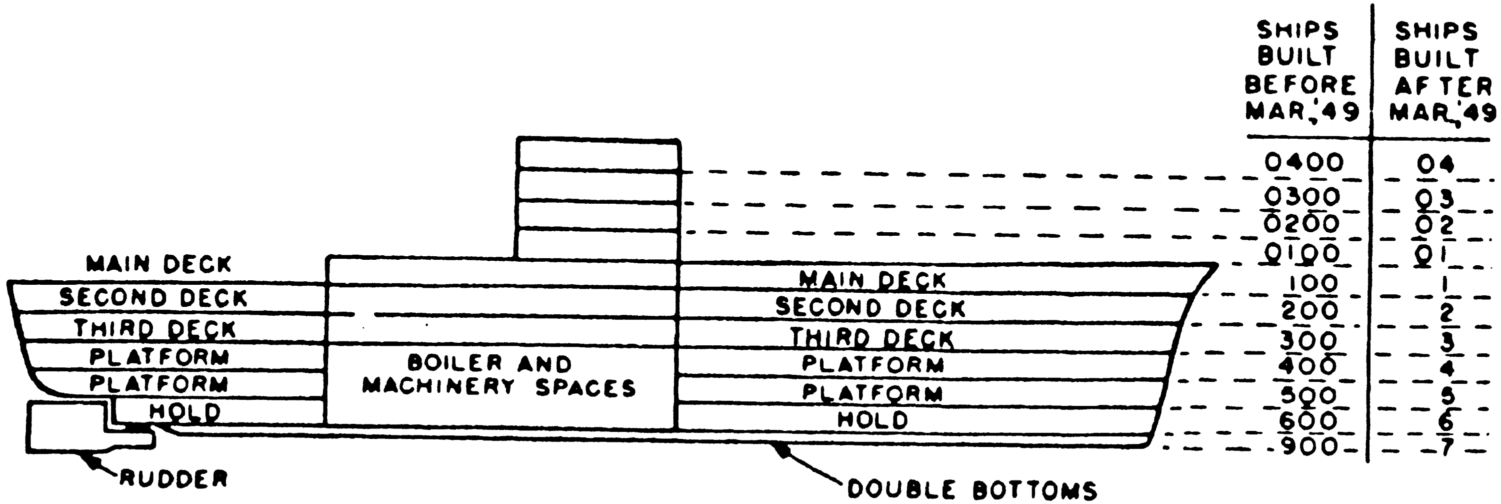
PARTS OF A SHIP



KEY WORDS: FORECASTLE, POOP, BULWARK, WEATHER DECK, FREEING PORTS, SCUPPERS, JACKSTAFF, FLAGSTAFF, GAFF

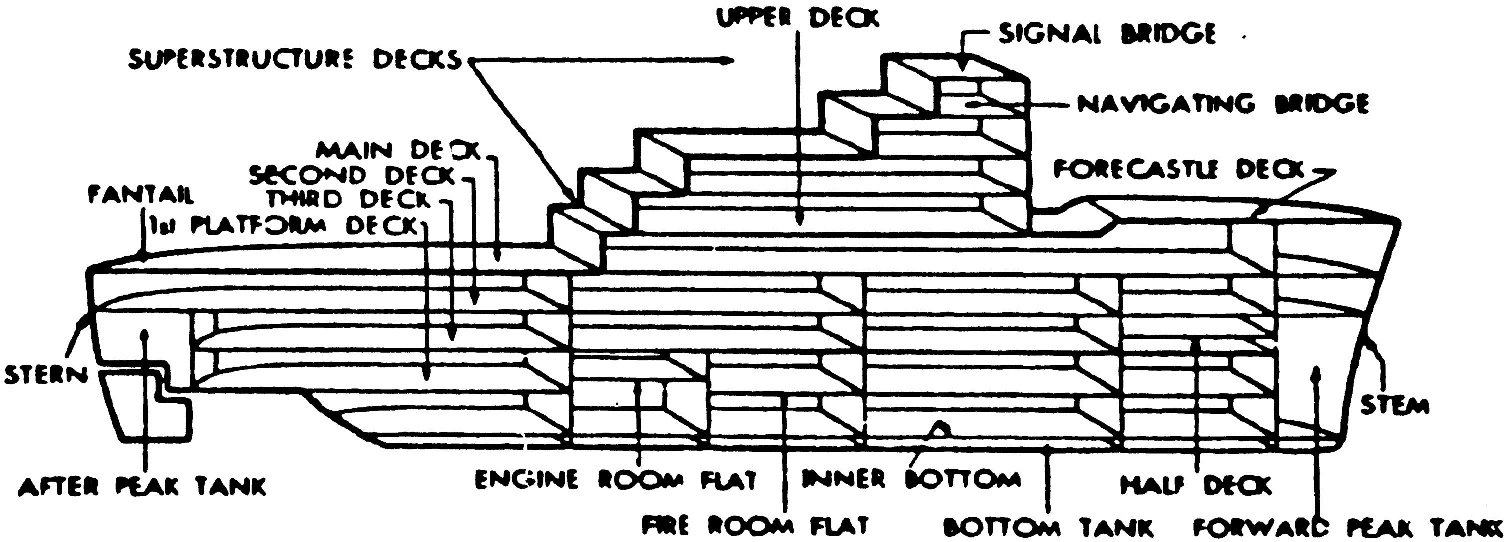
NOMENCLATURE

DECK NUMBERING SYSTEM - NAVY SYSTEM



NOMENCLATURE

DECKS AND BULKHEADS



KEY WORDS: MAIN DECK, FORECASTLE DECK, POOP DECK, PLATFORM DECKS, FLATS, COLLISION BULKHEAD, FOREPEAK TANK, AFTER PEAK TANK

5-4

NOMENCLATURE

BULKHEADS

BULKHEADS ARE THE VERTICAL PARTITION WALLS THAT DIVIDE THE SHIP INTO ROOMS OR COMPARTMENTS.

BULKHEADS ARE DISTINGUISHED BY THEIR LOCATION AND USE. EXAMPLES

- TRANSVERSE BULKHEADS
- LONGITUDINAL BULKHEADS
- WATERTIGHT (WT), OILTIGHT (OT), GASTIGHT BULKHEADS, NON-TIGHT (NT) BULKHEAD.
- FOREPEAK BULKHEAD
- COLLISION BULKHEAD
- AFTER PEAK BULKHEAD
- STRENGTH BULKHEADS
- NON-STRUCTURAL BULKHEADS

NOMENCLATURE

DECKS

THE UPPERMOST COMPLETE DECK RUNNING THE FULL LENGTH OF THE SHIP IS THE MAIN DECK.

THE NEXT COMPLETE DECK BELOW THE MAIN DECK IS THE SECOND DECK, AND SO FORTH.

A DECK WHICH DOES NOT RUN THE FULL LENGTH OF THE SHIP IS A PARTIAL DECK. PARTIAL DECKS BELOW THE MAIN DECK ARE CALLED PLATFORMS. THE UPPERMOST PLATFORM IS THE FIRST PLATFORM, ETC. PARTIAL DECKS ABOVE THE MAIN DECK INCLUDE THE FORECASTLE DECK (FORECASTLE IS PRONOUNCED "FOK-SLE"), THE POOP DECK AND UPPER DECKS OR SUPERSTRUCTURE DECKS.

A BROAD, OPEN DECK AREA AT THE STERN OF THE SHIP IS THE FANTAIL.

NOMENCLATURE

DOORS, HATCHES, SCUTTLES AND MANHOLES

- DOORS ARE CLOSURES IN BULKHEADS
  - WATERTIGHT (WT) DOORS
  - WEATHERTIGHT DOORS
  - NONTIGHT DOORS
  - JOINER DOORS
- HATCHES ARE CLOSURES IN DECKS
  - ACCESS HATCHES
  - CARGO HATCHES

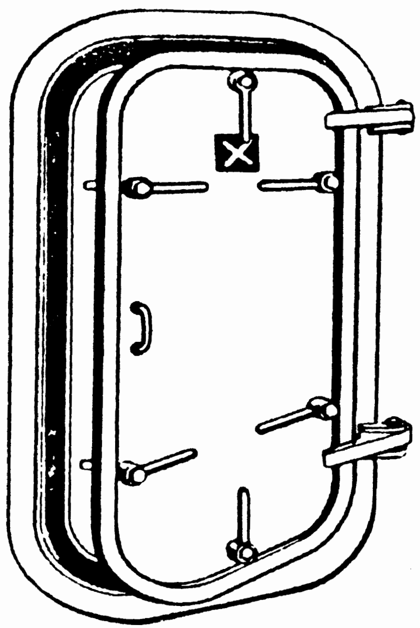
NOMENCLATURE

DOORS, HATCHES, SCUTTLES AND MANHOLES

- SCUTTLES ARE SMALL CLOSURES IN HATCHES, DECKS OR BULKHEADS
  - ESCAPE SCUTTLES ARE FITTED WITH QUICK-ACTING OPENING AND CLOSING MECHANISM
  - PASSING SCUTTLES ARE USED ON NAVAL COMBATANTS FOR PASSING AMMUNITION
- MANHOLES ARE SMALL CLOSURES, BOLTED OR DOGGED, AND ARE USED FOR INFREQUENT ACCESS TO TANKS AND VOIDS FOR MAINTENANCE OR REPAIR

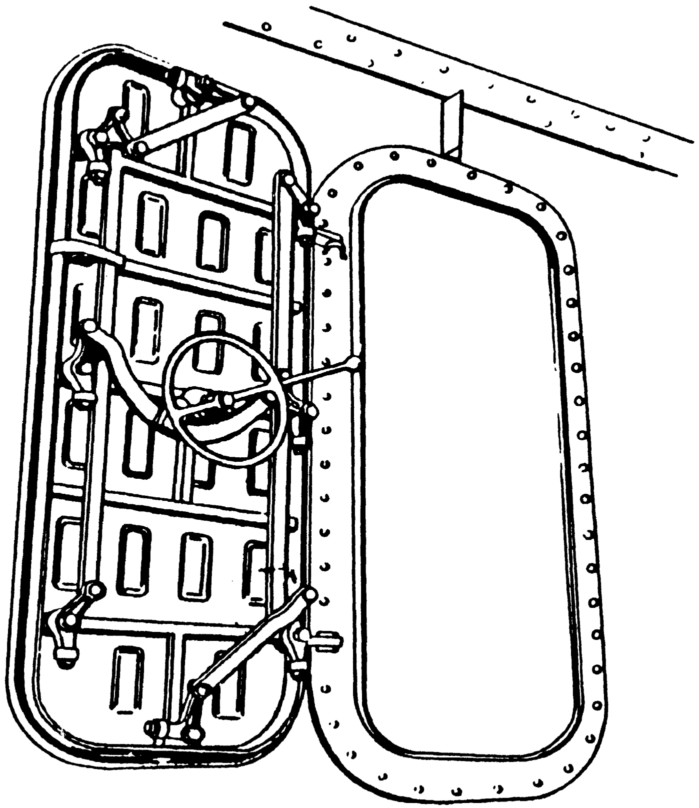
NOMENCLATURE

STANDARD WT DOOR



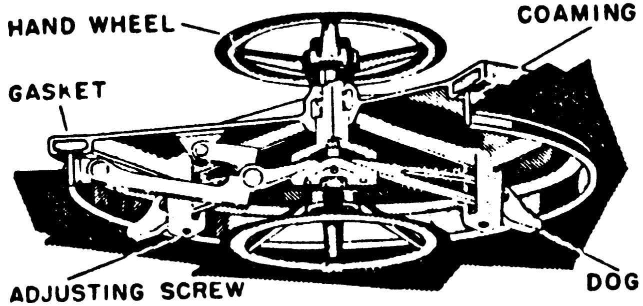
NOMENCLATURE

QUICK ACTING WT DOOR



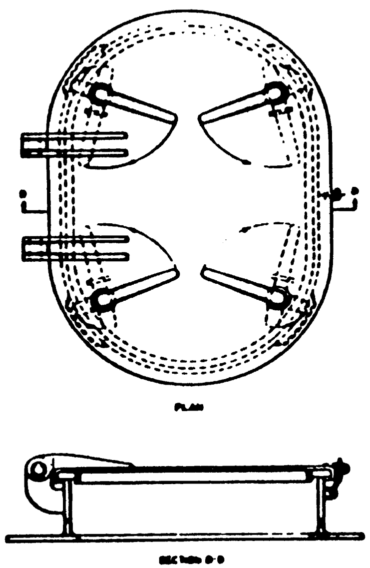
NOMENCLATURE

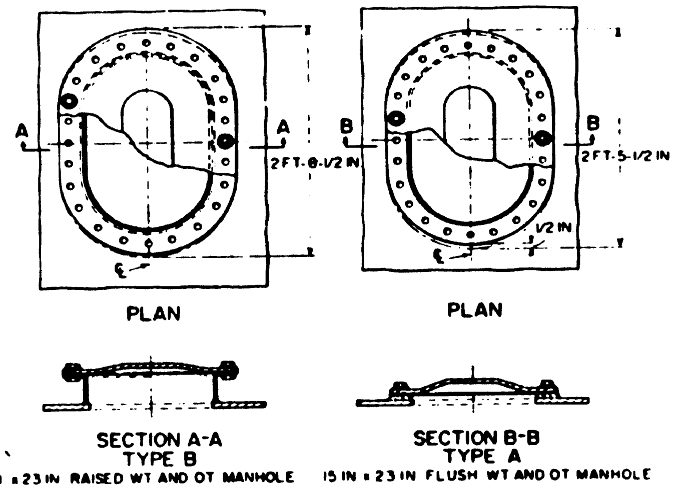
QUICK ACTING SCUTTLE



NOMENCLATURE

MANHOLES





NOMENCLATURE

SPACES ON BOARD SHIP

- A SPACE ABOARD SHIP THAT IS BOUNDED BY DECKS AND BULKHEADS IS CALLED A COMPARTMENT. IF THE BULKHEADS AND DECKS ARE WATERTIGHT THE COMPARTMENT IS A WATERTIGHT COMPARTMENT.
- LARGE SPACES BELOW DECK FOR THE STOWAGE OF CARGO ARE HOLDS.
- PASSAGEWAY IS THE NAUTICAL TERM FOR CORRIDORS ON BOARD SHIP.
- THE OVERHEAD OF A COMPARTMENT ON BOARD SHIP CORRESPONDS TO THE CEILING OF A ROOM ASHORE.
- ALTHOUGH THE OVERHEAD IN A STATEROOM IS SOMETIMES CALLED A CEILING, CEILING IS USUALLY USED TO MEAN WOOD COVERING PLACED ON THE TANK TOP IN A HOLD FOR PROTECTION FROM DAMAGE IN HANDLING CARGO.

NOMENCLATURE

SPACES ON BOARD SHIP (CON'T)

- THE TRADITIONAL NAME GIVEN TO THE SPACE IN WHICH FOOD IS PREPARED IS THE GALLEY.
- A GANGWAY IS THE STAIRWAY OR RAMP PROVIDED BY THE DOCK FACILITY USED FOR BOARDING OR DISEMBARKING FROM THE SHIP.
- ON NAVAL SHIPS THE AREA ADJACENT TO THE GANGWAY WHERE VISITORS ARE RECEIVED AND THE IN-PORT WATCH IS STOOD IS CALLED THE QUARTERDECK.
- LADDERS ARE USED FOR ACCESS BETWEEN DECKS. VERTICAL LADDERS ARE INSTALLED FOR ACCESS TO HOLDS, TANKS, AND SPACES WHERE HORIZONTAL ACCESS IS NOT POSSIBLE. INCLINED LADDERS ARE PROVIDED FOR PERSONNEL ACCESS IN FREQUENTLY USED AREAS. CONVENTIONAL STAIRWAYS, INSTALLED IN A STAIRWELL, ARE USED FOR PASSENGERS, WHEN CARRIED.
- A COMPANIONWAY IS AN ACCESS HATCH IN A DECK WITH A LADDER LEADING BELOW.

NOMENCLATURE

MORE PARTS OF A SHIP

BOOBY HATCH: AN ACCESS HATCH IN A WEATHER DECK PROTECTED BY A HOOD FROM SEA AND WEATHER.

BOOT TOPPING, BOOTTOP: THE SURFACE OF THE HULL BETWEEN THE LIGHT AND THE LOAD WATERLINES. SPECIAL PRESERVATIVE COATINGS ARE USED IN PAINTING THE BOOTTOP.

SEA CHEST: AN ENCLOSURE FITTED TO THE INSIDE OF THE UNDERWATER HULL AND OPEN TO THE SEA. SALT WATER TO BE USED FOR COOLING, FIRE AND FLUSHING SYSTEMS IS DRAWN FROM THE SEA CHEST.

'TWEEN DECKS: THE SPACE BETWEEN ANY TWO ADJACENT DECKS.

NOMENCLATURE

MORE PARTS OF A SHIP (CON'T)

PORT, PORTHOLE, PORTLIGHT, AIR PORT: A HINGED GLASS WINDOW, GENERALLY CIRCULAR, IN THE SHIP'S SIDE OR DECK HOUSE FOR LIGHT AND VENTILATION.

DEADLIGHT, FIXED LIGHT: A PORT WHICH DOES NOT OPEN.

DEADWOOD: ORIGINALLY, THE SOLID WOOD STRUCTURE AT THE STERN OF THE SHIP JUST ABOVE THE KEEL USED TO SUPPORT THE RUDDER POST. TODAY, THE SLENDER PORTION OF SINGLE SCREW SHIP JUST FORWARD OF THE STERN FRAME AND ABOVE THE KEEL.

SKEG: A DEEP VERTICAL FINLIKE PROJECTION ON THE BOTTOM OF A SHIP NEAR THE STERN. A SKEG IS TREATED AS AN APPENDAGE TO THE SHIP, WHEREAS THE DEADWOOD IS FAIRED INTO THE HULL.

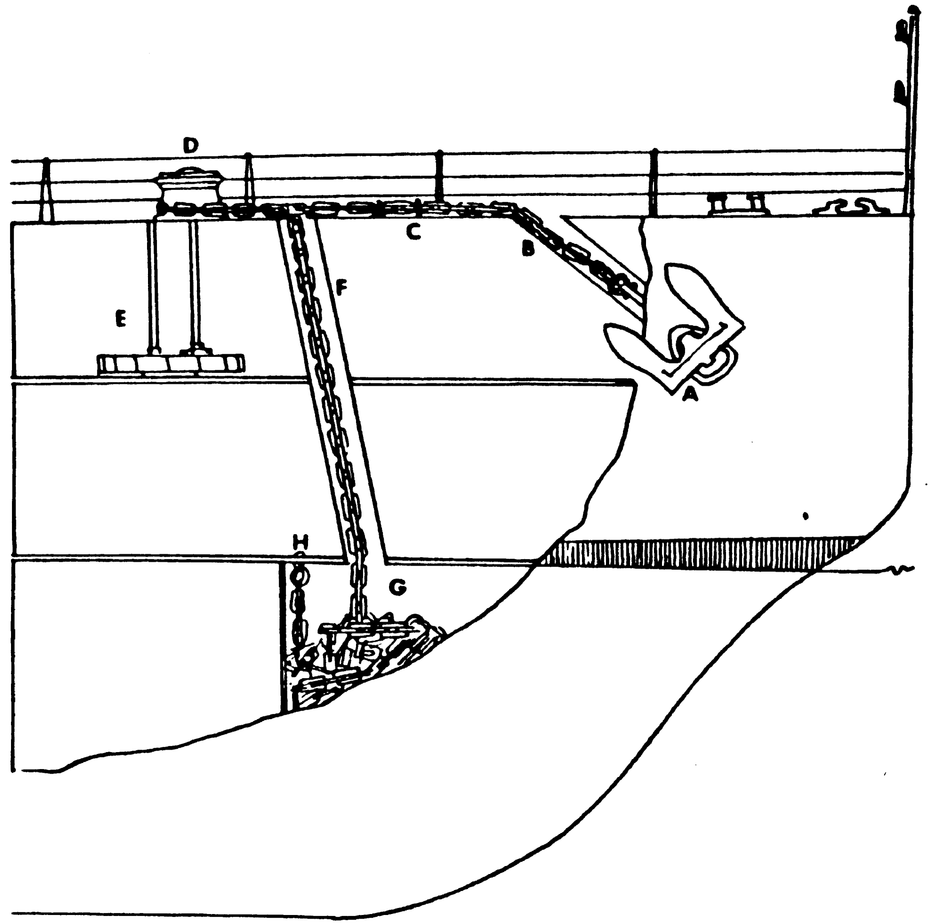
NOMENCLATURE

ANCHORING AND MOORING

- TACKLE IS PRONOUNCED "TAY-KLE"
- GROUND TACKLE REFERS TO THE ANCHORS, ANCHOR CHAINS, CABLES, WIRE ROPES, CHAIN STOPPERS AND OTHER GEAR ASSOCIATED WITH ANCHORING A SHIP TO THE BOTTOM
- MOORING REFERS TO MOORING A SHIP ALONGSIDE A PIER OR A QUAY (PRONOUNCED "KEY") OR MOORING TO A PERMANENT MOORING BUOY.
- MOORING FITTINGS INCLUDE CLEATS, BITTS, CHOCKS, ROLLER CHOCKS, BULLNOSE.

NOMENCLATURE

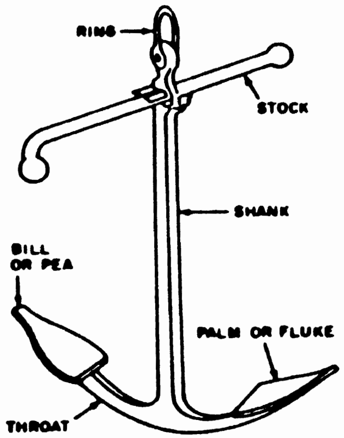
GROUND TACKLE



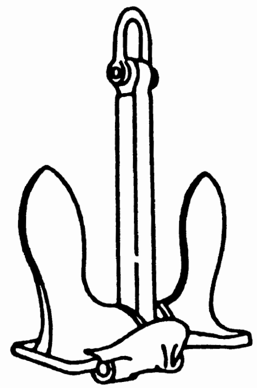
KEY WORDS: HAWSEPIPE, CHAIN LOCKER, BITTER END

NOMENCLATURE

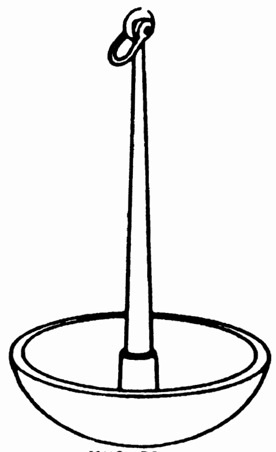
ANCHORS



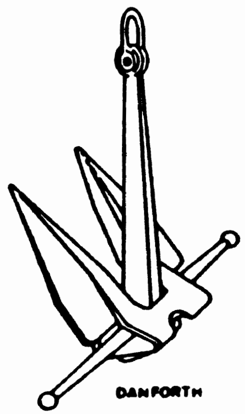
NAVY TYPE STOCK



COMMERCIAL STOCKLESS



MUSHROOM

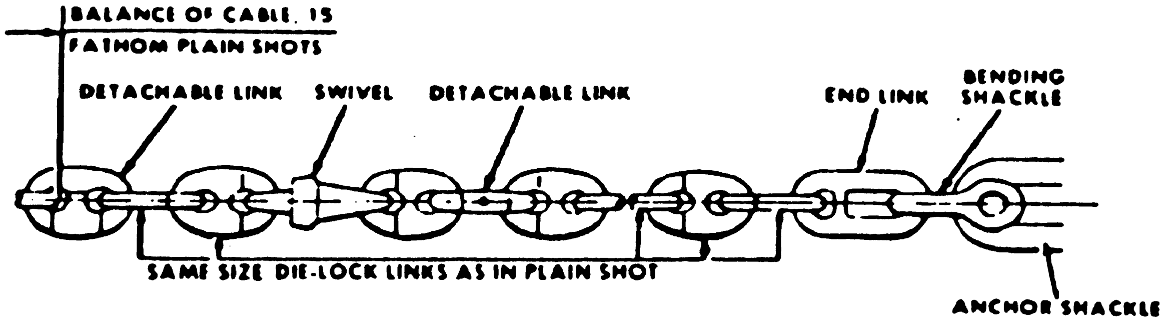


DANFORTH

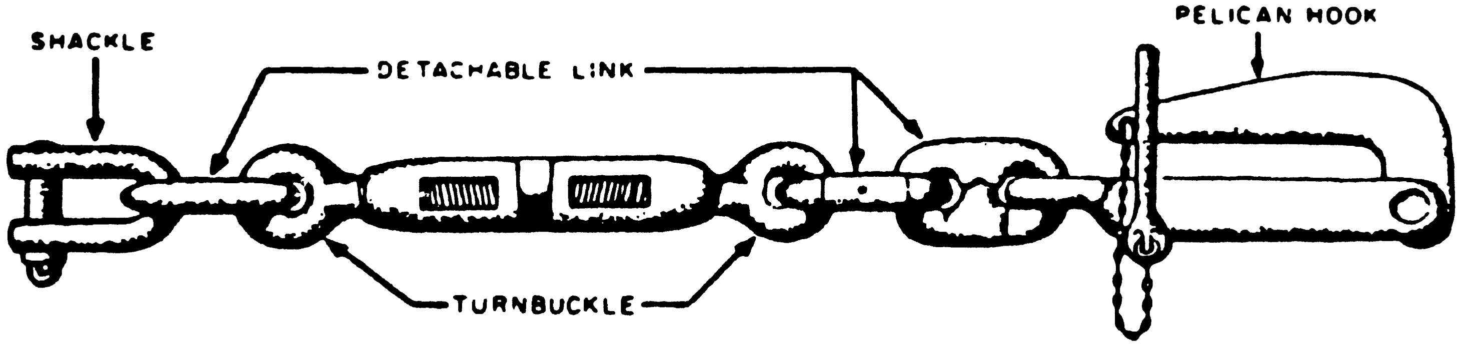
NOMENCLATURE

ANCHOR CHAIN AND CHAIN STOPPERS

A STANDARD SHOT OF ANCHOR CHAIN IS 15 FATHOMS IN LENGTH. A FATHOM IS 6 FEET.



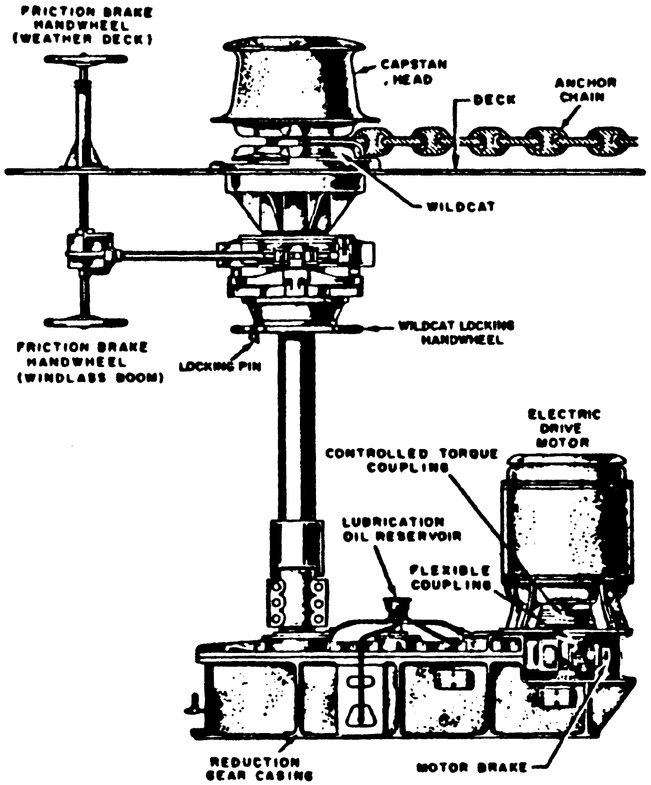
STANDARD OUTBOARD SWIVEL SHOT & METHOD OF ASSEMBLING



KEY WORDS: SHOT OF CHAIN, PELICAN HOOK, FATHOM, CHAIN STOPPER

NOMENCLATURE

VERTICAL SHAFT WINDLASS



KEY WORDS: WINDLASS, WILDCAT, CAPSTAN

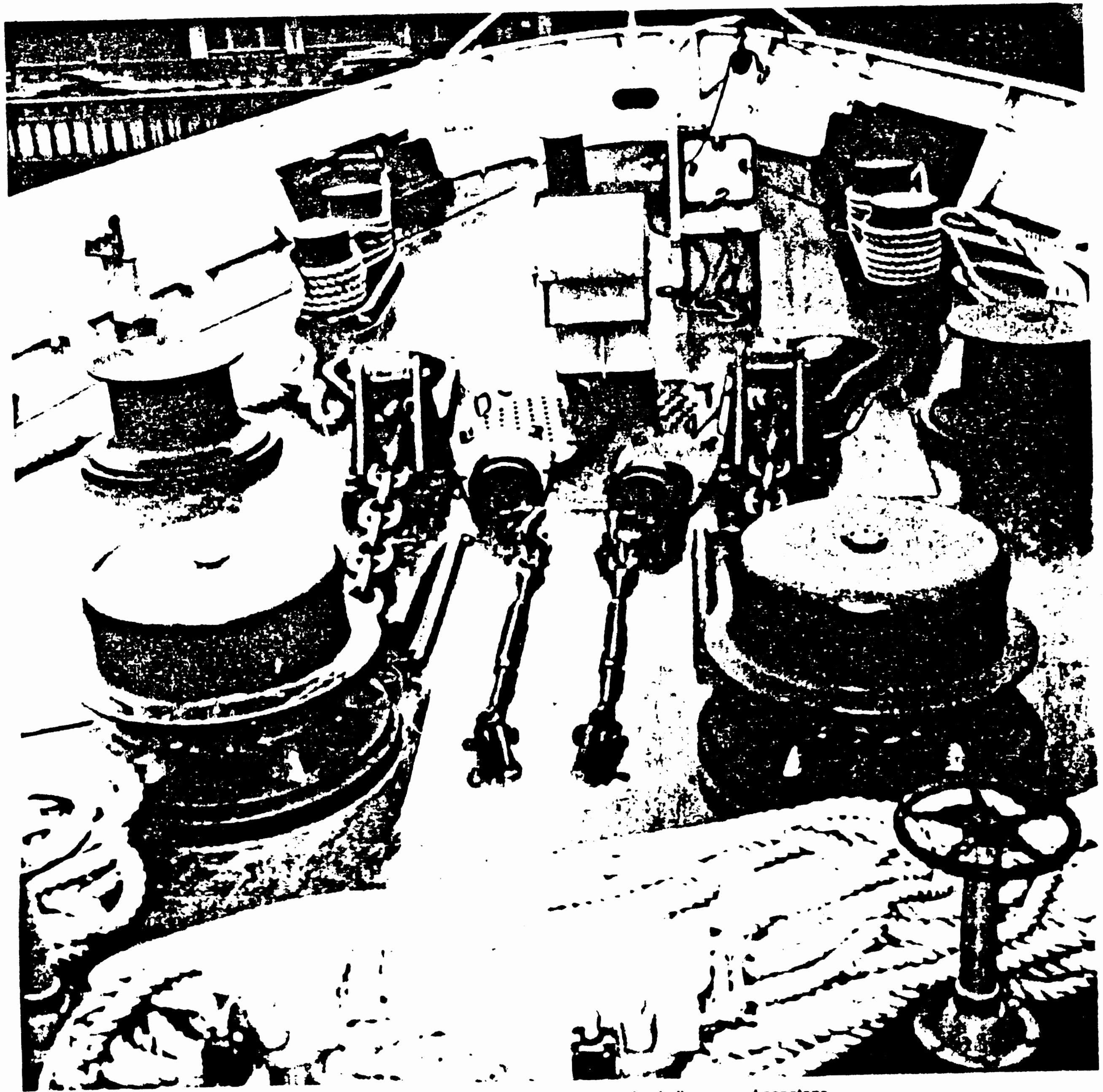


Fig. 15 Deck arrangement for vertical shaft windlasses and capstans

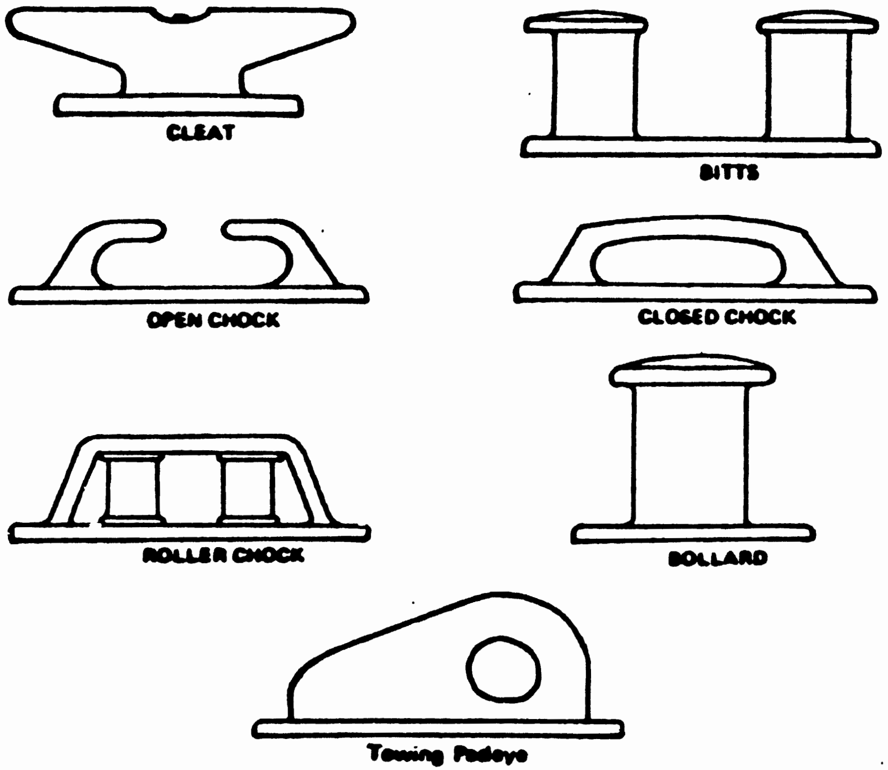
NOMENCLATURE

¦OREDECK ARRANGEMENT WITH VERTICAL SHAFT WINDLASSES ⁊ CAPSTANS

Figure 6-12. Riding and housing chain stoppers are made up of a turnbuckle inserted in a short section of chain, with a slip or pelican hook attached to one end of the chain and a shackle at the other end.

NOMENCLATURE

MOORING FITTINGS



KEY WORDS: BOLLARD, CHOCK, BITTS, CLEAT, PADEYE

BASIC NAVAL ARCHITECTURE

Unit Number: 6

Title: Nomenclature - 3

Tape Running Time: $36^{M}\ 30^{S}$

Reading Assignment: None

Additional References: (same as Unit 5)

Scope:

(same as Unit 5)

Key Points to Emphasize:

1. Modern trend is to use more expensive cargo gear to move cargo faster and reduce port time. More true for expensive ships carrying more expensive cargoes. (Less true for older ships carrying cargoes of opportunity to smaller ports (tramps)). Constantly emphasize the role of economics in making design and equipment decisions.

2. Structural nomenclature items will appear again in Unit 37.

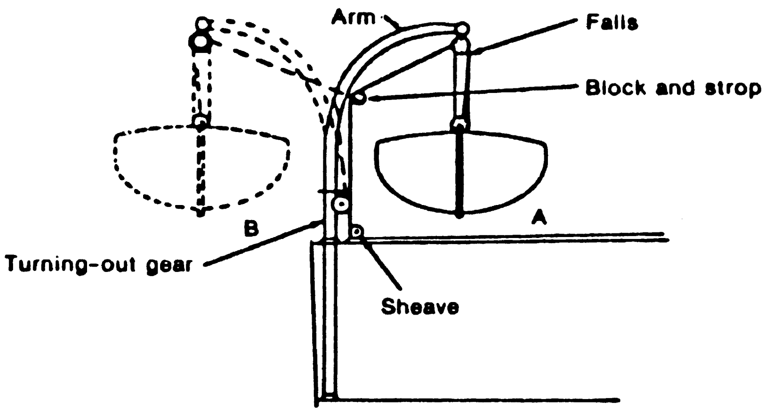
3. Emphasize nomenclature items or usage that is particularly relevant to sponsoring organization.

4. Correction to tape narration: stern casting will be cast steel, not cast iron.

Suggested Problem Assignment: None

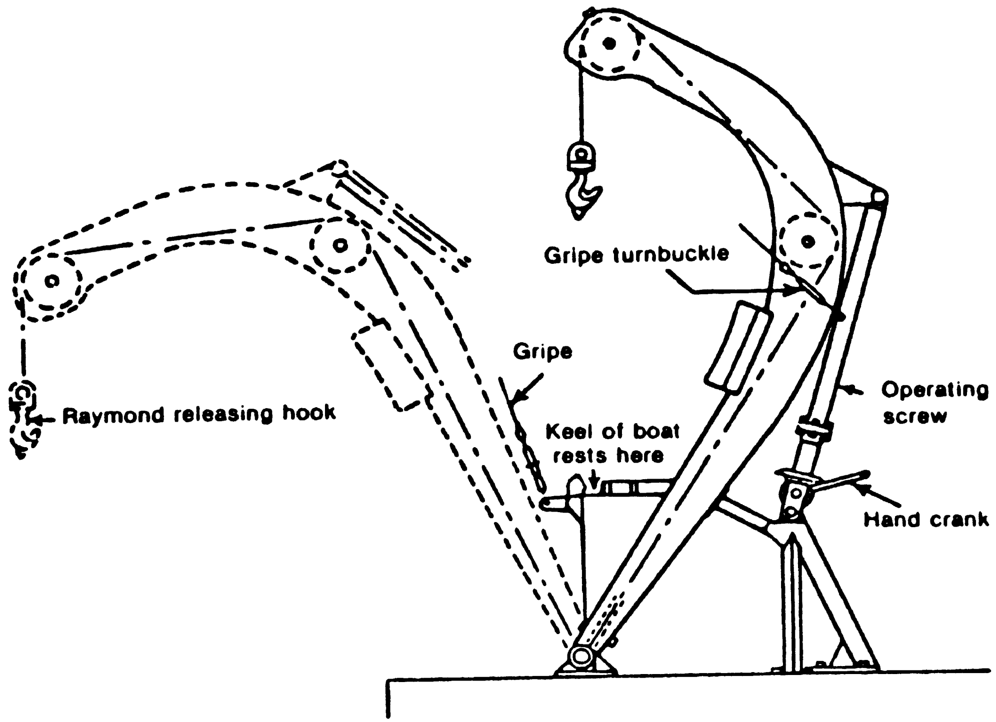
NOMENCLATURE

RADIAL DAVITS



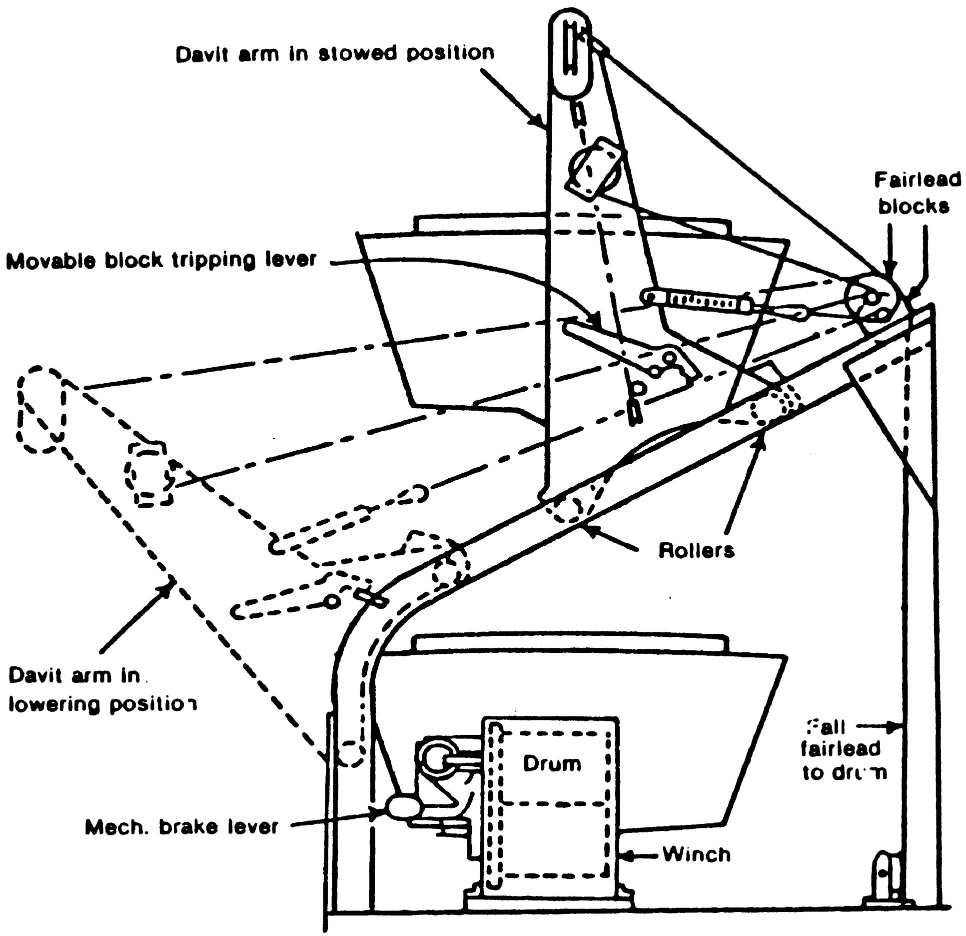
NOMENCLATURE

CRESENT DAVIT



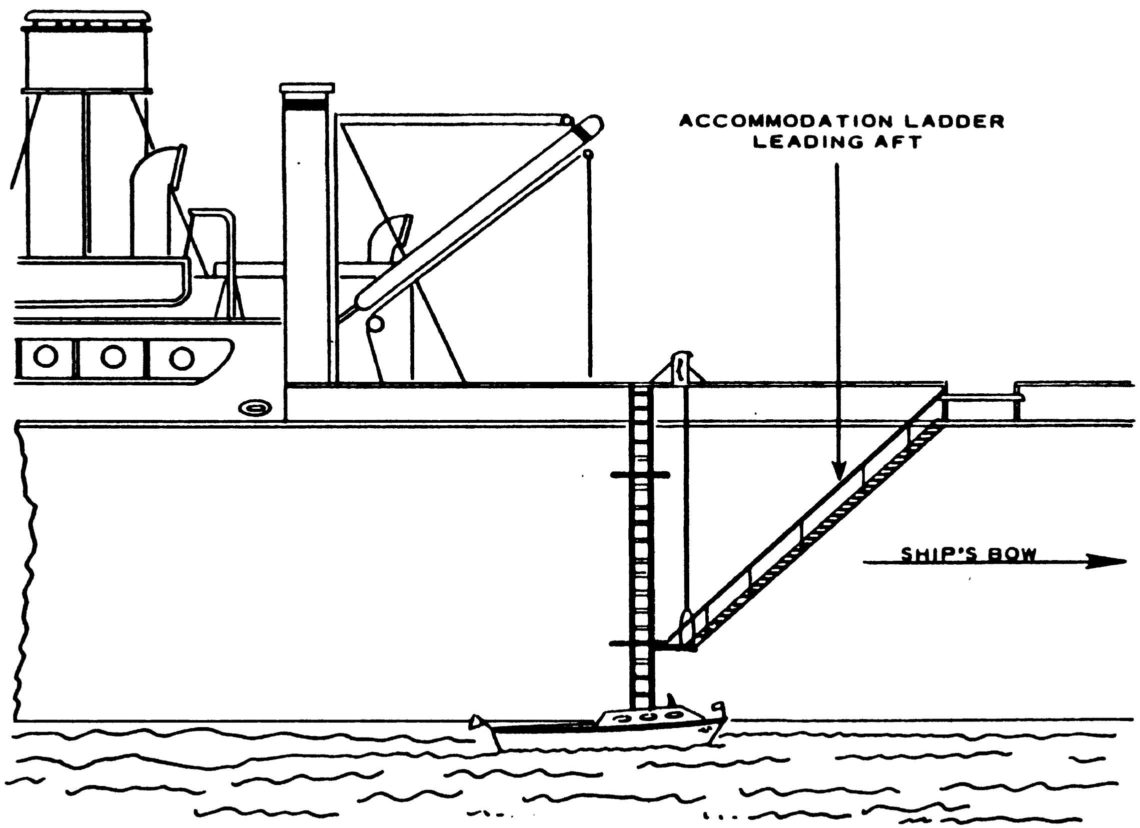
NOMENCLATURE

WELIN TRACKWAY GRAVITY DAVIT



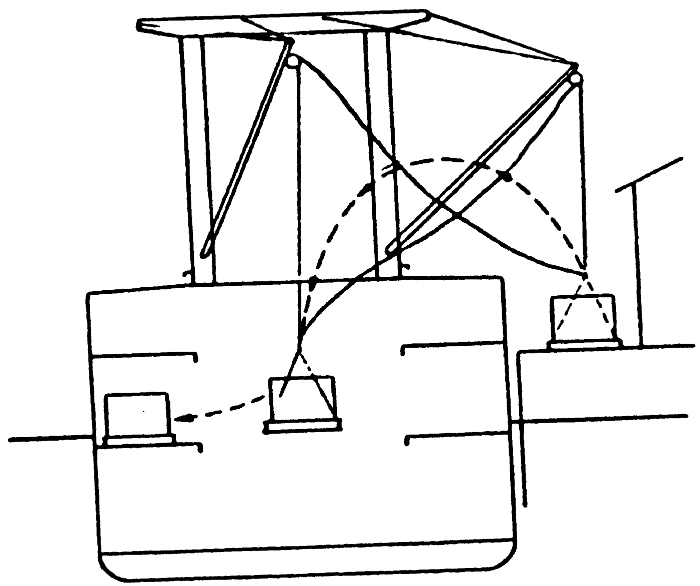
NOMENCLATURE

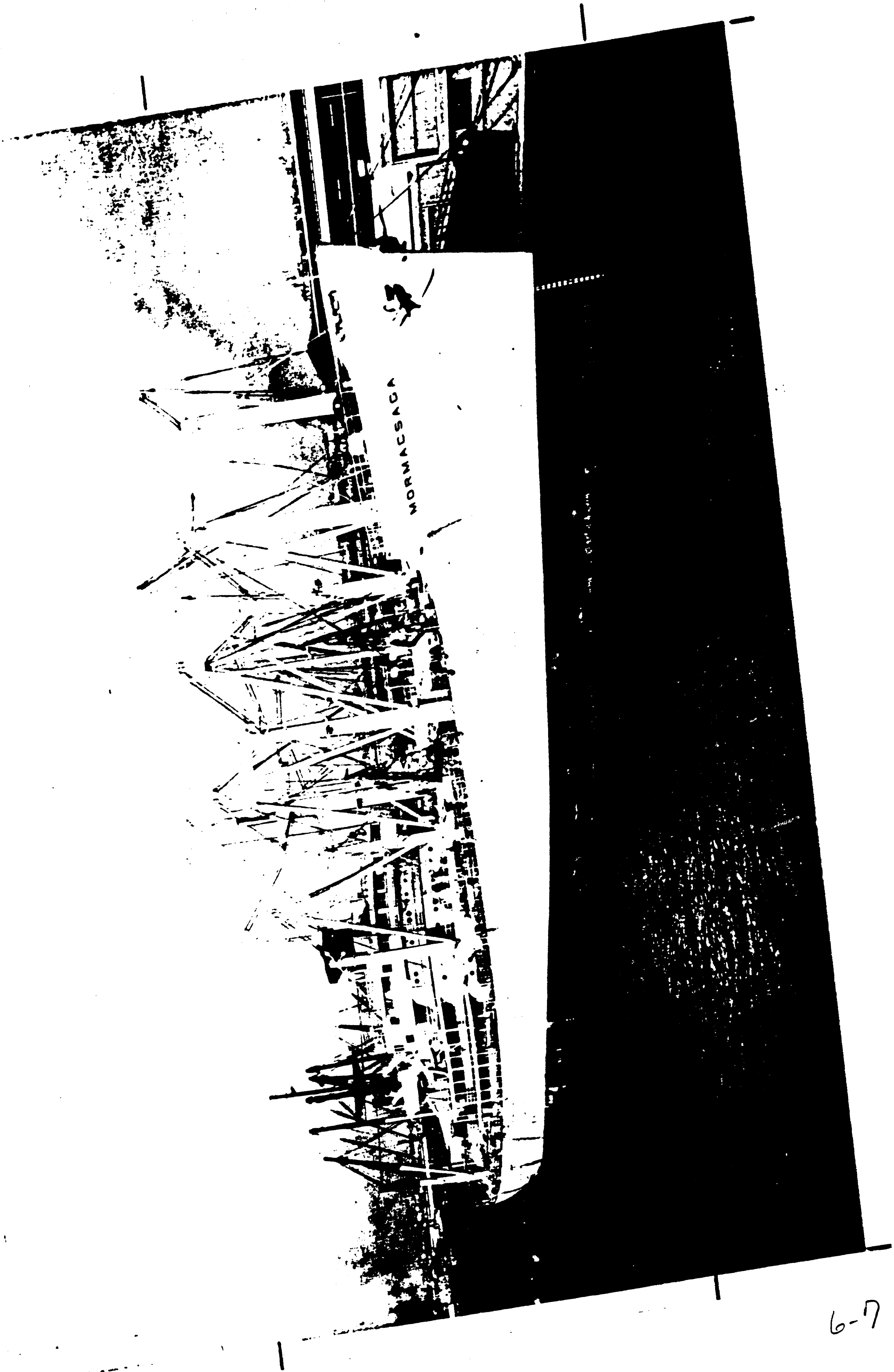
ACCOMODATION LADDER AND JACOB'S LADDER



NOMENCLATURE

CARGO HANDLING - THE BURTONING SYSTEM

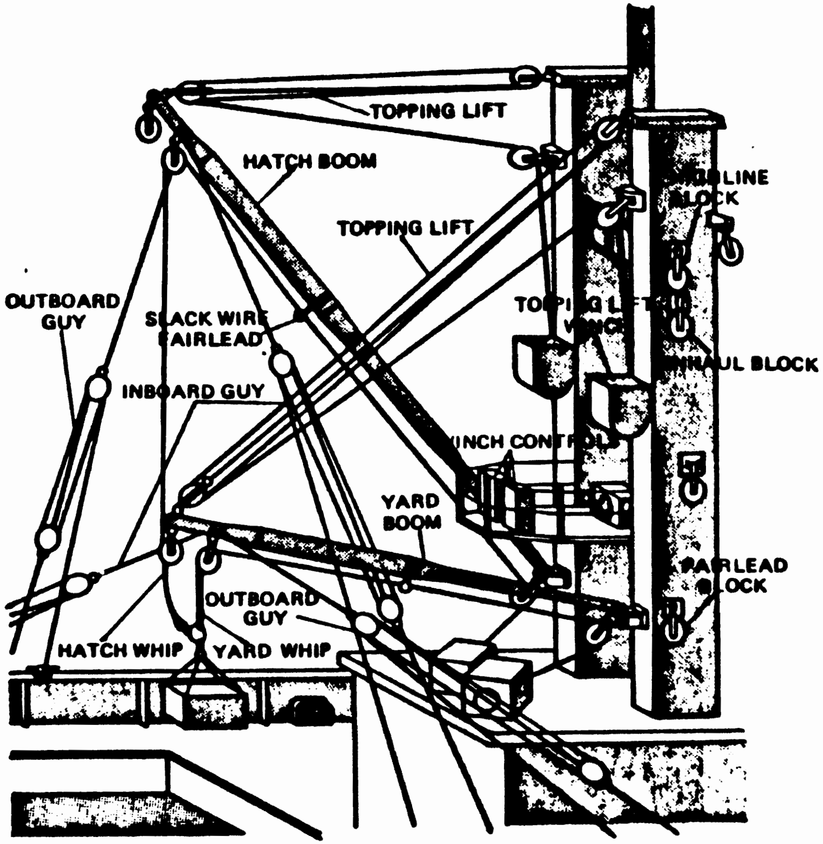




6-7

NOMENCLATURE

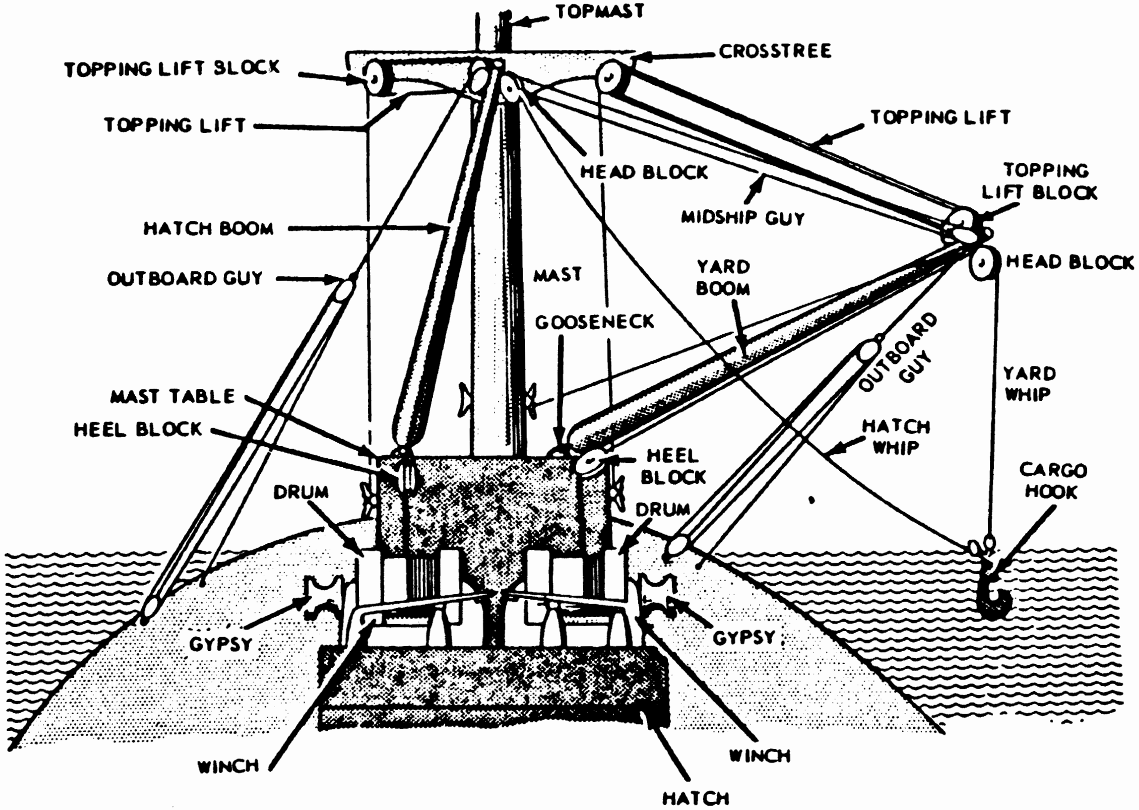
CARGO HANDLING GEAR



KEY WORDS: KINGPOST, HATCH BOOM, YARD BOOM, WHIP, GUY, FAIRLEAD, TOPPING LIFT

NOMENCLATURE

CARGO HANDLING GEAR

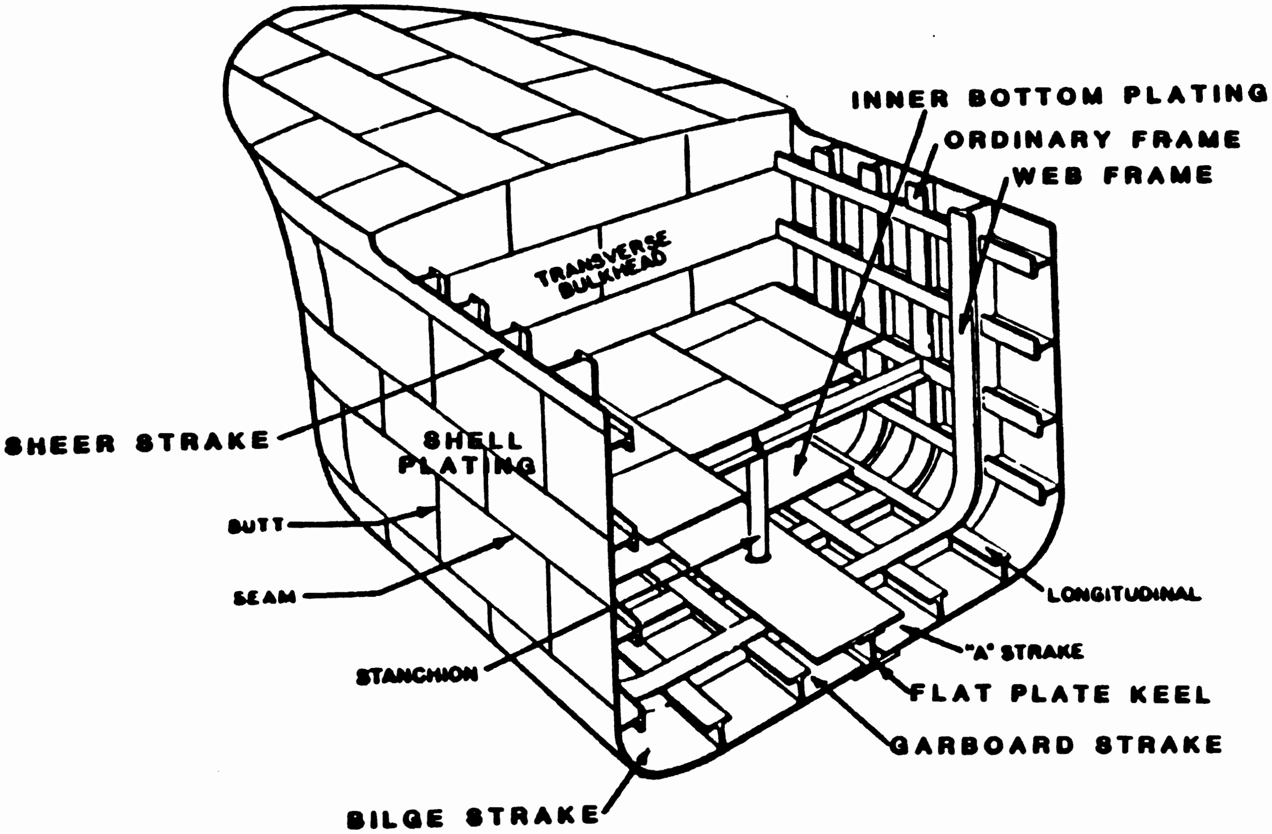


KEY WORDS: TOPPING LIFT, HATCH WHIP, YARD WHIP, CROSSTREE, GYPSY, GOOSENECK

STRUCTURAL TERMINOLOGY

SHELL PLATING:

STRAKES OF SHELL PLATING ARE DESIGNATED WITH LETTERS, STARTING WITH "A" AS THE FIRST STRAKE OUTBOARD OF THE FLAT PLATE KEEL. CERTAIN STRAKES HAVE SPECIAL NAMES -- GARBOARD STRAKE, BILGE STRAKE, AND SHEER STRAKE.



NOMENCLATURE

STRUCTURAL TERMINOLOGY

LONGITUDINALS ARE THE LONGITUDINAL STIFFNERS USED IN THE LONGITUDINAL FRAMING SYSTEM TO SUPPORT DECKS, FLATS, INNER BOTTOM, BOTTOM AND SIDE SHELL.

STRINGERS ARE LONGITUDINAL MEMBERS USED TO SUPPORT THE SIDE SHELL FRAMES AND PLATING. THE TERM IS USUALLY USED IN CONNECTION WITH TRANSVERSE SIDE FRAMING.

THE STRINGER PLATE IS THE OUTBOARD STRAKE OF PLATING ON ANY DECK.

THE MARGIN PLATE IS THE OUTBOARD STRAKE OF PLATING IN THE INNER BOTTOM.

NOMENCLATURE

STRUCTURAL TERMINOLOGY

GIRDERS ARE MAIN LONGITUDINAL MEMBERS WHICH SUPPORT DECK BEAMS, DECK STRUCTURE AND BOTTOM.

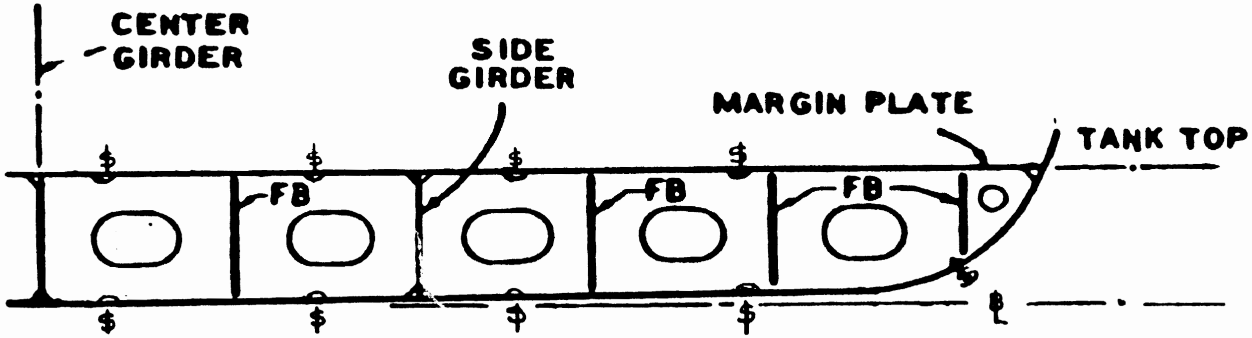
HATCH-SIDE GIRDERS FORM THE LONGITUDINAL BOUNDARIES OF HATCHES.

SIDE GIRDERS RUN LONGITUDINALLY IN THE INNER BOTTOM.

THE CENTER VERTICAL KEEL (CVK) IS ALSO KNOWN AS THE CENTER GIRDER, THE BOTTOM FLANGE OF THE CVK IS OFTEN HEAVIER THAN ADJACENT BOTTOM PLATING AND IS CALLED THE FLAT PLAT KEEL (FPK)

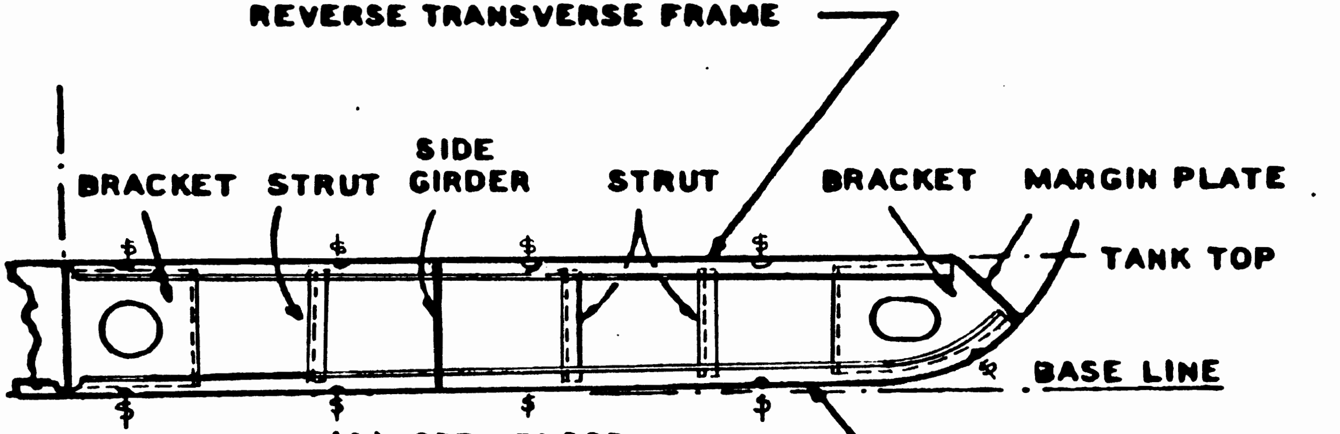
BEAMS ARE TRANSVERSE STRUCTURAL MEMBERS WHICH SUPPORT AND STIFFEN DECK PLATING

SOLID FLOORS ARE MADE UP OF VERTICAL PLATES (WHICH ARE ONLY "SOLID" IF THE FLOOR IS A WT OR AN OT BOUNDARY).



(B) SOLID FLOOR
HORIZONTAL MARGIN

OPEN FLOORS UTILIZE STRUTS FOR VERTICAL MEMBERS

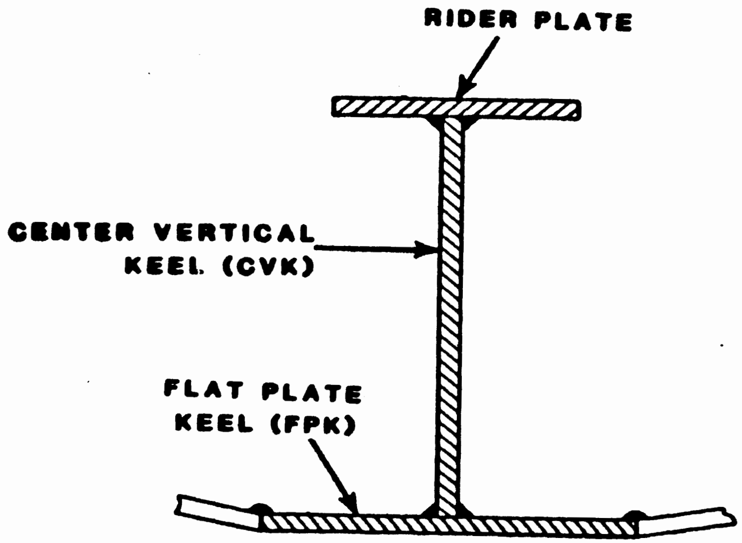


(A) OPEN FLOOR
TURNED-DOWN
MARGIN

NOMENCLATURE

STRUCTURAL TERMINOLOGY

KEEL CONSTRUCTION:



KEY WORDS: FPK, CVK, RIDER PLATE

NOMENCLATURE

FRAMING SYSTEMS

TRANSVERSE FRAMING SYSTEM

- TRANSVERSE MEMBERS INCLUDING

  FLOORS

  SIDE FRAMES

  BEAMS

  ARE CLOSELY SPACED (24" TO 36")

- LONGITUDINAL MEMBERS INCLUDING SIDE STRINGERS AND LONGITUDINAL GIRDERS IN BOTTOM AND DECKS ARE WIDELY SPACED

NOMENCLATURE

FRAMING SYSTEMS

LONGITUDINAL FRAMING SYSTEM

- LONGITUDINAL MEMBERS INCLUDING

  BOTTOM LONGITUDINALS

  SIDE LONGITUDINALS

  DECK LONGITUDINALS

  ARE CLOSELY SPACED (24" TO 36")

- TRANSVERSE MEMBERS, PRINCIPALLY DEEP WEB FRAMES ARE WIDELY SPACED (8' TO 12')

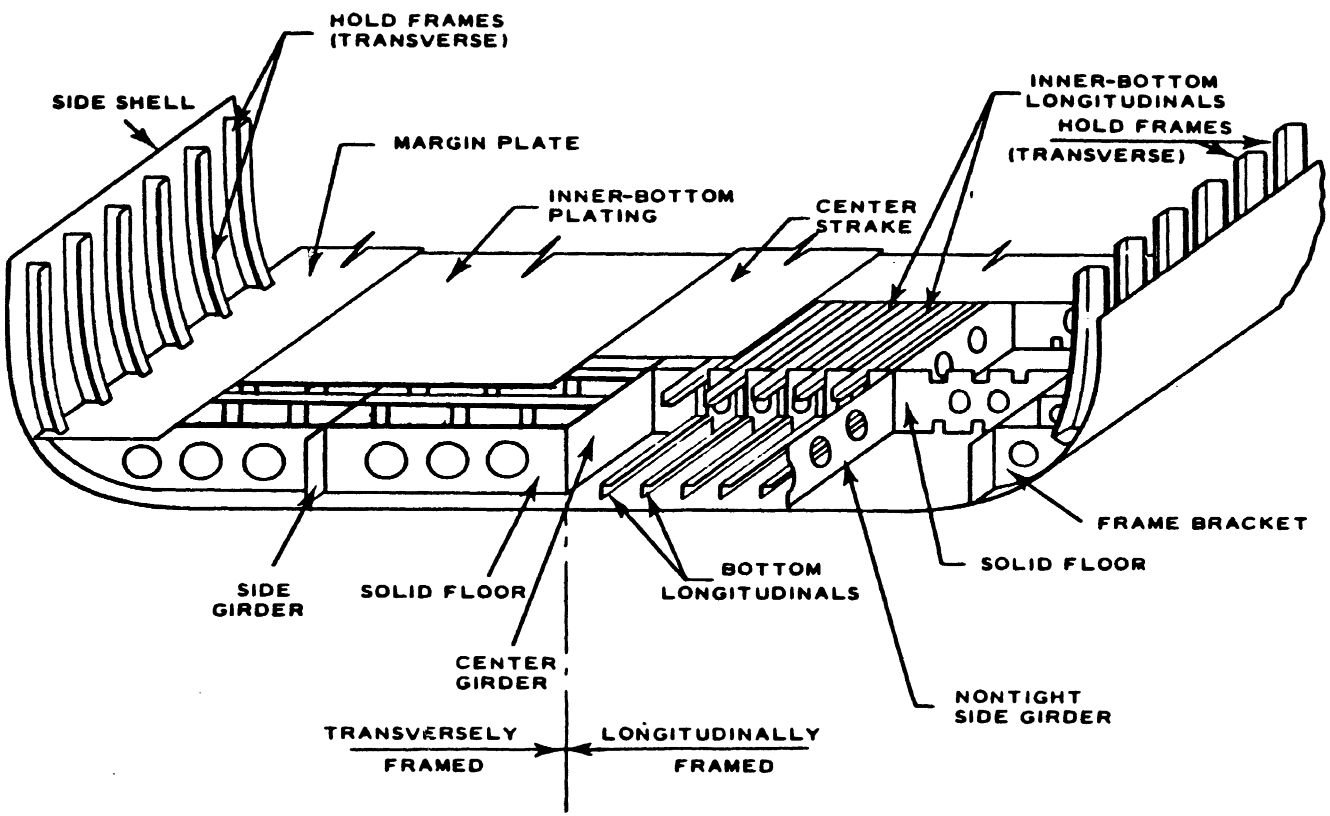
NOMENCLATURE

LONGITUDINAL VESUS TRANSVERSE FRAMING

- LONGITUDINAL FRAMING IS MORE EFFICIENT STRUCTURALLY, BUT-
- FOR SHIPS WHICH CARRY BREAK-BULK, RO/RO, OR CONTAINER CARGOES THE DEEP WEBS WHICH ARE USED WITH THE LONGITUDINAL FRAMING SYSTEMS INTERFERE WITH CARGO STOWAGE.
- DEEP WEBS ARE NO PROBLEM FOR LIQUID CARGOES AND BULK CARGOES. FOR THIS REASON TANKERS AND BULK CARRIERS ARE LONGITINALLY FRAMED.
- COMBINATION FRAMING IS OFTEN USED, LONGITUDINAL FRAMING IN INNER BOTTOM AND DECKS - TRANSVERSE FRAMING IN SIDE SHELL.

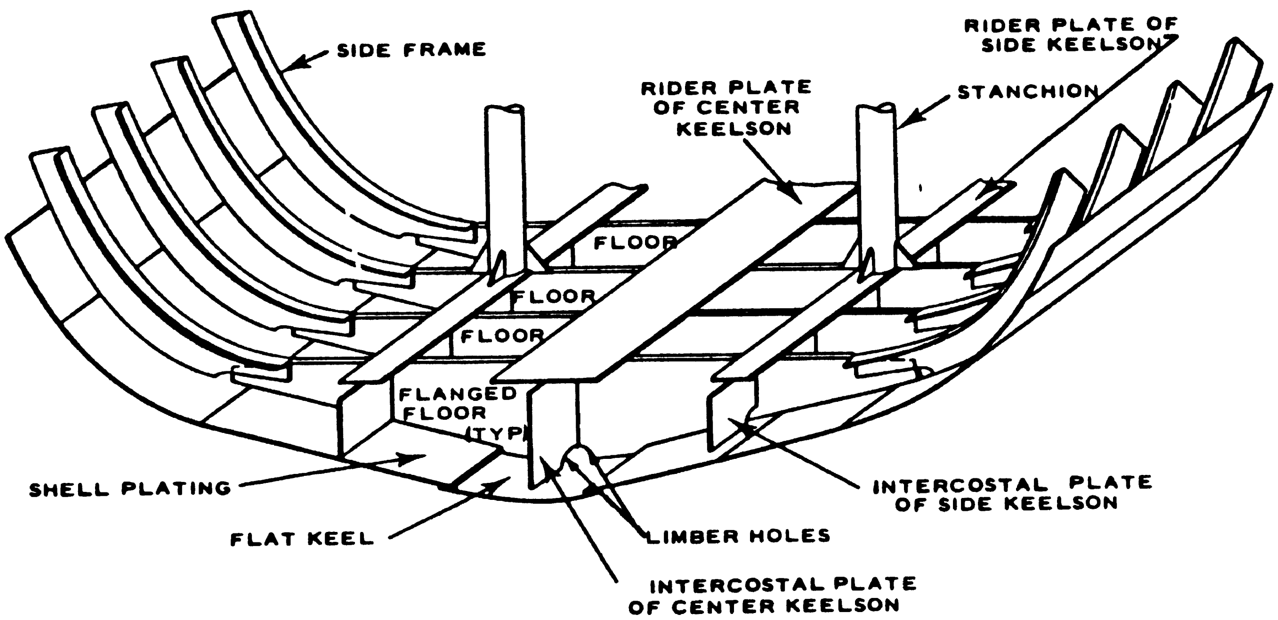
NOMENCLATURE

DOUBLE BOTTOM CONSTRUCTION



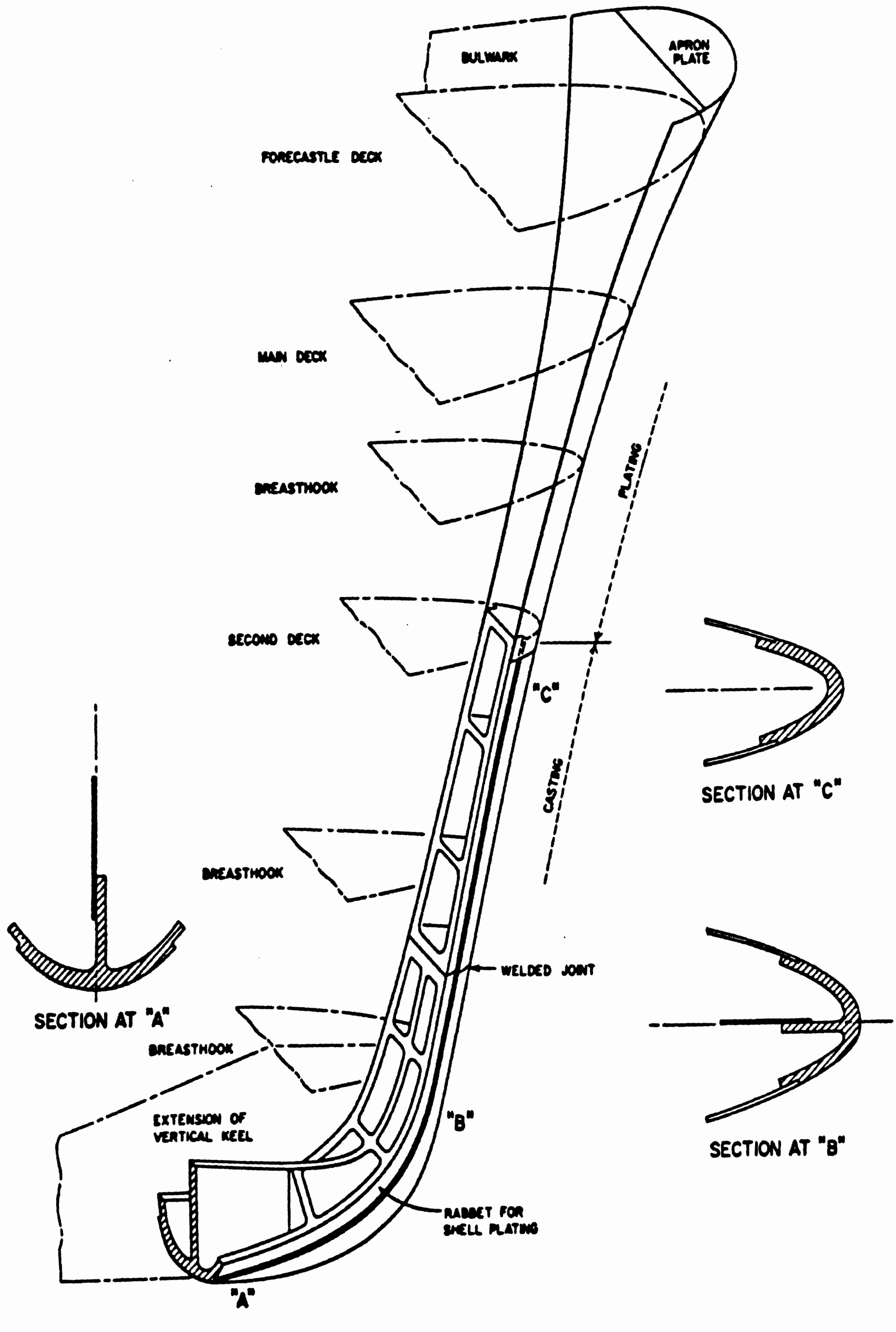
NOMENCLATURE

SINGLE BOTTOM CONSTRUCTION (SMALLER SHIPS)



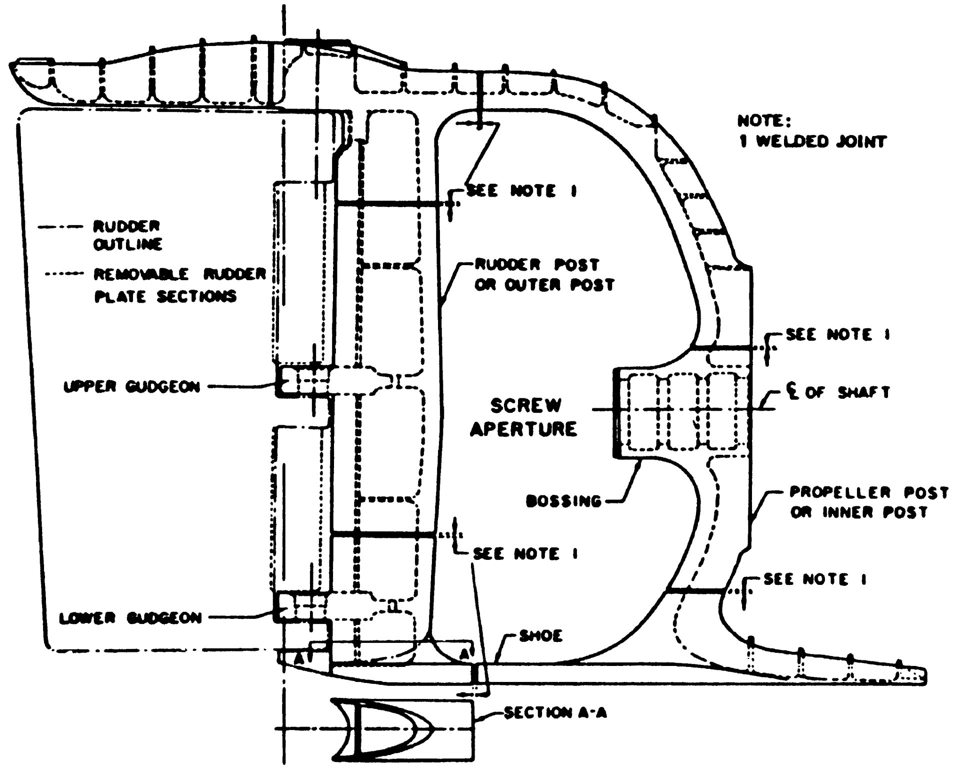
NOMENCLATURE

BOW STRUCTURE



NOMENCLATURE

STERN CONSTRUCTION



(A) STERN FRAME WITH PROPELLER APERTURE AND UNBALANCED RUDDER

NOMENCLATURE

STRUCTURAL TERMINOLOGY

A KEELSON IS A LONGITUDINAL GIRDER IN SINGLE BOTTOM CONSTRUCTION. THE CENTER KEELSON CORRESPONDS TO THE CVK.

SIDE KEELSONS CORRESPOND TO SIDE GIRDERS.

A RIDER PLATE IS A CONTINUOUS FLAT PLATE ATTACHED TO THE TOP (OR BOTTOM) OF A KEELSON OR A GIRDER

THE BILGE STRAKE IS THE STRAKE OF SHELL PLATING AT THE TURN OF THE BILGE.

THE SHEER STRAKE IS THE STRAKE OF SHELL PLATING WHOSE UPPER EDGE RUNS AT THE STRENGTH DECK LEVEL

BASIC NAVAL ARCHITECTURE

Unit Number: 7

Title: Dimension, form and flotation - 1

Tape Running Time: 27^{M} 48^{S}

Reading Assignment: MSD, pp 21-27

Additional References: PNA, pp 1-11, 42-44

SDC, pp 278-280

Scope:

The method of delineating a ship's hull form is introduced together with definitions of the dimensions used to define the hull form. Form coefficients are introduced.

Key Points to Emphasize:

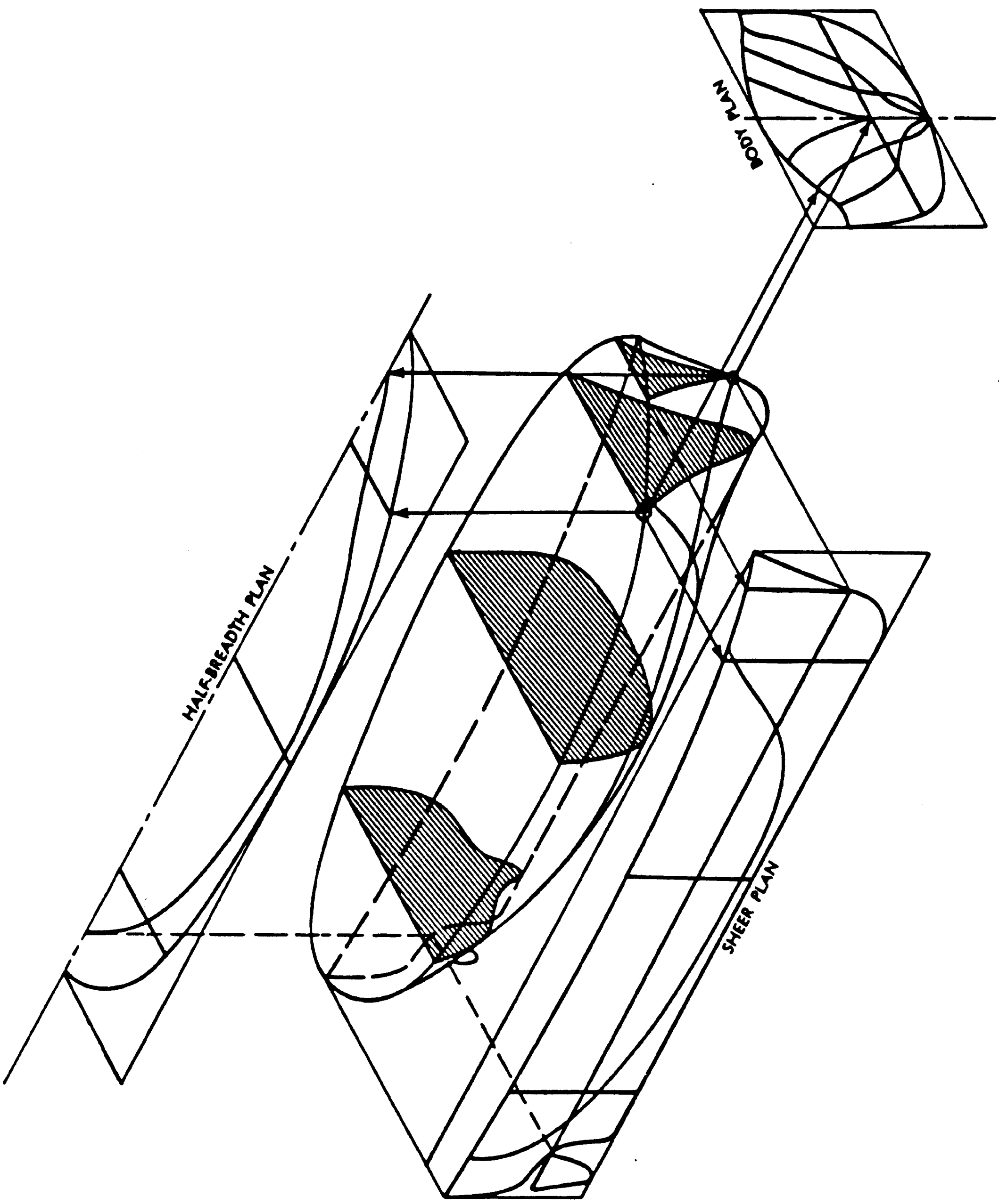
1. Make transparency from MSD, Fig 2-1, pp 22, and use to review video and define relationships between the three orthographic views of the ship's lines.

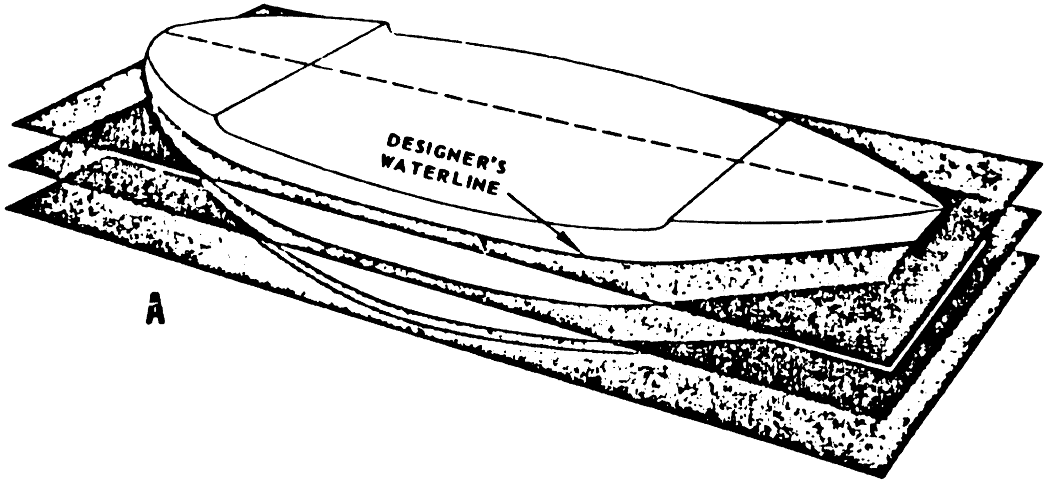
2. Emphasize relation of molded lines to structure and the relation of "displacement" to "molded displacement". Good illustration in SDC, Fig 3, pp 279.

3. Emphasize definitions of light ship weight, deadweight, displacement and tonnage.

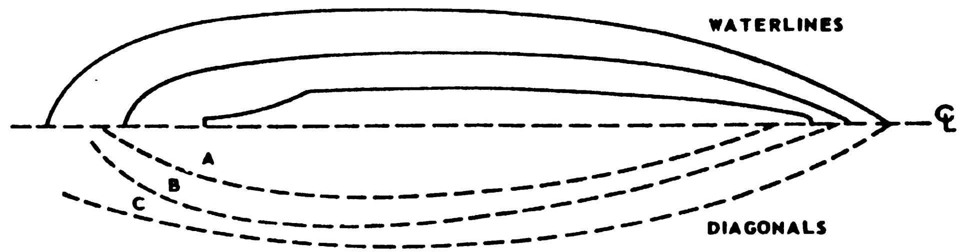
4. Define form coefficients in preparation for example in Unit 8.

Suggested Problem Assignment: None

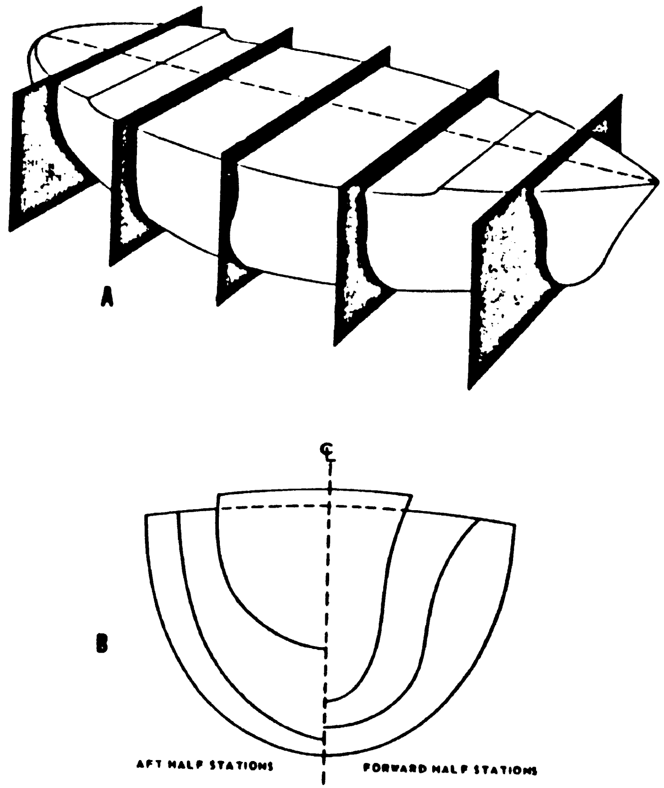

HALF-BREADTH PLAN
SHEER PLAN
BODY PLAN

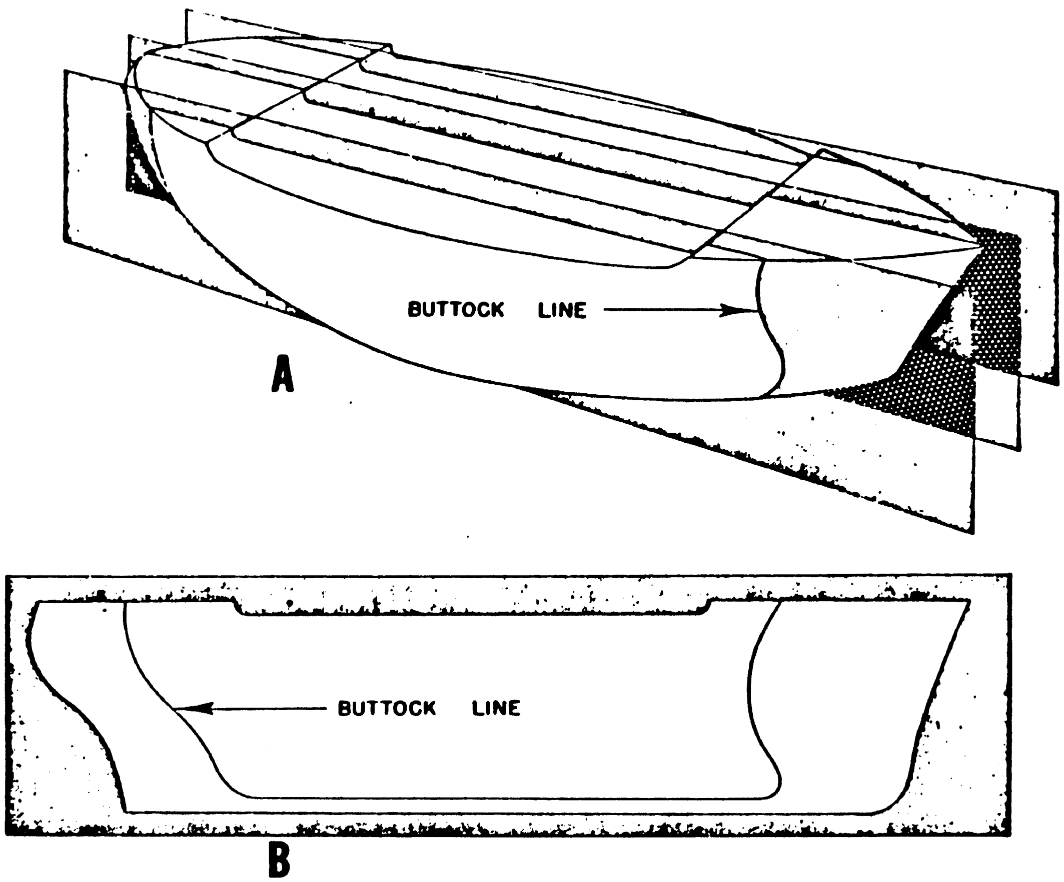


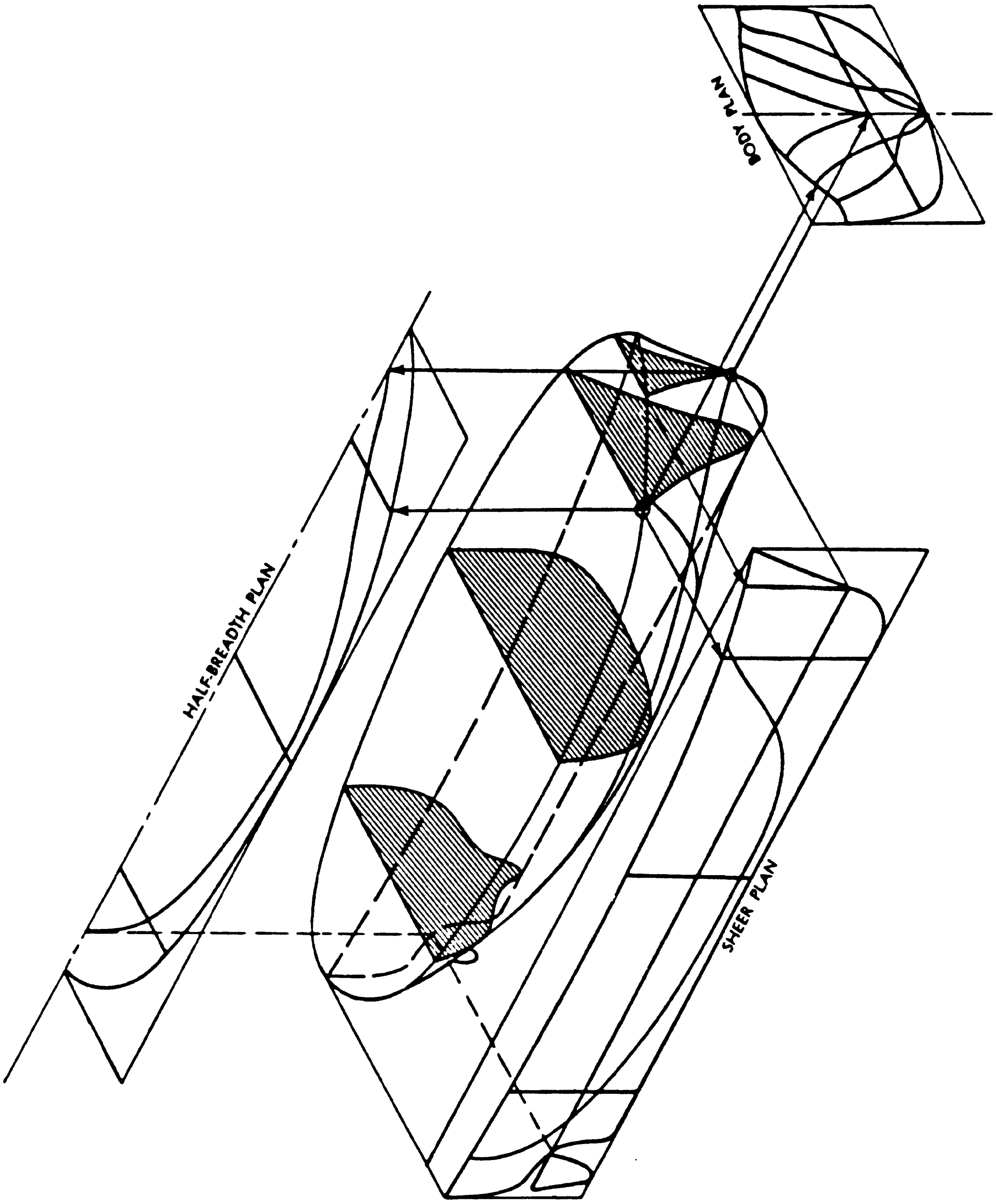
A

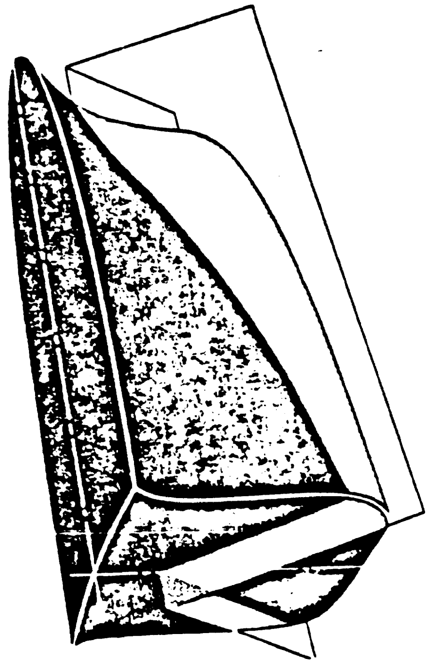


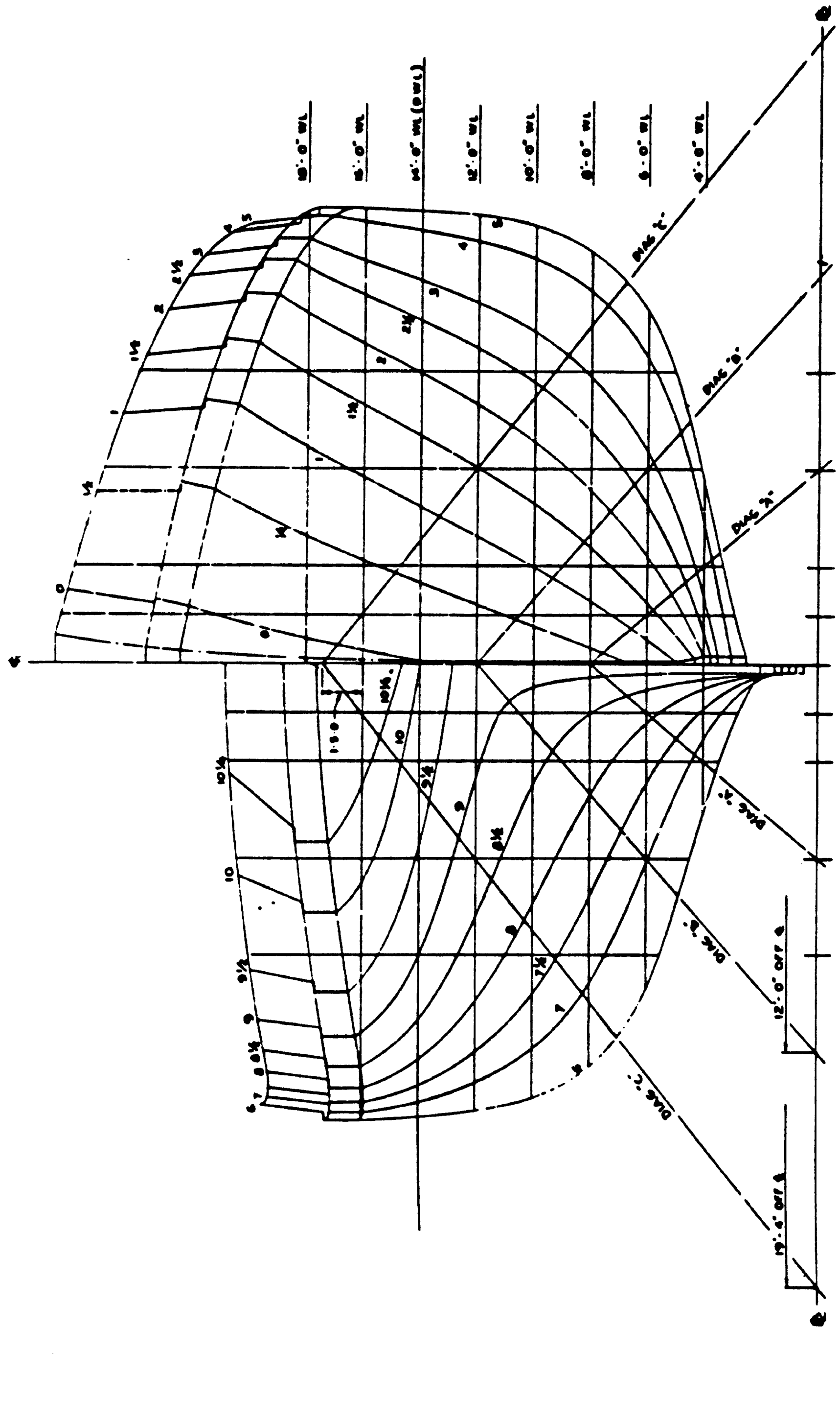
B

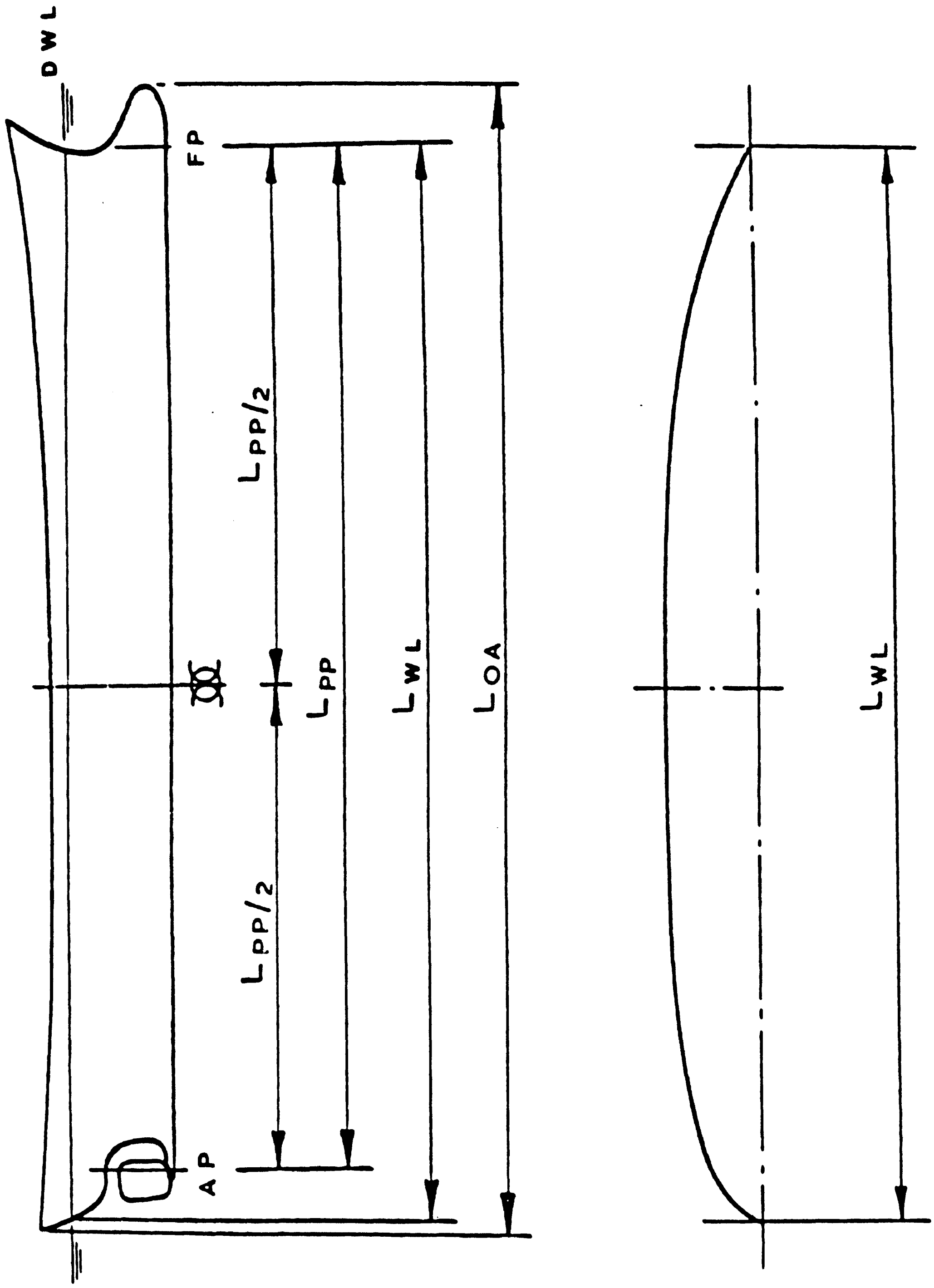

A
B
℄
AFT HALF STATIONS
FORWARD HALF STATIONS

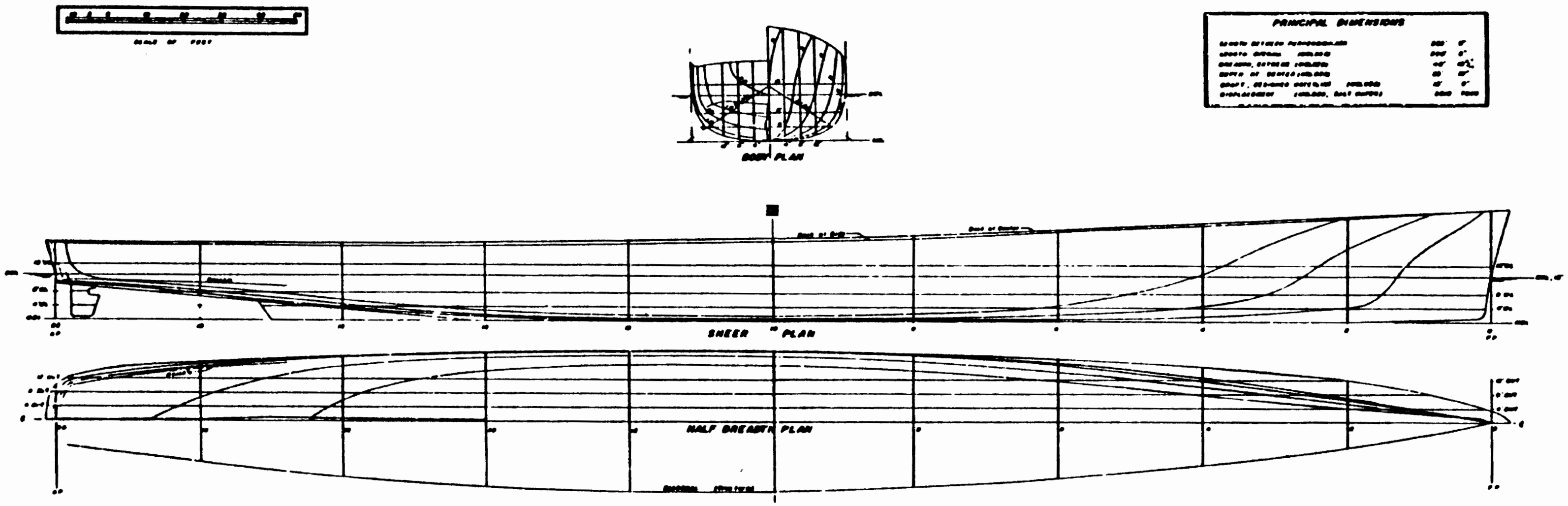

BUTTOCK LINE
A
BUTTOCK LINE
B

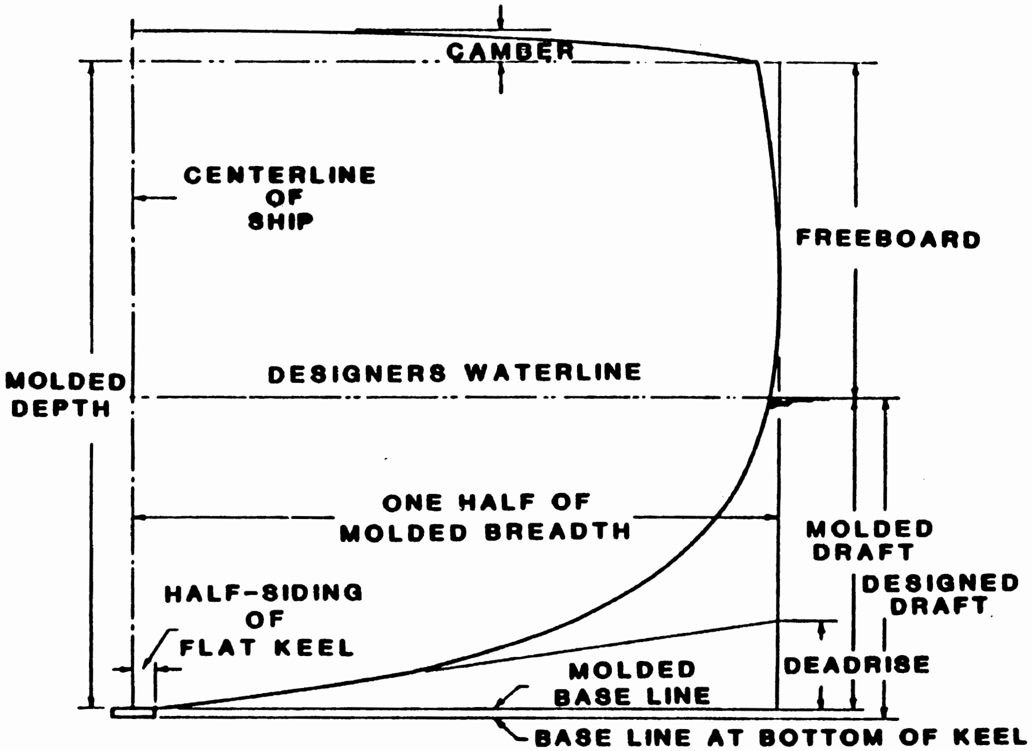

BODY PLAN
HALF-BREADTH PLAN
SHEER PLAN




14'-0" WL (DWL)
12'-0" WL
10'-0" WL
8'-0" WL
6'-0" WL
4'-0" WL
DIAG 'A'
DIAG 'B'
DIAG 'C'
12'-0" OFF ℄


DWL
FP
AP
$L_{PP}/2$
$L_{PP}/2$
L_{PP}
L_{WL}
L_{OA}
L_{WL}


SCALE OF FEET
BODY PLAN
PRINCIPAL DIMENSIONS
SHEER PLAN
HALF BREADTH PLAN


CAMBER
CENTERLINE OF SHIP
FREEBOARD
MOLDED DEPTH
DESIGNERS WATERLINE
ONE HALF OF MOLDED BREADTH
MOLDED DRAFT
DESIGNED DRAFT
HALF-SIDING OF FLAT KEEL
DEADRISE
MOLDED BASE LINE
BASE LINE AT BOTTOM OF KEEL

LIGHT SHIP, DEADWEIGHT AND DISPLACEMENT

LIGHT SHIP WEIGHT

+ DEADWEIGHT

= FULL LOAD DISPLACEMENT

UNITS OF WEIGHT AND DISPLACEMENT

U.S. MARINE PRACTICE:

1 LONG TON = 2240 LBS

OTHER UNITS:

1 SHORT TON = 2000 LBS

1 METRIC TON = 1 TONNE

= 1000 KILOGRAMS

= 2205 LBS

TONNAGE

TONNAGE IS A MEASURE OF THE INTERNAL VOLUME OF A SHIP

1 TON = 100 CUBIC FEET

DO NOT CONFUSE TONNAGE WITH DISPLACEMENT AND WEIGHT UNITS

CONSTANTS YOU SHOULD KNOW

SPECIFIC VOLUME OF SEA WATER (DENSITY FACTOR)

= 35 CUBIC FEET PER LONG TON OF SEA WATER

$$= 35 \frac{FT^3}{TON}$$

CONSTANTS YOU SHOULD KNOW

SPECIFIC VOLUME OF FRESH WATER

$$= \quad 35.9 \ \frac{FT^3}{TON}$$

WHICH IS SOMETIMES ROUNDED OFF TO:

$$36 \ \frac{FT^3}{TON}$$

STANDARD SYMBOLS

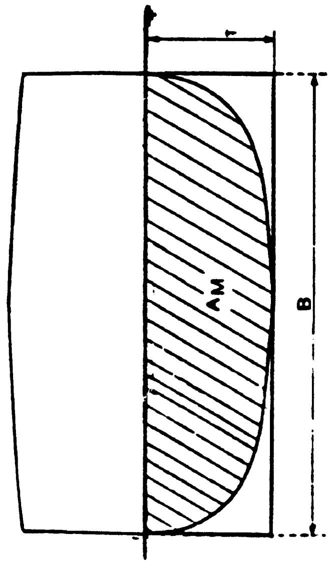
L_{pp}	LENGTH BETWEEN PERPENDICULARS
T	DRAFT
B	BEAM (OR BREADTH)
$\triangle$	DISPLACEMENT
∇	VOLUME OF DISPLACEMENT (CUBIC FEET)
A_m	AREA OF MIDSECTION AT DRAFT T
A_w OR A_{wp}	AREA OF WATER PLANE AT DRAFT T

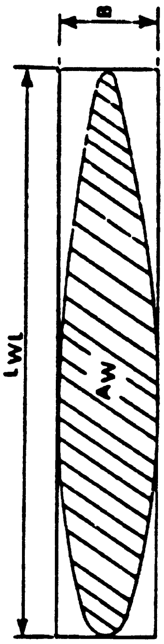
MIDSHIP SECTION COEFFICIENT

$$C_m = \frac{A_m}{BT}$$

WATERLINE COEFFICIENT
(WATERPLANE COEFFICIENT)

$$C_{wp} = \frac{A_{wp}}{B\ L_{pp}}$$


T
B
AM


B
LWL
AW

BLOCK COEFFICIENT

$$C_b = \frac{\nabla}{L_{pp}\ B\ T}$$

SINCE $\nabla = 35\,\Delta$ (SEA WATER)

$$C_b = \frac{35\,\Delta}{L_{pp}\ B\ T}$$

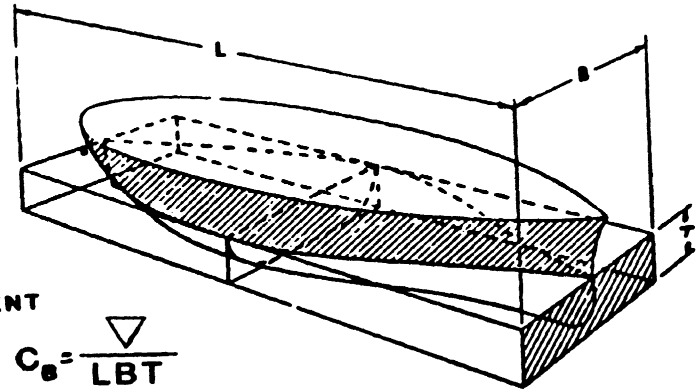
PRISMATIC COEFFICIENT

$$C_p = \frac{\nabla}{A_m \, L_{pp}}$$

SUBSTITUTING, $A_m = C_m BT$ GIVES

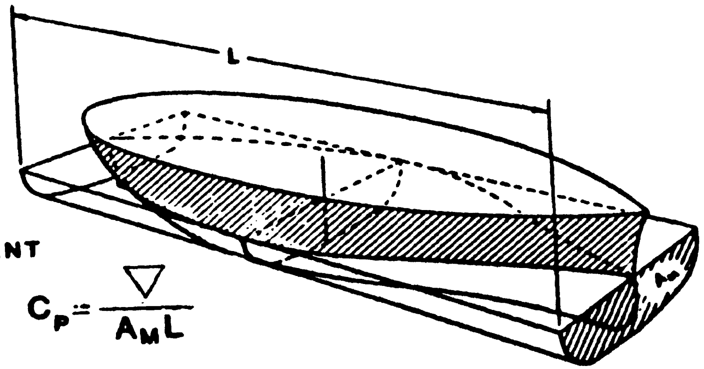
$$C_p = \frac{\nabla}{C_m \, B \, T \, L_{pp}} = \frac{C_b}{C_m}$$

OR $\boxed{C_b = C_p \, C_m}$



BLOCK COEFFICIENT

$$C_B = \frac{\nabla}{LBT}$$



PRISMATIC COEFFICIENT

$$C_P = \frac{\nabla}{A_M L}$$

RATIOS

LENGTH-BEAM RATIO $= \dfrac{L_{pp}}{B}$

LENGTH-DRAFT RATIO $= \dfrac{L_{pp}}{T}$

BEAM-DRAFT RATIO $= \dfrac{B}{T}$

TWO MORE COEFFICIENTS

$$\text{VOLUMETRIC COEFFICIENT} = \frac{\nabla}{L_{pp}^{3}}$$

$$\text{DISPLACEMENT LENGTH RATIO} = \frac{\Delta}{(L_{pp}/100)^{3}}$$

BASIC NAVAL ARCHITECTURE

Unit Number: 8

Title: Dimension, form and flotation - 2

Tape Running Time: $34^M\ 15^S$

Reading Assignment: MSD, pp 27-37

Additional References: PNA, pp 54-59, 70-73

Scope:

The purpose and use of form coefficients is explained by example. Centers of buoyancy and gravity, metacenter, GM, center of flotation are defined. The concept of moments is introduced and an example is given.

Key Points to Emphasize:

1. There is a great deal of fundamental material in this unit which should be reviewed and emphasized.

2. Review definitions of form coefficients and go over example given in video.

3. Explain the physical concepts of center of gravity and center of buoyancy. Stress alignment of forces in at-rest condition.

4. Explain the concept of a centroid, perhaps with a cardboard cut-out of a waterplane. Emphasize definition of LCF and the fact that this is the center about which the ship trims.

5. Review the definition of the metacenter and GM. Emphasize small angle limitations.

6. Explain the concept of moments. Go over the example. Emphasize tabular format.

Suggested Problem Assignment: 1, 2 or 3, 4 or 5

EXAMPLE

A NAVAL ARCHITECT IS STARTING ON THE DESIGN OF A PETROLEUM PRODUCTS CARRIER. THE OWNER HAS SPECIFIED A DEADWEIGHT OF ABOUT 40,000 LT.

EXAMPLE (CON'T)

FROM A STUDY OF OTHER SUCCESSFUL PRODUCTS CARRIERS THE NAVAL ARCHITECT DETERMINES THE FOLLOWING RATIOS AND COEFFICIENTS ARE APPROPRIATE-

EXAMPLE (CON'T)

DEADWEIGHT-TO-DISPLACEMENT RATIO=0.86

DISPLACEMENT-LENGTH RATIO =165

LENGTH-BEAM RATIO =7.5

BEAM-DRAFT RATIO =2.5

MIDSHIP SECTION COEFFICIENT =0.980

FIND: SHIP CHARACTERISTICS AND COEFFICIENTS

EXAMPLE (CON'T)

SOLUTION

1. $$\frac{DWT}{\Delta} = .86$$

$$\Delta = \frac{DWT}{.86} = \frac{40{,}000 \text{ LT}}{.86}$$

$$\Delta = 46{,}512 \text{ LT}$$

2. $$\frac{\Delta}{(L/100)^3} = 165$$

$$(L/100)^3 = \frac{\Delta}{165} = \frac{46{,}512 \text{ LT}}{165} = 281.9$$

$$(L/100) = 6.56$$

$$L = 656 \text{ FT}$$

EXAMPLE (CON'T)

SOLUTION

3. $$\frac{L}{B} = 7.50$$

$$B = \frac{L}{7.50} = \frac{656\ \text{FT}}{7.50}$$

$$\underline{\underline{B = 87.5\ \text{FT}}}$$

4. $$\frac{B}{T} = 2.50$$

$$T = \frac{B}{2.50} = \frac{87.5\ \text{FT}}{2.50}$$

$$\underline{\underline{T = 35.0\ \text{FT}}}$$

EXAMPLE (CON'T)

SOLUTION (CON'T)

5. $$C_b = \frac{\nabla}{L_{pp}BT} = \frac{35\Delta}{L_{pp}BT}$$

$$C_b = \frac{\left(35\ \frac{FT^3}{TON}\right)(46{,}512\ LT)}{(656\ FT)(87.5\ FT)(35.0\ FT)}$$

$$\underline{\underline{C_b = .810}}$$

6. $$C_p = \frac{C_b}{C_m} = \frac{.810}{.980}$$

$$\underline{\underline{C_p = .827}}$$

EXAMPLE (CONCLUDED)

RECAP: THE PRELIMINARY CHARACTERISTICS OF THE SHIP ARE:

L_{PP} = 656 FT

B = 87.5 FT

T = 35.0 FT

Δ = 46,512 LT

DWT = 40,000 LT

C_b = .810

C_p = .827

C_m = .980

CENTER OF BUOYANCY

THE CENTER OF BUOYANCY IS LOCATED AT THE GEOMETRIC CENTER (CENTROID) OF THE UNDERWATER VOLUME.

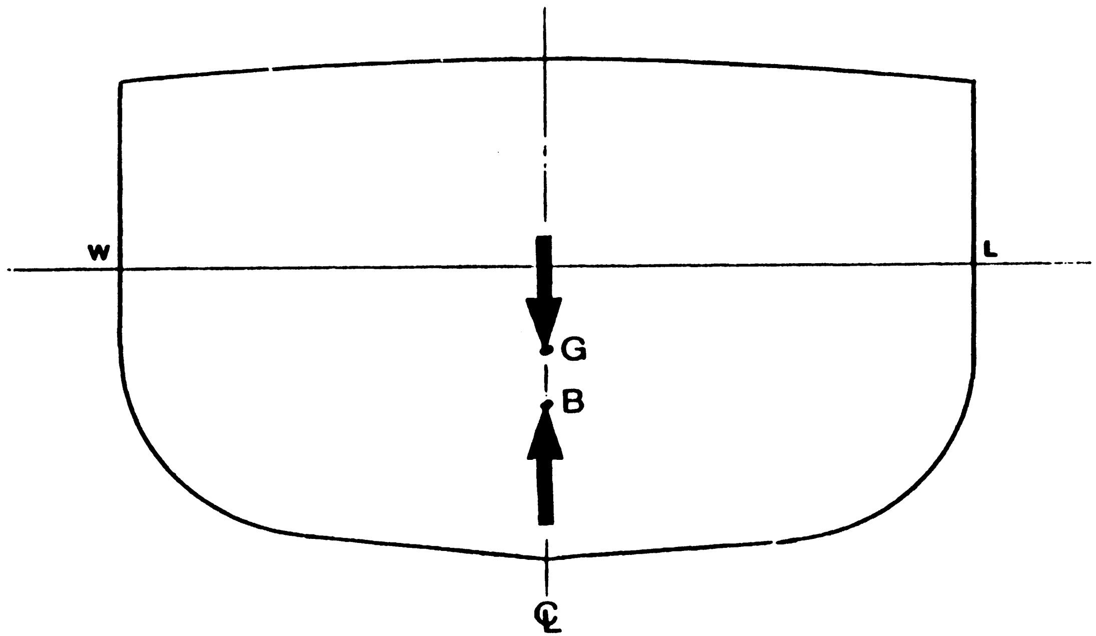
THE RESULTANT OF ALL BUOYANT FORCES ON THE HULL IS A SINGLE VERTICAL UPWARD FORCE ACTING THROUGH THE CENTER OF BUOYANCY.

CENTER OF GRAVITY

THE CENTER OF GRAVITY IS THE CENTER THROUGH WHICH ALL THE WEIGHT FORCES ACT IN A VERTICALLY DOWNWARD DIRECTION.

IMPORTANT FACT

WHEN A SHIP IS FLOATING AT REST, THE UPWARD BUOYANT FORCE AND THE DOWNWARD WEIGHT FORCE WILL ALWAYS BE IN THE SAME VERTICAL LINE.

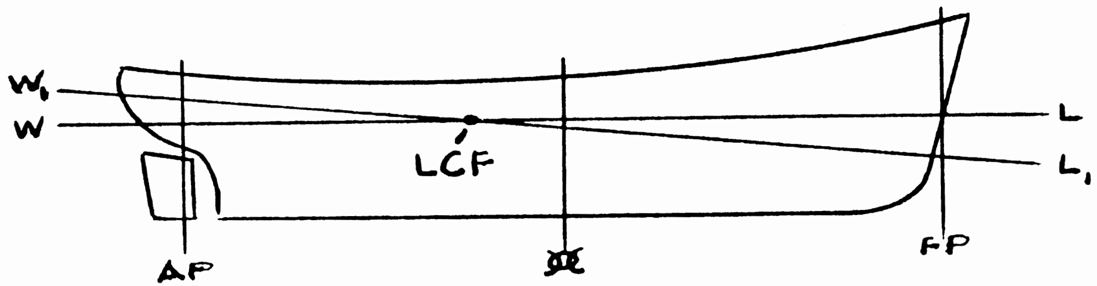


CENTER OF FLOTATION

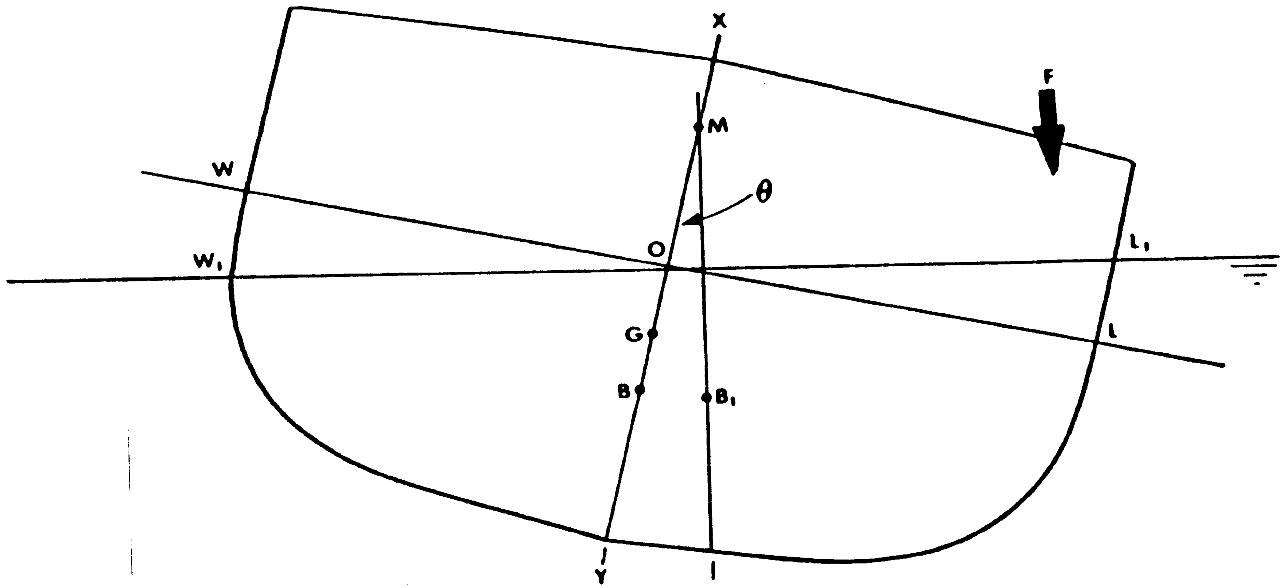
THE CENTER OF FLOTATION IS AT THE GEOMETRIC CENTER (CENTROID) OF THE WATERPLANE AT WHICH THE SHIP IS FLOATING.

IMPORTANT FACT

A SHIP TRIMS ABOUT A TRANSVERSE AXIS THROUGH THE CENTER OF FLOTATION.

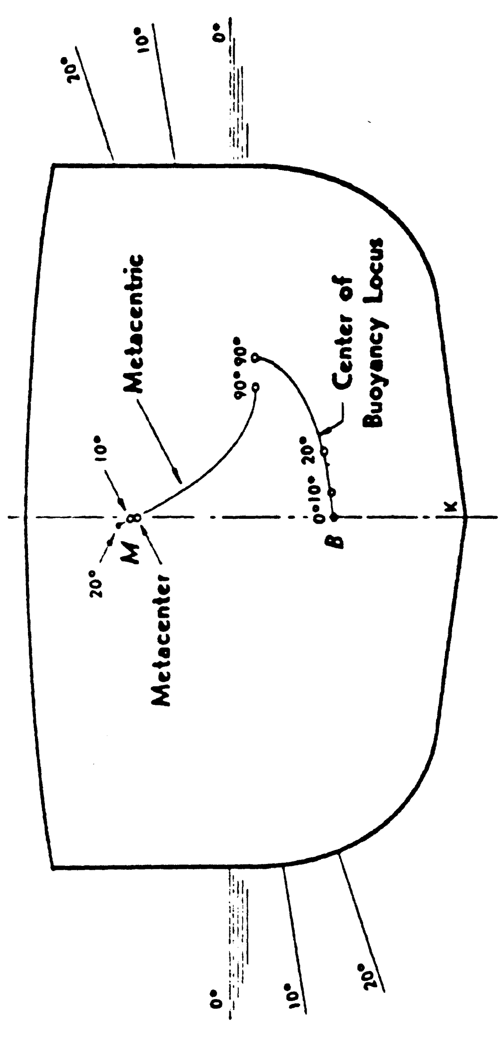


THE METACENTER, M



METACENTER

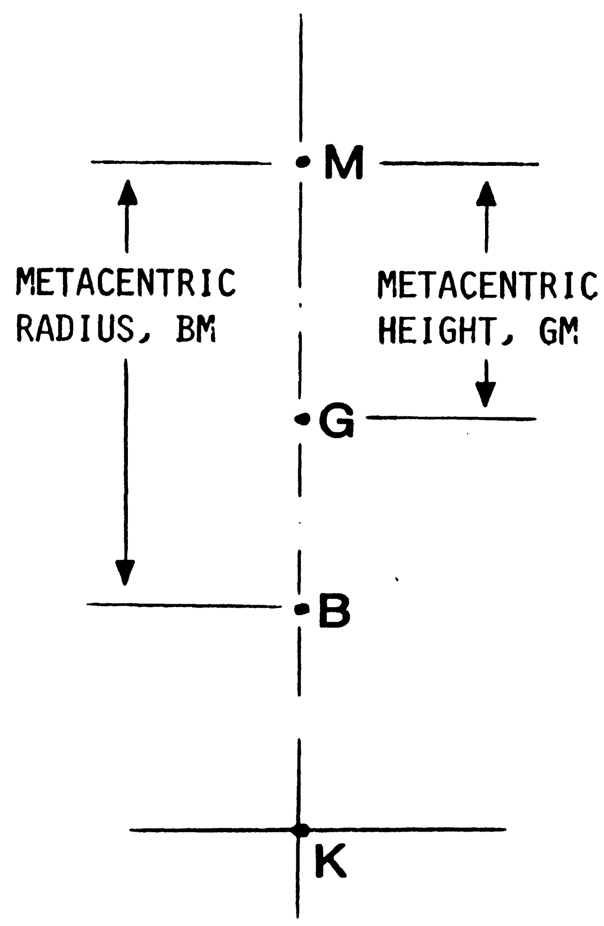
THE METACENTER IS THE INSTANTANEOUS CENTER OF THE PATH OF THE CENTER OF BUOYANCY AS THE SHIP INCLINES.



Metacentric
Metacenter
M
10°
20°
90° 90°
Center of
Buoyancy Locus
B
0° 10° 20°
K
0°
10°
20°

IMPORTANT FACT

THE METACENTER REMAINS IN A FIXED POSITION ON THE CENTERLINE ONLY FOR SMALL ANGLES OF INCLINATION, SAY 8° TO 12°


M
G
B
K
METACENTRIC
RADIUS, BM
METACENTRIC
HEIGHT, GM

METACENTRIC HEIGHT, GM

SINCE THE METACENTER IS USEFUL ONLY FOR SMALL ANGLES OF INCLINATION THE STUDY OF STABILITY USING THE METACENTRIC HEIGHT, GM IS CALLED INITIAL STABILITY.

LONGITUDINAL METACENTER

SO FAR WE HAVE LOOKED AT THE METACENTER AS THE SHIP INCLINES TO PORT OR STARBOARD.

THIS IS THE TRANSVERSE METACENTER

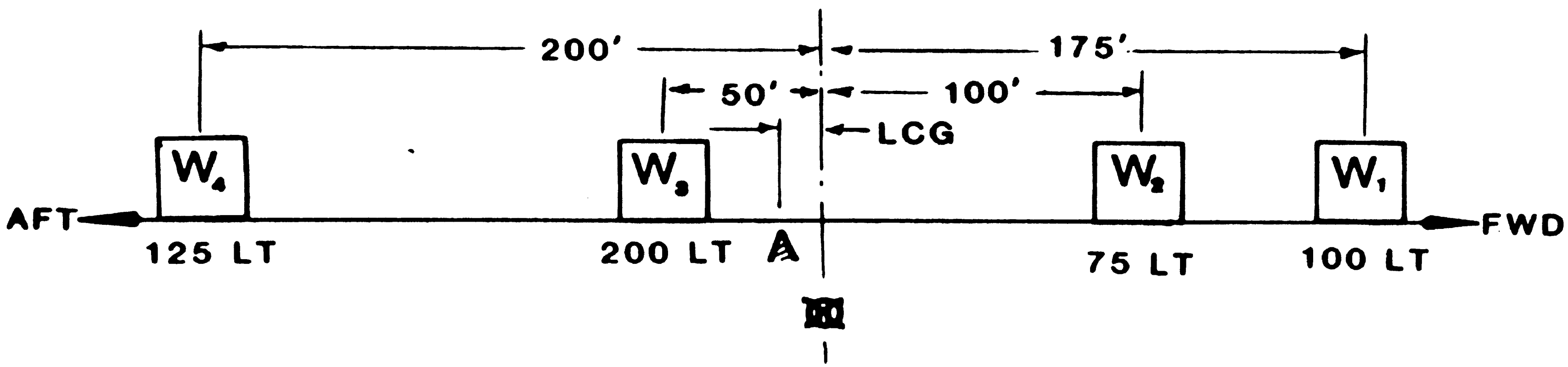
IN EXACTLY THE SAME WAY A LONGITUDINAL METACENTER MAY BE DEFINED AS THE SHIP TRIMS BOW UP OR DOWN.

NOTATION

METACENTRIC HEIGHT, GM, UNLESS OTHERWISE NOTED, MEANS TRANSVERSE METACENTRIC HEIGHT

IF LONGITUDINAL METACENTRIC HEIGHT, GM_L IS MEANT IT SHOULD ALWAYS BE DESIGNATED THAT WAY.

MOMENTS



GIVEN: WEIGHTS W_1, W_2, W_3, W_4; WEIGHTS AND DISTANCES AS SHOWN.

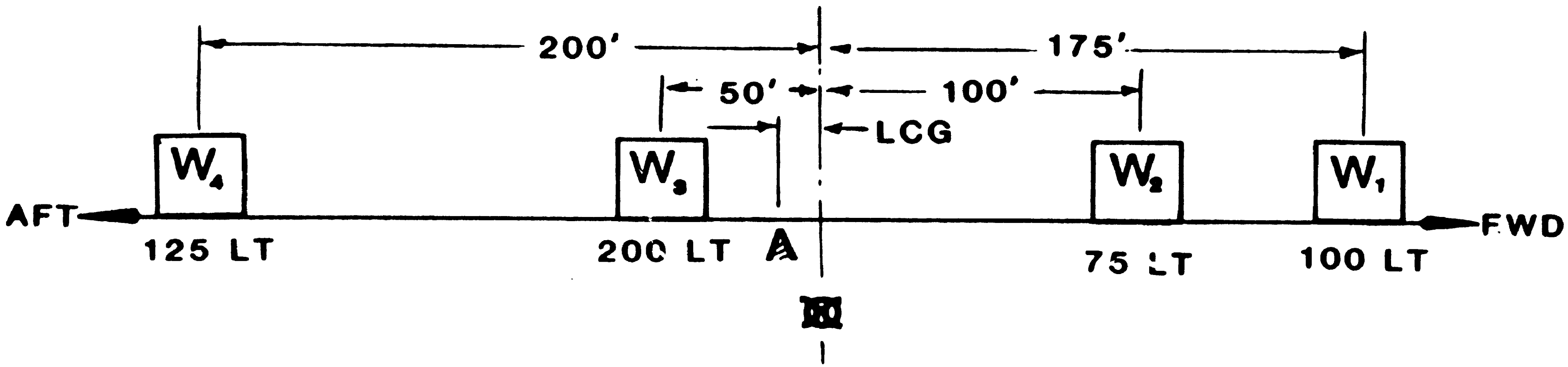
FIND: DISTANCE OF LCG FROM ⊗

ALGEBRAIC SOLUTION:

TAKING MOMENTS ABOUT THE LCG ~

$$\Sigma(\text{MOMENTS FWD. LCG}) = \Sigma(\text{MOMENTS AFT LCG})$$

MOMENTS (CON'T)



OR ~ $\sum(\text{MOM'TS FWD LCG}) - \sum(\text{MOM'TS AFT LCG}) = 0$

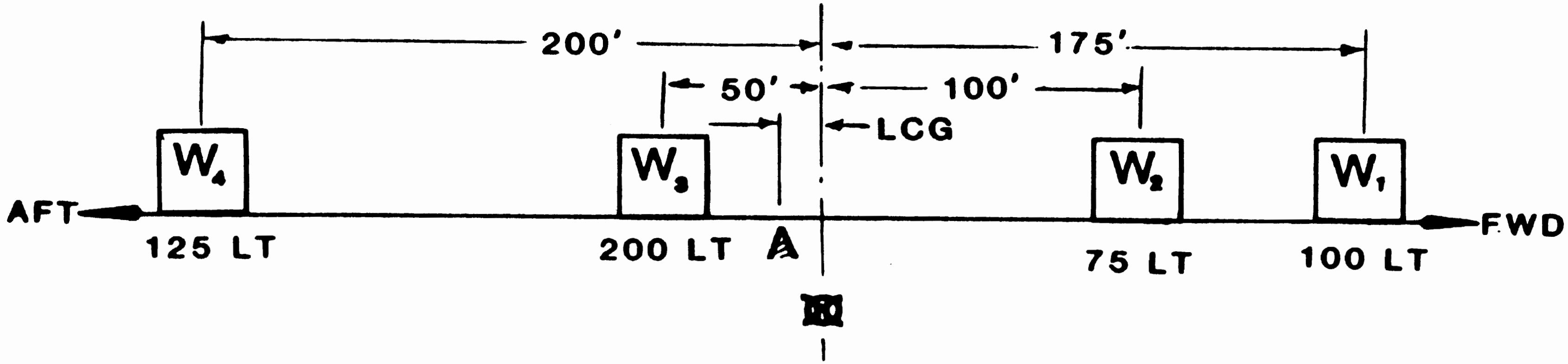
$(100\ \text{LT})(175' + \text{LCG}) + (75\ \text{LT})(100' + \text{LCG})$
$\quad - (200\ \text{LT})(50' - \text{LCG}) - (125\ \text{LT})(200' - \text{LCG}) = 0$

$17{,}500 + 100\ \text{LCG} + 7500 + 75\ \text{LCG}$
$\quad - 10{,}000 + 200\ \text{LCG} - 25{,}000 + 125\ \text{LCG} = 0$

$500\ \text{LCG} = 10{,}000$

LCG = 20.00 FT AFT ⊠

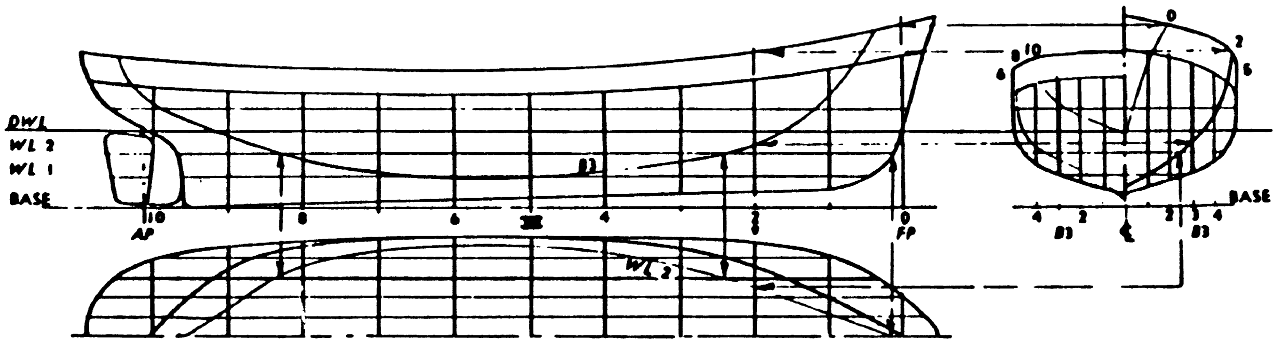
MOMENTS (CON'T)



TABULAR SOLUTION:

ITEM	WEIGHT LT	LCG FT FM ⊠	MOMENT FT-TONS
W_1	100	175 F	17,500 F
W_2	75	100 F	7,500 F
W_3	200	50 A	10,000 A
W_4	125	200 A	25,000 A
Σ	500	20.0A	10,000 A

LINES DRAWING



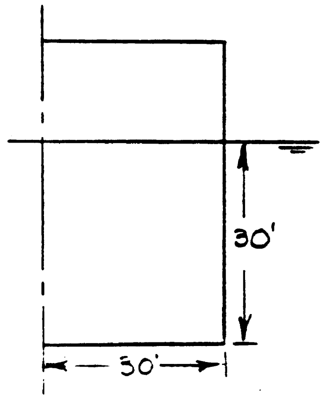
BASIC NAVAL ARCHITECTURE

Problem 1

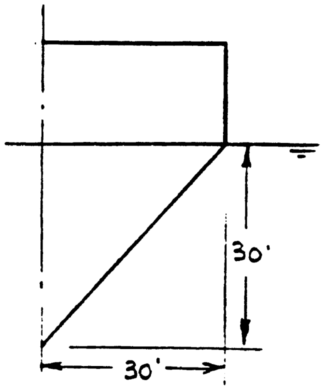
Problem Level: Basic

Calculate the Midship Section Coefficient of the sections shown below:

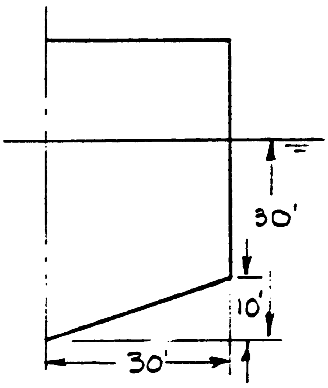
(a)



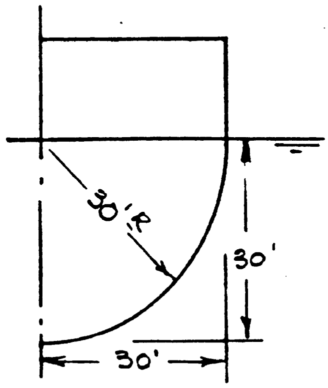
(b)



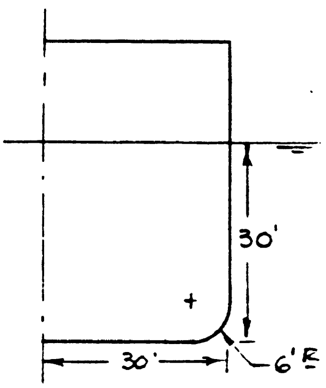
(c)



(d)



(e)



BASIC NAVAL ARCHITECTURE

Problem 2

Problem Level: Basic

A naval architect developing the concept design of a mobilization ship decides on the following dimensions, proportions and coefficients for his initial design:

L_{pp} = 560'-0"

L/B = 5.77

B/T = 3.23

C_p = .630

C_m = .980

Calculate:

a) Beam, B

b) Draft, T

c) Block Coefficient, C_b

d) Displacement volume, ∇

e) Displacement, salt water, Δ

f) Area of Midsection, A_m

g) Displacement-length ratio

BASIC NAVAL ARCHITECTURE

Problem 3

Problem Level: Basic

A proposed ship design has the following geometrical characteristics:

L_{oa}	=	640'-0"
L_{wl}	=	620'-0"
L_{pp}	=	600'-0"
B	=	60'-0"
T	=	20'-0"
∇	=	540,000 ft^3
A_m	=	1080 ft^2
A_w	=	27,900 ft^2

Calculate:

a) Displacement in salt water, Δ

b) Displacement in fresh water, Δ_{fw}

c) Block coefficient, C_b

d) Midship Section Coefficient, C_m

e) Prismatic Coefficient, C_p

f) Waterplane Coefficient, C_{WP}

g) Length-beam ratio, L_{pp}/B

h) Length-draft ratio, L_{pp}/T

i) Beam-draft ratio, B/T

j) Volumetric coefficient, ∇/L_{pp}^3

k) Displacement-length ratio, $\Delta/(L_{pp}/100)^3$

Problem 4

Problem Level: Basic

The coefficients and ratios of a typical harbor tug are shown in Gillmer, Table 2-1 (pp 33) and are repeated below:

C_b	=	.585
C_m	=	.892
C_p	=	.655
C_w	=	.800
L/B	=	4.18
L/T	=	9.33
B/T	=	2.23

(Note that these values represent an average. In practice there may be considerable variation.)

Using these ratios for a proposed tug design which has L_{pp} = 85.0 ft., find:

B

T

Δ (salt water)

Δ_{fw} (fresh water @ 36 ft^3/ton)

A_m

A_w

Volumetric Ratio

Displacement-Length Ratio

Problem 5

Problem Level: Intermediate

In developing the Concept Design of a cargo ship a naval architect starts with the following parameters for the full load condition:

Δ	=	15,000 L.T.
B	=	58'-0"
T	=	28'-0"
C_b	=	.770
C_p	=	.780

Find the required L_{pp} of the ship (to the nearest foot), the Midship Section Area (to the nearest square foot), C_M, and the Displacement-Length Ratio.
To check whether these dimensions and coefficients will provide adequate intact stability at full load the naval architect makes further estimates of the following parameters:

D/T	=	1.50
$\overline{KB}/T$	=	.520
$\overline{BM} \times T/B^2$	=	.080
$\overline{KG}/D$	=	.500

Find:

D

$\overline{KB}$

$\overline{BM}$

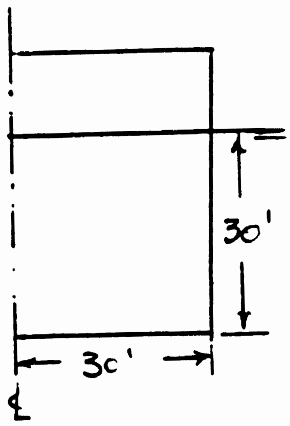
$\overline{KG}$

$\overline{GM}$

All dimensions above are molded dimensions.

REF: GILLMER, PP 27

(a)



$$C_M = \frac{A_M}{BT}$$

$B = 2 \times 30' = 60'$

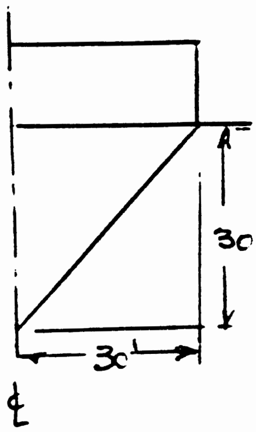
$T = 30'$

$A_M = 60' \times 30' = 1800 \text{ FT}^2$

$$C_M = \frac{1800 \text{ FT}^2}{60 \times 30 \text{ FT}^2}$$

$C_M = 1.00$

(b)



$$C_M = \frac{A_M}{BT}$$

$B = 2 \times 30' = 60'$

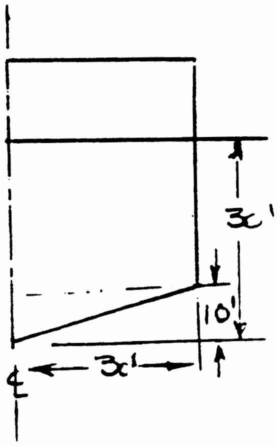
$T = 30'$

$A_M = \frac{1}{2} \times 60' \times 30' = 900 \text{ FT}^2$

$$C_M = \frac{900 \text{ FT}^2}{60 \times 30 \text{ FT}^2}$$

$C_M = 0.500$

(c)



$$C_M = \frac{A_M}{BT}$$

$B = 2 \times 30' = 60'$

$T = 30'$

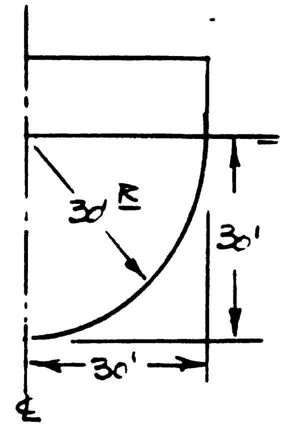
$A_M = 2 \times \frac{1}{2} \times 10' \times 30' + 60' \times 20'$

$A_M = 1500 \text{ FT}^2$

$$C_M = \frac{1500 \text{ FT}^2}{60 \times 30 \text{ FT}^2}$$

$C_M = 0.833$

(d)



$$C_M = \frac{A_m}{B\,T}$$

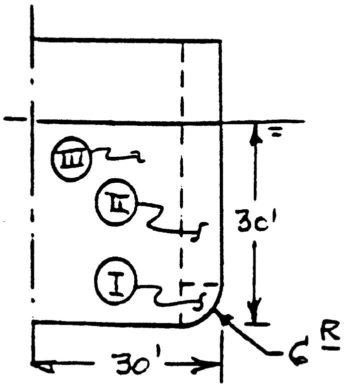
$$B = 2 \times 30' = 60'$$

$$T = 30'$$

$$A_M = \frac{1}{2} \times \pi \times (30')^2 = 1413.72 \text{ FT}^2$$

$$C_M = \frac{1413.72 \text{ FT}^2}{60 \times 30 \text{ FT}^2}$$

$$\boxed{C_M = 0.785}$$



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

$$B = 2 \times 30' = 60'$$

$$T = 30'$$

$$A_M = 2 \times (A_{I} + A_{II} + A_{III})$$

$$A_{I} = \frac{\pi}{4}(6)^2 = 28.27 \text{ FT}^2$$

$$A_{II} = 6' \times 24' = 144 \text{ FT}^2$$

$$A_{III} = 24' \times 30' = 720 \text{ FT}^2$$

$$A_{I} + A_{II} + A_{III} = 892.27 \text{ FT}^2$$

$$A_M = 2 \times (892.27) = 1784.54$$

$$C_m = \frac{A_m}{B\,T} = \frac{1784.54 \text{ FT}^2}{1800 \text{ FT}^2}$$

$$\boxed{C_m = .991}$$

GIVEN:

$L_{PP} = 560'-0''$
$L_{PP}/B = 5.77$
$B/T = 3.23$
$C_p = .630$
$C_m = .980$

(a)

$$\frac{L_{PP}}{B} = 5.77 \Rightarrow B = \frac{L_{PP}}{5.77} = \frac{560\text{ FT}}{5.77} \quad \therefore \boxed{B = 97'-0''}$$

(b)

$$\frac{B}{T} = 3.23 \Rightarrow T = \frac{B}{3.23} = \frac{97\text{ FT}}{3.23} \quad \therefore \boxed{T = 30'-0''}$$

(c) REF GILLMER P.27

$$C_p = \frac{C_b}{C_m} \Rightarrow C_b = C_p \cdot C_m = (.630)(.980) \quad \therefore \boxed{C_b = .617}$$

(d) REF GILLMER P.27

$$C_b = \frac{\nabla}{L_{PP} B T} \Rightarrow \nabla = C_b L_{PP} B T = (.617)(560\text{FT})(97\text{FT})(30\text{FT})$$

$$\therefore \boxed{\nabla = 1{,}005{,}463 \text{ FT}^3}$$

(e) REF GILLMER P.37

$$\Delta = \frac{\nabla}{35 \text{ FT}^3/\text{TON}} = \frac{1{,}005{,}463 \text{ FT}^3}{35 \text{ FT}^3/\text{TON}} \quad \therefore \boxed{\Delta = 28{,}728 \text{ TONS}}$$

(f) REF GILLMER P.27

$$C_m = \frac{A_m}{BT} \Rightarrow A_m = C_m B T = (.980)(97\text{FT})(30\text{FT})$$

$$\therefore \boxed{A_m = 2{,}852 \text{ FT}^2}$$

(g) REF GILLMER P.27

$$\text{DISPL-LENGTH RATIO} = \frac{\Delta}{(L_{pp}/100)^3} = \frac{28{,}728 \text{ TONS}}{(560 \text{ FT}/100)^3}$$

$\therefore$ **DISPL-LENGTH RATIO = 163.58**

GIVEN :
$L_{pp} = 600'-0''$
$B = 60'-0''$
$T = 20'-0''$
$\nabla = 540,000\ FT^3$
$A_m = 1,080\ FT^2$
$A_w = 27,900\ FT^2$

NOTE - L_{OA} AND L_{WL} ARE NOT NEEDED FOR THE FOLLOWING CALCULATIONS.

(a) REF GILLMER P37

$$\Delta = \frac{\nabla}{35\ FT^3/TON} = \frac{540,000\ FT^3}{35\ FT^3/TON} \quad \therefore \quad \boxed{\Delta = 15,429\ TONS}$$

(b) REF GILLMER P37

$$\Delta_{FW} = \frac{\nabla}{36\ FT^3/TON} = \frac{540,000\ FT^3}{36\ FT^3/TON} \quad \therefore \quad \boxed{\Delta = 15,000\ TONS}$$

(c) REF GILLMER P27

$$C_b = \frac{\nabla}{L_{pp} B T} = \frac{540,000\ FT^3}{(600FT)(60FT)(20FT)} \quad \therefore \quad \boxed{C_b = .750}$$

(d) REF GILLMER P27

$$C_m = \frac{A_m}{BT} = \frac{1,080\ FT^2}{(60FT)(20FT)} \quad \therefore \quad \boxed{C_m = .900}$$

(e) REF GILLMER P27

$$C_p = \frac{\nabla}{A_m L_{pp}} = \frac{540,000\ FT^3}{(1,080\ FT^2)(600\ FT)} \quad \therefore \quad \boxed{C_p = .833}$$

(f) REF GILLMER P27

$$C_{WP} = \frac{A_W}{B\ L_{pp}} = \frac{27,900\ FT^2}{(60FT)(600FT)} \quad \therefore \quad \boxed{C_{WP} = .775}$$

8 35

(g)

LENGTH · BEAM RATIO $= \frac{L_{PP}}{B} = \frac{600\,FT}{60\,FT} = \boxed{10.00}$

(h)

LENGTH - DRAFT RATIO $= \frac{L_{PP}}{T} = \frac{600\,FT}{20\,FT} = \boxed{30.00}$

(i)

BEAM - DRAFT RATIO $= \frac{B}{T} = \frac{60\,FT}{20\,FT} = \boxed{3.00}$

(j)

VOL. COEFF. $= \frac{\nabla}{L_{pp}^3} = \frac{540{,}000\,FT^3}{(600\,FT)^3} = \boxed{.003}$

(k)

DISPL - LENGTH RATIO $= \frac{\Delta}{(L_{pp}/100)^3} = \frac{15{,}429\ TONS}{(600\,FT/100)^3} = \boxed{71.43\ \frac{TONS}{FT^3}}$

GIVEN:
$C_b = .585$
$C_m = .892$
$C_p = .655$
$C_{wp} = .800$
$L_{pp}/B = 4.18$
$L_{pp}/T = 9.33$
$B/T = 2.23$

$L_{pp} = 85.0 \text{ FT}$

(a) $\frac{L_{pp}}{B} = 4.18 \Rightarrow B = \frac{L_{pp}}{4.18}$ $\therefore$ **B = 20.3 FT**

(b) $\frac{L_{pp}}{T} = 9.33 \Rightarrow T = \frac{L_{pp}}{9.33}$ $\therefore$ **T = 9.1 FT**

(c) REF GILLMER P.27, 37

$$C_b = \frac{\nabla}{L_{pp}BT} \Rightarrow \nabla = C_b L_{pp} B T = (.585)(85.0\text{FT})(20.3\text{FT})(9.1\text{FT})$$

$$\nabla = 9{,}186 \text{ FT}^3$$

$$\Delta = \frac{\nabla}{35 \text{ FT}^3/\text{TON}} = \frac{9{,}186 \text{ FT}^3}{35 \text{ FT}^3/\text{TON}}$$ $\therefore$ **Δ = 262 TONS**

(d) REF GILLMER P.37

$$\Delta_{FW} = \frac{9{,}186 \text{ FT}^3}{36 \text{ FT}^3/\text{TON}}$$ $\therefore$ **Δ_{FW} = 255 TONS**

(e) REF GILLMER P.27

$$C_m = \frac{A_m}{BT} \Rightarrow A_m = C_m B T = (.892)(20.3\text{FT})(9.1\text{FT})$$

$\therefore$ **$A_m = 165 \text{ FT}^2$**

(f) REF GILLMER P.27

$$C_{wp} = \frac{A_w}{B L_{pp}} \Rightarrow A_w = C_{wp} B L_{pp} = (.800)(20.3\text{FT})(85.0\text{FT})$$

$\therefore$ **$A_w = 1{,}380 \text{ FT}^2$**

(g) REF GILLMER P.27

$$\text{VOL. COEFF.} = \frac{\nabla}{L_{pp}^3} = \frac{9{,}186\ FT^3}{(85.0\ FT)^3} = \boxed{.015}$$

(h) REF GILLMER P.27

$$\text{DISPL-LENGTH RATIO} = \frac{\Delta}{(L_{pp}/100)^3} = \frac{262\ TONS}{(85.0\ FT/100)^3} = \boxed{427\ \frac{TONS}{FT^3}}$$

SUMMARY OF A TYPICAL HARBOR TUG CHARACTERISTICS ARE LISTED BELOW:

$L_{pp} = 85'-0''$

$B = 20'-4''$

$T = 9'-1''$

$\Delta = 262$ LT

$\Delta_{FW} = 255$ LT

$C_b = .585$

$C_p = .655$

$C_m = .892$

$\nabla / L_{pp}^3 = .015$

$\Delta/(L/100)^3 = 427$ LT/FT^3

GIVEN: Δ = 15,000 L.T.
B = 58'-0"
T = 28'-0"
C_b = .770
C_p = .780

FIND L_{pp} - REF GILLMER P.27, 37

$$C_b = \frac{\nabla}{L_{pp} B T} \Rightarrow L_{pp} = \frac{\nabla}{C_b B T} = \frac{(35\ FT^3/TON)\ \Delta}{C_b B T}$$

$$L_{pp} = \frac{(35\ FT^3/TON)(15{,}000\ TONS)}{(.770)(58.0\ FT)(28.0\ FT)}$$

$$\therefore \boxed{L_{pp} = 420\ FT}$$

FIND A_m - REF GILLMER P.27, 37

$$C_p = \frac{\nabla}{A_m L_{pp}} \Rightarrow A_m = \frac{\nabla}{C_p L_{pp}} = \frac{(35\ FT^3/TON)\ \Delta}{C_p\ L_{pp}}$$

$$A_m = \frac{(35\ FT^3/TON)(15{,}000\ TONS)}{(.780)(420\ FT)}$$

$$\therefore \boxed{A_m = 1{,}603\ FT^2}$$

FIND C_m - REF GILLMER P.27

$$C_p = \frac{C_b}{C_m} \Rightarrow C_m = \frac{C_b}{C_p} = \frac{.770}{.780} \quad \therefore \boxed{C_m = .987}$$

FIND DISPL.-LENGTH RATIO - REF GILLMER P.27

$$\text{DISPL.-LENGTH RATIO} = \frac{\Delta}{(L_{pp}/100)^3} = \frac{15{,}000\ TONS}{(420\ FT/100)^3} = \boxed{202.46\ \frac{TONS}{FT^3}}$$

GIVEN: $D/T = 1.50$
$\overline{KB}/T = .520$
$\overline{BM} \cdot T/B^2 = .080$
$\overline{KG}/D = .500$

FIND D -

$$\frac{D}{T} = 1.50 \Rightarrow D = (1.50)T = (1.50)(28.0\text{ FT}) \quad \therefore \boxed{D = 42.00\text{ FT}}$$

FIND $\overline{KB}$ -

$$\frac{\overline{KB}}{T} = .520 \Rightarrow \overline{KB} = (.520)T = (.520)(28.0\text{ FT}) \quad \therefore \boxed{\overline{KB} = 14.56\text{ FT}}$$

FIND $\overline{BM}$ -

$$\frac{\overline{BM} \cdot T}{B^2} = .080 \Rightarrow \overline{BM} = \frac{(.080)B^2}{T} = \frac{(.080)(58.0\text{ FT})^2}{28.0\text{ FT}} \quad \therefore \boxed{\overline{BM} = 9.61\text{ FT}}$$

FIND $\overline{KG}$ -

$$\frac{\overline{KG}}{D} = .500 \Rightarrow \overline{KG} = (.500)D = (.500)(42.0\text{ FT}) \quad \therefore \boxed{\overline{KG} = 21.00\text{ FT}}$$

FIND $\overline{GM}$ - REF GILLMER P. 330

$$\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG} = 14.56\text{ FT} + 9.61\text{ FT} - 21.00\text{ FT}$$

$$\therefore \boxed{\overline{GM} = 3.17\text{ FT}}$$

BASIC NAVAL ARCHITECTURE

Unit Number: 9

Title: Dimension, form and flotation - 3

Tape Running Time: 27^{M} 35^{S}

Reading Assignment: MSD, pp 37-41

Additional References: PNA, pp 10-11, 20-39 (definitions only)

Scope:

Archimedes' Principle is introduced and explained. Hydrostatic parameters are defined. Curves of Form are introduced.

Key Points to Emphasize:

1. Explain Archimedes' Principle with physical significance. See PNA, pp 10.

2. List the various hydrostatic parameters, items 1-16 on DD 692. Displacement and other curves, and explain their purpose.

3. Display the Curves of Form furnished with course. Show FFG-7 Bonjean's Curves.

4. Go over change of draft example in MSD, pp 38-39.

Suggested Problem Assignment: 6 or 7, one of 10, 11 or 12

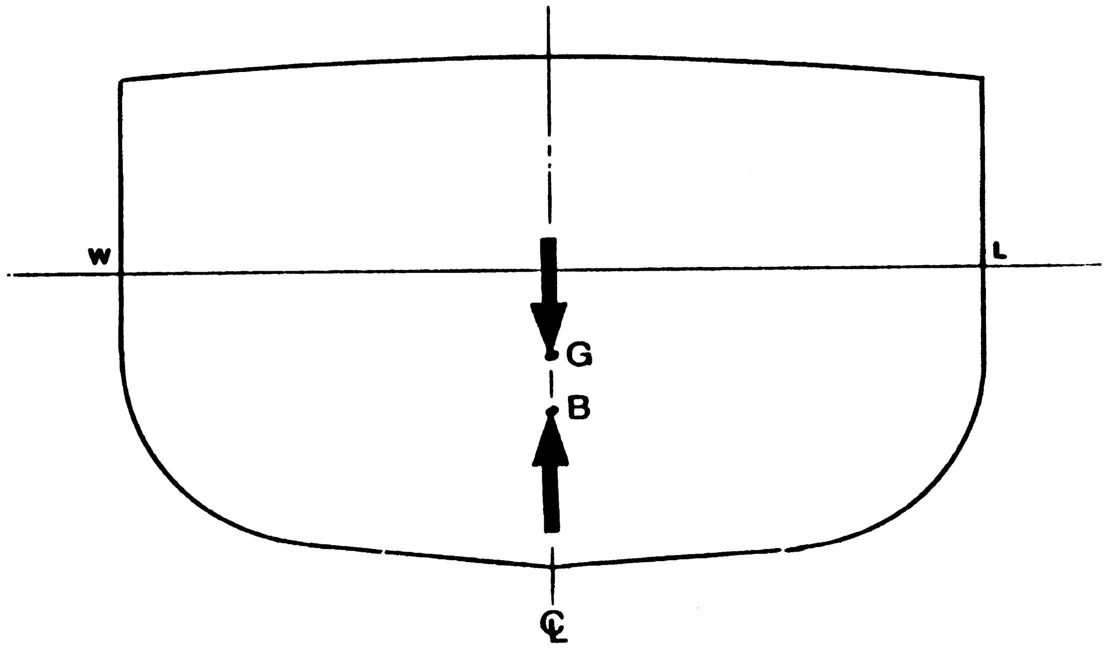
<u>ARCHIMEDES PRINCIPLE</u>

(PER: *MODERN SHIP DESIGN*, pp 37)

THE TOTAL WEIGHT OF THE FLOATING VESSEL, INCLUDING ALL THAT IT CONTAINS OR THAT IS ATTACHED, MUST EQUAL THE WEIGHT OF THE WATER IT DISPLACES.

IMPORTANT FACT

WHEN A SHIP IS FLOATING AT REST, THE UPWARD BUOYANT FORCE AND THE DOWNWARD WEIGHT FORCE WILL ALWAYS BE IN THE SAME VERTICAL LINE.



CURVES OF FORM

ALSO KNOWN AS

HYDROSTATIC CURVES

FURNISHED WITH MODERN SHIP DESIGN:

- DD 692 CLASS DESTROYER (1 SHEET)

FURNISHED WITH BASIC NAVAL ARCHITECTURE PROBLEM BOOK:

- FFG-7 CLASS FRIGATE (2 SHEETS)
- USCG WMEC ("BEAR CLASS") CUTTER (1 SHEET)
- MARAD PD-214 MOBILIZATION SHIP (CONTAINER SHIP VARIANT) (1 SHEET)

CURVES OF FORM (CON'T)

NOTE THAT FOR THE FOUR EXAMPLE SHIPS WHOSE CURVES OF FORM ARE FURNISHED, EACH HAS THE SCALES ORGANIZED IN A SLIGHTLY DIFFERENT WAY.

THE VARIATIONS ARE TYPICAL OF THOSE FOUND IN PRACTICE.

CURVES OF FORM (CON'T)

CAUTION:

ALWAYS BE CAREFUL TO NOTE WHETHER CURVES OF FORM ARE REFERENCED TO MOLDED BASELINE OR BOTTOM OF KEEL

CURVES OF FORM (CON'T)

DISPLACEMENT CURVE

- ALWAYS PRESENTED FOR SALT WATER ($35\ FT^3$/TON)
- SOMETIMES PRESENTED FOR FRESH WATER (35.9 OR $36\ FT^3$/TON)
- IF NOT OTHERWISE DESIGNATED INCLUDES SHELL PLATING AND APPENDAGES
- MOLDED DISPLACEMENT IS SOMETIMES PRESENTED

CURVES OF FORM (CON'T)

DISPLACEMENT CURVE:

- IF ONLY DISPLACEMENT IN SALT WATER IS GIVEN, TO FIND DISPLACEMENT IN FRESH WATER AT THE SAME DRAFT, MULTIPLY BY 35/35.9

$$\Delta_{FW} = \Delta \frac{35}{35.9}$$

CURVES OF FORM (CON'T)

- DISPLACEMENT IS ALWAYS GIVEN IN LONG TONS (2240 LBS)
  (FOREIGN SHIPS WILL BE IN METRIC TONS (2205 LBS))

CURVES OF FORM (CON'T)

TO USE DISPLACEMENT CURVE:

- ENTER WITH MEAN DRAFT (AVERAGE OF DRAFT FWD AND DRAFT AFT)
- READ DISPLACEMENT ON DISPLACEMENT SCALE

CURVES OF FORM (CON'T)

TONS PER INCH IMMERSION (TPI)

- TPI IS THE WEIGHT WHICH WHEN ADDED (OR REMOVED) WILL CAUSE ONE INCH INCREASE (OR DECREASE) IN MEAN DRAFT
- MUST BE ADDED (OR REMOVED) AT THE CENTER OF FLOTATION FOR PARALLEL SINKAGE. AT OTHER LOCATIONS THE CHANGE IN DRAFT WILL NOT BE THE SAME.

CURVES OF FORM (CON'T)

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

NOTE: TO FIND A_{wp} FROM CURVES OF FORM:

$$A_{wp} = (TPI)(420)$$

CURVES OF FORM (CON'T)

CHANGE IN DRAFTS WHEN PASSING FROM SALT WATER TO FRESH WATER: (SEE MODERN SHIP DESIGN, pp 38-39 FOR DERIVATION)

FROM SALT WATER TO FRESH WATER SHIP SINKS DEEPER, DRAFTS INCREASE.

$$\text{DRAFT INCREASE} = d = \frac{\Delta}{35\ \text{TPI}}$$

CURVES OF FORM (CON'T)

FROM FRESH WATER TO SALT WATER SHIP RISES, DRAFTS DECREASE

$$\text{DRAFT DECREASE} = d = -\frac{\Delta}{35\ \text{TPI}}$$

CURVES OF FORM (CON'T)

VERTICAL CENTER OF BUOYANCY (KB, VCB)

- HEIGHT OF CENTER OF BUOYANCY ABOVE BOTTOM OF KEEL (KB) OR ABOVE MOLDED BASELINE (VCB)

- FOUND FROM ORIGINAL INTEGRATION OF OFFSETS.

CURVES OF FORM (CON'T)

LONGITUDINAL CENTER OF BUOYANCY (LCB)

- DISTANCE OF THE CENTER OF BUOYANCY FORWARD OR AFT OR AMIDSHIPS,
- FOUND FROM ORIGINAL INTEGRATION OF OFFSETS.

CURVES OF FORM (CON'T)

LONGITUDINAL CENTER OF FLOTATION (LCF)

- DISTANCE OF THE CENTER OF FLOTATION (CENTROID OF THE WATERPLANE) FORWARD OR AFT OF AMIDSHIPS.
- ON DD 692 CURVES OF FORM THE CENTER OF FLOTATION IS CALLED THE CENTER OF GRAVITY OF THE WATERPLANE (POOR USAGE)
- NOTE THAT THE SHIP TRIMS ABOUT A TRANSVERSE AXIS THROUGH THE CENTER OF FLOTATION

CURVES OF FORM (CON'T)

TRANSVERSE METACENTER (KM)

- HEIGHT OF THE TRANSVERSE METACENTER ABOVE THE BOTTOM OF THE KEEL
- K, BY DEFINITION, IS AT THE BOTTOM OF THE KEEL, BUT, BE CAREFUL. KM IS SOMETIMES REFERRED TO THE MOLDED BASELINE. FOR EXAMPLE, PD-214.
- IF NO SUBSCRIPT, KM MEANS TRANSVERSE METACENTER, KM_T.

CURVES OF FORM (CON'T)

LONGITUDINAL METACENTER:

- USUALLY GIVEN AS KM_L, THE HEIGHT OF THE LONGITUDINAL METACENTER ABOVE THE BOTTOM OF THE KEEL.
- SOMETIMES GIVEN AS LONGITUDINAL METACENTRIC RADIUS, BM_L. THEN

$$KM_L = BM_L + KB$$

- MUST HAVE SUBSCRIPT L, BM_L SOMETIMES, AS IN TEXT, BM' TO DESIGNATE LONGITUDINAL METACENTER.

CURVES OF FORM (CON'T)

MOMENT TO TRIM ONE INCH (MTI)

- THE MOMENT IN FOOT-TONS WHICH WILL CAUSE A CHANGE OF TRIM OF ONE INCH.
- TRIM IS THE DIFFERENCE IN DRAFTS, FORWARD AND AFT, FOR EXAMPLE:

$$T_f = 19' - 0"$$

$$T_a = 18' - 6"$$

$$\text{TRIM} = t = 6" \text{ DOWN BY THE BOW}$$

- IF A BOW-DOWN MOMENT WERE APPLIED TO CHANGE TRIM ONE INCH THE TRIM WOULD INCREASE FROM 6" TO 7".

CURVES OF FORM (CON'T)

MOMENT TO TRIM ONE INCH (MTI)

- $$MTI = \frac{GM_L}{12\ L}$$
- GM_L IS USUALLY A LARGE NUMBER, BUT MAY NOT BE KNOWN IN EARLY STAGE DESIGN WHEN MTI IS CALCULATED
- MTI MAY BE APPROXIMATED BY -

$$MTI = \frac{BM_L}{12\ L}$$

- BUT DON'T EVER TRY TO SAY THAT $BM_t = GM_t$!!!

CURVES OF FORM (CON'T)

CORRECTION TO DISPLACEMENT
FOR ONE FOOT TRIM

SOMETIMES KNOWN AS,

CHANGE OF DISPLACEMENT
FOR ONE FOOT TRIM AFT

CURVES OF FORM (CON'T)

CORRECTION TO DISPLACEMENT (CON'T)

- THE CURVES OF FORM ARE ENTERED WITH MEAN DRAFT, THE AVERAGE OF THE DRAFTS FORE AND AFT, WHICH IS ALSO THE DRAFT AMIDSHIPS
- A SHIP TRIMS ABOUT THE LCF WHICH MEANS THAT THE DRAFT AT THE LCF DOES NOT CHANGE
- IF THE LCF IS NOT AMIDSHIPS THIS CAUSES AN ERROR IN THE DISPLACEMENT READ FROM THE CURVES

CURVES OF FORM (CON'T)

CORRECTION TO DISPLACEMENT (CON'T)

- CORRECTION = CDITA $= 12 \dfrac{TPI \times LCF}{L}$

CURVES OF FORM (CON'T)

- SIGN OF CORRECTION

LCF	TRIM	CORR
AFT	AFT	+
FWD	FWD	+
AFT	FWD	-
FWD	AFT	-

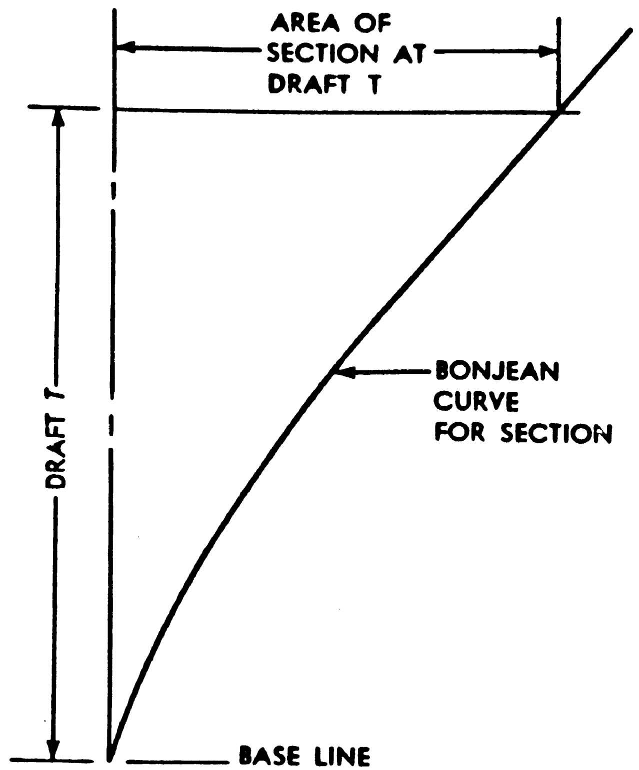
CURVES OF FORM (CON'T)

BONJEAN'S CURVES

- BONJEAN'S CURVES SHOW THE AREA OF A SECTION AS A FUNCTION OF DRAFT - ONE CURVE FOR EACH STATION.

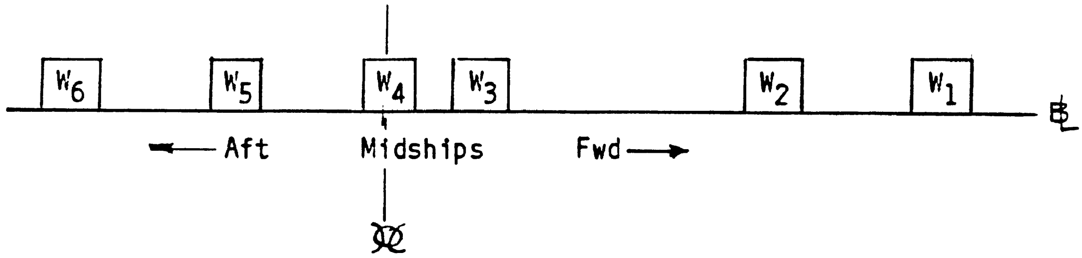
CURVES OF FORM (CON'T)

BONJEAN'S CURVES



Problem 6

Problem Level: Basic



Find the LCG of the system of weights shown above and tabulated below. Use a tabular format for your calculation.

	Weight, lt	Location, ft, F or A
W_1	100	250.00 F
W_2	50	175.00 F
W_3	75	50.00 F
W_4	200	0.00
W_5	175	100.00 A
W_6	200	125.00 A

BASIC NAVAL ARCHITECTURE

Problem 7

Problem Level: Basic

Find the LCG and the VCG of the system of weights tabulated below. Use a tabular format for your calculation.

Weight, lt	Long'l Location, ft	Vertical Location, ft a ℄
10.00	220.00 F	5.50
120.00	200.00 F	20.00
85.00	150.00 F	55.00
265.00	22.00 F	35.00
32.50	46.00 A	2.00
210.00	61.00 A	68.50
160.00	183.50 A	26.50
112.00	206.00 A	40.50

Problem 10

Problem Level: Basic

A PD-214-type container ship displaces 29,800 tons in salt water at 35 ft^3/ton at a mean draft of 30'-0". Find the mean draft in fresh water of 36 ft^3/ton if there is no change in weights on board. Tons per Inch Immersion at the 30'-0" draft is 95.8 tons/in.

BASIC NAVAL ARCHITECTURE

Problem 11

Problem Level: Basic

An amphibious supply ship is moored in fresh water (35.9 ft^3/ton) at a mean draft of 24'-0". At this draft the displacement is found to be 15,500 long tons and the area of the waterplane is 27,700 ft^2. The ship gets underway and proceeds to a shipyard in salt water (35.0 ft^3/ton). While underway she burns 200 tons of fuel oil. Find the mean draft upon arrival at the shipyard.

Problem 12

Problem Level: Intermediate

A ship floats at draft, T_o, in river water of density 63 lb/ft^3. When floating in seawater (35 ft^3/ton), a weight of 175 tons must be added to have the ship float at T_o. What is the ship's displacement after the weight addition?

FIND LCG - REF GILLMER P. 330

WEIGHT (L.T.)	LOCATION* (FT)	MOMENT (FT-TONS)
100	-250.00	-25,000
50	-175.00	-8,750
75	-50.00	-3,750
200	0.00	0
175	100.00	17,500
200	125.00	25,000
800		5,000

$$LCG = \frac{\text{MOMENT}}{\text{WEIGHT}} = \frac{5{,}000 \text{ FT-TONS}}{800 \text{ TONS}} \quad \therefore \quad \boxed{LCG = 6.25 \text{ FT } (A)}$$

* F IS -, A IS +.

FIND LCG AND VCG - REF GILLMER P.330

WEIGHT (L.T.)	LONGITUDINAL* LOCATION (FT)	LONGITUDINAL* MOMENT (FT-TONS)	VERTICAL** LOCATION (FT)	VERTICAL** MOMENT (FT-TONS)
10.00	-220.00	-2,200.00	5.50	55.00
120.00	-200.00	-24,000.00	20.00	2,400.00
85.00	-150.00	-12,750.00	55.00	425.00
265.00	-22.00	-5,830.00	35.00	9,275.00
32.50	46.00	1,495.00	2.00	65.00
210.00	61.00	12,810.00	68.50	14,385.00
160.00	183.50	29,360.00	26.50	4,240.00
112.00	206.00	23,072.00	40.50	4,536.00
994.50		21,957.00		35,381.00

$$LCG = \frac{\text{LONG MOM}}{\text{WEIGHT}} = \frac{21{,}957 \text{ FT-}\cancel{\text{TONS}}}{994.50 \cancel{\text{TONS}}} \quad \therefore \boxed{LCG = 22.08 \text{ FT (A)}}$$

$$VCG = \frac{\text{VERT MOM}}{\text{WEIGHT}} = \frac{35{,}381 \text{ FT-}\cancel{\text{TONS}}}{994.50 \cancel{\text{TONS}}} \quad \therefore \boxed{VCG = 35.58 \text{ FT ABV B.L.}}$$

* F IS −, A IS +.

** ABV B.L. IS +.

GIVEN - PD-214
$\Delta = 29{,}800$ TONS IN S.W. OF 35 FT^3/TON
$T_m = 30'-0''$
TPI = 95.8 TONS/IN AT $T = 30'-0''$.

FIND T_m IN F.W. OF 36 FT^3/TON. - REF GILLMER PP38-39.

NOTE: MASS DENSITY OF S.W. = 1.9903 LBS·SEC^2/FT^4 AT 59°F.
MASS DENSITY OF F.W. = 1.9383 LBS·SEC^2/FT^4 AT 59°F.
SPECIFIC GRAVITY OF A FLUID IS DEFINED AS THE RATIO OF DENSITY OF THE FLUID TO THAT OF THE FRESH WATER. THUS, THE SPECIFIC GRAVITY OF S.W., δ, IS

$$\delta = \frac{1.9903}{1.9383} = 1.027$$

AND THE SPECIFIC GRAVITY OF F.W., δ_1, IS

$$\delta_1 = \frac{1.9383}{1.9383} = 1.000$$

CORRESPONDINGLY, THE DENSITY FACTOR OF S.W. IS,

$$\frac{2{,}240\ LBS/TON}{(1.9903\ LBS\cdot SEC^2/FT^4)(32.17\ FT/SEC^2)} = 35\ \frac{FT^3}{TON}$$

AND THE DENSITY FACTOR OF F.W. IS,

$$\frac{2{,}240\ LBS/TON}{(1.9383\ LBS\cdot SEC^2/FT^4)(32.17\ FT/SEC^2)} = 36\ \frac{FT^3}{TON}.$$

USING DENSITY FACTORS, SPECIFIC GRAVITY OF A FLUID CAN BE CALCULATED AS

$$\delta = \frac{36\ FT^3/TON}{35\ FT^3/TON} = 1.027 \quad \text{FOR S.W.}$$

AND

$$\delta_1 = \frac{36\ FT^3/TON}{36\ FT^3/TON} = 1.000 \quad \text{FOR F.W.}$$

FOR A GIVEN SHIP,
DISPLACEMENT IN S.W. = DISPLACEMENT IN F.W.

$$\nabla_{S.W.} = (35)\Delta = \frac{(35)(36)\Delta}{(36)} = \frac{(36)\Delta}{(36/35)} = \frac{(36)\Delta}{\delta}$$

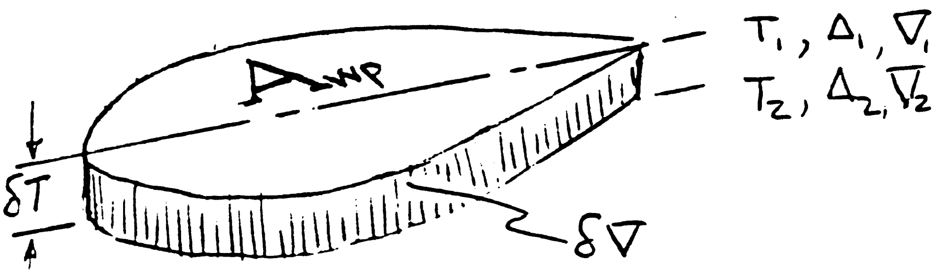
$$\nabla_{F.W.} = (36)\Delta = \frac{(36)(36)\Delta}{(36)} = \frac{(36)\Delta}{(36/36)} = \frac{(36)\Delta}{\delta_1}.$$

$$d = \frac{36\Delta}{35\ TPI}\left[\frac{1}{\delta_1} - \frac{1}{\delta}\right] = \frac{36(29{,}800\ TON)}{35(95.8\ TON/IN)}\left[\frac{1}{1} - \frac{1}{36/35}\right] = 8.89\ IN$$

$$\therefore T_m^{FW} = T_m^{SW} + \frac{d}{12\ IN/FT} = 30.00\ FT + \frac{8.89\ IN}{12\ IN/FT} = \boxed{30.74\ FT}$$

APPROACH:

THE ACTUAL WEIGHT OF THE SHIP INITIALLY IN FRESH WATER WAS 15,500 LT. THE WEIGHT OF THE SHIP UPON ARRIVAL AT THE SHIPYARD IN SALT WATER WILL BE THE SAME, LESS THE 200 LT OF FUEL OIL BURNED IN TRANSIT, BUT THE VOLUME OF DISPLACEMENT WILL BE DIFFERENT IN EACH CASE. THE DIFFERENCE IN THE VOLUMES DIVIDED BY THE AREA OF THE WATERPLANE WILL YIELD THE CHANGE IN MEAN DRAFT. (NOT ENOUGH INFORMATION IS PROVIDED TO CALCULATE THE CHANGES IN DRAFTS FORE AND AFT)



SOLUTION:

WEIGHT OF SHIP ~~BEFORE~~ = WEIGHT OF SHIP AFTER − 200 LT

WEIGHT BEFORE = 15,500 LT

VOLUME BEFORE = $15,500 \times 35.9 \frac{FT^3}{TON} = 556,450\ FT^3$

LESS F.O. BURNED = −200

WEIGHT AFTER = 15,300 LT

VOLUME AFTER = $15,300 \times 35.0 \frac{FT^3}{TON} = 535,500\ FT^3$

CHANGE IN VOLUME, $\delta\nabla = -20,950\ FT^3$

CHANGE IN DRAFT, $\delta T = \frac{\delta\nabla}{A_{WP}} = \frac{-20,950\ FT^3}{27,700\ FT^2}$

$\delta T = .756\ FT = 9.08''$

$T_{M_1} = 24' - 0''$
$\delta T = -9''$
$T_{M_2} = 23' - 3''$

MEAN DRAFT UPON ARRIVAL = 23'-3"

APPROACH

IN THIS CASE, SINCE THE DRAFTS BEFORE AND AFTER ARE THE SAME, THE VOLUMES BEFORE AND AFTER WILL BE THE SAME. THE BASIS FOR THE EQUATION IS:

VOLUME BEFORE = VOLUME AFTER.

SOLUTION:

WEIGHT BEFORE $= \Delta_1$ LT

VOLUME BEFORE $= \Delta_1 \times \dfrac{2240 \frac{LB}{TON}}{63 \frac{LB}{FT^3}} = \Delta_1 \times 35.56 \frac{FT^3}{TON}$

WEIGHT AFTER $= \Delta_1 + 175$ LT.

VOLUME AFTER $= (\Delta_1 + 175) \cdot 35.0 \frac{FT^3}{TON}$

THEN ~

$$35.56\Delta_1 = 35.0(\Delta_1 + 175)$$

$$35.56\Delta_1 - 35.0\Delta_1 = 35.0 \cdot 175$$

$$.56\Delta_1 = 6125$$

$$\Delta_1 = \frac{6125}{.56}$$

$$\boxed{\Delta_1 = 10{,}938 \text{ LT.}}$$

Unit Number: 10

Title: Dimension, form and flotation - 4

Tape Running Time: 42^M 30^S

Reading Assignment: MSD, pp 322-328

Additional References: PNA, pp 11-13

Scope:

The graphical significance of the mathematical processes of differentiation and integration are explained. Numerical integration using the Trapezoidal Rule and Simpson's Rule is introduced. Examples of the calculation of displacement from the area under a Sectional Area Curve are given.

Key Points to Emphasize:

1. This is a long unit covering a great deal of material. Depending on the emphasis the instructor wishes to give to the subject he may wish to either extend the length of the class period, or devote an extra period to the subject, if necessary, at the expense of a future unit.

2. Emphasize only the graphical interpretation of differentiation and integration-slopes and areas. Student should be able to recognize a derivative and an integral sign when he sees these syumbols in the text, but it is not necessary that he understand the processes in an analytical sense.

3. Go over the Trapezoidal Rule, selection of intervals and multipliers and formatting of a calculation in tabular form.

4. Same for Simpson's Rule.

5. Emphasize meaning of area under the Sectional Area Curve.

6. Review examples.

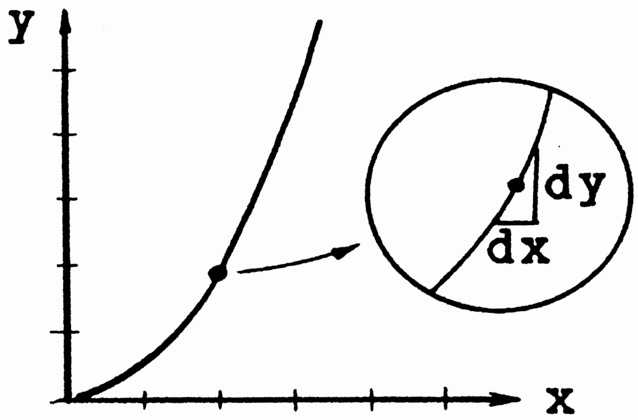
Suggested Problem Assignment: One or two of 13, 14, 15

DIFFERENTIATION

DIFFERENTIATION IS A PROCESS OF
DIFFERENTIAL CALCULUS

CONSIDER A MATHEMATICAL FUNCTION

$$y = \frac{1}{2}x^2$$



$$\text{SLOPE} = \frac{dy}{dx} = \frac{\text{RISE}}{\text{RUN}}$$

16.2

DIFFERENTIATION (CON'T)

FINDING THE DERIVATIVE, $\frac{dy}{dx}$, OF A MATHEMATICAL FUNCTION CORRESPONDS TO FINDING THE SLOPE OF THE CURVE

THERE IS A DEFINITE SET OF RULES FOR FINDING THE DERIVATIVES OF MATHEMATICAL FUNCTIONS.

FOR EXAMPLE:

DIFFERENTIATION (CON'T)

EXAMPLE:

FOR THE FUNCTION, $y = \frac{1}{2}x^2$

FOLLOWING THE RULES GIVES:

$$\frac{dy}{dx} = \frac{1}{2}(2)(x) = x$$

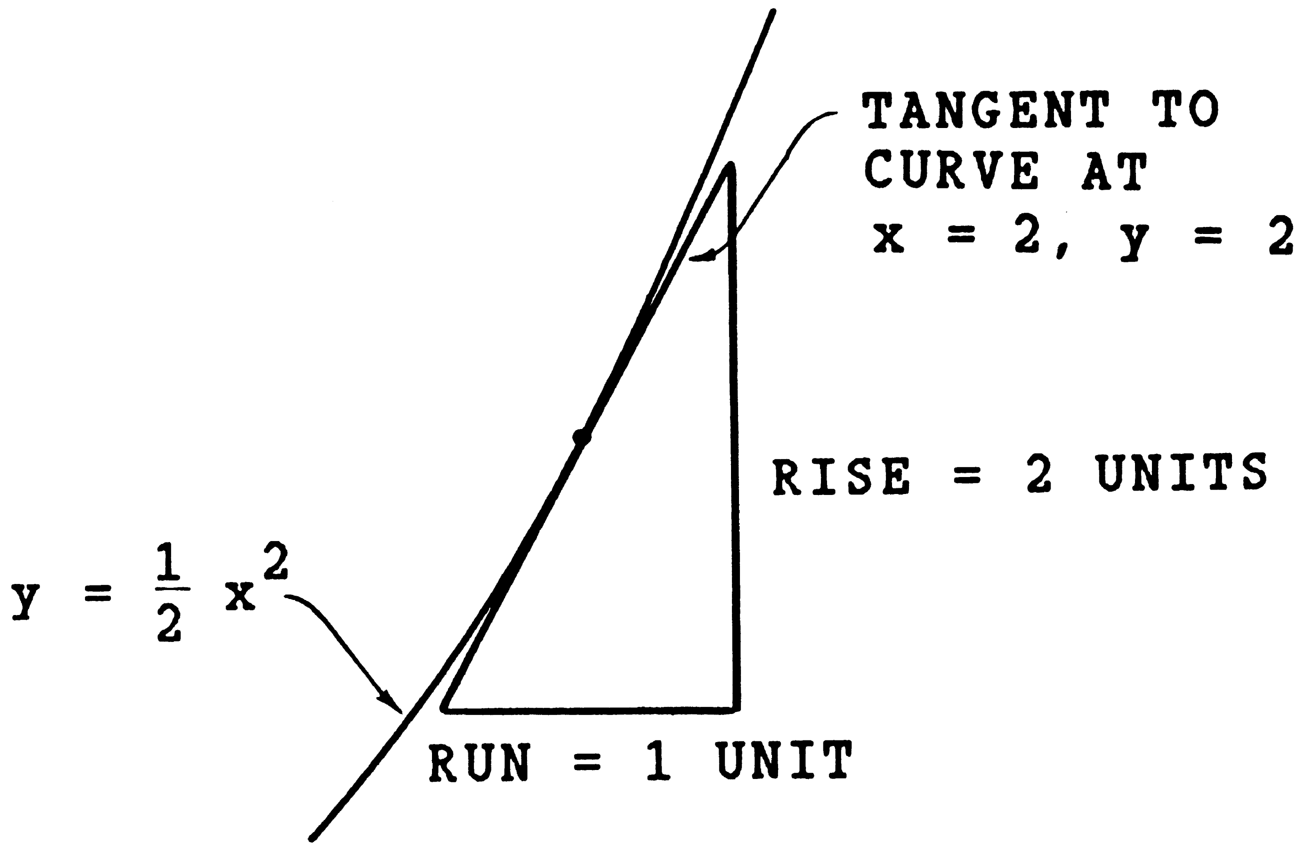
AT THE POINT X = 2, $\frac{dy}{dx} = 2$

WHICH MEANS THAT AT THIS POINT THE SLOPE OF THE CURVE IS:

$$\text{SLOPE} = \frac{dy}{dx} = \frac{\text{RISE}}{\text{RUN}} = \frac{2}{1}$$

DIFFERENTIATION (CON'T)

$$\text{SLOPE} = \frac{\text{RISE}}{\text{RUN}}$$



INTEGRATION

INTEGRATION IS A PROCESS OF INTEGRAL CALCULUS

INTEGRATION CORRESPONDS TO FINDING THE AREA UNDER A CURVE

THERE IS ALSO A DEFINITE SET OF RULES FOR FINDING THE INTEGRAL OF MATHEMATICAL FUNCTIONS.

INTEGRATION (CON'T)

FOR EXAMPLE THE INTEGRAL OF THE FUNCTION, $y=x$

$$\int x \, dx = \frac{1}{2} x^2 + \text{A CONSTANT}$$

INTEGRATION IS THE INVERSE PROCESS OF DIFFERENTIATION

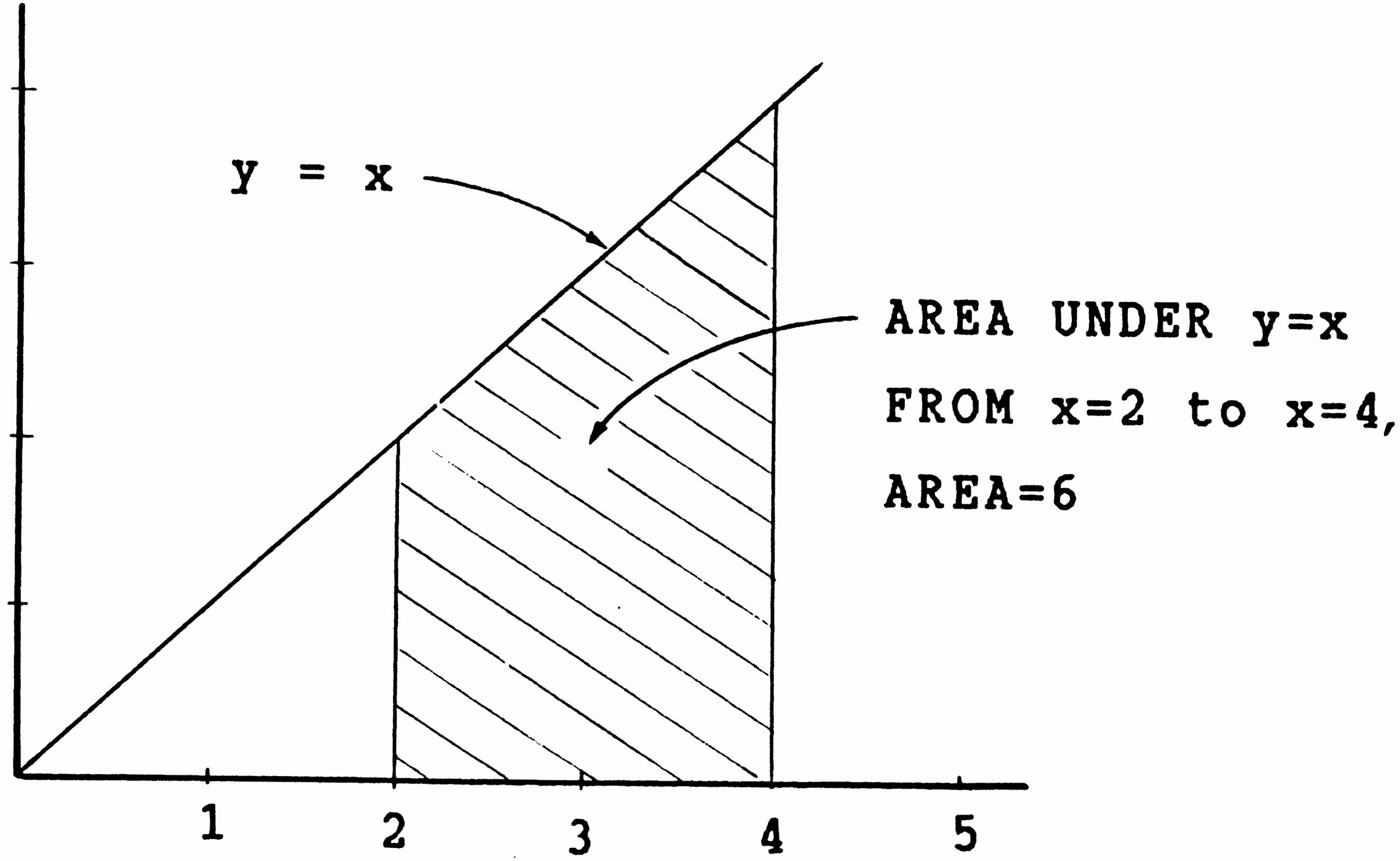
TO FIND THE AREA UNDER $y=x$ BETWEEN $x=2$ AND $x=4$ WE EVALUATE THE INTEGRAL AT THESE POINTS

<u>INTEGRATION (CON'T)</u>

$$\int_{x=2}^{x=4} x\,dx = \left[\frac{1}{2}x^2\right]_{x=2}^{x=4} = \left[\frac{1}{2}(4)^2\right] - \left[\frac{1}{2}(2)^2\right] = 6$$

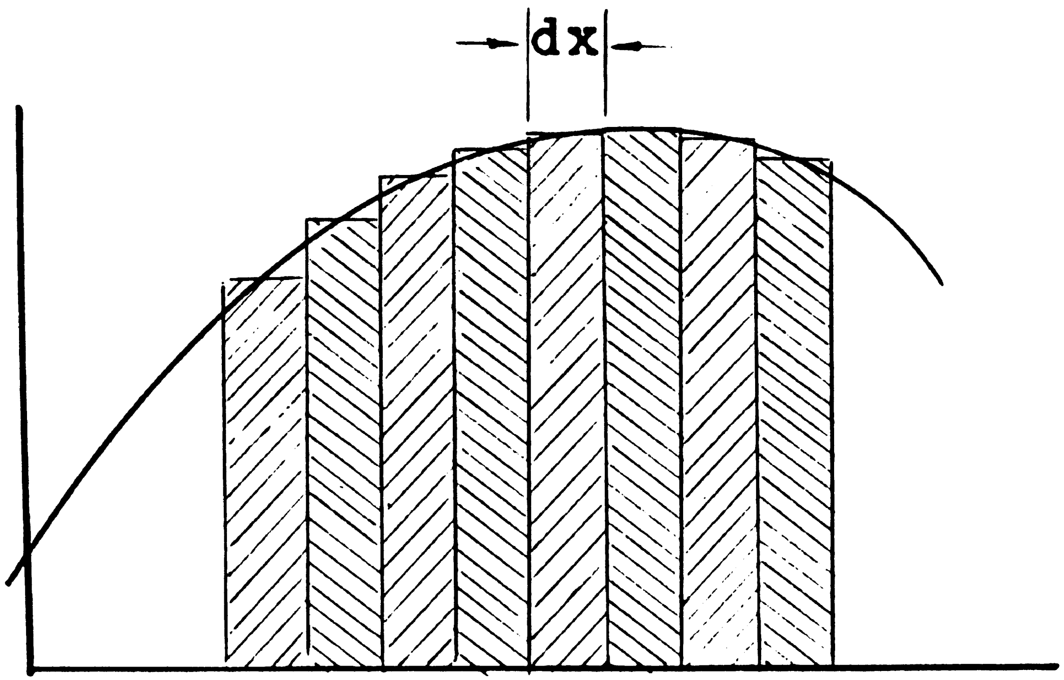
INTEGRATION (CON'T)

GRAPH OF THE FUNCTION $y = x$:



INTEGRATION (CON'T)

WE MAY THINK OF AN INTEGRAL AS BEING THE SUM OF A NUMBER OF SMALL AREAS, EACH dx WIDE



DIFFERENTIAL AND INTEGRAL CALCULUS IS USED IN DERIVING MANY OF THE FORMULAS IN NAVAL ARCHITECTURE,

HOWEVER,

PRACTICAL INTEGRATION IS ALWAYS DONE USING NUMERICAL METHODS

WE WILL DISCUSS TWO NUMERICAL INTEGRATION METHODS --

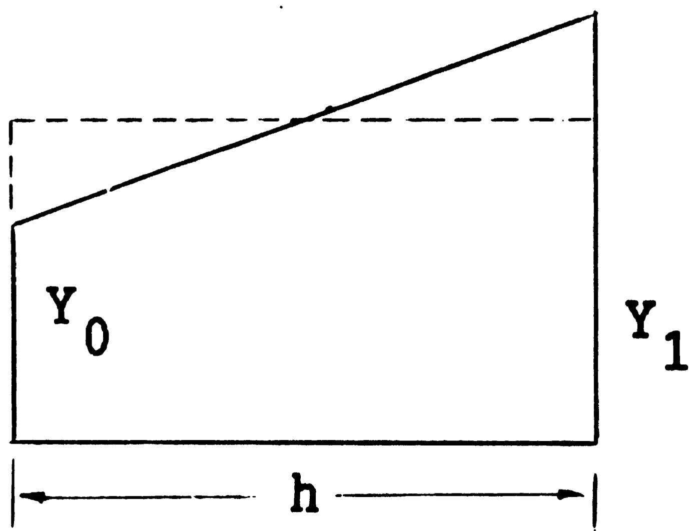
- TRAPEZOIDAL RULE
- SIMPSON'S RULE

TRAPEZOIDAL RULE

REF: APPENDIX B, *MODERN SHIP DESIGN*

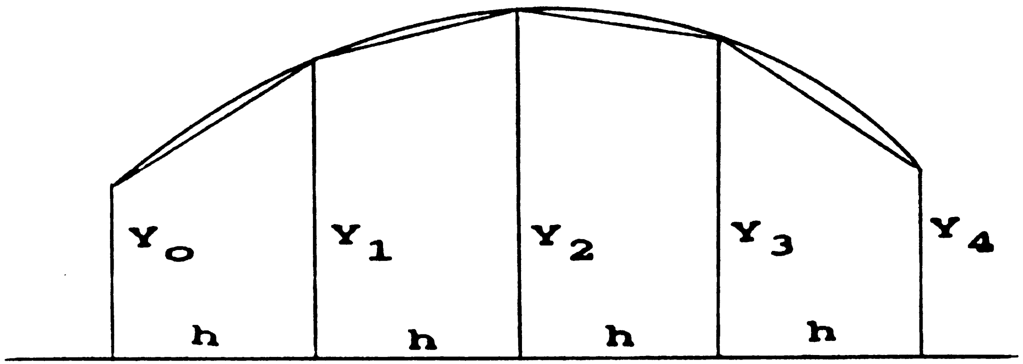
THE AREA OF A TRAPEZOID IS:

$$AREA = h\left[\frac{1}{2}Y_0 + \frac{1}{2}Y_1\right]$$



TRAPEZOIDAL RULE (CON'T)

CONSIDER SEVERAL TRAPEZOIDS



FOR CONSTANT STATION SPACING, h:

$$AREA = h \left[\left(\frac{1}{2} Y_0 + \frac{1}{2} Y_1\right) + \left(\frac{1}{2} Y_1 + \frac{1}{2} Y_2\right) + \left(\frac{1}{2} Y_2 + \frac{1}{2} Y_3\right) + \left(\frac{1}{2} Y_3 + \frac{1}{2} Y_4\right) \right]$$

$$AREA = h \left[\frac{1}{2} Y_0 + Y_1 + Y_2 + Y_3 + \frac{1}{2} Y_4 \right]$$

TRAPEZOIDAL RULE (CON'T)

FOR CONSTANT STATION SPACING, h AND

n ORDINATES FROM n=o TO n=n,

$$AREA = h\left[\frac{1}{2} Y_o + Y_1 + \cdot\cdot\cdot\cdot\cdot Y_{n-1} + \frac{1}{2} Y_n\right]$$

MULTIPLIERS:

$$\frac{1}{2}, 1, 1, 1, \cdot\cdot\cdot\cdot\cdot 1, 1, \frac{1}{2}$$

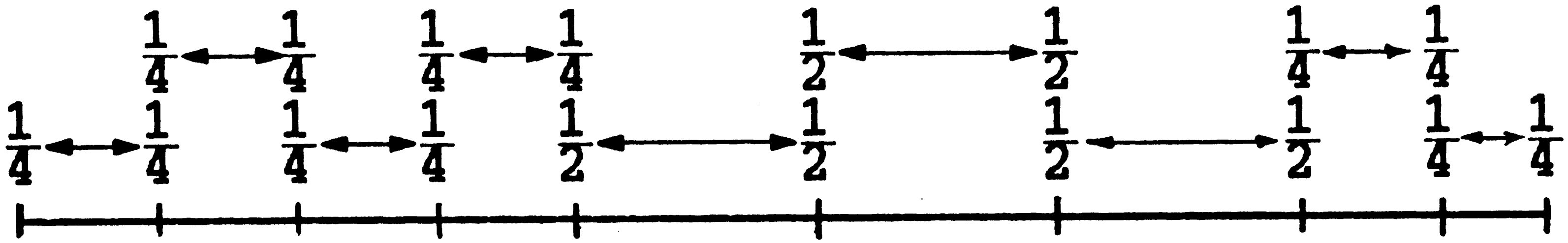
TRAPEZOIDAL RULE (CON'T)

TRAPEZOIDAL RULE RECAP:

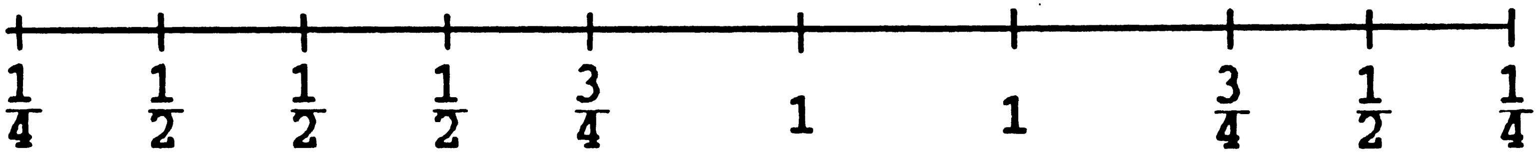
- THE STATION SPACING MUST BE CONSTANT
- THERE CAN BE ANY NUMBER OF STATIONS, EVEN OR ODD
- THE MULTIPLIERS FOR THE END ORDINATES ARE 1/2
- THE MULTIPLIERS FOR ALL OTHER ORDINATES ARE ONE.

TRAPEZOIDAL RULE (CON'T)

HOW TO DO HALF STATIONS:



MULTIPLIERS NOW CHANGE TO:



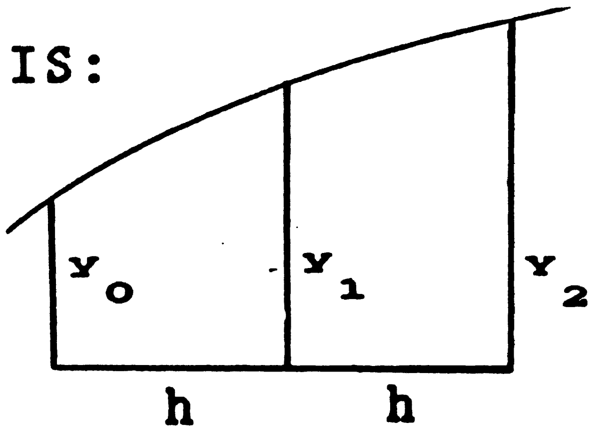
SIMPSON'S (FIRST) RULE

REFERENCE: APPENDIX B OF *MODERN SHIP DESIGN*

THE AREA UNDER A SECOND ORDER (PARABOLIC) CURVE IS:

NOTE:

THREE ORDINATES

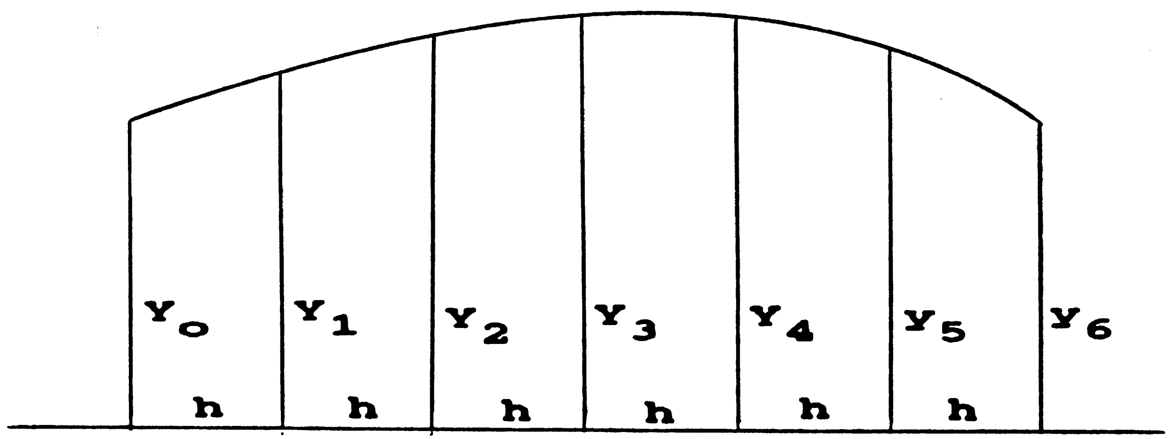


$$\text{AREA} = \frac{h}{3}\left[y_0 + 4y_1 + y_2\right]$$

$$\text{MULTIPLIERS:} \quad \frac{h}{3}\left[1, \quad 4, \quad 1\right]$$

SIMPSON'S RULE

CONSIDER SEVERAL SIMPSON'S INTERVALS



$$\text{AREA} = \frac{h}{3}\left[(y_0+4y_1+y_2) + (y_2+4y_3+y_4) + (y_4+4y_5+y_6)\right]$$

$$\text{MULTIPLIERS:} \quad \frac{h}{3}\left[1, \quad 4, \quad 2, \quad 4, \quad 2, \quad 4, \quad 1\right]$$

10.15

SIMPSON'S RULE

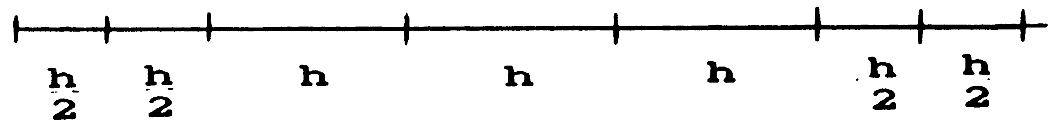
RECAP

- THERE MUST BE UNIFORM STATION SPACING
- THERE MUST BE AN ODD NUMBER OF STATIONS. IF THE FIRST STATION IS 0 THIS MEANS THAT THE LAST STATION MUST BE AN EVEN NUMBER
- MULTIPLY THE STATION SPACING BY 1/3
- THE SEQUENCE OF MULTIPLIERS IS,

  1, 4, 2, 4, 2, 4.....2, 4, 1

SIMPSON'S RULE

HALF STATIONS



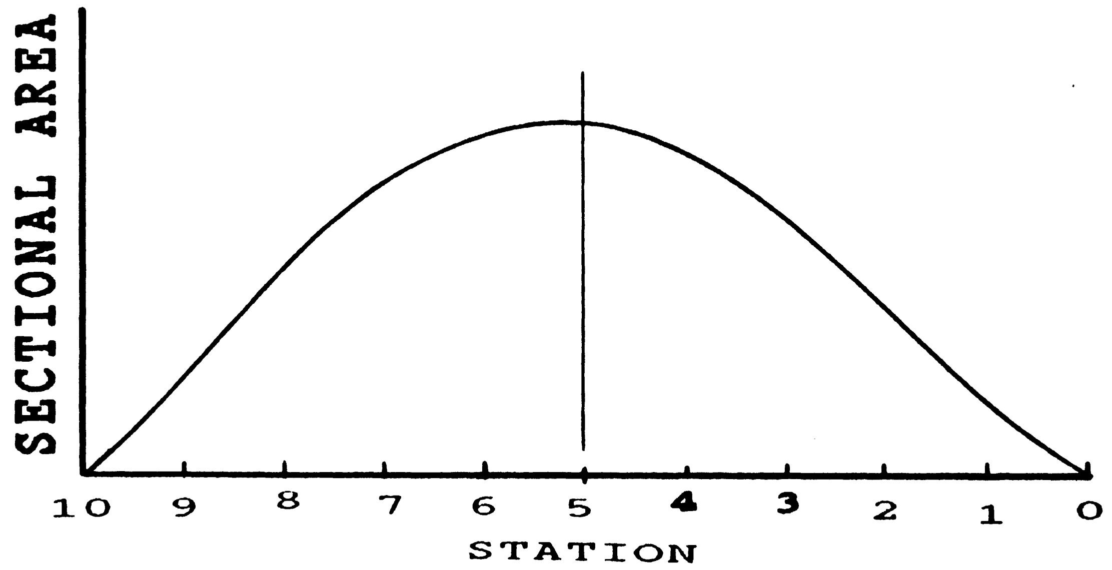
THE MULTIPLIERS ARE NOW,

1/2, 2, 3/2, 4, 2, 4, 3/2, 2, 1/2

(PROOF LEFT TO STUDENT)

SECTIONAL AREA CURVE

THE SECTIONAL AREA CURVE IS A PLOT OF THE AREA OF EACH STATION UP TO A SPECIFIED WATERLINE, USUALLY THE DESIGN WATERLINE.



SECTIONAL AREA CURVE

PROPERTIES:

- THE AREA UNDER THE SECTIONAL CURVE IS THE VOLUME OF DISPLACEMENT OF THE SHIP
- THE LONGITUDINAL CENTROID OF THE AREA UNDER THE SECTIONAL AREA CURVE IS THE LCB.

SECTIONAL AREA CURVE (CON'T)

15'-6" WL

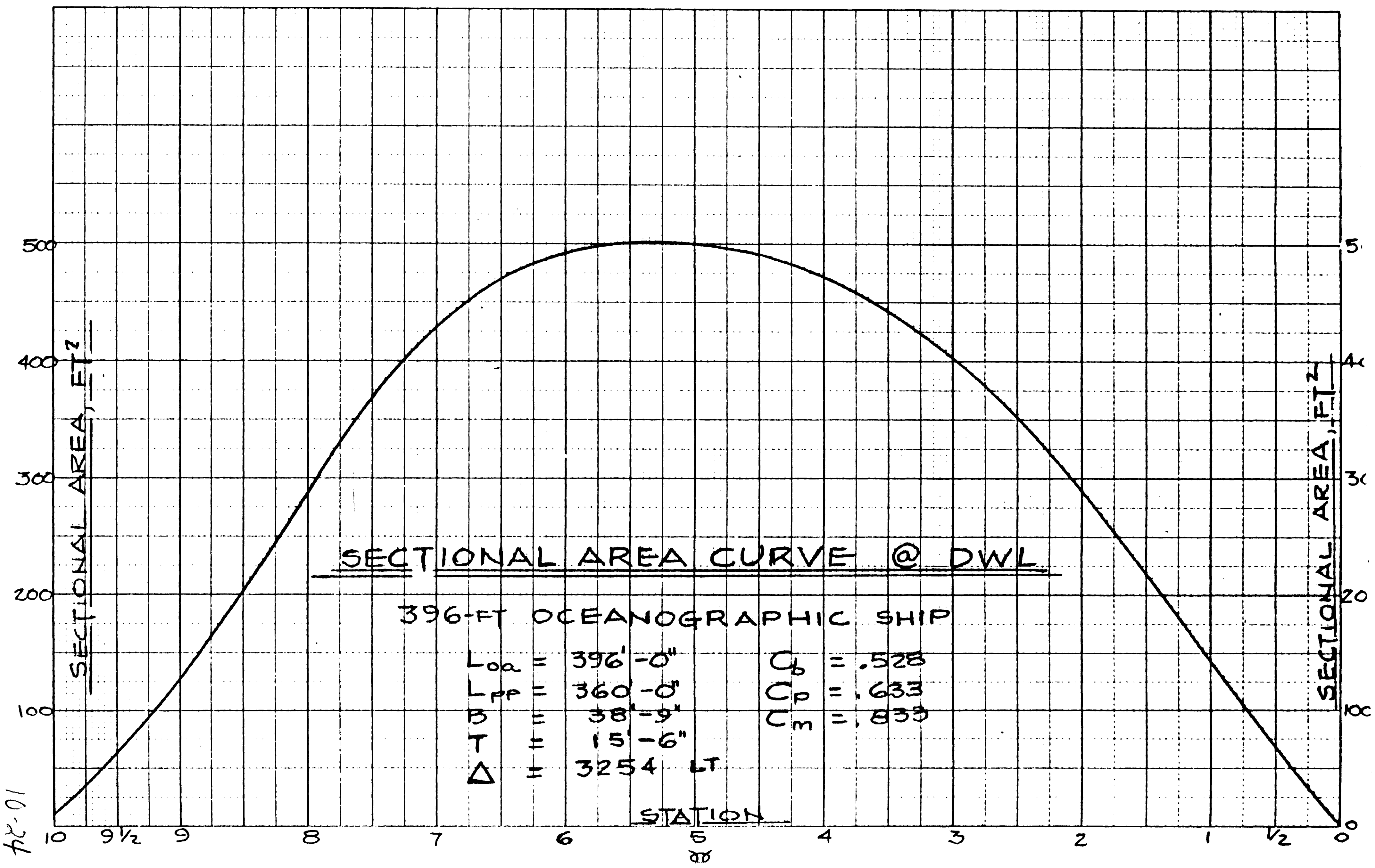
STA	AREA FT^2	SM	f(V)	LVR	f(LM)
0	0	1/2	0	5	0
1/2	65	2	130	4 1/2	585
1	135	1 1/2	202.5	4	810
2	290	4	1160	3	3480
3	405	2	810	2	1620
4	475	4	1900	1	1900
					8395 F
5	500	2	1000	0	
6	492	4	1968	1	1968
7	430	2	860	2	1720
8	283	4	1132	3	3396
9	133	1 1/2	199.5	4	798
9 1/2	70	2	140	4 1/2	630
10	10	1/2	5	5	25
			$\Sigma f(V) = 9507$		8537 A
					8395 F
				$\Sigma f(LM) =$	142 A

S = 36.0 FT

$\nabla = \frac{36.0}{3}(9507) = 114,084 \text{ FT}^2$

$\Delta = 3260$ LT

$LCB = 36.0 \times \frac{142}{9507} A = 0.54 \text{ FT } A$



SECTIONAL AREA CURVE @ DWL
396-FT OCEANOGRAPHIC SHIP
Loa = 396'-0"
Lpp = 360'-0"
B = 38'-9"
T = 15'-6"
Δ = 3254 LT
Cb = .528
Cp = .633
Cm = .833
SECTIONAL AREA, FT²
STATION
10 9½ 9 8 7 6 5 4 3 2 1 ½ 0
100 200 300 400 500

COMPARISON OF INTEGRATION METHODS

ASSUME: SIMPSON'S RULE WITH 20 STATIONS AND 4 HALF STATIONS IS MOST ACCURATE

	Δ	DIFF	LCB	DIFF
SIMPSON'S (20 AND 4)	3254	-	0.95'A	-
SIMPSON'S (10 AND 2)	3260	.18%	0.54'A	.11%
TRAPEZOIDAL (20 AND 4)	3249	.15%	0.89'A	.02%
TRAPEZOIDAL (10 AND 2)	3236	.55%	0.73'A	.06%

BASIC NAVAL ARCHITECTURE

Problem 13

Problem Level: Basic

The half-breadths of a transom-stern ship are tabulated below. There are eleven stations spaced 25.50 ft apart. The waterline starts at Station 0 and terminates at Station 10.

(a) The offsets are given in feet-inches-eighths. Convert the offsets to feet in decimal form.

(b) Use the attached tabular form to computer A_w and LCF. The Simpson's Rule multipliers are shown on the form. Note that since the offsets are given in half-breadths, it is necessary to multiply the area and the moment by 2 as shown in the computation at the bottom of the form.

Station	Half-breadth
0	0 - 0 - 0
1	6 - 2 - 4
2	12 - 2 - 0
3	16 - 4 - 3
4	18 - 3 - 0
5	18 - 9 - 0
6	19 - 0 - 5
7	18 - 7 - 5
8	17 - 5 - 6
9	15 - 2 - 6
10	4 - 6 - 3

Area of Waterplane
Longitudinal Centroid of Waterplane (LCF)

Station	Half-Breadth	Simpson's Mult.	Functions of Half-Breadths	Lever Arm (Stations)	Functions of Long'l Moment
FP 0		1		5	F
1		4		4	F
2		2		3	F
3		4		2	F
4		2		1	F
					Sum F
5		4		0	
6		2		1	A
7		4		2	A
8		2		3	A
9		4		4	A
AP 10		1		5	A
		f(A) =			Sum A
					Sum F
				f(M) =	F or A

Station Spacing = s = ______________

Total Area (both sides) $= 2 \times f(A) \times \frac{s}{3} =$ ____________________

Moment of Waterplane about $= 2 \times f(M) \times \frac{s^2}{3} =$ ____________________

Centroid of Waterplane about $= \frac{f(M)}{f(A)} \times s =$ ____________________ F or A

BASIC NAVAL ARCHITECTURE

Problem 14

Problem Level: Basic

From Bonjean's Curves for the FFG7-Class frigate, tabulate the Sectional Areas for all 20 stations below the 14'-0" WL.

On 8-1/2" x 11" graph paper plot the Sectional Area Curve (Curve of Areas). Use a horizontal scale of 1 station = 1/2 inch and a vertical scale of 1" = 100 ft^2.

Prepare a tabular calculation sheet and using Simpson's Rule calculate the Displacement (s.w.) and LCB (without appendages) at this waterline.

Compare the values you have obtained with the values of displacement and LCB obtained from the Curves of Form. How do you account for the difference?

Problem 15

Problem Level: Basic

A clean ballast tank on a PD-214-Type container ship encloses the waterplane areas tabulated below:

	Height above ℄	Tank W.P. Area
Bottom of Tank	1.00	0.0
	2.00	52.5
	3.00	92.1
	4.00	101.7
	5.00	101.7
	6.00	101.7
Top of Tank	7.00	101.7

Use the Trapezoidal Rule to calculate the molded capacity of the tank:

(a) in ft^3

(b) in long tons

(c) in gallons

NOTES

1. THE TABLE "DECIMALS OF A FOOT" IN THE APPENDIX IS A CONVENIENT WAY TO CONVERT FEET-INCHES-EIGHTHS

(a)

STA	HALF-BREADTHS FT-IN-EIGTHS	HALF-BREADTHS DECIMAL
0	0 - 0 - 0	0.000
1	6 - 2 - 4	6.203
2	12 - 2 - 0	12.167
3	16 - 4 - 3	16.365
4	18 - 3 - 0	18.250
5	18 - 9 - 0	18.750
6	19 - 0 - 5	19.052
7	18 - 7 - 5	18.552
8	17 - 5 - 6	17.479
9	15 - 2 - 6	15.229
10	4 - 6 - 3	4.531

(b) FROM PP 2

A_w = 7,459.99 FT^2

LCF = 12.67 FT AFT ⊄

Area of Waterplane
Longitudinal Centroid of Waterplane (LCF)

Station	Half-Breadth	Simpson's Mult.	Functions of Half-Breadths	Lever Arm (Stations)	Functions of Long'l Moment
FP 0	0.000	1	0.000	5	0.00 F
1	6.203	4	24.812	4	99.25 F
2	12.167	2	24.334	3	73.00 F
3	16.365	4	65.460	2	130.92 F
4	18.250	2	36.500	1	36.50 F
					339.67 Sum F
5	18.750	4	75.000	0	0.00
6	19.052	2	38.104	1	38.10 A
7	18.552	4	74.208	2	148.42 A
8	17.479	2	34.958	3	104.87 A
9	15.229	4	60.916	4	243.66 A
AP 10	4.531	1	4.531	5	22.66 A
		f(A) =	438.823		557.71 Sum A
					339.67 Sum F
				f(M) =	218.04 F or A

Station Spacing = s = 25.50

Total Area (both sides) $= 2 \times f(A) \times \frac{s}{3} =$ 7,459.99 FT²

Moment of Waterplane about $= 2 \times f(M) \times \frac{s^2}{3} =$ 94,520.34 FT³

Centroid of Waterplane about $= \frac{f(M)}{f(A)} \times s =$ 12.67 FT F or (A)

STA	AREA (BOTH SIDES) FT2	SM	FUNCTIONS OF VOLUME f(V)	LVR (STA)	FUNCTIONS OF LONG'L MMT f(LM)
0	0	1	0	10	0
1	50	4	200	9	1800
2	115	2	230	8	1840
3	182	4	728	7	5096
4	240	2	480	6	2880
5	293	4	1172	5	5860
6	340	2	680	4	2720
7	385	4	1540	3	4620
8	420	2	840	2	1680
9	445	4	1780	1	1780
10	460	2	920	0	ΣF=28,276
11	455	4	1820	1	1820
12	438	2	876	2	1752
13	405	4	1620	3	4860
14	353	2	706	4	2824
15	295	4	1180	5	5900
16	225	2	450	6	2700
17	158	4	632	7	4424
18	107	2	214	8	1712
19	52	4	208	9	1872
20	5	1	5	10	50

$\Sigma f(V) = 16,261$ $\Sigma A = 27,914$

—CONTINUED—

(CONTINUED)

$\Sigma A = 27,914$

$\Sigma' F = 28,276$

$\Sigma_1 f(V) = 16,281$ $\Sigma_1 f(LM) = 362$ FWD.

STATION SPACING, $s = \frac{408}{20} = 20.40$ FT.

VOLUME (BOTH SIDES) $= f(V) \times \frac{S}{3} = 16,281 \times \frac{20.40}{3}$

$\nabla = 110,711 \text{ FT}^3$

DISPLACEMENT (S.W.) $= \frac{\nabla}{35} = \frac{110,711 \text{ FT}^3}{35 \text{ FT}^3/\text{TON}}$

$\Delta = 3163$ LT.

LONG'L CTR. OF BUOY. = LCB $= \frac{f(LM)}{f(V)} \times S$

$= \frac{362 \text{ F}}{16,281} \times 20.40$

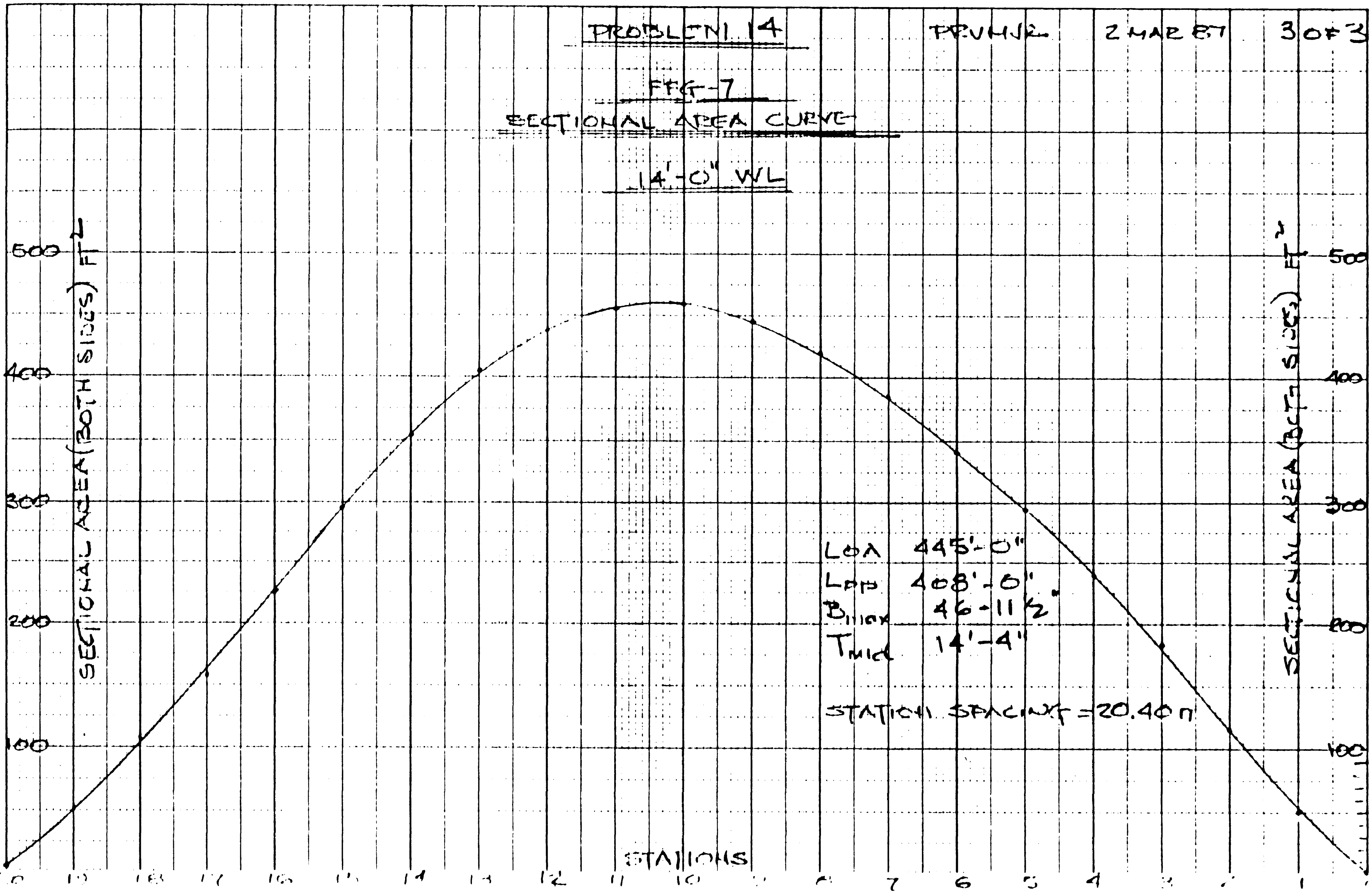
LCB = 0.46 FT FWD ⊗

NOTE: THE AREAS TAKEN FROM BONJEAN'S CURVES INCLUDE THE SHELL PLATING, BUT DO NOT INCLUDE RUDDERS, PROPELLERS, SHAFTS, STRUTS, ROLLING FINS AND OTHER APPENDAGES

FROM THE CURVES OF FORM

$\Delta = 3263$ LT

LCB = 0.0 FT FW ⊗



PROBLEM 14
PRVHJR
2 MAR 87
3 OF 3
FFG-7
SECTIONAL AREA CURVE
14'-0" WL
SECTIONAL AREA (BOTH SIDES) FT²
500
400
300
200
100
LOA 445'-0"
LPP 408'-0"
BMAX 46'-11½"
TMID 14'-4"
STATION SPACING = 20.40 FT
STATIONS
20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

STA.	AREA FT^2	TM	f(V)
1	0.0	½	0.0
2	52.5	1	52.5
3	92.1	1	92.1
4	101.7	1	101.7
5	101.7	1	101.7
6	101.7	1	101.7
7	101.7	½	50.85

$\sum_1 f(V) = 500.55$

STATION SPACING, S, = 1.00 FT.

VOLUME = $\sum_1 f(V) \times S$ = 500.55 × 1.00   VOL = 500.55 FT^3

THE BALLAST TANK WILL BE FILLED WITH SALT WATER AT 35.0 FT^3/TON. ALSO 1 FT^3 = 7.48 GALS

MLD. CAPACITY OF TANK (@ 100%) = $\frac{500.55}{35}$ = 14.30 LT

= 500.55 × 7.48 = 3744 GAL

RECAP: MOLDED CAPACITY OF TANK
- (a) 500.55 FT^3
- (b) 14.30 LT (SW)
- (c) 3744 GALS.

BASIC NAVAL ARCHITECTURE

Unit Number: 11

Title: The ship at rest - static stability - 1

Tape Running Time: $32^M\ 40^S$

Reading Assignment: MSD, pp 51-58

Additional References: PNA, pp 54-59, 70-73 (repeated)

Scope:

The concepts of stable, neutral, and unstable equilibrium are introduced and related to the positions of C_T and M. Small inclinations due to transverse shift of weight on board are discussed. Initial stability is defined. Stability at large angle, the righting arm G2 and the Static Stability Curve is introduced. Formula for BM is introduced. Moment of Inertia is discussed.

Key Points to Emphasize:

1. Emphasize that when the vertical gravitational and buoyant forces are not in a vertical line the ship is not in equilibrium and will tend to right or upset. G2 is a measure of the separation.

2. Distinguish between the cases of the ship inclined due to external forces and the ship inclined due to the shift of transverse weight on board.

3. Emphasize the effect of a shift of weight on board on ship's center of gravity.

4. Emphasize formula: $G_1G_2 = \frac{wl}{\Delta} = GM \tan\theta$

5. Explain moment of inertia and formulas for rectangular area.

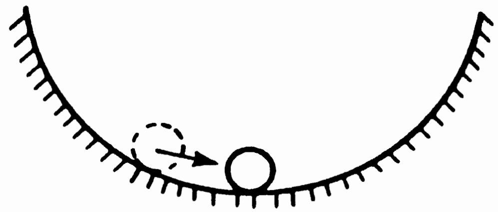
6. Explain $BM = I/\nabla$ and go over example.

Suggested Problem Assignment: 8 or 9, one of 16, 17 or 18, one of 23, 24, 25

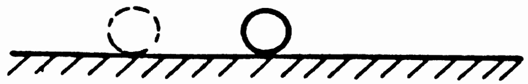
STATIC STABILITY

STATES OF EQUILIBRIUM

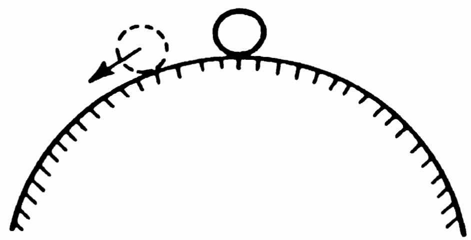
STABLE



NEUTRAL

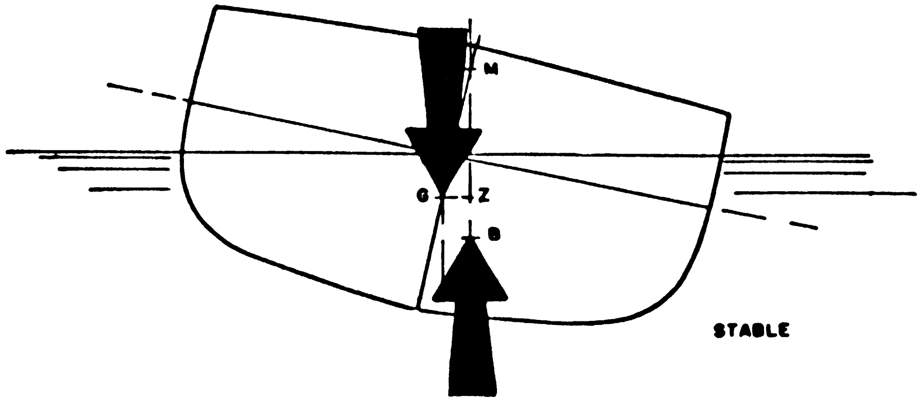


UNSTABLE



STATIC STABILITY (CON'T)

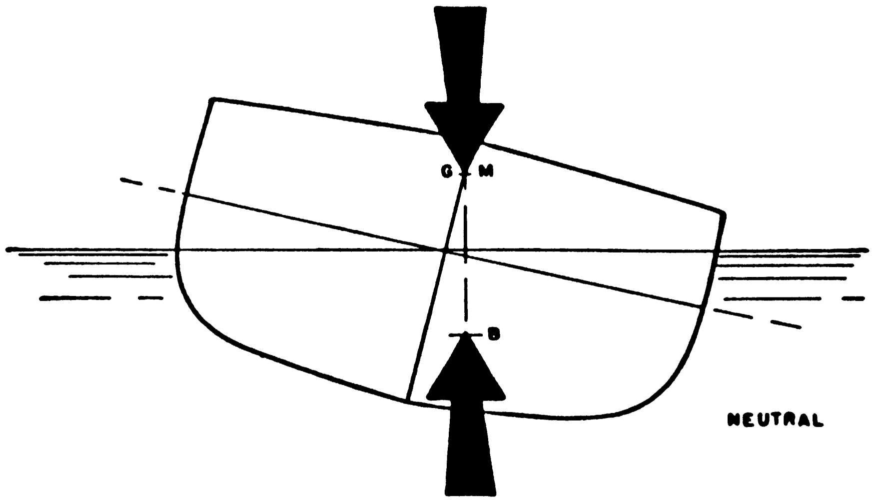
STABLE EQUILIBRIUM



RIGHTING MOMENT ACTS TO RESTORE SHIP TO UPRIGHT POSITION. GM IS POSITIVE

STATIC STABILITY (CON'T)

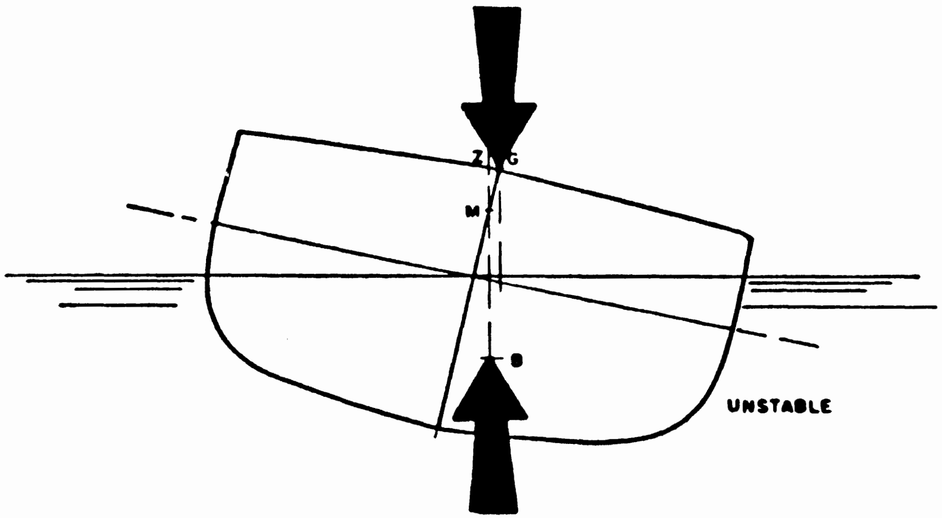
NEUTRAL EQUILIBRIUM



WEIGHT AND BUOYANCY FORCES ARE IN A VERTICAL LINE. THE SHIP REMAINS IN THIS POSITION. GM = 0

STATIC STABILITY (CON'T)

UNSTABLE EQUILIBRIUM



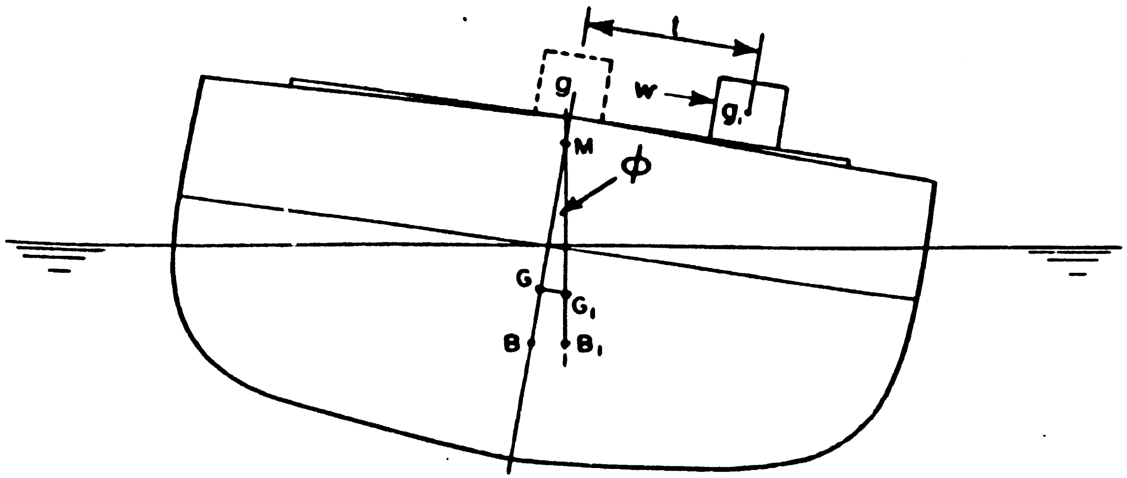
UPSETTING MOMENT ACTS TO INCREASE THE ANGLE OF HEEL. GM IS NEGATIVE

11-5

STATIC STABILITY (CON'T)

INCLINED EQUILIBRIUM

SHIFT OF WEIGHT, w, THRU DISTANCE, t, CAUSES SHIFT IN CG FROM G TO G_1



GM IS STILL MEASURED ON THE CENTERLINE

STATIC STABILITY (CON'T)

METACENTRIC HEIGHT, GM

THE METACENTRIC HEIGHT, GM IS A MEASURE OF INITIAL STABILITY

AT ANGLES LARGER THAN, SAY 7° - 12° M NO LONGER FALLS ON THE CENTERLINE

AT THESE ANGLES GM NO LONGER HAS ANY SIGNIFICANCE.

STATIC STABILITY (CON'T)

LONGITUDINAL STABILITY

SIMILAR IN PRINCIPLE TO TRANSVERSE STABILITY, BUT-

GM_L, BM_L AND KM_L ARE MUCH LARGER NUMBERS

NOTATION:

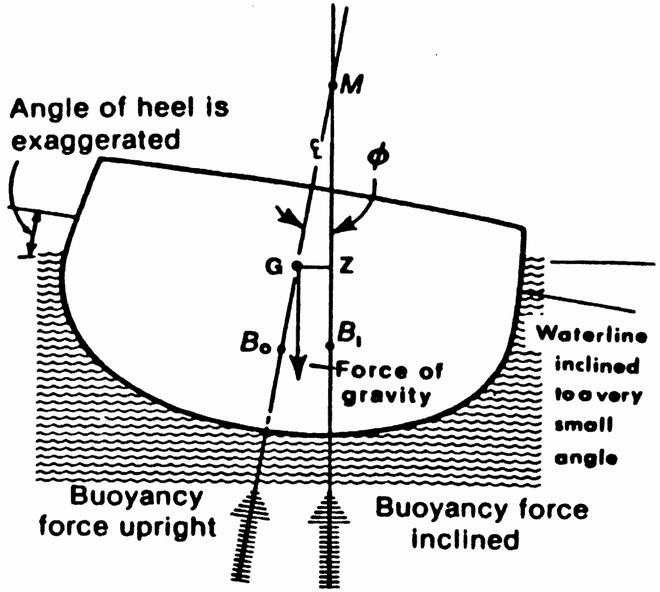
LONGITUDINAL METACENTER IS DESIGNATED, EITHER

M_L OR M'

STATIC STABILITY (CON'T)

RIGHTING ARM, GZ

THE HORIZONTAL SEPARATION BETWEEN THE WEIGHT FORCE AND THE BUOYANT FORCE IS THE RIGHTING ARM, GZ



STATIC STABILITY (CON'T)

RIGHTING MOMENT

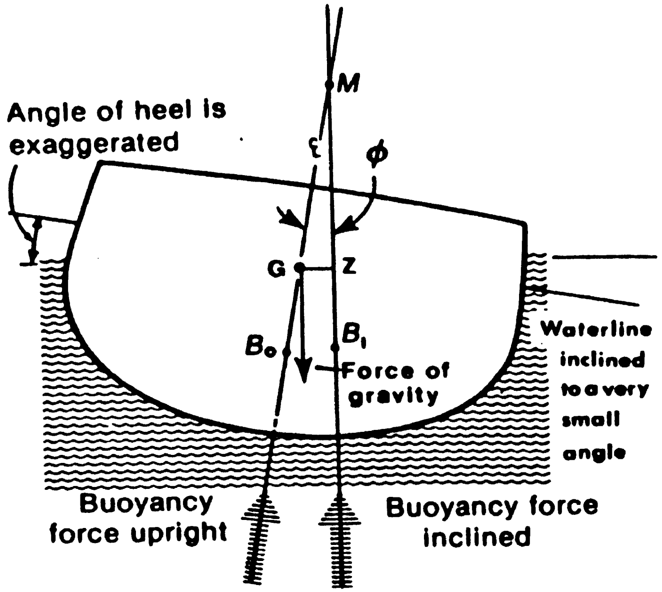
THE RIGHTING MOMENT IS

$$RM = \Delta \; GZ$$

GZ IS DEFINED OVER THE FULL RANGE OF ANGLES OF INCLINATION, ϕ

STATIC STABILITY (CON'T)

RIGHTING MOMENT



AT SMALL ANGLES,

$$GZ = GM \sin \phi$$

AND

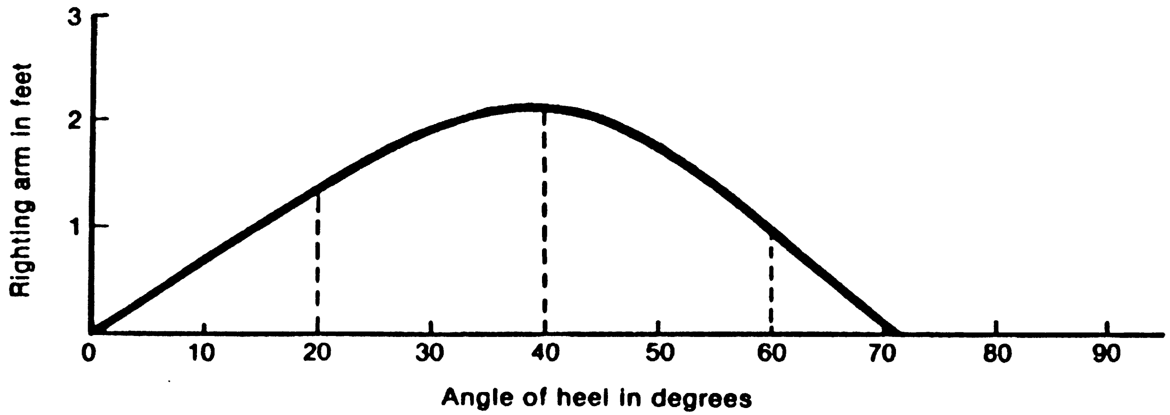
$$RM = \Delta\, GZ = \Delta\, GM \sin \phi$$

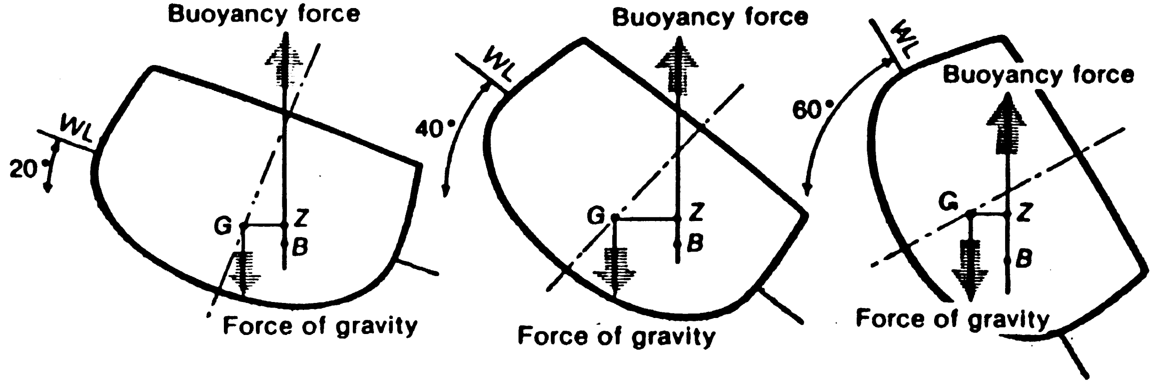
STATIC STABILITY (CON'T)

STATIC STABILITY CURVE

THE PLOT OF GZ VERSUS ANGLE OF HEEL
IS CALLED THE STATIC STABILITY CURVE

STATIC STABILITY (CON'T)





GZ = 1.4 feet

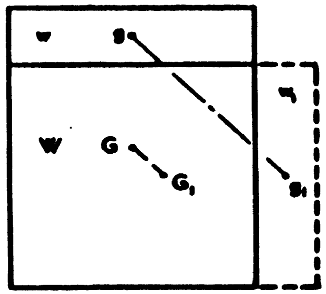
GZ = 2.0 feet

GZ = 1 foot

STATIC STABILITY (CON'T)

SHIFT OF WEIGHT ON BOARD

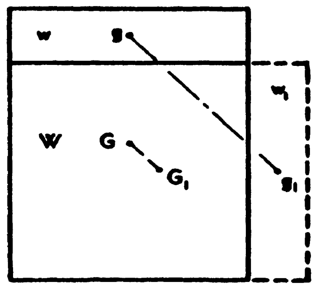
A SHIFT OF A SMALL WEIGHT, w, FROM g TO g_1, CAUSES A SHIFT IN THE CENTER OF GRAVITY OF THE SYSTEM FROM G TO G_1



IMPORTANT: GG_1 IS ALWAYS PARALLEL TO gg_1

STATIC STABILITY (CON'T)

SHIFT OF WEIGHT ON BOARD



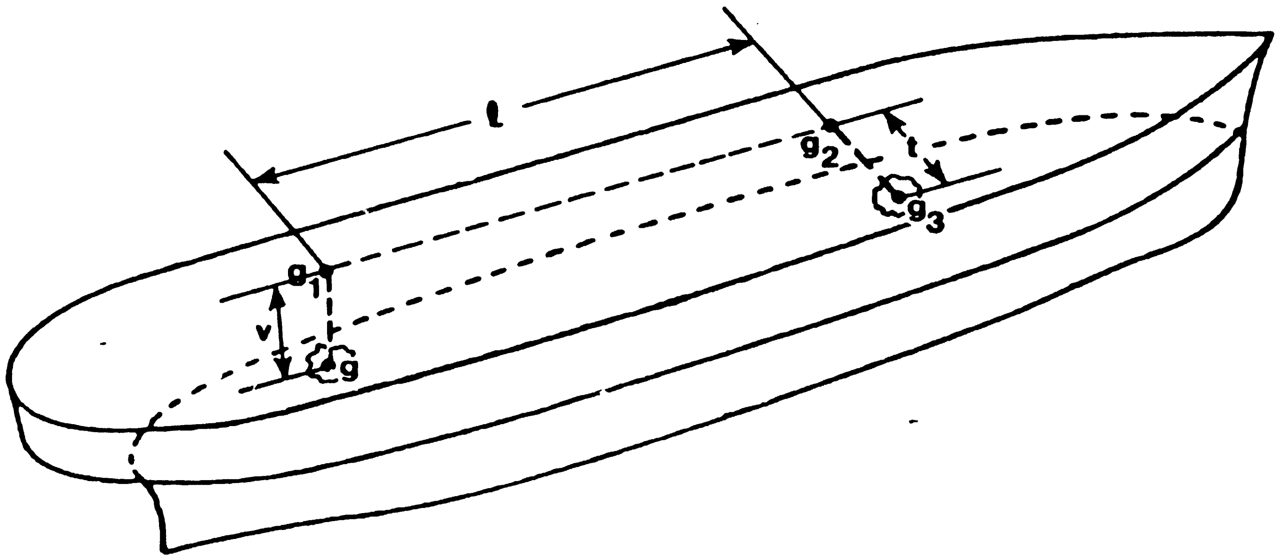
FROM PRINCIPLE OF MOMENTS-

$$\Delta GG_1 = w\ gg_1$$

$$GG_1 = \frac{w\ gg_1}{\Delta}$$

STATIC STABILITY (CON'T)

SHIFT OF WEIGHT ON BOARD



VERTICAL SHIFT: $GG_1 = \frac{wv}{\Delta}$

LONGITUDINAL SHIFT: $G_1G_2 = \frac{wl}{\Delta}$

TRANSVERSE SHIFT: $G_2G_3 = \frac{wt}{\Delta}$

STATIC STABILITY (CON'T)

SHIFT OF WEIGHT ON BOARD

FOR TRANSVERSE WEIGHT SHIFTS AT SMALL ANGLES-

$$G_2G_3 = \frac{wt}{\Delta} = GM \tan \phi$$

FOR LONGITUDINAL WEIGHT SHIFTS (ANGLES WILL USUALLY BE SMALL)-

$$G_1G_2 = \frac{wl}{\Delta} = GM_L \tan \theta$$

WHERE θ = TRIM ANGLE

STATIC STABILITY (CON'T)

METACENTRIC RADIUS, BM

STUDENT SHOULD STUDY DERIVATION ON PP 57, MODERN SHIP DESIGN

THE IMPORTANT RESULTS ARE

$$BM = \frac{I}{\nabla} \quad \text{(TRANSVERSE)}$$

AND

$$BM_L = \frac{I_L}{\nabla} \quad \text{(LONGITUDINAL)}$$

STATIC STABILITY (CON'T)

METACENTRIC RADIUS, BM

I = TRANSVERSE MOMENT OF INERTIA OF WATERPLANE

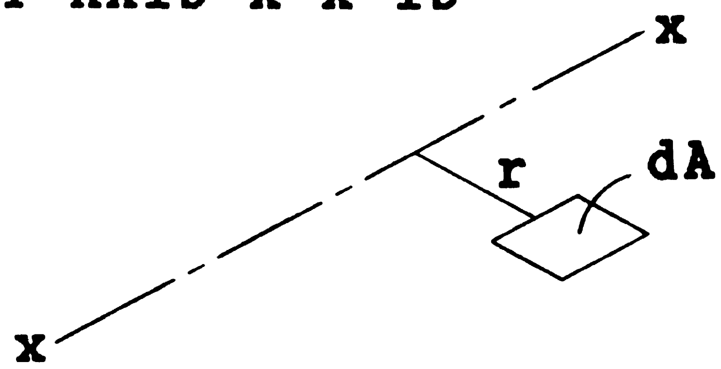
I_L = LONGITUDINAL MOMENT OF INERTIA OF WATERPLANE

MORE ABOUT MOMENT OF INERTIA COMING!

STATIC STABILITY (CON'T)

MOMENT OF INERTIA

THE MOMENT OF A SMALL AREA, dA ABOUT AXIS x-x IS



$$dM_x = r\ dA$$

THE MOMENT OF INERTIA OF dA ABOUT x-x IS

$$dI_x = r^2\ dA$$

STATIC STABILITY (CON'T)

MOMENT OF INERTIA

WHEN THESE SMALL AREAS ARE INTEGRATED OVER THE WHOLE WATERPLANE THE RESULT IS-

$$I = 2\int_{o}^{L} \frac{r^3}{3}\,dx$$

THE 2 IS TO ACCOUNT FOR BOTH SIDES OF THE SHIP

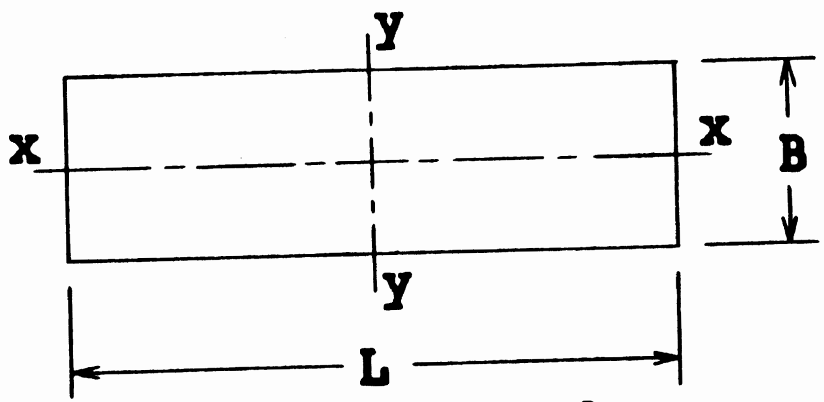
THIS INTEGRATION IS DONE NUMERICALLY

SEE TABLE 3-1 IN MODERN SHIP DESIGN

STATIC STABILITY (CON'T)

MOMENT OF INERTIA

MOMENT OF INERTIA OF A RECTANGULAR WATERPLANE



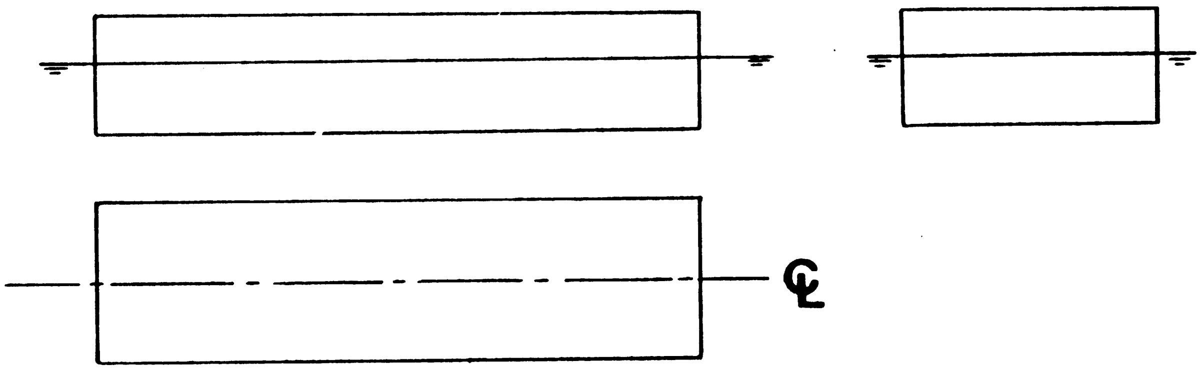
$$I = I_{xx} = \frac{B^3 L}{12}$$

$$I_L = I_{yy} = \frac{L^3 B}{12}$$

STATIC STABILITY (CON'T)

EXAMPLE

FIND GM OF RECTANGULAR BARGE IN SALT WATER



GIVEN

L = 120' - 0"
B = 35' - 0"
T = 10' - 0"
KG = 6.00 FT ABOVE K

STATIC STABILITY (CON'T)

EXAMPLE

1. **FIND $\triangle$ AND ∇:**

$$\nabla = 120.0 \text{ FT} \times 35.0 \text{ FT} \times 10.0 \text{ FT} = 42{,}000 \text{ FT}^3$$

$$\triangle = \frac{120.0 \text{ FT} \times 35.0 \text{ FT} \times 10.0 \text{ FT}}{35 \text{ FT}^3/\text{TON}} = 1{,}200 \text{ LT}$$

2. **FIND I:**

$$I = \frac{(35.0 \text{ FT})^3 (120.0 \text{ FT})}{12} = 428{,}750 \text{ FT}^4$$

3. **FIND BM:**

$$BM = \frac{I}{\nabla} = \frac{428{,}750 \text{ FT}^4}{42{,}000 \text{ FT}^3} = 10.21 \text{ FT}$$

STATIC STABILITY (CON'T)

EXAMPLE

4. FIND KB. FOR A RECTANGULAR BARGE KB WILL BE JUST 1/2 THE DRAFT

$$KB = \frac{10.0 \text{ FT}}{2} = 5.00 \text{ FT}$$

5. FIND GM

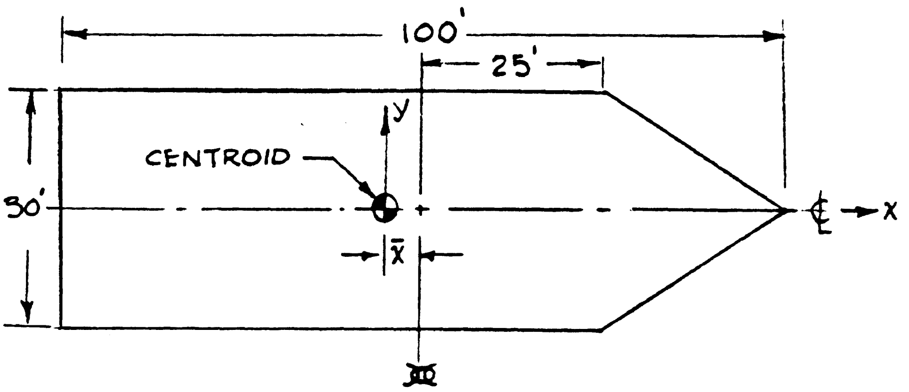
BM	=	10.21 FT	
KB	=	5.00 FT	A. BL
KM	=	15.21 FT	A. BL
− KG	=	6.00 FT	A. BL
GM	=	9.21 FT	

Problem 8

Problem Level: Basic

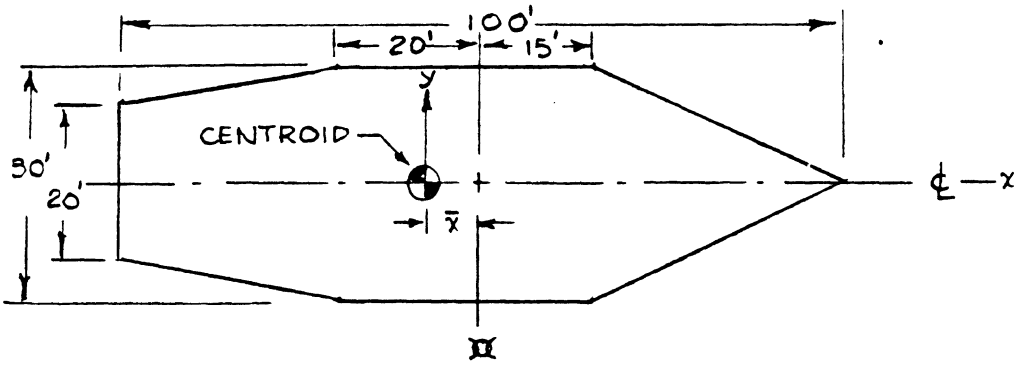
Formulas for area, coordinates of centroidal axes, and moment of inertia of plane geometrical forms are given in the Appendix to the Problem Book. Using these formulas compute the area, centroidal axis, and moment of inertia for the figures shown below:

(a)



Find A, I_{xx}, I_{yy}

(b)



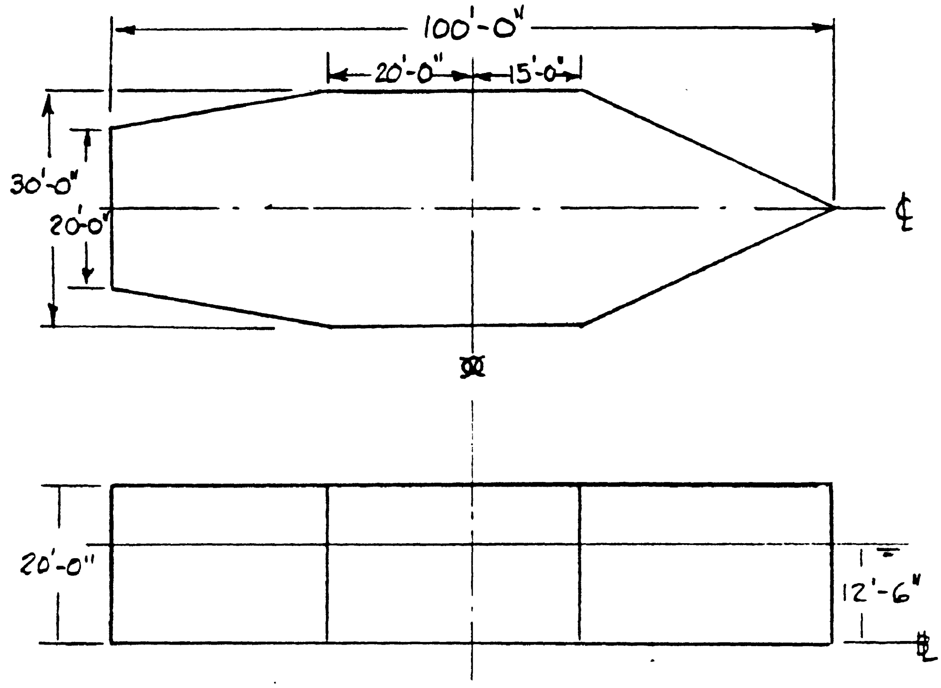
Find A, $\bar{x}$, I_{xx}, I_{yy}

Problem 9

Problem Level: Basic

A barge with vertical sides has the form shown below. Determine the following characteristics of the barge:

a) Displacement in salt water
b) Displacement in fresh water (@ 36 ft^3/ton)
c) Waterplane area
d) Centroid of the waterplane (Longitudinal Center of Flotation)
e) Vertical and Longitudinal location of the centroid of the underwater volume (KB, LCB)



BASIC NAVAL ARCHITECTURE

Problem 16

Problem Level: Basic

Refer to the Curves of Form for the BEAR Class cutters. Identify the following curves and use the appropriate scaling factors to determine the values for the hydrostatic parameters at a mean draft of 13'-0".

Δ	TPI	KM_t
Δ_{fw}	MTI	C_b
KB	CD1"TA	C_p
LCB	Wetted Surface, S	C_M
LCF	KM_L	C_{WP}

Problem 17

Problem Level: Basic

Using the information obtained from the Curves of Form for the BEAR Class cutter at the 13'-0" draft, find:

Moment of Inertia of waterplane about the ℄ and about a transverse axis through the CF.

Area of the 13'-0" waterplane

Area of the Midship Section

Problem 18

Problem Level: Basic

A BEAR Class cutter is floating in salt water at the following drafts and KG:

T_f	=	12'-0"
T_a	=	13'-6"
KG	=	19.50' above B_L

Find the following:

Displacement
LCG
TPI
MTI
LCF
GM_t

Problem 23

Problem Level: Basic

A rectangular barge has the following dimensions, drafts, and KG:

L_{pp}	=	175'-0"
B	=	35'-0"
T_f	=	10'-0"
T_a	=	10'-0"
KG	=	8.00 ft above ℄

Find:
- (a) Volume of Displacement
- (b) Displacement in salt water
- (c) Transverse Moment of Inertia of the waterplane (i.e. Moment of Inertia about the ℄)
- (d) Transverse Metacentric Radius, BM_t
- (e) KB
- (f) KM_t
- (g) GM_t

Problem 24

Problem Level: Basic

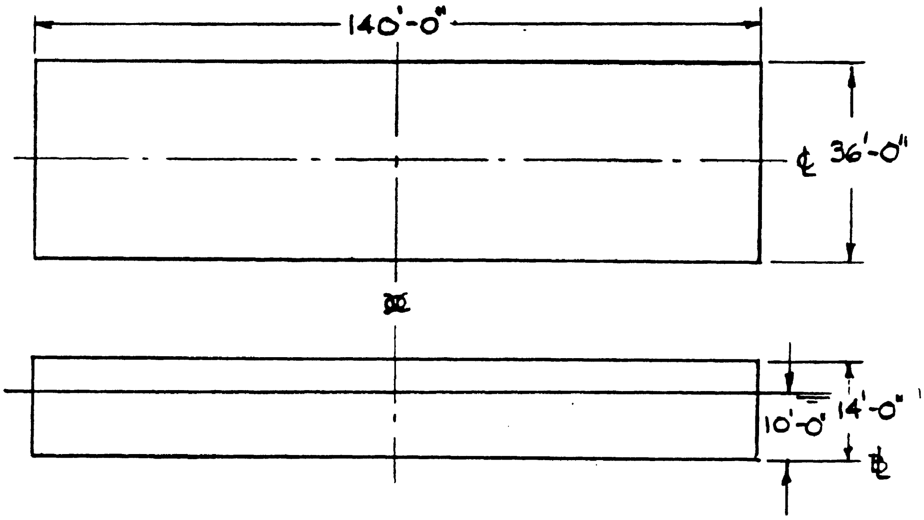
Refer to Problem 13. For the waterplane offsets of the transom-stern ship given in the problem compute the transverse Moment of Inertia of the waterplane using the Trapezoidal Rule as in Table 3-1, pp 57, Gillmer. Use a tabular form for the calculation.

BASIC NAVAL ARCHITECTURE

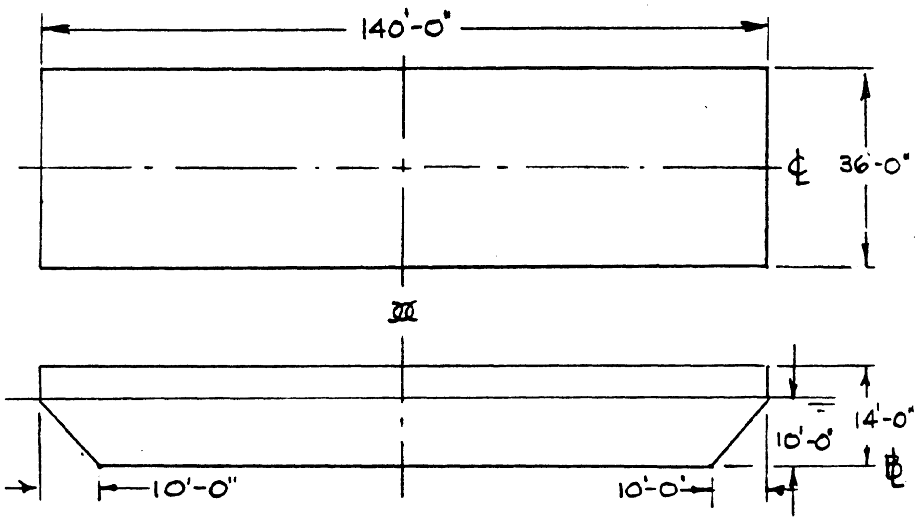
Problem 25

Problem Level: Basic

a) A rectangular barge has the dimensions shown below. Find Δ, Δ_{fw}, KB, BM_t, KM_t, TPI.

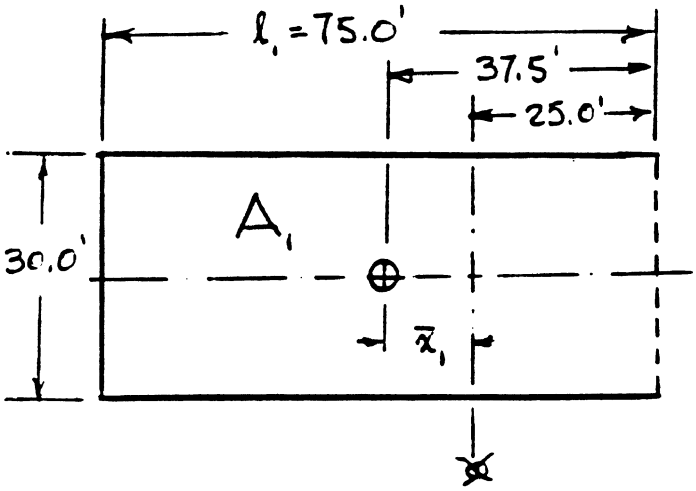


b) The barge shown below has similar dimensions to that shown above, except that bow and stern rake have been added. Find the new Δ_1, KB, KM_T.



c) If KG = 8.00' above the ℄ find GM_T of the barge in (b) above.

(a) DECOMPOSE THE FIGURE INTO A RECTANGLE AND A TRIANGLE:



RECTANGLE:

AREA, $A_1 = Bl_1 = 30.0' \times 75.0'$

$A_1 = 2250.0\ FT^2$

CENTROID, $x_1 = \frac{l_1}{2} - 25.0'$

$x_1 = 12.5'$ AFT ⊗

MOMENTS OF INERTIA:

$I_{o_{xx_1}} = \frac{B^3 l_1}{12} = \frac{30.0^3 \times 75.0}{12}$

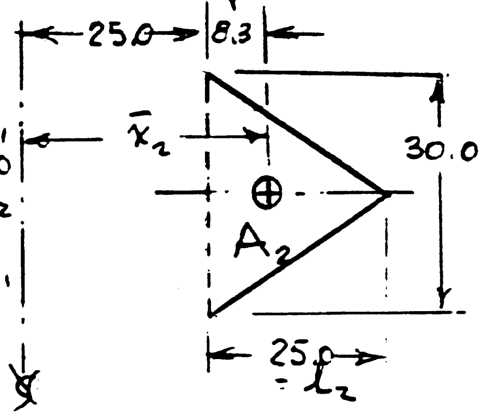
$I_{o_{xx_1}} = 168{,}750\ FT^4$

$I_{o_{yy_1}} = \frac{B l_1^3}{12} = \frac{30.0 \times 75.0^3}{12}$

$I_{o_{yy_1}} = 1{,}054{,}687.5\ FT^4$

CENTROID OF ▷ $= \frac{1}{3} \times 25.0' = 8.3'$

TRIANGLE:



AREA, $A_2 = \frac{1}{2} B l_2$

$= \frac{1}{2} \cdot 30.0' \times 25.0'$

$A_2 = 375.0\ FT^2$

CENTROID, $\bar{x}_2 = 25.0' + 8.3'$

$\bar{x}_2 = 33.3'$ FWD ⊗

MOM'TS OF INERTIA:

$I_{c_{xx}} = 2\frac{(B/2)^3 l_2}{12} = \frac{2 \cdot 15.0^3 \times 25.0}{12}$

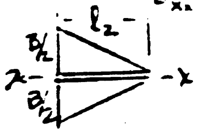
$I_{c_{xx_2}} = 14{,}062.5\ FT^4$

$I_{c_{yy_2}} = \frac{B l_2^3}{36} = \frac{30.0 \times 25.0^3}{36}$

$I_{c_{yy_2}} = 13{,}020.8\ FT^4$

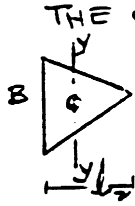
NOTE ON AXES:

FOR $I_{c_{xx}}$ USE 2 TRIANGLES



USE FORMULA FOR AXIS ON BASE. THEN, $I_{c_{xx}} = 2 \cdot \frac{(B/2)^3 l_2}{12}$

FOR $I_{c_{yy}}$ THE AXIS IS THRU THE CENTROID, THEN



$I_{c_{yy}} = \frac{B l_2^3}{36}$

NOTE: REFER TO "PROPERTIES OF GEOMETRIC SECTION" IN APPENDIX FOR FORMULAS FOR AREAS, CENTROIDS, AND MOMENT OF INERTIA.

(a) (CON'T)

FIND CENTROID OF COMBINED AREAS. USE TABULAR FORMAT

ITEM	AREA FT^2	LVR* FT	MOM'T. FT^3
A_1 (rectangle)	2250	+12.5	+28125.0
A_2 (triangle)	375	−33.3	−12487.5
$A_1 + A_2$	2625	+5.95	+15637.5

$$\text{CENTROID} = \frac{+15637.5}{2625} = +5.95$$

SIGNS: + = AFT ⊗
− = FWD ⊗

THE MOMENTS OF INERTIA OF EACH AREA, $i_{o_{xx}}$ AND $i_{o_{yy}}$ ABOUT ITS OWN CENTROID HAS BEEN COMPUTED ON PP 1. THESE MUST NOW BE TRANSFERRED TO THE CENTROID OF THE COMBINED FIGURE USING THE TRANSFER OF AXES FORMULA:

$$I = i_c + Ad^2$$

WHERE d IS THE SHIFT DISTANCE. WITH THE COMPONENT AREA MOMENTS OF INERTIA ON THE SAME AXIS THE MOMENTS OF INERTIA CAN SIMPLY BE SUMMED

FOR THE TRANSVERSE MOMENT OF INERTIA (ABOUT THE X-AXIS) SINCE THE CENTROIDS OF BOTH AREAS ARE ALREADY ON THE SAME AXIS, THE X-AXIS THEN

$$I_{xx} = 168{,}750\ FT^4 + 14{,}062.5\ FT^4 = 182{,}812.5\ FT^4$$

FOR I_{yy}, MOMENTS OF INERTIA FOR BOTH THE RECTANGLE AND THE TRIANGLE MUST BE TRANSFERRED TO THE CENTROID OF THE COMBINED AREA 5.95' AFT ⊗

(a) (CON'T)

THEN ~

$$d_1 = 12.50' - 5.95' = 6.55'$$

$$A_1 d_1^2 = 2250 \times 6.55^2 = 96{,}530.6 \text{ FT}^4$$

$$i_{o_{yy_1}} = \text{(FROM PP 1)} = 1{,}054{,}687.5 \text{ FT}^4$$

$$I_{yy_1} = i_{o_{yy_1}} + A_1 d_1^2 = 1{,}151{,}218.1 \text{ FT}^4$$

$$d_2 = 33.3' + 5.95' = 39.25'$$

$$A_2 d_2^2 = 375 \times 39.25^2 = 577{,}710.9 \text{ FT}^4$$

$$i_{o_{yy_2}} = \text{(FROM PP 1)} = 13{,}020.8 \text{ FT}^4$$

$$I_{yy_2} = i_{o_{yy_2}} + A_2 d_2^2 = 590{,}731.7 \text{ FT}^4$$

FINALLY ~

$$I_{yy} = I_{yy_1} + I_{yy_2} = 1{,}151{,}218.1 + 590{,}731.7$$

$$I_{yy} = 1{,}741{,}949.8 \text{ FT}^4$$

(a) RECAP:

	$A =$	2625 FT²
CENTROID,	$\bar{x} =$	5.95 FT AFT ℄
	$I_{xx} =$	182,812.5 FT⁴
	$I_{yy} =$	1,741,949.8 FT⁴

(b) THE SOLUTION TO THIS PROBLEM WILL BE WORKED BY THE TABULAR METHOD. THE TRIANGULAR AREAS AFT WILL BE TREATED AS DEDUCTIONS AND ASSIGNED A NEGATIVE SIGN IN THE "AREA" COLUMN. THIS ALSO CAUSES THE SIGN TO CHANGE IN THE "MOMENT" COLUMN AND THE "MOMENT OF INERTIA" AND "Ad^2" COLUMNS. THE SIGMA SYMBOL (Σ) INDICATES SUMMATION. DISTANCES ARE ROUNDED TO TWO DECIMAL PLACES, AREAS TO ONE DECIMAL PLACE, MOMENTS AND MOMENTS OF INERTIA ARE ROUNDED TO THE NEAREST WHOLE NUMBER.

ITEM	AREA FT^2	LVR FT	MOMT FT^3	TRANS. MOM'T OF INERTIA i_{oxx} FT^4	d FT	Ad^2 FT^4	LONG'L MOM'T OF INERTIA i_{oyy} FT^4	d FT	Ad^2 FT^4
A_1	1950.0	+ 17.50	+ 34,125	+146,250	0	–	+686,563	11.43	+ 254,758
A_2	525.0	-26.67	-14,002	+ 19,687	0	–	+ 35,729	32.74	+362,751
MINUS: A_3	-75.0	+ 40.00	- 3,000	- 104	13.33	-13,327	- 3,750	33.93	- 86,343
MINUS: A_4	-75.0	+ 40.00	- 3,000	- 104	13.33	-13,327	- 3,750	33.93	- 86,343
	Σ 2325	+ 6.07	Σ 14,123	Σ 165,729 - 26,653		Σ -26,653	Σ 714,792 + 644,823		Σ 644,823

$A = 2325\ FT^2$, $\bar{x} = 6.07$ AFT ⊗

$I_{xx} = 139,076\ FT^4$

$I_{yy} = 1,359,615\ FT^4$

NOTE: THIS PROBLEM IS A CONTINUATION OF PROBLEM 8, PART (b). THE WATERPLANE CHARACTERISTICS ARE THE SAME AND THAT CALCULATION NEED NOT BE REPEATED

(a) SINCE THE BARGE IS "WALL SIDED" THE VOLUME OF DISPLACEMENT WILL SIMPLY ~~BE~~ THE AREA OF THE WATERPLANE MULTIPLIED BY THE DRAFT.

$$\nabla = A_{wp} \cdot T$$

FROM 8(b) $A_{wp} = 2325 \text{ FT}^2$

THEN, $\nabla = 2325 \times 12.50 \text{ FT}^3$

$$\nabla = 29063 \text{ FT}^3$$

$$\Delta = \frac{29063 \text{ FT}^3}{35 \text{ FT}^3/\text{TON}}$$

(a) $\boxed{\Delta = 830 \text{ LT}}$

(b) $$\Delta_{fw} = \frac{29063 \text{ FT}^3}{36 \text{ FT}^3/\text{TON}}$$

(b) $\boxed{\Delta_{fw} = 807 \text{ LT}}$

(c) FROM 8(b) $\boxed{A_{wp} = 2325 \text{ FT}^2}$

(d) FROM 8(b) $\boxed{LCF = 6.07 \text{ FT A. } ⊠}$

(e) SINCE THE BARGE IS WALL SIDED THE CENTROID OF THE UNDERWATER VOLUME WILL BE AT THE SAME LONGITUDINAL LOCATION AS THE LCF. THE VERTICAL LOCATION WILL BE AT HALF THE DRAFT. NOTE THAT THIS IS ONLY TRUE FOR WALL SIDED PROBLEMS.

$\boxed{KB = 6.25 \text{ FT A. BL}}$

$\boxed{LCB = 6.07 \text{ FT A. } ⊠}$

NOTE: CURVES OF FORM ARE NORMALLY PLOTTED FROM THE BOTTOM OF THE KEEL RATHER THAN FROM THE BASE LINE, A FREQUENT SOURCE OF ERRORS IN CALCULATIONS USING MOLDED DIMENSIONS. IN THE CASE OF THE "BEAR" CLASS CUTTERS THE BASE LINE IS 3/4" ABOVE THE BOTTOM OF THE KEEL.

ITEM	READING IN INCHES	SCALE FACTOR	VALUE
Δ	16.33	100	1633 LT (SW)
Δ_{fw}	16.33	$100 \times \frac{35.0}{35.9}$	1592 LT (FW)
KB	8.13	1.0	8.13 ABOVE K
LCB	1.73	1.0	1.73 FT AFT ⊗
LCF	13.80	1.0	13.80 FT AFT ⊗
TPI	17.60	1.0	17.60 LT PER IN. IMMER.
MTI	25.73	10.0	257.3 FT-TONS PER IN. TRIM
CD1"TA	0.93	1.0	+0.93 LT PER INCH TRIM AFT
S	20.92	500	10460 FT^2
KM_L	5.02	100	502 FT ABOVE K.
KM_t	20.08	1.0	20.08 FT ABOVE K
C_b	.452	—	
C_p	.595	—	
C_m	.760	—	
C_{wp}	.765	—	

KEY RELATIONSHIPS:

1. $BM_T = \frac{I_T}{\nabla}$; $BM_L = \frac{I_L}{\nabla}$

2. $BM_T = KM_T - KB$; $BM_L = KM_L \quad KB$

3. $TPI = \frac{A_{WP}}{420}$

$\therefore A_{WP} = 420 \times TPI$

4. $C_m = \frac{A_m}{BT}$

$\therefore A_m = C_m \times B \times T$

SOLUTION:

$KM_T = 20.08$ FT A.K. $\qquad KM_L = 502$ FT A.K.

$KB = 8.13$ FT A.K. $\qquad KB = 8.13$ FT A.K.

$BM_T = 11.95$ FT $\qquad BM_L = 493.87$ FT

$\Delta = 1633$ LT

$\nabla = 1633 \times 35 \frac{FT^3}{LT} = 57{,}155\ FT^3$

$I_T = 11.95 \times 57{,}155\ FT^4$ $\qquad I_L = 493.87 \times 57{,}155\ FT^4$

$I_T = 683{,}002\ FT^4$ $\qquad I_L = 28{,}227{,}140\ FT^4$

$A_{WP} = 420 \times TPI = 420 \times 17.60$

$A_{WP} = 7392\ FT^2$

$A_m = C_m \times B \times T = .760 \times 38.00 \times 13.00$

$A_m = 375\ FT^2$

"BEAR" CLASS CUTTER

$T_f = 12'-0"$

$T_a = 13'-6"$

$T_m = 12'-9" = 12.75'$

TRIM = 1'-6" = 18" BY STERN

@ $T_m = 12.75$, $\Delta_o = 1582$ LT. (SW)

CD1"TA = 0.90 LT/INCH TRIM.

CORRECTION = +.90 × 18" = +16.2 LT

$\Delta_1 = 1598.2$ LT

AT LEVEL TRIM THE LCG WILL BE AT THE SAME LONGITUDINAL LOCATION AS THE LCB. FROM THE CURVES OF FORM ~

AT LEVEL TRIM, $LCG_o = LCB_o = 1.35$ FT AFT ⊗

THE TRIM MUST BE CAUSED BY A TRIMMING MOMENT ~

TRIMMING MOM'T = MTI × TRIM IN INCHES

MTI = 25.30 × 20 = 506 FT-TONS/IN

TRIMMING MOM'T = 506 × 18" = 9108 FT-TONS

THE SHIFT IN THE CENTER OF GRAVITY WILL BE ~

$$G_oG_1 = \frac{w \times d}{\Delta} = \frac{\text{TRIM. MOM'T}}{\Delta}$$

$$G_oG_1 = \frac{9108}{1598} = 5.70 \text{ FT. AFT}$$

SINCE LCG_o = 1.35 FT AFT ⊗

THEN LCG_1 = 7.05 FT AFT ⊗

FROM THE CURVES OF FORM ~

$$LCF = 13.80 \text{ FT. AFT } ⊗$$

NOTE: A CENTRAL ASSUMPTION IN MOST HYDROSTATIC FORMULAS IS THAT THE SHIP IS "WALL-SIDED". WITH THIS ASSUMPTION A CHANGE OF TRIM CAUSED BY A SHIFT IN THE CENTER OF GRAVITY WILL CAUSE A CHANGE IN THE UNDERWATER HULL FORM SUCH THAT THE CENTER OF BUOYANCY WILL ALIGN ITSELF VERTICALLY WITH THE CENTER OF GRAVITY, BUT THE SHAPE OF THE WATERPLANE REMAINS THE SAME. THUS THE LCF DOES NOT CHANGE WITH SMALL CHANGES OF TRIM. THE FACT THAT THIS ASSUMPTION IS GOOD ONLY FOR SMALL TRIM CHANGES IS CONFIRMED BY EXAMINING THE SHAPE OF THE LCF CURVE FOR THIS SHIP.

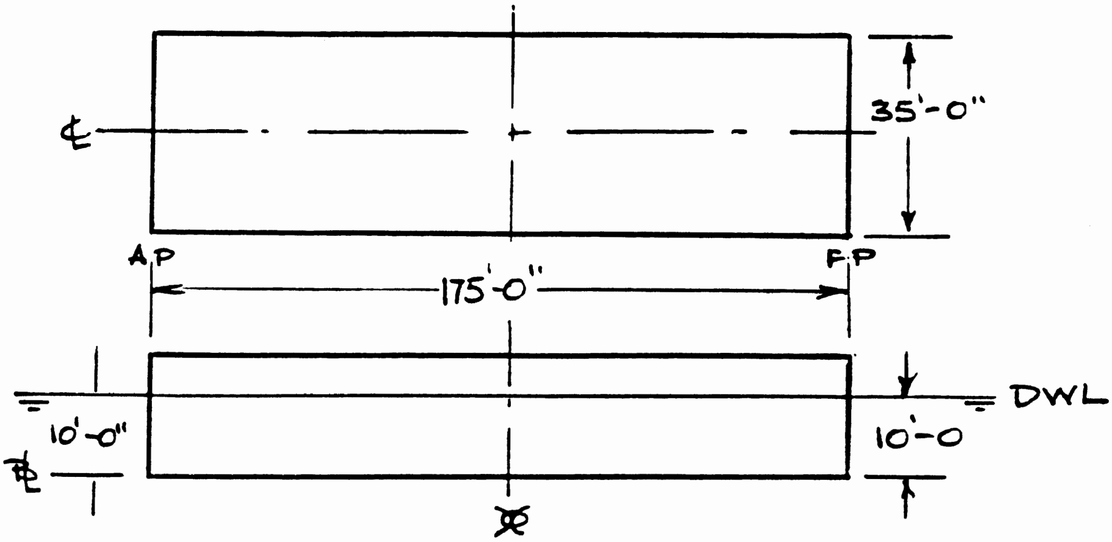
FROM THE CURVES OF FORM ~

$$KM_t = 20.14 \text{ FT A.K.}$$

GIVEN $KG = 19.50$ FT A.K.

$$GM_T = 0.64 \text{ FT}$$

REF: GILLMER, pp 53-58



GIVEN:

$L_{pp} = 175'\text{-}0"$

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

$T_f = T_a = 10'\text{-}0"$

$KG = 8.00$ a. BL

(a) $\nabla = L_{pp} \times B \times T = (175\ \text{FT})(35\ \text{FT})(10\ \text{FT});$ — **$\nabla = 61,250\ \text{FT}^3$**

(b) $\Delta = \dfrac{\nabla}{35} = \dfrac{(175)(35)(10)}{35}\ \dfrac{\text{FT}^3}{\text{FT}^3/\text{LT}}$ — **$\Delta = 1,750\ \text{LT}$**

(c) $I_t = \dfrac{B^3 L}{12} = \dfrac{(35)^3(175)}{12}\ \text{FT}^4$ — **$I_t = 625,260\ \text{FT}^4$**

(d) $BM_t = \dfrac{I_t}{\nabla} = \dfrac{(35)^{3\,2}(175)}{(12)(175)(35)(10)}\ \dfrac{\text{FT}^4}{\text{FT}^3}$ — **$BM_t = 10.21\ \text{FT}$**

(e) SINCE THE HULL FORM IS COMPLETELY WALL SIDED–

$KB = \dfrac{T}{2} = \dfrac{10.00}{2}\ \text{FT}$ — **$KB = 5.00$ FT a. BL**

(f) $KM_t = KB + BM_t = 5.00' + 10.21'$ — **$KM_t = 15.21$ FT a BL**

(g) $GM_t = KM_t - KG = 15.21' - 8.00'$ — **$GM_t = 7.21\ \text{FT}$**

REF: GILLMER, pp 57

STA	HALF-BREADTH, FT	CUBES OF HALF-BREADTHS FT^3	TM	FUNCTIONS OF CUBES, f(I)
0	0.000	0.00	½	0.00
1	6.203	238.67	1	238.67
2	12.167	1801.15	1	1801.15
3	16.365	4382.76	1	4382.76
4	18.250	6078.39	1	6078.39
5	18.750	6591.80	1	6591.80
6	19.052	6915.47	1	6915.47
7	18.552	6385.17	1	6385.17
8	17.479	5340.10	1	5340.10
9	15.229	3531.95	1	3531.95
10	4.531	93.02	½	46.51

$\sum f(I) = 41,311.97$

STATION SPACING, S = 25.50 FT.

$$I_t = \frac{2}{3} \times S \times \sum f(I) = \frac{2}{3} \times 25.50 \times 41,311.97 \ FT^4$$

$$I_t = 702,303 \ FT^4$$

REF: GILLMER, pp 53-58

(a) $\nabla = (140.0 \text{ FT})(36.0 \text{ FT})(10.0 \text{ FT}) = 50,400 \text{ FT}^3$

$\Delta = \frac{\nabla}{35} = \frac{(140.0)(36.0)(10.0) \text{ FT}^3}{(35.0) \text{ FT}^3/\text{LT}}$; **$\Delta = 1,440$ LT**

$\Delta_{fw} = \frac{\nabla}{36} = \frac{(140.0)(36.0)(10.0) \text{ FT}^3}{(36.0) \text{ FT}^3/\text{LT}}$; **$\Delta_{fw} = 1,400$ LT.**

KB FOR WALLSIDED BARGE $= \frac{T}{2} = \frac{10 \text{ FT}}{2}$ **KB = 5.00′ a℄**

$BM_t = \frac{I_t}{\nabla} = \frac{B^3 L}{12 BLT} = \frac{(36)^3(140)}{(12)(36)(140)(10)}$; **$BM_t = 10.80$ FT.**

$KM_t = KB + BM_t = 5.00' + 10.80'$; **$KM_t = 15.80'$ a℄**

$TPI = \frac{A_{WP}}{420} = \frac{(140)(36)}{420}$ **TPI = 12.0 T/IN**

(b) CALCULATE KB. USE TABULAR FORMAT.

ITEM	CALC'N	VOL	VCB	MOM'T.
RECT. BARGE	140 × 36 × 10	50,400	5.00	252,000
BOTH END RAKES	2 × ½ × 10 × 10 × 36	− 3,600	3.33	− 11,988
		46,800	5.13	240,012

$\Delta = \frac{46,800 \text{ FT}^3}{35 \text{ FT}^3/\text{TON}}$ **$\Delta = 1,337$ LT**

KB = 5.13 FT **KB = 5.13′ a℄**

$BM_t = \frac{I_t}{\nabla} = \frac{(36)^3(140)}{(12)(46,800)} = 11.63$ FT

$KM_t = 16.73$ FT **$KM_t = 16.73'$ a℄**

KG = 8.00 FT

$GM_T = 8.76$ FT **$GM_T = 8.76$ FT**