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
2901 Baxter Rd.
Ann Arbor, MI 48109-2150

Volume I Units 1-11

UMTRI The University of Michigan Transportation Research Institute
A project of the SNAME Ship Production Committee Education and Training Panel

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.


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.
Acknowledgements

The development of this course was funded by the National Shipbuilding Research Program and administered under a contract with the University of Michigan Transportation Research Institute.

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.
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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

Introduction ........................................................................................................ 1 unit
(Units 1)
Ship Types and Ship Systems ........................................................................... 2.5 units
(Units 2, 3 and 4)
Nomenclature ..................................................................................................... 2.5 units
(Units 4, 5 and 6)
Dimension, Form and Flotation ....................................................................... 4 units
(Units 7, 8, 9 and 10)
The Ship and Rest-Static Stability ................................................................... 4 units
(Units 11, 12, 13 and 14)
Ship Hazards and Vulnerability ....................................................................... 4 units
(Units 15, 16, 17 and 18)
Submarine Hydrostatics .................................................................................. 1 unit
(Units 19)
Forces Opposed To Propulsion ........................................................................ 2.5 units
(Units 20, 21 and 22)
Propulsive Forces and Propulsion Systems .................................................... 2.5 units
(Units 22, 23 and 24)
Propulsive Requirements and Power Selection ............................................ 2 units
(Units 25 and 26)
Maneuverability and Ship Control ................................................................... 1 unit
(Units 27)
The Ship in Motion with The Sea .................................................................... 2 units
(Units 28 and 29)
The Strength And Structure Of Ships ............................................................ 10 units
(Units 30 thru 39)
The Ship Design Process .................................................................................. 3 units
(Units 40, 41, and 42)
Shipbuilding Methods .................................................................................... 3 units
(Units 43, 44 and 45)
Total ............................................................................................................... 45 units
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. A class period of an hour and half, or two fifty-minute periods would be optimal.
(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:


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.

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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.

* 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.
<table>
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<th>Homework</th>
<th>Basic Naval Architecture - Introduction</th>
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<td><strong>Parts of a ship. Decks and bulkheads. Doors, hatches, scuttles, manholes. Spaces on board ship. Anchoring and mooring.</strong></td>
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<td><strong>Boat handling equipment. Cargo handling equipment. Dunnage, sparring and ceiling. Structural nomenclature. Strakes, stringers, floors, double and single bottoms, keels, stem castings, stern castings.</strong></td>
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<td><strong>Ship geometry. Dimensions. Freeboard and draft. Displacement and tonnage. Lines drawing. Form coefficients.</strong></td>
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<td><strong>Form coefficients example. Centers - CG, CB, metacenter, GM. Moments. Example of LCG calculation.</strong></td>
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<td>Unit 9</td>
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<td><strong>Basic Naval Architecture - Dimension, Form and Flotation - 4</strong></td>
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<td>Gillmer pages 51-58</td>
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<td>Gillmer pages 58-68</td>
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<td>Transverse weight shift example. Inclining experiment, example. Cross curves of stability. Corrections for actual KG. Corrections to static stability curve.</td>
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<td>Gillmer pages 68-70</td>
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<td>Gillmer pages 329-331</td>
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### Unit 17

**Basic Naval Architecture - Ship Hazards and Vulnerability - 3**


#### 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**


#### 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**


#### Homework
- Problems: Previously Unassigned
- Readings: Gillmer pages 95-102, 106-110

#### Videotape Information
- Time: 36 minutes
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## Unit 25

**Basic Naval Architecture - Propulsive**  
**Requirements and Power Selection - 1**

Homework  
Problems - 53, 54

Readings  
Gillmer pages 133-141

### Videotape Information

Time= 30 minutes  
AVMATH® ED47

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

## Unit 26

**Basic Naval Architecture - Propulsive**  
**Requirements and Power Selection - 2**

Homework  
Problems - 55, 56, 57

Readings  
Gillmer pages 141-149

### Videotape Information

Time= 37 minutes  
AVMATH® ED48

- Power prediction example. Standard series.  
- Service power margin. Engine selection.  
- Steam propulsion. Nuclear power.  
- Comparisons.

## Unit 27

**Basic Naval Architecture - Maneuverability and Ship Control**

Homework  
Problems - Previously Unassigned

Readings  
Gillmer pages 151-169

### Videotape Information

Time= 37 minutes  
AVMATH® ED49

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

## Unit 28

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

Homework  
Problems - Previously Unassigned

Readings  
Gillmer pages 235-243

### Videotape Information

Time= 38 minutes  
AVMATH® ED50

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<td>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.</td>
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### Unit 45

**Basic Naval Architecture - Shipbuilding Methods - 3**

**Homework**
- Problems - None

**Readings**
- Gillmer pages - None

**Videotape Information**
- Time= 39 minutes
- AVMASTW ED67

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

APPENDIX
TO
PROBLEM SET

CONTENTS:

. Tables of Density and Kinematic Viscosity of Fresh Water
. Stability Data Sheet and General Stability Diagram for CVE 105
. Selected Tables Reprinted from Manual of Steel Construction
  - Properties and Dimensions of Selected Steel Shapes
  - Properties of Geometric Sections
  - Decimals of an Inch and Foot Conversion Table
  - Selected Beam Diagrams and Formulas
. Excerpts from American Bureau of Shipping Rules for Building and Classing Steel Vessels, 1987
Table of Kinematic Viscosity of Water

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

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

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# STABILITY l A SHEET

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## 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. x

## FINAL CONDITION

- DISPLACEMENT (W) = W x (X)
- NET VERTICAL MOMENT = w x Kg = \(7a - 7b\) = ________ FT. TONS
- KB = (w x Kg) ± wxkg = __________ FT.
- NET VIRTUAL SHIFT = \(F.S. + 1 + oy\) = \(F.S. + 8 + 9\) = __________ FT.
- KG = __________ FT.

## NET INCLINING MOMENT

- NET INCL. MOM. = ________ FT.
- NET INCL. ARM AT O" = ________ 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
## W SHAPES Dimensions

<table>
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<tr>
<th>Designation</th>
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<th>Flange $t_f$</th>
<th>Distance $T$</th>
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## W SHAPES Properties

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<th>Torsional constant $Z_t$</th>
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### American Institute of Steel Construction

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**Note:** The tables and diagrams are excerpts from the W SHAPES Dimensions and Properties sections of the American Institute of Steel Construction's manual. The data includes measurements such as area, depth, thickness, and properties related to structural steel sections. The tables represent different sections with varying dimensions, and the properties include weight, section properties, and elastic and torsional constants.
## W SHAPES
### Dimensions

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<th>Web Thickness tw</th>
<th>Flange Thickness tf</th>
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### Properties

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### S SHAPES Dimensions

| Designation | Area $A$ (in.$^2$) | Depth $d$ (in.) | Web Thickness $t_w$ (in.) | Flange Thickness $t_f$ (in.) | Flange Distance $T$ (in.) | Web Distance $k$ (in.) | Max. 
|-------------|--------------------|----------------|---------------------------|---------------------------|------------------------|----------------------| Fas. in. | Fas. in.
| S 24 x 121 | 35.6               | 24.50          | 0.800 1 3/8 14/16        | 0.805 8                   | 1.090 1 3/4 20/2      | 2 1/2                | 1 3/4      | 1
| S 24 x 108 | 31.2               | 24.50          | 0.702 1 8/16 11/16       | 0.880 7/8 1 3/4 20/2     | 2 1/2                  | 1 3/4      | 1
| S 24 x 100 | 29.3               | 24.00          | 0.745 7/8 1 1/2          | 0.725 7 1/4 1 3/4 20/2   | 2 1/2                  | 1 3/4      | 1
| S 24 x 80  | 26.5               | 24.00          | 0.625 6/16 11/16         | 0.715 7/4 1 3/4 20/2     | 2 1/2                  | 1 3/4      | 1
| S 24 x 65  | 23.5               | 24.00          | 0.500 5/16 11/16         | 0.700 7 1/4 1 3/4 20/2   | 2 1/2                  | 1 3/4      | 1
| S 20 x 96  | 28.2               | 20.30          | 0.800 1 3/4 15/16        | 0.790 6 1/4 1 3/4 20/2   | 2 1/2                  | 1 3/4      | 1
| S 20 x 86  | 25.3               | 20.30          | 0.660 1 1/4 11/16        | 0.790 6 1/4 1 3/4 20/2   | 2 1/2                  | 1 3/4      | 1
| S 20 x 75  | 22.0               | 20.00          | 0.635 6/16 11/16         | 0.691 7/4 1 3/4 20/2     | 2 1/2                  | 1 3/4      | 1
| S 18 x 70  | 18.0               | 18.00          | 0.711 1 3/4 16/16        | 0.691 7/4 1 3/4 20/2     | 2 1/2                  | 1 3/4      | 1
| S 18 x 66  | 16.1               | 18.00          | 0.641 1 1/4 11/16        | 0.691 7/4 1 3/4 20/2     | 2 1/2                  | 1 3/4      | 1
| S 18 x 54  | 14.7               | 15.00          | 0.550 5/16 11/16         | 0.640 7/16 1 3/4 20/2    | 2 1/2                  | 1 3/4      | 1
| S 18 x 49  | 12.5               | 15.00          | 0.411 4/16 11/16         | 0.591 7/4 1 3/4 20/2     | 2 1/2                  | 1 3/4      | 1
| S 18 x 40  | 14.7               | 12.00          | 0.687 1 3/4 16/16        | 0.550 7/4 1 3/4 20/2     | 2 1/2                  | 1 3/4      | 1
| S 18 x 33  | 10.3               | 12.00          | 0.479 6/16 11/16         | 0.501 7/4 1 3/4 20/2     | 2 1/2                  | 1 3/4      | 1
| S 18 x 25  | 9.35               | 12.00          | 0.350 5/16 11/16         | 0.491 7/4 1 3/4 20/2     | 2 1/2                  | 1 3/4      | 1
| S 18 x 23  | 10.3               | 10.00          | 0.504 1 3/4 16/16        | 0.491 7/4 1 3/4 20/2     | 2 1/2                  | 1 3/4      | 1
| S 18 x 18  | 6.77               | 8.00           | 0.441 4/16 11/16         | 0.461 4/4 1/2 1 2/3 20/2 | 2 1/2                  | 1 3/4      | 1
| S 18 x 14  | 5.41               | 8.00           | 0.311 3/16 11/16         | 0.461 4/4 1/2 1 2/3 20/2 | 2 1/2                  | 1 3/4      | 1
| S 18 x 13  | 5.88               | 7.00           | 0.450 1 3/4 16/16        | 0.380 3/16 11/16         | 2 1/2                  | 1 3/4      | 1
| S 18 x 12  | 4.50               | 7.00           | 0.271 2/16 11/16         | 0.401 4/4 1/2 1 2/3 20/2 | 2 1/2                  | 1 3/4      | 1
| S 18 x 11  | 5.07               | 6.00           | 0.465 1 3/4 16/16        | 0.365 3/16 11/16         | 2 1/2                  | 1 3/4      | 1
| S 18 x 10  | 3.67               | 6.00           | 0.232 2/16 11/16         | 0.332 3/16 11/16         | 2 1/2                  | 1 3/4      | 1
| S 18 x 9  | 4.34               | 5.00           | 0.494 1 3/4 16/16        | 0.324 3/16 11/16         | 2 1/2                  | 1 3/4      | 1
| S 18 x 8  | 2.94               | 5.00           | 0.216 2/16 11/16         | 0.304 3/16 11/16         | 2 1/2                  | 1 3/4      | 1
| S 18 x 4  | 2.79               | 4.00           | 0.326 1 3/4 16/16        | 0.296 2/16 1 2/3 20/2    | 2 1/2                  | 1 3/4      | 1
| S 18 x 3  | 2.26               | 4.00           | 0.193 2/16 11/16         | 0.263 2/16 1 2/3 20/2    | 2 1/2                  | 1 3/4      | 1
| S 18 x 2  | 2.21               | 3.00           | 0.349 1 3/4 16/16        | 0.260 2/16 1 2/3 20/2    | 2 1/2                  | 1 3/4      | 1
| S 18 x 1  | 1.67               | 3.00           | 0.170 2/16 11/16         | 0.230 2/16 1 2/3 20/2    | 2 1/2                  | 1 3/4      | 1

### S SHAPES Properties

**Nominal**

- **Flange Stress** $s_f$: 36,000 psi
- **Web Stress** $s_w$: 50,000 psi
- **Shear Stress** $s_s$: 20,000 psi
- **Moment of Inertia $I$**:
  - **Axial $I_x$**:
  - **Axial $I_y$**:
- **Area $A$**:
  - **Axial $A_x$**:
  - **Axial $A_y$**:
- **Modulus of Elasticity $E$**:
  - **Axial $E_x$**:
  - **Axial $E_y$**:

**Section Modulus $S$**

- **Axial $S_x$**:
- **Axial $S_y$**:

**Torsional Constant $J_x$**

- **Axial $J_x$**:
- **Axial $J_y$**

**Plastic Module $Z_p$**

- **Axial $Z_p$**:

---

**Notes:**

- All dimensions are in inches.
- All stresses are in psi.
- All sections are in the plane of the flange.
- All moduli are in ksi.

---

**American Institute of Steel Construction**
### ANGLES

#### Equal legs and unequal legs

**Properties for designing**

<table>
<thead>
<tr>
<th>Size and Thickness</th>
<th>( h )</th>
<th>Weight per foot</th>
<th>Area</th>
<th>( r_x )</th>
<th>( r_y )</th>
<th>( r )</th>
<th>( \tan \alpha )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 8 \times 1 )</td>
<td>1/2</td>
<td>2.7</td>
<td>11.5</td>
<td>2.80</td>
<td>3.36</td>
<td>8.32</td>
<td>2.48</td>
</tr>
<tr>
<td>( 1 )</td>
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<td>8.32</td>
<td>2.48</td>
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<tr>
<td>( 1 \frac{1}{2} )</td>
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<td>2.7</td>
<td>11.5</td>
<td>2.80</td>
<td>3.36</td>
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</tr>
<tr>
<td>( 2 )</td>
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<td>2.7</td>
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<td>8.32</td>
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<tr>
<td>( 2 \frac{1}{2} )</td>
<td>1/2</td>
<td>2.7</td>
<td>11.5</td>
<td>2.80</td>
<td>3.36</td>
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</tr>
</tbody>
</table>

### ANGLES

#### Equal legs and unequal legs

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<table>
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<tr>
<th>Size and Thickness</th>
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<th>( r_x )</th>
<th>( r_y )</th>
<th>( r )</th>
<th>( \tan \alpha )</th>
</tr>
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<tbody>
<tr>
<td>( 6 \times 6 \times 1 )</td>
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<td>2.7</td>
<td>11.5</td>
<td>2.80</td>
<td>3.36</td>
<td>8.32</td>
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<td>( 1 \frac{1}{2} )</td>
<td>1/2</td>
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<td>( 2 )</td>
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<td>( 2 \frac{1}{2} )</td>
<td>1/2</td>
<td>2.7</td>
<td>11.5</td>
<td>2.80</td>
<td>3.36</td>
<td>8.32</td>
<td>2.48</td>
</tr>
</tbody>
</table>

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*
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 \( = \frac{wL}{2} \)
\( R = V \) \( = \frac{wL}{2} \)
\( V_x \) \( = w \left( \frac{L}{2} - x \right) \)
\( M_{max.} \) (at center) \( = \frac{wL^2}{6} \)
\( M_x \) \( = \frac{wL^2}{2} (1-x) \)
\( \Delta_{max.} \) (at center) \( = \frac{wL^3}{24EI} \)
\( A_x \) \( = \frac{wL^3}{24EI} \left( \frac{L^2}{2} - 2x^4 + x^2 \right) \)

2. SIMPLE BEAM—LOAD INCREASING UNIFORMLY TO ONE END
Total Equiv. Uniform Load \( = 18W \left( \frac{L}{6} \right) = 1.0264W \)
\( R_1 = V_x \) \( = \frac{W}{3} \)
\( R_2 = V_x \) \( = \frac{2W}{3} \)
\( V_x \) \( = W - \frac{w}{3} \)
\( M_{max.} \) (at \( \frac{L}{2} - 0.5775L \)) \( = \frac{2W}{3} \left( \frac{L}{3} - \frac{w^2}{2} \right) \)
\( M_x \) \( = \frac{W}{3} \left( \frac{L^2}{2} - x^2 \right) \)
\( \Delta_{max.} \) (at \( \frac{L}{2} - 0.5192L \)) \( = \frac{0.0134 \cdot W^3}{EI} \)
\( A_x \) \( = \frac{W^3}{120EI} \left( \frac{3x^4 - 10x^3 + 7x}{4} \right) \)

3. SIMPLE BEAM—LOAD INCREASING UNIFORMLY TO CENTER
Total Equiv. Uniform Load \( = 4W \)
\( R = V \) \( = \frac{W}{2} \)
\( V_x \) \( = \frac{W}{2} \left( \frac{L}{2} - 4x^6 \right) \)
\( M_{max.} \) (at center) \( = \frac{W^2}{6} \)
\( M_x \) \( = \frac{W^2}{2} (1-x) \)
\( \Delta_{max.} \) (at center) \( = \frac{W^3}{120EI} \)
\( A_x \) \( = \frac{W^3}{60EI} \left( \frac{5L}{8} - 4x^3 \right) \)

4. SIMPLE BEAM—UNIFORM LOAD PARTIALLY DISTRIBUTED
\( R_1 = V_x \) \( = \frac{wL}{2} \left( \text{max. when } x < \frac{L}{2} \right) \)
\( R_2 = V_x \) \( = \frac{wL}{2} \left( \text{max. when } x > \frac{L}{2} \right) \)
\( V_x \) \( = w \left( \text{when } x > \frac{L}{2} \text{ and } x + \frac{L}{2} \right) \)
\( M_{max.} \) (at \( x + \frac{L}{2} \)) \( = R_1 \left( \frac{L}{2} + \frac{L}{2} \right) \)
\( M_x \) \( = \frac{wL^2}{2} \left( \frac{L}{2} - x \right) \)
\( \Delta_{max.} \) (at \( x + \frac{L}{2} \)) \( = \frac{wL^3}{24EI} \left( \frac{L}{2} - \frac{x}{2} \right) \)
\( A_x \) \( = \frac{wL^3}{24EI} \left( \frac{L}{2} - \frac{x}{2} \right)^2 \)

5. SIMPLE BEAM—UNIFORM LOAD PARTIALLY DISTRIBUTED AT ONE END
\( R_1 = V_x \) \( = \frac{wL}{2} \left( \text{max. when } x < a \right) \)
\( R_2 = V_x \) \( = \frac{wL}{2} \left( \text{max. when } x > a \right) \)
\( V_x \) \( = w \left( \text{when } x > a \right) \)
\( M_{max.} \) (at \( x = a \)) \( = R_1 \left( a + \frac{L}{2} \right) \)
\( M_x \) \( = \frac{wL^2}{6} \left( \frac{L}{2} - a \right) \)
\( \Delta_{max.} \) (at \( x = a \)) \( = \frac{wL^3}{24EI} \left( \frac{L}{2} - a \right) \)
\( A_x \) \( = \frac{wL^3}{24EI} \left( \frac{L}{2} - a \right)^2 \)

6. SIMPLE BEAM—UNIFORM LOAD PARTIALLY DISTRIBUTED AT EACH END
\( R_1 = V_x \) \( = w \left( \frac{L}{2} - a \right) + \omega c^2 \)
\( R_2 = V_x \) \( = w \left( \frac{L}{2} - c \right) + \omega c^2 \)
\( V_x \) \( = w \left( \text{when } x < a \right) \)
\( V_x \) \( = w \left( \text{when } x > a \right) \)
\( M_{max.} \) (at \( x = a \)) \( = R_1 \left( a \right) \)
\( M_x \) \( = \frac{wL^2}{6} \left( \frac{L}{2} - a \right) \)
\( \Delta_{max.} \) (at \( x = a \)) \( = \frac{wL^3}{24EI} \left( \frac{L}{2} - a \right) \)
\( A_x \) \( = \frac{wL^3}{24EI} \left( \frac{L}{2} - a \right)^2 \)
BEAM DIAGRAMS AND FORMULAS
For various static loading conditions

For meaning of symbols, see page 2111.

7. SIMPLE BEAM—CONCENTRATED LOAD AT CENTER

Total Equiv. Uniform Load = 2P
R = V
M max. (at point of load) = P1/4
M2 = P2/8 (when x < 1/2)
Δmax. (at point of load) = P10/48EI
Ax = P8/48EI (3/16 - 4xa)

8. SIMPLE BEAM—CONCENTRATED LOAD AT ANY POINT

Total Equiv. Uniform Load = 8Peb
R1 = V3 (max. when a < b)
R2 = V6 (max. when a > b)
M max. (at point of load) = Pab
M3 = Pbx (when x < a)
Δmax. (at x = a + 2b/s when a > b) = P(ba + 2b) V/2a (a + 2b)
Ax = Pab/8EIT
Ax = Pbx/8EIT (1/2 - ba^2 - ax)

9. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS
   SYMMETRICALLY PLACED

Total Equiv. Uniform Load = 8P/9
R = V
M max. (between loads) = P9
M8 = P9/2 (when x < a)
Δmax. (at center) = P9/34EI (3/16 - 4a^2)
Ax = P9/34EI (3/16 - 2ax - a)
Ax = P9/34EI (3/16 - 3ax - a)

10. SIMPLE BEAM—TWO EQUAL CONCENTRATED LOADS
    UNSYMMETRICALLY PLACED

R1 = V3 (max. when a < b)
R2 = Vs (max. when a > b)
V3 (when x > a and < (1 - b)) = P3/4 (1 - a + b)
M1 = R1a
M2 = R2b
M3 = Rs
M4 = Rnx (when x > a and < (1 - b)) = Rnx - P(x - a)

11. SIMPLE BEAM—TWO UNEQUAL CONCENTRATED LOADS
    UNSYMMETRICALLY PLACED

R1 = V1
R2 = V2 (max. when a < b)
V3 (when x > a and < (1 - b)) = R1 - P3
M1 = R1a
M2 = R2b
M3 = Rsa
M4 = Rsb
M5 = Rs
M6 = Rnx (when x > a and < (1 - b)) = Rnx - P(x - a)

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

Total Equiv. Uniform Load = wL
R1 = V1
R2 = V2 max.
V3 = R1 - wx
M max. = wL/2
Δmax. (at x = 3L/8) = 9wL/8
Ax = 9wL/8
Ax = 16EI
Ax = wL/2 (1 + 2L^2)^1/2 = 4214
Ax = 16EI
Δmax. (at x = 16/1 (1 + 2L^2)^1/2 = 4214
Ax = 16EI
Ax = wL/8 (1 + 2L^2)^1/2 = 4214
Ax = 16EI
For meaning of symbols, see page 2111.

18. CANTILEVER BEAM—LOAD INCREASING UNIFORMLY TO FIXED END

<table>
<thead>
<tr>
<th>Condition</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Equiv. Uniform Load</td>
<td>$\frac{2}{3}W$</td>
</tr>
<tr>
<td>$R - V$</td>
<td>$W$</td>
</tr>
<tr>
<td>$V_x$</td>
<td>$W \frac{x^2}{16}$</td>
</tr>
<tr>
<td>$M_{max.}$ (at fixed end)</td>
<td>$\frac{Wl}{4}$</td>
</tr>
<tr>
<td>$M_x$</td>
<td>$\frac{Wx^2}{24}$</td>
</tr>
<tr>
<td>$\Delta_{max.}$ (at free end)</td>
<td>$\frac{Wl}{16} \frac{EI}{24E1}$</td>
</tr>
</tbody>
</table>

19. CANTILEVER BEAM—UNIFORMLY DISTRIBUTED LOAD

<table>
<thead>
<tr>
<th>Condition</th>
<th>Formula</th>
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</thead>
<tbody>
<tr>
<td>Total Equiv. Uniform Load</td>
<td>$4wl$</td>
</tr>
<tr>
<td>$R - V$</td>
<td>$w$</td>
</tr>
<tr>
<td>$V_x$</td>
<td>$wx$</td>
</tr>
<tr>
<td>$M_{max.}$ (at fixed end)</td>
<td>$\frac{wl^2}{2}$</td>
</tr>
<tr>
<td>$M_x$</td>
<td>$\frac{wx^2}{6}$</td>
</tr>
<tr>
<td>$\Delta_{max.}$ (at free end)</td>
<td>$\frac{wl^2}{16} \frac{EI}{24E1}$</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Condition</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Equiv. Uniform Load</td>
<td>$\frac{8}{3}w$</td>
</tr>
<tr>
<td>$R - V$</td>
<td>$\frac{w}{3}$</td>
</tr>
<tr>
<td>$V_x$</td>
<td>$wx$</td>
</tr>
<tr>
<td>$M_{max.}$ (at fixed end)</td>
<td>$\frac{3wl}{2}$</td>
</tr>
<tr>
<td>$M_x$</td>
<td>$\frac{wx^2}{6}$</td>
</tr>
<tr>
<td>$\Delta_{max.}$ (at deflected end)</td>
<td>$\frac{lw^2}{24E1}$</td>
</tr>
</tbody>
</table>

21. CANTILEVER BEAM—CONCENTRATED LOAD AT ANY POINT

<table>
<thead>
<tr>
<th>Condition</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Equiv. Uniform Load</td>
<td>$\frac{8Pb}{l}$</td>
</tr>
<tr>
<td>$R - V$</td>
<td>$P$</td>
</tr>
<tr>
<td>$M_{max.}$ (at fixed end)</td>
<td>$Pb$</td>
</tr>
<tr>
<td>$M_x$ (when $x &gt; a$)</td>
<td>$P \left(\frac{x}{a} - 1\right)$</td>
</tr>
<tr>
<td>$\Delta_{max.}$ (at free end)</td>
<td>$\frac{Pb\left(l - 3a - b\right)}{6E1}$</td>
</tr>
<tr>
<td>$\Delta_a$ (at point of load)</td>
<td>$\frac{Pb\left(l - 3a - b\right)}{6E1}$</td>
</tr>
<tr>
<td>$\Delta_x$ (when $x &lt; a$)</td>
<td>$\frac{Pb\left(l - 3a - b\right)}{6E1}$</td>
</tr>
<tr>
<td>$\Delta_x$ (when $x &gt; a$)</td>
<td>$\frac{P\left(l - x\right)^2}{\frac{12E1}{3a}} \left(3a - b + 1 + x\right)$</td>
</tr>
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</table>

22. CANTILEVER BEAM—CONCENTRATED LOAD AT FREE END

<table>
<thead>
<tr>
<th>Condition</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Equiv. Uniform Load</td>
<td>$8P$</td>
</tr>
<tr>
<td>$R - V$</td>
<td>$P$</td>
</tr>
<tr>
<td>$M_{max.}$ (at fixed end)</td>
<td>$P$</td>
</tr>
<tr>
<td>$M_x$</td>
<td>$P \left(\frac{x}{a} - 1\right)$</td>
</tr>
<tr>
<td>$\Delta_{max.}$ (at free end)</td>
<td>$P \frac{a}{6E1}$</td>
</tr>
<tr>
<td>$\Delta_a$ (at both ends)</td>
<td>$P \frac{a}{6E1}$</td>
</tr>
<tr>
<td>$\Delta_x$ (when $x &lt; a$)</td>
<td>$P \frac{a}{12E1}$</td>
</tr>
<tr>
<td>$\Delta_x$ (when $x &gt; a$)</td>
<td>$P \frac{a^2}{12E1}$</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Condition</th>
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</tr>
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<tbody>
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</tr>
<tr>
<td>$R - V$</td>
<td>$P$</td>
</tr>
<tr>
<td>$M_{max.}$ (at both ends)</td>
<td>$P \frac{a}{2}$</td>
</tr>
<tr>
<td>$M_x$</td>
<td>$P \left(\frac{x}{a} - 1\right)$</td>
</tr>
<tr>
<td>$\Delta_{max.}$ (at deflected end)</td>
<td>$P \frac{a}{12E1}$</td>
</tr>
<tr>
<td>$\Delta_a$ (at both ends)</td>
<td>$P \frac{a^2}{12E1}$</td>
</tr>
<tr>
<td>$\Delta_x$ (when $x &lt; a$)</td>
<td>$P \frac{a^2}{12E1}$</td>
</tr>
<tr>
<td>$\Delta_x$ (when $x &gt; a$)</td>
<td>$P \frac{a^2}{12E1}$</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Condition</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Equiv. Uniform Load</td>
<td>$4P$</td>
</tr>
<tr>
<td>$R - V$</td>
<td>$P$</td>
</tr>
<tr>
<td>$M_{max.}$ (at both ends)</td>
<td>$P \frac{a}{2}$</td>
</tr>
<tr>
<td>$M_x$</td>
<td>$P \left(\frac{x}{a} - 1\right)$</td>
</tr>
<tr>
<td>$\Delta_{max.}$ (at deflected end)</td>
<td>$P \frac{a}{12E1}$</td>
</tr>
<tr>
<td>$\Delta_a$ (at both ends)</td>
<td>$P \frac{a^2}{12E1}$</td>
</tr>
<tr>
<td>$\Delta_x$ (when $x &lt; a$)</td>
<td>$P \frac{a^2}{12E1}$</td>
</tr>
<tr>
<td>$\Delta_x$ (when $x &gt; a$)</td>
<td>$P \frac{a^2}{12E1}$</td>
</tr>
</tbody>
</table>
## Properties of Parabola and Ellipse

### Parabola

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>P = B² - H</td>
<td>Area = ½ HB</td>
</tr>
<tr>
<td>x = y² - P</td>
<td>y = f(P)</td>
</tr>
<tr>
<td>Height-H</td>
<td>0.56 H</td>
</tr>
<tr>
<td>½ Base = B</td>
<td>Major semi-axis = B</td>
</tr>
<tr>
<td>Ordinate = y</td>
<td>c. of g. = 0.375 B</td>
</tr>
<tr>
<td>Abscissa = H</td>
<td>H/2</td>
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### Ellipse

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x²/H²) + (y²/B²) = 1</td>
<td>x = (H - B)/B² = y²</td>
</tr>
<tr>
<td>y = (B - H)/H² = x²</td>
<td>y = (B - H)/B²</td>
</tr>
<tr>
<td>Approximate ¼ perimeter</td>
<td>B²/2 (H² + B²)</td>
</tr>
<tr>
<td>Minor semi-axis = B</td>
<td>Ordinate = y</td>
</tr>
</tbody>
</table>

### Area Between Parabolic Curve and Secant

- Center of gravity (shaded area)
- Apex
- Any secant
- h = lb (2B - b) / B²
- m = Hb² / 4B²
- Shaded area = ½ bm

Length b may vary from 0 to 2B

---

### Properties of the Circle

- Circumference = 2πr = 3.14159 d
- Diameter = 0.31831 circumference
- Area = 3.14159 r²

- Arc a = π² r² / 180°
- Angle A = 100π² r² / 180°
- Radius r = 4π² r² / 8 b
- Chord c = 2√2 b - b² = 2 r sin A / 2
- Rise b = r - ½ √4 r² - b² = r - ½ tan A
- y = b - r + √r² - b²

Diameter of circle of equal periphery as square = 1.27286 side of square
Side of square of equal periphery as circle = 0.78539 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 ncp = ½ (length of arc ncp X r)

- Area of Circle X ¼

- 0.0067296 X r² X y

### Circular Segment

- r = radius of circle
- x = chord
- b = rise

Area of Segment ncp = Area of Sector ncp - Area of triangle ncp

Length of arc ncp X r = x (r - b)

Area of Segment ncp = Area of Circle - Area of Segment ncp

### Values for Functions of π

- π² = 9.8695904, log = 0.9942997
- π² = 0.3183099, log = T.0025011

- π² = 31.49149, log = 1.6032121
- π² = 0.1012121

- π = 1.772453, log = 0.2485749
- π = 0.0322518

Note: Log of fractions such as 0.5025011 and 0.5085300 may also be written 0.5025011 - 10 and 0.5085300 - 10 respectively.
## Properties of Geometric Sections

### Square

**Axes of moments through center**

\[ A = d^3 \]
\[ c = \frac{d}{2} \]
\[ I = \frac{d^4}{12} \]
\[ S = \frac{d^3}{8} \]
\[ r = \frac{d}{\sqrt{12}} = 0.288675 \, d \]
\[ Z = \frac{d^3}{4} \]

### Square

**Axes of moments on base**

\[ A = d^3 \]
\[ c = d \]
\[ I = \frac{d^4}{8} \]
\[ S = \frac{d^3}{8} \]
\[ r = \frac{d}{\sqrt{8}} = 0.577350 \, d \]

### Square

**Axes of moments on diagonal**

\[ A = d^3 \]
\[ c = \frac{d}{\sqrt{2}} = 0.707107 \, d \]
\[ I = \frac{d^4}{12} \]
\[ S = \frac{d^3}{8} \]
\[ r = \frac{d}{\sqrt{12}} = 0.288675 \, d \]
\[ Z = \frac{2d^3}{3} = \frac{d^3}{3 \sqrt{2}} = 0.226702d^3 \]

### Rectangle

**Axes of moments through center**

\[ A = \frac{bd}{3} \]
\[ c = \frac{d}{2} \]
\[ I = \frac{bd^3}{12} \]
\[ S = \frac{bd^3}{6} \]
\[ r = \frac{d}{\sqrt{12}} = 0.288675 \, d \]
\[ Z = \frac{bd^3}{4} \]

### Hollow Rectangle

**Axes of moments through center**

\[ A = \frac{bd - b^2d_1}{2} \]
\[ c = \frac{d}{2} \]
\[ I = \frac{bd^3 - b^2d_1^3}{12} \]
\[ S = \frac{bd^3 - b^2d_1^3}{6d} \]
\[ r = \frac{\sqrt{b^2d_1^3 - b^2d_1^3}}{12} \]
\[ Z = \frac{b^2d_1^3}{4} - \frac{bd_1^3}{4} \]
PROPERTIES OF GEOMETRIC SECTIONS

EQUAL RECTANGLES
Axis of moments through center of gravity

\[ A = b (d - d_1) \]
\[ c = \frac{d}{2} \]
\[ I = \frac{b (d^2 - d_1^2)}{12} \]
\[ S = \frac{b (d^2 - d_1^2)}{6d} \]
\[ r = \sqrt{\frac{d_1^2 - d_1^2}{12(d - d_1)}} \]
\[ Z = \frac{b}{4} \left( d^2 - d_1^2 \right) \]

UNEQUAL RECTANGLES
Axis of moments through center of gravity

\[ A = bh + bh_1 \]
\[ c = \frac{5h_1 bh + bh_1 (d - 3h_1 bh)}{A} \]
\[ I = \frac{bh^2 + bh_1 h + bh_1^2 (d - 3h_1 bh)}{12} + bh_1 y_1 h \]
\[ S = \frac{1}{2} \]
\[ b_1 = \frac{1}{c} \]
\[ r = \frac{1}{A} \]
\[ Z = \frac{A}{2} \left[ d - \left( \frac{t + b_1}{2} \right) \right] \]

TRIANGLE
Axis of moments through center of gravity

\[ A = \frac{bd}{2} \]
\[ c = \frac{2d}{3} \]
\[ I = \frac{bd^2}{24} \]
\[ S = \frac{bd^2}{24} \]
\[ r = \frac{d}{\sqrt{18}} = 0.235702 d \]

TRIANGLE
Axis of moments on base

\[ A = \frac{bd}{2} \]
\[ c = d \]
\[ I = \frac{bd^2}{12} \]
\[ S = \frac{bd^2}{12} \]
\[ r = \frac{d}{\sqrt{6}} = 0.408248 d \]

TRAPEZOID
Axis of moments through center of gravity

\[ A = \frac{d(b + b_1)}{2} \]
\[ c = \frac{2(d + b_1)}{3} \]
\[ I = \frac{d^2(b_1 + 4bb_1 + b_1)}{36} + (b + b_1) \]
\[ S = \frac{d^2(b_1 + 4bb_1 + b_1)}{12} + (b + b_1) \]
\[ r = \frac{d}{6(b + b_1)} \sqrt{2(b_1 + 4bb_1 + b_1)} \]

CIRCLE
Axis of moments through center

\[ A = \frac{\pi d}{4} \]
\[ c = \frac{d}{2} \]
\[ I = \frac{\pi d^4}{64} \]
\[ S = \frac{\pi d^4}{32} \]
\[ r = \frac{d}{4} \]
\[ Z = \frac{d^3}{6} \]

HOLLOW CIRCLE
Axis of moments through center

\[ A = \frac{\pi (d^2 - d_1^2)}{4} \]
\[ c = \frac{d}{2} \]
\[ I = \frac{\pi (d^2 - d_1^2)}{32d} \]
\[ S = \frac{\pi (d^2 - d_1^2)}{32d} - d^4 \]
\[ r = \frac{\sqrt{d^4 + d^4}}{4} \]
\[ Z = \frac{d^3}{6} - \frac{d_1^3}{6} \]

HALF CIRCLE
Axis of moments through center of gravity

\[ A = \frac{\sqrt{R^2}}{2} \]
\[ c = R \left( 1 - \frac{4}{3r} \right) \]
\[ I = R^2 \left( \frac{7}{8} - \frac{8}{9r^2} \right) \]
\[ S = \frac{R^2}{32} (32 - 4r) \]
\[ r = \frac{\sqrt{R^2 - 64}}{6r} \]
\[ Z = \frac{d^3}{6} - \frac{d_1^3}{6} \]
**Properties of Geometric Sections**

**Parabola**
- \( A = \frac{4}{3}ab \)
- \( m = \frac{2}{3}a \)
- \( l_s = 10 \frac{a+b}{175} \)
- \( l_z = \frac{a}{15} ab^2 \)
- \( I_s = 32 \frac{ab}{105} \)

**Half Parabola**
- \( A = \frac{a}{2} \)
- \( n = \frac{a}{b} \)
- \( l_s = 10 \frac{a+b}{175} \)
- \( I_s = 19 \frac{ab}{105} \)
- \( I_z = 16 \frac{ab}{15} \)

**Complement of Half Parabola**
- \( A = \frac{1}{3}ab \)
- \( m = \frac{7}{10}a \)
- \( n = \frac{3}{5}b \)
- \( l_s = 52 \frac{a+b}{2100} \)
- \( I_a = \frac{1}{80} ab^4 \)

**Parabolic Fillet in Right Angle**
- \( a = \frac{1}{2}\sqrt{2} \)
- \( b = \frac{1}{2}\sqrt{2} \)
- \( A = \frac{1}{6} \)
- \( m = n = \frac{4}{5} \)
- \( l_s = l_z = 11 \frac{a+b}{2100} \)

**Half Ellipse**
- \( A = \frac{1}{2} a b \)
- \( m = \frac{4a}{3} \)
- \( I_s = a b \left( \frac{\pi}{8} - \frac{a}{3} \right) \)
- \( I_z = \frac{a}{8} a b^2 \)

**Quarter Ellipse**
- \( A = \frac{1}{4} a b \)
- \( n = \frac{4}{9} \)
- \( I_s = a b \left( \frac{\pi}{16} - \frac{4}{9} \right) \)
- \( I_z = \frac{a}{16} a b^2 \)

**Elliptic Complement**
- \( A = a b \left( 1 - \frac{\pi}{4} \right) \)
- \( m = \frac{a}{6} (1 - \frac{\pi}{4}) \)
- \( n = \frac{b}{6} (1 - \frac{\pi}{4}) \)
- \( I_s = a b \left( \frac{\pi}{16} - \frac{1}{36} (1 - \frac{\pi}{4}) \right) \)
- \( I_z = a b \left( \frac{\pi}{16} - \frac{1}{36} (1 - \frac{\pi}{4}) \right) \)

*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

\[ n = \text{Number of sides} \]
\[ \alpha = \frac{360}{n} \]
\[ a = 2\sqrt{R^2 - R_1^2} \]
\[ R = \frac{a}{2 \sin \alpha} \]
\[ R_1 = R \tan \alpha \]
\[ A = \frac{1}{2} n a^2 \cot \alpha = \frac{1}{2} n R^2 \sin 2\alpha = n R_1^2 \tan \alpha \]
\[ I_R - I_1 = \frac{A(6R^2 - a^2)}{24} = \frac{A(2R_1^2 + a^2)}{48} \]
\[ I_1 - I_2 = \frac{6R^2 - a^2}{24} = \sqrt{\frac{12R_1^2 + a^2}{12}} \]

ANGLE
Axis of moments through center of gravity

\[ \tan 2\gamma = \frac{2K}{1 - K^2} \]
\[ K = \frac{1}{2}(t(b + c) - a) \]
\[ l_x = \frac{1}{3} \left( (d - y)^2 + b^2 - a^2 \right)^{1/2} \]
\[ l_y = \frac{1}{3} \left( (t(b - x)^2 + dx^2 - c(x - t)^2 \right) \]
\[ l_z = l_x \sin \theta + l_y \cos \theta + K \sin 2\gamma \]
\[ l_w = l_x \cos \theta + l_y \sin \theta + K \sin 2\gamma \]

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

\[ I_z = I_x \sin \alpha + I_y \cos \alpha \]
\[ I_y = I_x \cos \alpha + I_y \sin \alpha \]
\[ f_B = M \left( \gamma \sin \alpha + \gamma \cos \alpha \right) \]

where M is bending moment due to force F.

TRIGONOMETRIC FORMULAS

\[ \text{Radius} \: AF = 1 = \sin^2 A + \cos^2 A = \sin A \cos A = \cos A \sin A = \tan A \cot A \]
\[ \text{Sine} \: A = \cos A = \frac{1}{\cos A} = \cos A \tan A = \sqrt{1 - \cos^2 A} = BC \]
\[ \text{Cosine} \: A = \sin A = \frac{1}{\sin A} = \sin A \cot A = \sqrt{1 - \sin^2 A} = AC \]
\[ \text{Tangent} \: A = \sin A \tan A \cot A = \sin A \cos A = \cos A \sec A = FD \]
\[ \text{Cotangent} \: A = \cos A \cot A \sec A = \cos A \cos A = \cos A \cosec A = HG \]
\[ \text{Secant} \: A = \tan A \cosec A = \tan A \sec A = AD \]
\[ \text{Cosecant} \: A = \cot A \cosec A = \cot A \cosec A = AG \]

RIGHT ANGLED TRIANGLES

\[ a^2 = b^2 + c^2 \]
\[ b^2 = a^2 - c^2 \]
\[ c^2 = a^2 + b^2 \]

<table>
<thead>
<tr>
<th>Known</th>
<th>A</th>
<th>B</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>a, b</td>
<td>( \tan A = \frac{a}{b} )</td>
<td>tan B = ( \frac{b}{a} )</td>
<td>a</td>
</tr>
<tr>
<td>a, c</td>
<td>( \sin A = \frac{a}{c} )</td>
<td>( \cos B = \frac{b}{c} )</td>
<td>c</td>
</tr>
<tr>
<td>A, a</td>
<td>90° - A</td>
<td>b tan A</td>
<td>a</td>
</tr>
<tr>
<td>A, b</td>
<td>90° - A</td>
<td>c sin A</td>
<td>b</td>
</tr>
<tr>
<td>A, c</td>
<td>90° - A</td>
<td>a ( \frac{c^2 - a^2}{2} )</td>
<td>a</td>
</tr>
</tbody>
</table>

OBELICANGLED TRIANGLES

\[ s = a + b + c \]
\[ s = b^2 + c^2 - 2bc \cos A \]
\[ b^2 = a^2 + b^2 - 2ab \cos C \]

<table>
<thead>
<tr>
<th>Known</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>a, b, c</td>
<td>( \tan \frac{A}{2} = \frac{K}{a-b} )</td>
<td>( \tan \frac{B}{2} = \frac{K}{b-a} )</td>
<td>( \tan \frac{C}{2} = \frac{K}{c-a} )</td>
<td>a</td>
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<tr>
<td>a, A, B</td>
<td>( \sin B = \frac{a \sin A}{b} )</td>
<td>( \sin A = \frac{b \sin B}{a} )</td>
<td>( \sin A = \frac{b \sin B}{a} )</td>
<td>( \frac{180° - (A+B)}{2} )</td>
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<tr>
<td>a, b, A</td>
<td>( \sin B = b \sin \frac{A}{a} )</td>
<td>( \sin C = b \sin \frac{A}{a} )</td>
<td>( \sin B = b \sin \frac{A}{a} )</td>
<td>( \frac{180° - (A+B)}{2} )</td>
</tr>
<tr>
<td>a, b, c</td>
<td>( \tan A = \frac{a \sin C}{b - a \cos C} )</td>
<td>( \tan B = \frac{b \sin C}{a - b \cos C} )</td>
<td>( \tan C = \frac{c \sin A}{b - c \cos A} )</td>
<td>( \frac{180° - (A+B)}{2} )</td>
</tr>
</tbody>
</table>
### DECIMALS OF AN INCH
For each 64th of an inch
With Millimeter Equivalents

<table>
<thead>
<tr>
<th>Fraction</th>
<th>1⁄64ths</th>
<th>Decimal</th>
<th>Millimeters (Approx.)</th>
<th>Fraction</th>
<th>1⁄64ths</th>
<th>Decimal</th>
<th>Millimeters (Approx.)</th>
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American Institute of Steel Construction
### Decimals of a Foot
For each 32nd of an inch

<table>
<thead>
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<th>Inch</th>
<th>0</th>
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<th>3</th>
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<th>5</th>
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BASIC NAVAL ARCHITECTURE

Excerpts From

Rules for Building and Classing

Steel Vessels, 1987

Rules for Building and Classing Steel Vessels

is revised yearly and published by:

American Bureau of Shipping
45 Eisenhower Drive
P. O. Box 910
Paramus, New Jersey 07653-0910

copies may be ordered directly from the publisher.
Pillars and Deck Girders

11.1 General

All tiers of beams are supported by pillars or by means which are not less effective. ‘Tweendeck 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 \( W_p \) 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.

\[
W_p = (1.232 - 0.00452l/r)A
\]
\[
W_p = (7.83 - 0.345l/r)A
\]

\( l = \) 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 \( \text{cm}^2 \) or \( \text{in.}^2 \)

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.

\[
W = 0.715bh_s
\]
\[
W = 0.02bh_s
\]

\( b = \) 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 1.015 \( W \) \( \text{cm}^2 \) or 0.16 \( W \) \( \text{in.}^2 \), where \( W \) is obtained from the following equation.

\[
W = 107bhs \text{ metric tons} \quad W = 0.03bhs \text{ long tons}
\]

\( b = \) 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.

$$SM = 4.74cbh^2 \text{ cm}^3 \quad SM = 0.0025cbh^2 \text{ in}^3$$

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
\[ h = \text{height as required by Section 10 for the beams supported, in m or ft} \]
\[ l = \text{span between supporting girders or bulkheads, or between girder and side frame, in m or ft. Where an effective bracket is fitted at the side frame, the length } l \text{ may be modified. See 9.3.3.} \]

11.7.3 Proportions
Girders are to have a depth of not less than 0.0583 \( \text{ft} \) (0.7 \( \text{in. per ft of span} \) l), the thickness is not to be less than 1 mm per 100 mm (0.01 \( \text{in. per in.} \) ) of depth plus 4 mm (0.16 \( \text{in.} \) ), but is not to be less than 8.5 mm (0.34 \( \text{in.} \) ) where the face area is 38 cm² (6 \( \text{in.} \) ), 10 mm with 63 cm² (0.40 \( \text{in. with 10 in.} \)), 12.5 mm with 127 cm² (0.50 \( \text{in. with 20 in.} \)) and 15 mm with 190 cm² (0.60 \( \text{in. with 30 in.} \) ).

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 \( \text{in.} \) ), at every second frame where it exceeds 400 mm (16 \( \text{in.} \) ) and at every frame where it exceeds 600 mm (24 \( \text{in.} \) ).

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 0.0833 \( \text{ft} \) (1 \( \text{in. per ft of span} \) 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 \( \text{cm}^3 \) or \( \text{in.}^3 \) 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
\[ SM = K(AB + CD)h l \text{ cm}^2 \]
\[ SM = 0.000527K(AB + CD)h l \text{ cm}^3 \]

b Where Girders are not Fitted on the Line of the Hatch Side Beyond the Hatchway
\[ SM = KABh l \text{ cm}^3 \]
\[ SM = 0.000527KABh l \text{ in.}^3 \]

\( A \) = length of the hatchway, in \( \text{m or ft} \)
\( B \) = distance from the centerline to the midpoint between the hatch side and the line of the toes of the beam knees, in \( \text{m or ft} \)
\( C \) = 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 \( \text{m or ft} \); 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 \( \text{m or ft} \)
\( h \) = height for the beams of the deck under consideration as given in Section 10, in \( \text{m or ft} \)
\( l \) = distance from the toe of the beam knee to the centerline plus 0.305 m (1 ft), in \( \text{m or ft} \)
\( K = 2.20 + 1.29(F/N) \) when \( F/N \leq 0.6 \)
\( = 4.28 - 2.17(F/N) \) when \( F/N > 0.6 \)
\( N \) = one-half the breadth of the vessel in \( \text{way of the hatch-end beam} \)
\( F \) = distance from the side of the vessel to the hatch side girder
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 \( SM_{hs} \) not less than obtained from the following equation.

\[
SM_{hs} = SM(Q)
\]

\( SM = \) required section modulus in ordinary-strength material as determined elsewhere in this section
\( Q = \) as defined in 6.13.3
Unit Number: 1
Title: Introduction
Tape Running Time: 44M 45S
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.
INTRODUCTION

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 \( \theta \).
EXAMPLE No. 1 (CON'T)

SOLUTION:

\[
\tan \theta = \frac{w t}{G M \Delta}
\]

\[
\tan \theta = \frac{(1200 \text{ ft}) \times (50.0 \text{ ft})}{(3.40 \text{ ft}) \times (28,000 \text{ ft})}
\]

\[
\tan \theta = .1050
\]

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

\[
\theta = 6.0^\circ
\]

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 X 10^6 FT^2.

THE APPLICABLE FORMULAE ARE:

FRICTIONAL RESISTANCE \[ R_f = C_f \frac{\rho}{2} S \sqrt{v^2} \]

FRICTIONAL COEFFICIENT \[ C_f = \frac{0.075}{(\log \text{Re} - 2)^2} \]

REYNOLDS NUMBER \[ \text{Re} = \frac{vL}{\nu} \]
EXAMPLE NO. 2 (CONT'

\[ v = \text{velocity in ft/sec} \]

\[ v = 10 \text{ knots} \times 1.688 \text{ ft/sec/knot} = 16.88 \text{ ft/sec} \]

\[ L = 600 \text{ ft} \quad \text{(given)} \]

\[ \nu = \text{kinematic viscosity of sea water at 59°F} \]

\[ \nu = 1.2791 \times 10^{-5} \text{ ft}^2/\text{sec} \quad \text{(from tables)} \]

\[ \rho = \text{density of sea water at 59°F} \]

\[ \rho = 1.9905 \text{ lb/sec}^2/\text{ft}^4 \quad \text{(from tables)} \]

\[ S = \text{wetted surface in ft}^2 \]

\[ S = 2.0 \times 10^6 \text{ ft}^2 \quad \text{(given)} \]
INTRODUCTION

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,
   \[ Cf = \frac{0.075}{(\log Re - 2)^2} \]
   \[ = \frac{0.075}{(\log(7.918 \times 10^8) - 2)^2} \]
   \[ = \frac{0.075}{(8.8986 - 2)^2} \]
   \[ = \frac{0.075}{(6.8986)^2} \]
   \[ = 0.001576 \]
   \[ Cf = 1.576 \times 10^{-3} \]
INTRODUCTION

EXAMPLE NO. 2 (CON'T)

3. FRICTIONAL RESISTANCE:

\[ R_f = C_f \frac{9}{2} S v^2 \]

\[ = (1.2791 \times 10^{-3})(1.9905 \frac{\text{LB sec}^2}{\text{FT}^4})(2.0 \times 10^6 \text{FT}^2)(16.88 \frac{\text{FT}}{\text{SEC}})^2 \]

\[ = 725.5 \times 10 \ \text{LB} \]

\[ R_f = 7255 \ \text{LB} \]

FRICTIONAL RESISTANCE: \( R_f = 7255 \ \text{LB} \)
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,
16,148.0 ft² 
247.6 ft² 
5,912.2 ft² 
\[ \frac{22,307.8}{ft²} \]
is preferable to

\[ 16,148.0 \, ft² + 247.6 \, ft² + 5,912.2 \, ft² = 22,307.8 \, ft². \]

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 \( \frac{1}{2} \)" in diameter is:

\[ \text{Area} = 35.50 \times 3.141592654 = 111.5265392. \]

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 \( \frac{1}{2} \)"
- 35.5"
- 35.50"
- 35.500"

In this example, 35 \( \frac{1}{2} \)" means 35 \( \frac{1}{2} \) 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.
Unit Number: 2
Title: Ship types and ship systems - 1
Tape Running Time: 34M 0S
Reading Assignment: Modern Ship Design (MSD), pp 3-10
Additional References: Ship Design and Construction (SDC), pp 1-13

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 CO2 room. MGN’s supply is therefore 29 hatch covers per ship; all being one-piece watertight 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-deep 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’

<table>
<thead>
<tr>
<th>Description</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (o.a.)</td>
<td>198.80m</td>
</tr>
<tr>
<td>Length (b.p.)</td>
<td>186.40m</td>
</tr>
<tr>
<td>Breadth</td>
<td>32.20m</td>
</tr>
<tr>
<td>Depth</td>
<td>20.45m</td>
</tr>
<tr>
<td>Draught</td>
<td>9.15m</td>
</tr>
<tr>
<td>Deadweight</td>
<td>24,180 tonnes</td>
</tr>
<tr>
<td>Containers</td>
<td>1,936TEU</td>
</tr>
<tr>
<td>Trailers</td>
<td>27 x 40ft</td>
</tr>
<tr>
<td>Propulsion</td>
<td>Sulzer 7RTA76</td>
</tr>
<tr>
<td>Output</td>
<td>23,030 bhp</td>
</tr>
<tr>
<td>Speed</td>
<td>17.80 knots</td>
</tr>
</tbody>
</table>

A container-laden Sea Wolf caught by the aerial camera as she transited the English Channel
Full Frame (A)

Z PACECO "NEW
PORTAIN TAR CRANES REC.
INSTALLED AT HOWLAND
HOK - STATION ISLAND,
ALSO CAPABLE OF HANDLING
BEYOND PANAMAX SHIPS
(135' OUT REACH
(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-cylinder diesel engine is capable of developing over 22,000 bhp.

The ship’s propulsion plant is designed to operate unattended and all plant functions are monitored by Siemens’s 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 auxiliary 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 up to 300 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 weather-tight closure for the mooring of the ship. The ship is also equipped with Omnhithruster 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. establishes an affiliation with three other prominent companies to assist in the design and expedite the supply of equipment for the container ship. 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
‘Anchorage’ To Serve Pacific Northwest

Bay Shipbuilding Corp. of Sturgeon Bay, Wis., recently delivered the M/V Sea-Land Anchorage, which is the first 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.

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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 Omnitruster bow and stern thrusters which greatly enhance its maneuverability.

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Proven Performance

Circle 183 on Reader Service Card

Maritime Reporter/Engineering News
NEWBUILDING

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 III. 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."

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 3.458:1 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.
PROFILE AND GENERAL ARRANGEMENT PLANS
OF THE 31 000 GRT NORTH SEA FERRIES
NORSEA & NORSUN

MAY 1987

26B

THE
MOTOR
SHIP

ACCOMM LADDER
SHELL DOOR
BUNKER DOOR
STABILISER OPENING

LIFT SPACE
FAN ROOM
LIFERAFT LAUNCHING DAVITS

ER CASING
LIFE BOATS
143 PERSONS EACH
LIFE BOAT/RESCUE
24 PERSON

ENGINE CASING
CREW MESS ROOM
CREW REC ROOM
CREW ACCOMMODATION

OFFICERS ACCOMMODATION
OFFICERS LOUNGE

FAN ROOM
FAN ROOM
FAN ROOM

WHEEL HOUSE
GYRO

NAV BRIDGE
DECK
A DECK
B DECK
C DECK
D DECK
E DECK

STERN RAMP
DOOR

LAUNCHING DAVITS

Bridge Deck

A Deck

Passenger Accommodation
**PRINCIPAL PARTICULARS**

<table>
<thead>
<tr>
<th>Norsea</th>
<th>Norsun</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length, oa</strong></td>
<td>178.9m</td>
</tr>
<tr>
<td><strong>Length, bp</strong></td>
<td>169.8m</td>
</tr>
<tr>
<td><strong>Breadth, extreme</strong></td>
<td>25.4m</td>
</tr>
<tr>
<td><strong>Depth, mid (to F dk)</strong></td>
<td>7.85m</td>
</tr>
<tr>
<td><strong>Draught, max</strong></td>
<td>6.13m</td>
</tr>
<tr>
<td><strong>Draught, scantling</strong></td>
<td>6.2%</td>
</tr>
<tr>
<td><strong>Deadweight</strong></td>
<td>6 340 tonne</td>
</tr>
<tr>
<td><strong>Gross register (approx)</strong></td>
<td>31 600 ton</td>
</tr>
<tr>
<td><strong>Service speeds</strong></td>
<td>16.5 &amp; 18.5 knots</td>
</tr>
<tr>
<td><strong>Engines</strong></td>
<td>2 x Wärtsilä-Sulzer 24/40</td>
</tr>
<tr>
<td><strong>Total moc</strong></td>
<td>19 200kW (26 100 bhp)</td>
</tr>
<tr>
<td><strong>Passengers</strong></td>
<td>1 250</td>
</tr>
<tr>
<td><strong>Cabins</strong></td>
<td>446/452</td>
</tr>
<tr>
<td><strong>Crew</strong></td>
<td>107</td>
</tr>
<tr>
<td><strong>Cargo space</strong></td>
<td>2 250 lane m</td>
</tr>
<tr>
<td><strong>Cargo capacity</strong></td>
<td>180 trailers, 850 cars, or a mixture of both</td>
</tr>
<tr>
<td><strong>No of decks</strong></td>
<td>8</td>
</tr>
<tr>
<td><strong>Classification</strong></td>
<td>Lloyds + 100A1</td>
</tr>
<tr>
<td></td>
<td>Ferry + LMC &amp; UMS SOLAS</td>
</tr>
<tr>
<td></td>
<td>Short International Voyage</td>
</tr>
</tbody>
</table>

**PRINCIPAL EQUIPMENT**

<table>
<thead>
<tr>
<th>Norsea</th>
<th>Norsun</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Engines</strong></td>
<td>Wärtsilä-Sulzer</td>
</tr>
<tr>
<td><strong>Propellers &amp; bowthrusters</strong></td>
<td>F Tacke</td>
</tr>
<tr>
<td><strong>Ratings</strong></td>
<td>Wärtsilä-Vasa</td>
</tr>
<tr>
<td><strong>Access equipment</strong></td>
<td>Siemens</td>
</tr>
<tr>
<td><strong>Conditioning</strong></td>
<td>Winel</td>
</tr>
<tr>
<td><strong>Holders</strong></td>
<td>Becker</td>
</tr>
<tr>
<td><strong>Lifters</strong></td>
<td>Ross Industrie</td>
</tr>
<tr>
<td><strong>Ring gear</strong></td>
<td>Hatse</td>
</tr>
<tr>
<td><strong>Fire systems</strong></td>
<td>Saarloos</td>
</tr>
<tr>
<td><strong>Fire equipment</strong></td>
<td>Electrolux Marine</td>
</tr>
<tr>
<td><strong>Boat davits</strong></td>
<td>Schat</td>
</tr>
<tr>
<td><strong>Commercial vessel</strong></td>
<td>Byers</td>
</tr>
<tr>
<td><strong>Boats</strong></td>
<td>Wein Lambie</td>
</tr>
<tr>
<td><strong>Elevating pump system</strong></td>
<td>Frank Mohn</td>
</tr>
<tr>
<td><strong>Gear system</strong></td>
<td>Otis Elevator</td>
</tr>
<tr>
<td><strong>Dining</strong></td>
<td>Evac</td>
</tr>
<tr>
<td><strong>Signal type</strong></td>
<td>Boll &amp; Kirch</td>
</tr>
</tbody>
</table>

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MAY 1987

268
INFORMATIONAL CUTLINES

one of
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-
Front cover photo features VCC Exxon Long Beach. Recently delivered by NASSCO, she'll serve in Alaskan trades. More tumultuous international tanker market is discussed on p.18.
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 sister ship. 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 23.3m openings. The covers are of open construction, designed to accept a uniformly distributed load of 1.75 tonnes/m² 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 propulsion 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'**

<table>
<thead>
<tr>
<th>Description</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (o.a)</td>
<td>286.90m</td>
</tr>
<tr>
<td>Length (b.p)</td>
<td>275.00m</td>
</tr>
<tr>
<td>Breadth (mid)</td>
<td>47.00m</td>
</tr>
<tr>
<td>Depth (to upper deck)</td>
<td>24.00m</td>
</tr>
<tr>
<td>Draught (mid)</td>
<td>17.80m</td>
</tr>
<tr>
<td>Main engine</td>
<td>H&amp;W MAN-B&amp;W</td>
</tr>
<tr>
<td>Hold volume</td>
<td>194,254m³</td>
</tr>
<tr>
<td>Speed (service)</td>
<td>13.6 knots</td>
</tr>
</tbody>
</table>

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 regime that will ensure savings being made on installation time. This latter contributed to the 'common pool' 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.
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
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 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.

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. The exciter supplies 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.

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...
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 board its liner Queen Elizabeth 2. Nine 9-cylinder MAN-B&W 56/64 series engines producing a total of 94,500 kW (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 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 58/64 engine series (The Motor Ship special supplement, March 1985) has been developed for a power range between 5,884 and 11,033 kW (8,000 and 15,000 bhp), to provide an overall cost effectiveness for a large bore, four-stroke engine. The characteristics of this engine's 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 31,588/64 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 700 kW 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 7,000 kW 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 communal 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 MOTOR SHIP, DECEMBER 1985

Engine News

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

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.
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 84m 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 × 10^8Nm, nearly 12 times that of each generator.

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 testing 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 propeller 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 33)
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 sub-synchronous speed for maneuvering 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 converters 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 converters 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 converters. They are air-cooled 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.

**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 70)

![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 Avel-Lindberg ensures that the monitoring system will continue to function irrespective of main power failures.](image)
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 synchro-phasing is to permit the optimum blade angle for the propellers to be used with minimal 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 engine room 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 engine-room 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 engine room 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

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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 converters it is necessary that:

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

In combinator mode the propulsion motors are supplied, at variable frequency, by the synchro-converters and are running at a speed set by either the Lips propeller system or by speed setting switches on the engineer's 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 converter system.

The converter/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 converter 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:

\[ \text{Motor torque} = K I_f I_p \]

Where:

- \( K \) = motor torque constant
- \( I_f \) = armature current
- \( I_p \) = 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/converter 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 converter 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 over-current.

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 buses and operates at powers up to 44MW per shaft, the actual level being dependent on the generators connected to the buses.

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.
| Length, m | 211.6m | | 183.0m | | 73.6m |
| Beam, m | 38.0m | | 22.0m | | 18.0m |
| Draught, m | 7.76m | | 7.76m | | 15.0m |
| Gross register | 65500 | | 21500 | | 16000 |
| Engine | 850 tons | | 4400 tons | | 2550 tons |

**Principal Suppliers**

<table>
<thead>
<tr>
<th>Category</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air conditioning</td>
<td>Semco</td>
</tr>
<tr>
<td>Ventilation</td>
<td>Lohman &amp; Stollerfeind</td>
</tr>
<tr>
<td>Freshwater generator</td>
<td>Atlas Copco</td>
</tr>
<tr>
<td>Governors</td>
<td>Eliza</td>
</tr>
<tr>
<td>Boilers</td>
<td>Wartsila Vasa</td>
</tr>
<tr>
<td>Auxiliary engines</td>
<td>Siemens</td>
</tr>
<tr>
<td>A/C</td>
<td>ABB cookie</td>
</tr>
<tr>
<td>Fire fighting</td>
<td>H. A. Schröder</td>
</tr>
<tr>
<td>Steering</td>
<td>AB Bofors</td>
</tr>
<tr>
<td>Lamps</td>
<td>Philips</td>
</tr>
<tr>
<td>PA &amp; TV system</td>
<td>International Fairey-Osborn</td>
</tr>
<tr>
<td>Refrigerating units</td>
<td>C. W. Robbins</td>
</tr>
<tr>
<td>Switchboards</td>
<td>Schiehallion Engineering Co.</td>
</tr>
<tr>
<td>Stevedoring</td>
<td>Alfa-Laval</td>
</tr>
</tbody>
</table>
Unit Number: 3
Title: Ship types and ship systems - 2
Tape Running Time: 33M 50S
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.)
**BOEING NATO Patrol Missile Hydrofoil (PHM)**

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Hullborne (foils retracted)</th>
<th>Hullborne (foils extended)</th>
<th>Foilborne (nominal)</th>
<th>Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>131 2 feet</td>
<td>222 2 feet</td>
<td>8.8 feet</td>
<td>231 long tons</td>
</tr>
<tr>
<td>Beam</td>
<td>28 2 feet</td>
<td>23.2 feet</td>
<td>27.7 m</td>
<td>235 metric tons</td>
</tr>
<tr>
<td>Draft</td>
<td>6.2 feet</td>
<td>7.1 m</td>
<td>2.7 m</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>12 knots</td>
<td>In excess of 40 knots</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Propulsion**
- Hullborne: 2 diesels with 2 waterjets
- Foilborne: 1 gas turbine with waterjet

**Crew**
- 21
U.S.S. OLYMPIA (SSN 717)
Los Angeles-Class Attack Submarine
Newport News Shipbuilding

Photograph by Judi Baldwin, Newport News Shipbuilding
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 - $L_p$, $L_W$, $L_{OA}$, 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.)
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)
Lpp
LWL
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

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
-----
sterne 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
SHIP TYPES AND SHIP SYSTEMS

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.
SHIP TYPES AND SHIP SYSTEMS

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.
SHIP TYPES AND SHIP SYSTEMS

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.
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

[Diagram showing ship dimensions with labels L_PP/2, L_PP, L_PP/2, L_WL, L_OA, L_WL.]
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


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
Lape Running Time: 38'38"
Reading Assignment: None
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
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
THE PANTAIL.

A broad, open deck area at the stern of the ship is

or superstructure deck.

Pronounced "rock-stle". The poop deck and upper decks

include the forecastle deck (forecastle is

first platform, etc.). Partital decks above the main

platforms. The uppermost platform is the

is a partial deck. Partial decks below the main deck

a deck which does not run the full length of the ship

second deck, and so forth.

The next complete deck below the main deck is the

of the ship is the main deck.

The uppermost complete running the full length

deks

nomencalture
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 SCUTTLE

HAND WHEEL
GASKET
ADJUSTING SCREW
COAMING
DOG
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.


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

ANCHOR CHAIN AND CHAIN STOPPERS

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

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

VERTICAL SHAFT WINDLASS

KEY WORDS: WINDLASS, WILDCAT, CAPSTAN
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.
MOORING FITTINGS

KEY WORDS: BOLLARD, CHOCK, BITTS, CLEAT, PADEYE
BASIC NAVAL ARCHITECTURE

Unit Number: 6
Title: Nomenclature - 3
Tape Running Time: 36\textsuperscript{M} 30\textsuperscript{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 \textbf{steel}, not cast iron.

Suggested Problem Assignment: None
NOMENCLATURE

CRESSENT DAVIT

- Raymond releasing hook
- Gripe
- Gripe turnbuckle
- Operating screw
- Keel of boat rests here
- Hand crank
NOMENCLATURE

WELIN TRACKWAY GRAVITY DAVIT

Davit arm in stowed position

Movable block tripping lever

Davit arm in lowering position

Rollers

Fairlead blocks

Mech. brake lever

Drum

Fall fairlead to drum

Winch
NOMENCLATURE

ACCOMODATION LADDER AND JACOB'S LADDER
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 stiffeners 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.
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).

OPEN FLOORS UTILIZE STRUTS FOR VERTICAL MEMBERS
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')
LONGITUDINAL VERSUS TRANSVERSE FRAMING

- LONGITUDINAL FRAMING IS MORE EFFICIENT STRUCTURALLY, BUT-

- FOR SHIPS WHICH CARRY BREAK-BULK, RO/RO, OR CONTAINER CARGOES THE DEEP WEBBS WHICH ARE USED WITH THE LONGITUDINAL FRAMING SYSTEMS INTERFERE WITH CARGO STOWAGE.

- DEEP WEBBS ARE NO PROBLEM FOR LIQUID CARGOES AND BULK CARGOES. FOR THIS REASON TANKERS AND BULK CARRIERS ARE LONGITUDINALLY 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

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
Unit Number: 7
Title: Dimension, form and flotation - 1
Tape Running Time: 27M 48S
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
FREEBOARD
IMOLDED
DESIQNERS
WATERLINE
ONE HALF OF
MOLDED BREADTH
HALF-SIDING
OF
FLAT KEEL
MOLDED
BASE LINE
BASE LINE AT BOTTOM OF KEEL
CAMBER
CENTERLINE
OF
SHIP
MOLDED
DEPTH
FREEBOARD
MOLDED
DRAFT
DEADRISE
DESIGNED
DRAFT
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)

\[ = 35 \text{ CUBIC FEET PER LONG TON OF SEA WATER} \]

\[ = 35 \frac{\text{FT}^3}{\text{TON}} \]
CONSTANTS YOU SHOULD KNOW

SPECIFIC VOLUME OF FRESH WATER

\[ = 35.9 \, \text{FT}^3/\text{TON} \]

WHICH IS SOMETIMES ROUNDED OFF TO:

\[ 36 \, \text{FT}^3/\text{TON} \]
STANDARD SYMBOLS

LENGTH BETWEEN PERPENDICULARS
DRAFT
BEAM (OR BREADTH)
DISPLACEMENT
VOLUME OF DISPLACEMENT (CUBIC FEET)
AREA OF MIDSECTION AT DRAFT T
AREA OF WATER PLANE AT DRAFT T

\( L_{pp} \)
\( T \)
\( B \)
\( \triangle \)
\( \triangledown \)
\( A_m \)
\( A_w \)
MIDSHIP SECTION COEFFICIENT

\[ C_m = \frac{A_m}{BT} \]
WATERLINE COEFFICIENT
(WATERPLANE COEFFICIENT)

\[ C_{wp} = \frac{A_{wp}}{B \cdot L_{pp}} \]
BLOCK COEFFICIENT

\[
C_b = \frac{\Delta}{L_{pp} B_T}
\]

\[
\Delta = 35 \Delta \quad \text{(SEA WATER)}
\]

\[
C_b = \frac{35 \Delta}{L_{pp} B_T}
\]

SINCE
PRISMATIC COEFFICIENT

\[ C_p = \frac{\triangle}{A_m \ L_{pp}} \]

SUBSTITUTING, \( A_m = C_m BT \) GIVES

\[ C_p = \frac{\triangle}{C_m \ BT \ L_{pp}} = \frac{C_b}{C_m} \]

OR \[ C_b = C_p \ C_m \]
BLOCK COEFFICIENT

$$C_b = \frac{\Delta}{LBT}$$

PRISMATIC COEFFICIENT

$$C_P = \frac{\Delta}{A_M L}$$
\[
\frac{L_{pp}}{B} = \frac{L_{pp}}{T} = \frac{B}{T}
\]
TWO MORE COEFFICIENTS

VOLUMETRIC COEFFICIENT = \( \frac{\nabla}{L_{pp}^3} \)

DISPLACEMENT LENGTH RATIO = \( \frac{\Delta}{(L_{pp}/100)^3} \)
Unit Number: 8
Title: Dimension, form and flotation - 2
Tape Running Time: 34M 15S
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. \[
\frac{DWT}{\Delta} = 0.86
\]
\[
\Delta = \frac{DWT}{0.86} = \frac{40,000 \text{ LT}}{0.86}
\]
\[
\Delta = 46,512 \text{ LT}
\]

2. \[
\frac{\Delta}{\left(\frac{L}{100}\right)^3} = 165
\]
\[
\left(\frac{L}{100}\right)^3 = \frac{\Delta}{165} = \frac{46,512 \text{ LT}}{165} = 281.9
\]
\[
\left(\frac{L}{100}\right) = 6.56
\]
\[
L = 656 \text{ FT}
\]
EXAMPLE (CON'T)

SOLUTION

3. \[
\frac{L}{B} = 7.50
\]
\[
B = \frac{L}{7.50} = \frac{656 \text{ ft}}{7.50}
\]
\[
B = 87.5 \text{ ft}
\]

4. \[
\frac{B}{T} = 2.50
\]
\[
T = \frac{B}{2.50} = \frac{87.5 \text{ ft}}{2.50}
\]
\[
T = 35.0 \text{ ft}
\]
EXAMPLE (CON'T)

SOLUTION (CON'T)

5. \[ C_b = \frac{\Delta}{L_{pp}BT} = \frac{35\Delta}{L_{pp}BT} \]

\[ C_b = \frac{(35 \text{ ft}^3)(46.512 \text{ LT})}{(656 \text{ ft})(87.5 \text{ ft})(35.0 \text{ ft})} \]

\[ C_b = 0.810 \]

6. \[ C_p = \frac{C_b}{C_m} = \frac{0.810}{0.980} \]

\[ C_p = 0.827 \]
EXAMPLE (CONCLUDED)

RECAP: THE PRELIMINARY CHARACTERISTICS OF THE SHIP ARE:

\[ L_{PP} = 656 \text{ ft} \]
\[ B = 87.5 \text{ ft} \]
\[ T = 35.0 \text{ ft} \]
\[ \Delta = 46,512 \text{ LT} \]
\[ \text{DWT} = 40,000 \text{ LT} \]
\[ C_b = 0.810 \]
\[ C_p = 0.827 \]
\[ C_m = 0.980 \]
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.
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.
IMPORTANT FACT

THE METACENTER REMAINS IN A FIXED POSITION ON THE CENTERLINE ONLY FOR SMALL ANGLES OF INCLINATION, SAY 8° TO 12°
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.
LONGITUDDINAL 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 LONGITUDDINAL 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, IS MEANT IT SHOULD ALWAYS BE DESIGNATED THAT WAY.
GIVEN: weights $W_1, W_2, W_3, W_4$; weights and distances as shown.

FIND: distance of LCG from 30

ALGEBRAIC SOLUTION:

Taking moments about the LCG:

$$\sum (\text{moments fwd. LCG}) = \sum (\text{moments aft LCG})$$
MOMENTS (CON'T)

\[ \sum \text{(mom' ts FWD LCG)} - \sum \text{(mom' ts AFT LCG)} = 0 \]

\[ (100 \text{ LT})(175' + \text{LCG}) + (75 \text{ LT})(100' + \text{LCG}) \]
\[ - (200 \text{ LT})(50' - \text{LCG}) - (125 \text{ LT})(200' - \text{LCG}) = 0 \]

\[ 17,500 + 100 \text{ LCG} + 7500 + 75 \text{ LCG} \]
\[ - 10,000 + 200 \text{ LCG} - 25,000 + 125 \text{ LCG} = 0 \]

\[ 500 \text{ LCG} = 10,000 \]

\[ \underline{\text{LCG} = 20.00 \text{ FT AFT \_\_\_\_\_\_\_\_\_\_}} \]
**MOMENTS (CONT')**

![Diagram showing weight distribution](image)

**TABULAR SOLUTION:**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>WEIGHT LT</th>
<th>LCG FT</th>
<th>MOMENT PT-TONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_1$</td>
<td>100</td>
<td>175</td>
<td>17,500</td>
</tr>
<tr>
<td>$W_2$</td>
<td>75</td>
<td>100</td>
<td>7,500</td>
</tr>
<tr>
<td>$W_3$</td>
<td>200</td>
<td>50</td>
<td>10,000</td>
</tr>
<tr>
<td>$W_4$</td>
<td>125</td>
<td>200</td>
<td>25,000</td>
</tr>
<tr>
<td>$\Sigma$</td>
<td>500</td>
<td>20.0A</td>
<td>10,000A</td>
</tr>
</tbody>
</table>
Problem 1

Problem Level: Basic

Calculate the Midship Section Coefficient of the sections shown below:

(a)  
(b)  
(c)  
(d)  
(e)
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:

\[
\begin{align*}
L_{pp} &= 560' - 0'' \\
L/B &= 5.77 \\
B/T &= 3.23 \\
C_p &= 0.630 \\
C_m &= 0.980
\end{align*}
\]

Calculate:

a) Beam, B
b) Draft, T
c) Block Coefficient, \(C_b\)
d) Displacement volume, \(\nabla\)
e) Displacement, salt water, \(\triangle\)
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:

\[ L_{oa} = 640' \text{-0"} \]
\[ L_{wl} = 620' \text{-0"} \]
\[ L_{pp} = 600' \text{-0"} \]
\[ B = 60' \text{-0"} \]
\[ T = 20' \text{-0"} \]
\[ \nabla = 540,000 \text{ ft}^3 \]
\[ A_m = 1080 \text{ ft}^2 \]
\[ A_w = 27,900 \text{ ft}^2 \]

Calculate:

a) Displacement in salt water, \( \Delta \)
b) Displacement in fresh water, \( \Delta_{fw} \)
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, \( \nabla/\text{L}_{pp}^3 \)
k) Displacement-length ratio, \( \Delta/(\text{L}_{pp}/100)^3 \)
BASIC NAVAL ARCHITECTURE

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:

\[
\begin{align*}
C_b &= 0.585 \\
C_m &= 0.892 \\
C_p &= 0.655 \\
C_w &= 0.800 \\
L/B &= 4.18 \\
L/T &= 9.33 \\
B/T &= 2.23
\end{align*}
\]

(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:

\[
\begin{align*}
\Delta & \quad \text{(salt water)} \\
\Delta_{fw} & \quad \text{(fresh water @ 36 ft}^3/\text{ton)} \\
A_m & \\
A_w & \\
\text{Volumetric Ratio} \\
\text{Displacement-Length Ratio}
\end{align*}
\]
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:

\[
\begin{align*}
\Delta &= 15,000 \text{ L.T.} \\
B &= 58'0" \\
T &= 28'0" \\
C_b &= .770 \\
C_p &= .780
\end{align*}
\]

Find the required \( L_{bp} \) 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:

\[
\begin{align*}
D/T &= 1.50 \\
\overline{KB}/T &= .520 \\
\overline{BM} \times T/B^2 &= .080 \\
\overline{KG}/D &= .500
\end{align*}
\]

Find:

\[
\begin{align*}
D \\
\overline{KB} \\
\overline{BM} \\
\overline{KG} \\
\overline{GM}
\end{align*}
\]

All dimensions above are molded dimensions.
Problem 1

REF: GILLMEYER, PP 27

(a)

\[ C_m = \frac{A_m}{B \cdot T} \]

\[ B = 2 \times 30' = 60' \]

\[ T = 30' \]

\[ A_m = 60' \times 30' = 1800 \text{ ft}^2 \]

\[ C_m = \frac{1800 \text{ ft}^2}{60 \times 30 \text{ ft}^2} \]

\[ C_m = 1.00 \]

(b)

\[ C_m = \frac{A_m}{B \cdot T} \]

\[ B = 2 \times 30' = 60' \]

\[ T = 30' \]

\[ A_m = \frac{1}{2} \times 60' \times 30' = 900 \text{ ft}^2 \]

\[ C_m = \frac{900 \text{ ft}^2}{60 \times 30 \text{ ft}^2} \]

\[ C_m = 0.500 \]

(c)

\[ C_m = \frac{A_m}{B \cdot T} \]

\[ B = 2 \times 30' = 60' \]

\[ T = 30' \]

\[ A_m = 2 \times \frac{1}{2} \times 10' \times 30' + 60' \times 20' \]

\[ A_m = 1500 \text{ ft}^2 \]

\[ C_m = \frac{1500 \text{ ft}^2}{60 \times 30 \text{ ft}^2} \]

\[ C_m = 0.833 \]
\[ C_m = \frac{A_m}{B \cdot T} \]

\[ B = 2 \times 30^\circ = 60^\circ \]
\[ T = 30^\circ \]
\[ A_m = \frac{1}{2} \pi \times (30^\circ)^2 = 1413.72 \text{ ft}^2 \]
\[ C_m = \frac{1413.72}{60 \times 30} \text{ ft}^2 \]
\[ C_m = 0.785 \]

\[ C_m = \frac{A_m}{B \cdot T} \]
\[ B = 2 \times 30^\circ = 60^\circ \]
\[ T = 30^\circ \]
\[ A_m = 2 \times (A_\oplus + A_\circlearrowleft + A_\circlearrowright) \]
\[ A_\oplus = \frac{\pi}{4} (6')^2 = 28.27 \text{ ft}^2 \]
\[ A_\circlearrowleft = 6' \times 24' = 144 \text{ ft}^2 \]
\[ A_\circlearrowright = 24' \times 30' = 720 \text{ ft}^2 \]
\[ A_\oplus + A_\circlearrowleft + A_\circlearrowright = 892.27 \text{ ft}^2 \]
\[ A_m = 2 \times (892.27) = 1784.54 \]
\[ C_m = \frac{A_m}{B \cdot T} = \frac{1784.54}{1500} \text{ ft}^2 \]
\[ C_m = .991 \]
Given:
\[ \frac{L_p}{B} = 5.97 \quad \Rightarrow \quad B = \frac{L_p}{5.97} = \frac{560}{5.97} \quad \therefore \quad B = 97.0'' \]

\[ \frac{B}{T} = 3.23 \quad \Rightarrow \quad T = \frac{B}{3.23} = \frac{97}{3.23} \quad \therefore \quad T = 30.0'' \]

(c) Ref. Gilmer P.27

\[ C_p = \frac{C_b}{C_m} \quad \Rightarrow \quad C_b = C_p \cdot C_m = (0.630)(0.980) \quad \therefore \quad C_b = 0.617 \]

(d) Ref. Gilmer P.27

\[ C_b = \frac{\nabla}{L_p BT} \quad \Rightarrow \quad \nabla = C_b L_p BT = (0.617)(560)(57)(30) \quad \therefore \quad \nabla = 1,005,463 \text{ ft}^3 \]

(e) Ref. Gilmer P.37

\[ \Delta = \frac{\nabla}{35 \text{ ft}^3/\text{Ton}} = \frac{1,005,463 \text{ ft}^3}{35 \text{ ft}^3/\text{Ton}} \quad \therefore \quad \Delta = 28,728 \text{ Tons} \]

(f) Ref. Gilmer P.27

\[ C_m = \frac{A_m}{B_T} \quad \Rightarrow \quad A_m = C_m BT = (0.980)(97)(30) \quad \therefore \quad A_m = 2,852 \text{ ft}^2 \]
(g) Ref Gillmer P.27

\[
\text{Displ. Length Ratio} = \frac{\Delta}{(\text{Lpp/100})^3} = \frac{28.728 \text{ Tons}}{(560 \text{ ft/100})^3}
\]

\[
\therefore \text{Displ. Length Ratio} = 163.58
\]
Problem 3

Given:
- \( L_{pp} = 600' \cdot 0'' \)
- \( B = 60' \cdot 0'' \)
- \( T = 20' \cdot 0'' \)
- \( \Delta = 540,000 \text{ ft}^2 \)
- \( A_m = 1,080 \text{ ft}^2 \)
- \( A_w = 27,900 \text{ ft}^2 \)

Note: \( L_{pp} \) and \( L_{ww} \) are not needed for the following calculations.

(a) Ref. Gilmer P37

\[ \Delta = \frac{\Delta}{35 \text{ ft}^2/\text{ton}} = \frac{540,000 \text{ ft}^3}{35 \text{ ft}^2/\text{ton}} \]

\[ \therefore \Delta = 15,429 \text{ tons} \]

(b) Ref. Gilmer P37

\[ \Delta_{pw} = \frac{\Delta}{36 \text{ ft}^2/\text{ton}} = \frac{540,000 \text{ ft}^3}{36 \text{ ft}^2/\text{ton}} \]

\[ \therefore \Delta = 15,000 \text{ tons} \]

(c) Ref. Gilmer P27

\[ C_b = \frac{\Delta}{L_{pp}B_T} = \frac{540,000 \text{ ft}^3}{(600 \times 60 \times 20)} \]

\[ \therefore C_b = .750 \]

(d) Ref. Gilmer P24

\[ C_m = \frac{A_m}{B_T} = \frac{1,080 \text{ ft}^2}{60 \times 20} \]

\[ \therefore C_m = .900 \]

(e) Ref. Gilmer P27

\[ C_p = \frac{\Delta}{A_mL_{pp}} = \frac{540,000 \text{ ft}^3}{(1,080 \text{ ft}^2)(600 \text{ ft})} \]

\[ \therefore C_p = .823 \]

(f) Ref. Gilmer P27

\[ C_{wp} = \frac{A_w}{B \cdot L_{pp}} = \frac{27,900 \text{ ft}^2}{60 \times 600} \]

\[ \therefore C_{wp} = .775 \]
(g) \[ \text{Length:Beam Ratio} = \frac{L_{PP}}{B} = \frac{600\text{FT}}{60\text{FT}} = 10.00 \]

(h) \[ \text{Length:Draft Ratio} = \frac{L_{PP}}{T} = \frac{600\text{FT}}{20\text{FT}} = 30.00 \]

(i) \[ \text{Beam:Draft Ratio} = \frac{B}{T} = \frac{60\text{FT}}{20\text{FT}} = 3.00 \]

(\text{j}) \[ \text{Vol. Coeff.} = \frac{V}{L_{PP}^3} = \frac{540.000 \text{FT}^3}{(600 \text{FT})^3} = 0.003 \]

(k) \[ \text{Displ. Length Ratio} = \frac{\Delta}{(L_{PP}/100)^3} = \frac{15.429 \text{Tons}}{(600 \text{FT}/100)^3} = \frac{71.43 \text{Tons}}{\text{FT}^3} \]
GIVEN:  
\( C_b = 0.585 \)  
\( C_m = 0.892 \)  
\( C_p = 0.655 \)  
\( C_{wp} = 0.600 \)  
\( L_{pp}/B = 4.18 \)  
\( L_{pp}/T = 9.33 \)  
\( B/T = 2.23 \)  
\( L_{pp} = 85.0 \text{ ft} \)

(a) \( \frac{L_{pp}}{B} = 4.18 \Rightarrow B = \frac{L_{pp}}{4.18} \)  
\( \therefore B = 20.3 \text{ ft} \)

(b) \( \frac{L_{pp}}{T} = 9.33 \Rightarrow T = \frac{L_{pp}}{9.33} \)  
\( \therefore T = 9.1 \text{ ft} \)

(c) Ref. Gillmer P.27, 37
\[
C_b = \frac{\Delta}{L_{pp}BT} \Rightarrow \Delta = C_b \cdot L_{pp}BT = (0.585)(85.0 \text{ ft})(20.3 \text{ ft})(9.1 \text{ ft})
\]
\( \Delta = 9186 \text{ ft}^3 \)
\[
\Delta = \frac{\Delta}{35 \text{ ft}^3/\text{Ton}} = \frac{9186 \text{ ft}^3}{35 \text{ ft}^3/\text{Ton}} \Rightarrow \Delta = 262 \text{ Tons} \)

(d) Ref. Gillmer P.37
\[
\Delta_{fw} = \frac{9186 \text{ ft}^3}{36 \text{ ft}^3/\text{Ton}} \Rightarrow \Delta_{fw} = 255 \text{ Tons} \)

(e) Ref. Gillmer P.27
\[
C_m = \frac{A_m}{BT} \Rightarrow A_m = C_m \cdot BT = (0.892)(20.3 \text{ ft})(9.1 \text{ ft})
\]
\( A_m = 165 \text{ ft}^2 \)

(f) Ref. Gillmer P.27
\[
C_{wp} = \frac{A_w}{B \cdot L_{pp}} \Rightarrow A_w = C_{wp} \cdot B \cdot L_{pp} = (0.600)(20.3 \text{ ft})(85 \text{ ft})
\]
\( A_w = 1380 \text{ ft}^2 \)
(g) Ref: Gilmer P.27

\[
\text{Vol Cof Eff} = \frac{\nabla}{L_{pp}^3} = \frac{9,186 \text{ ft}^3}{(85.0 \text{ ft})^3} = 0.015
\]

(h) Ref: Gilmer P.27

\[
\text{Displ- Length Ratio} = \frac{\Delta}{(L_{pp}/100)^3} = \frac{262 \text{ Tons}}{(850 \text{ ft}/100)^3} = 42.7 \text{ Tons/ft}^3
\]

Summary of a typical harbor tug characteristics are listed below:

- \(L_{pp} = 85' - 0''\)
- \(B = 20' - 4''\)
- \(T = 9' - 1''\)
- \(\Delta = 262 \text{ LT}\)
- \(\Delta_{fv} = 255 \text{ LT}\)
- \(C_b = 0.585\)
- \(C_p = 0.655\)
- \(C_m = 0.892\)
- \(\nabla/ L_{pp}^3 = 0.015\)
- \(\Delta/(L/100)^3 = 42.7 \text{ LT/ft}^3\)
PROBLEM 5

GIVEN: \( \Delta = 16,000 \text{ L.T.} \)
\( B = 58^\circ - 0'' \)
\( T = 28^\circ - 0'' \)
\( C_b = .790 \)
\( C_p = .780 \)

FIND \( L_{pp} \) - REF GILLMER P.27,37

\[
C_b = \frac{\nabla}{L_{pp}B T} \quad \Rightarrow \quad L_{pp} = \frac{\nabla}{C_b B T} = \frac{(35 \text{ ft}^2/\text{Ton}) \Delta}{C_b B T}
\]
\[
L_{pp} = \frac{(35 \text{ ft}^2/\text{Ton})(15,000 \text{Tons})}{(.790)(58.05')(28.05')}
\]
\( \therefore \quad L_{pp} = 420 \text{ FT} \)

FIND \( A_m \) - REF GILLMER P.27,37

\[
C_p = \frac{\nabla}{A_m L_{pp}} \quad \Rightarrow \quad A_m = \frac{\nabla}{C_p L_{pp}} = \frac{(35 \text{ ft}^2/\text{Ton}) \Delta}{C_p L_{pp}}
\]
\[
A_m = \frac{(35 \text{ ft}^2/\text{Ton})(15,000 \text{Tons})}{(.780)(420 \text{ FT})}
\]
\( \therefore \quad A_m = 1,603 \text{ ft}^2 \)

FIND \( C_m \) - REF GILLMER P.27

\[
C_p = \frac{C_b}{C_m} \quad \Rightarrow \quad C_m = \frac{C_b}{C_p} = \frac{.790}{.780} \quad \therefore \quad C_m = .987
\]

FIND DISPL.-LENGTH RATIO - REF GILLMER P.27

\[
\text{DISPL.-LENGTH RATIO} = \frac{\Delta}{(L_{pp}/100)^3} = \frac{15,000 \text{Tons}}{(420 \text{ FT}/100)^3} = \frac{202.46 \text{Tons}}{\text{FT}^3}
\]
GIVEN: \[ \frac{D}{T} = 1.50 \]
\[ \frac{K_B}{T} = 0.520 \]
\[ \frac{B_M \cdot T}{B^2} = 0.080 \]
\[ \frac{K_G}{D} = 0.500 \]

**Find D:**
\[ \frac{D}{T} = 1.50 \Rightarrow D = (1.50)T = (1.50)(28.0 \text{ FT}) \]
\[ \therefore D = 42.00 \text{ FT} \]

**Find \( K_B \):**
\[ \frac{K_B}{T} = 0.520 \Rightarrow K_B = (0.520)T = (0.520)(28.0 \text{ FT}) \]
\[ \therefore K_B = 14.56 \text{ FT} \]

**Find \( B_M \):**
\[ \frac{B_M \cdot T}{B^2} = 0.080 \Rightarrow B_M = \frac{(0.080)B^2}{T} = \frac{(0.080)(28.0 \text{ FT})}{28.0 \text{ FT}} \]
\[ \therefore B_M = 9.61 \text{ FT} \]

**Find \( K_G \):**
\[ \frac{K_G}{D} = 0.500 \Rightarrow K_G = (0.500)D = (0.500)(42.0 \text{ FT}) \]
\[ \therefore K_G = 21.00 \text{ FT} \]

**Find \( G_M \):** REF: GILMER P. 330
\[ G_M = K_B + B_M - K_G = 14.56 \text{ FT} + 9.61 \text{ FT} - 21.00 \text{ FT} \]
\[ \therefore G_M = 3.17 \text{ FT} \]
Unit Number: 9
Title: Dimension, form and flotation - 3
Tape Running Time: 27M 35S
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
ARCHIMEDES PRINCIPLE

(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)
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
  \(35 \text{ ft}^3/\text{ton}\)

- SOMETIMES PRESENTED FOR FRESH WATER
  \(35.9 \text{ or } 36 \text{ ft}^3/\text{ton}\)

- 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.

\[
\text{DRAFT INCREASE } = d = \frac{\triangle}{35 \text{ TPI}}
\]
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
- IF NO SUBSCRIPT, KM MEANS TRANSVERSE METACENTER, KMₜ.
CURVES OF FORM (CON'T)

LONGITUDINAL METACENTER:

- **USUALLY GIVEN AS** $K_{ML}$, **THE HEIGHT OF THE LONGITUDINAL METACENTER ABOVE THE BOTTOM OF THE KEEL.**

- **SOMETIMES GIVEN AS** LONGITUDINAL METACENTRIC RADIUS, $BM_L$. **THEN**
  \[
  K_{ML} = BM_L + KB
  \]

- **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:

  \[ T_f = 19' - 0'' \]
  \[ T_a = 18' - 6'' \]

  TRIM = \( t = \) 6'' 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)

\[ \frac{G_{M}}{12L} = \frac{MTI}{It} \]

\[ G_{M} \text{ is usually a large number, but} \]
\[ \text{may not be known in early stage} \]

\[ \text{MTI may be approximated by} \]

\[ \frac{BM_{L}}{12L} = \frac{MTI}{It} \]

\[ BM_{T} = GM_{T} \]

\[ \text{But don't ever try to say that} \]
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 = $12 \frac{\text{TPI} \times \text{LCF}}{L}$
CURVES OF FORM (CON'T)

- **SIGN OF CORRECTION**

<table>
<thead>
<tr>
<th>LCF</th>
<th>TRIM</th>
<th>CORR</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFT</td>
<td>AFT</td>
<td>+</td>
</tr>
<tr>
<td>FWD</td>
<td>FWD</td>
<td>+</td>
</tr>
<tr>
<td>AFT</td>
<td>FWD</td>
<td>-</td>
</tr>
<tr>
<td>FWD</td>
<td>AFT</td>
<td>-</td>
</tr>
</tbody>
</table>
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

AREA OF SECTION AT DRAFT T

DRAFT T

BONJEAN CURVE FOR SECTION

BASE LINE
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.

<table>
<thead>
<tr>
<th></th>
<th>Weight, lt</th>
<th>Location, ft, F or A</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W_1$</td>
<td>100</td>
<td>250.00 F</td>
</tr>
<tr>
<td>$W_2$</td>
<td>50</td>
<td>175.00 F</td>
</tr>
<tr>
<td>$W_3$</td>
<td>75</td>
<td>50.00 F</td>
</tr>
<tr>
<td>$W_4$</td>
<td>200</td>
<td>0.00</td>
</tr>
<tr>
<td>$W_5$</td>
<td>175</td>
<td>100.00 A</td>
</tr>
<tr>
<td>$W_6$</td>
<td>200</td>
<td>125.00 A</td>
</tr>
</tbody>
</table>
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.

<table>
<thead>
<tr>
<th>Weight, lt</th>
<th>Long'1 location, ft</th>
<th>Vertical Location, ft a H</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.00</td>
<td>220.00 F</td>
<td>5.50</td>
</tr>
<tr>
<td>120.00</td>
<td>200.00 F</td>
<td>20.00</td>
</tr>
<tr>
<td>85.00</td>
<td>150.00 F</td>
<td>55.00</td>
</tr>
<tr>
<td>265.00</td>
<td>22.00 F</td>
<td>35.00</td>
</tr>
<tr>
<td>32.50</td>
<td>46.00 A</td>
<td>2.00</td>
</tr>
<tr>
<td>210.00</td>
<td>61.00 A</td>
<td>68.50</td>
</tr>
<tr>
<td>160.00</td>
<td>183.50 A</td>
<td>26.50</td>
</tr>
<tr>
<td>112.00</td>
<td>206.00 A</td>
<td>40.50</td>
</tr>
</tbody>
</table>
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.
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.
BASIC NAVAL ARCHITECTURE

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 GILMER P. 330

<table>
<thead>
<tr>
<th>WEIGHT (LT)</th>
<th>LOCATION (FT)</th>
<th>MOMENT (FT-TONS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>-250.00</td>
<td>-25,000</td>
</tr>
<tr>
<td>50</td>
<td>-175.00</td>
<td>-8,750</td>
</tr>
<tr>
<td>75</td>
<td>-50.00</td>
<td>-3,750</td>
</tr>
<tr>
<td>200</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>175</td>
<td>100.00</td>
<td>17,500</td>
</tr>
<tr>
<td>200</td>
<td>125.00</td>
<td>25,000</td>
</tr>
<tr>
<td>800</td>
<td></td>
<td>5,000</td>
</tr>
</tbody>
</table>

$$\text{LCG} = \frac{\text{MOMENT}}{\text{WEIGHT}} = \frac{5,000 \text{ FT-TONS}}{800 \text{ TONS}}$$

$$\therefore \text{LCG} = 6.25 \text{ FT (A)}$$

* F IS -, A IS +.
Problem 7

Find LCG and VCG - Ref Gillmer P330

<table>
<thead>
<tr>
<th>Weight (L.T.)</th>
<th>Longitudinal* Location (FT)</th>
<th>Longitudinal* Moment (FT-Tons)</th>
<th>Vertical** Location (FT)</th>
<th>Vertical** Moment (FT-Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.00</td>
<td>-220.00</td>
<td>-2,200.00</td>
<td>5.50</td>
<td>55.00</td>
</tr>
<tr>
<td>120.00</td>
<td>-200.00</td>
<td>-24,000.00</td>
<td>20.00</td>
<td>2,400.00</td>
</tr>
<tr>
<td>85.00</td>
<td>-150.00</td>
<td>-12,750.00</td>
<td>55.00</td>
<td>4,250.00</td>
</tr>
<tr>
<td>265.00</td>
<td>-22.00</td>
<td>-5,830.00</td>
<td>35.00</td>
<td>9,275.00</td>
</tr>
<tr>
<td>32.50</td>
<td>46.00</td>
<td>1,495.00</td>
<td>2.00</td>
<td>65.00</td>
</tr>
<tr>
<td>210.00</td>
<td>61.00</td>
<td>12,810.00</td>
<td>66.50</td>
<td>14,385.00</td>
</tr>
<tr>
<td>160.00</td>
<td>183.50</td>
<td>29,360.00</td>
<td>26.50</td>
<td>4,240.00</td>
</tr>
<tr>
<td>112.00</td>
<td>206.00</td>
<td>23,072.00</td>
<td>40.50</td>
<td>4,536.00</td>
</tr>
<tr>
<td>994.50</td>
<td></td>
<td>21,957.00</td>
<td>35,381.00</td>
<td></td>
</tr>
</tbody>
</table>

\[
\text{LCG} = \frac{\text{Long. Mom}}{\text{Weight}} = \frac{21,957 \text{ FT-Tons}}{994.50 \text{ L.T.}}
\]

\[
\text{LCG} = 22.08 \text{ FT (A)}
\]

\[
\text{VCG} = \frac{\text{Vett. Mom}}{\text{Weight}} = \frac{35,381 \text{ FT-Tons}}{994.50 \text{ L.T.}}
\]

\[
\text{VCG} = 35.58 \text{ FT ABV BL}
\]

\* F is - , A is + .

\** ABV BL is + .
**Problem 10**

**Given:**
\[ \Delta = 29,800 \text{ tons in S.W. of 35 ft}^3/\text{ton} \]
\[ T_m = 30' - 0" \]
\[ TP_1 = 95.8 \text{ tons/in at } T = 30' - 0" \]

**Find** \( T_m \) in F.W. of 36 ft\(^3\)/ton. - Ref Gilmer 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., \( \delta \), is
  \[ \delta = \frac{1.9903}{1.9383} = 1.027 \]
  \( \delta \) of F.W., \( \delta_1 \), is
  \[ \delta_1 = \frac{1.9383}{1.9383} = 1.000 \]
- Correspondingly, the density factor of S.W. is,
  \[ \frac{2,240 \text{ lbs/ton}}{(1.9903 \text{ lbs/sec}^2/\text{ft}^4)(32.17 \text{ ft/s}^2)} = 35 \text{ ft}^3/\text{ton} \]
- And the density factor of F.W. is,
  \[ \frac{2,240 \text{ lbs/ton}}{(1.9383 \text{ lbs/sec}^2/\text{ft}^4)(32.17 \text{ ft/s}^2)} = 36 \text{ ft}^3/\text{ton} \]
- Using density factors, specific gravity of a fluid can be calculated as
  \[ \delta = \frac{36 \text{ ft}^3/\text{ton}}{35 \text{ ft}^3/\text{ton}} = 1.027 \text{ for S.W.} \]
  \[ \delta_1 = \frac{36 \text{ ft}^3/\text{ton}}{36 \text{ ft}^3/\text{ton}} = 1.000 \text{ for F.W.} \]

For a given ship,
- Displacement in S.W. = Displacement in F.W.
  \[ \nabla_{\text{S.W.}} = (35) \Delta = \frac{(35)(36) \Delta}{(36)} = \frac{(36) \Delta}{(36/35)} = \frac{(36) \Delta}{\delta} \]
  \[ \nabla_{\text{F.W.}} = (36) \Delta = \frac{(36)(36) \Delta}{(36)} = \frac{(36) \Delta}{(36/36)} = \frac{(36) \Delta}{\delta_1} \]
  \[ d = \frac{36 \Delta}{35 \text{ TPI} \left[ \delta - \frac{1}{\delta} \right]} = \frac{36 (29,800 \text{ Tons})}{35 (95.8 \text{ Tons/in}) \left[ \frac{1}{\delta} - \frac{1}{36/35} \right]} = 8.89 \text{ in} \]
  \[ \therefore \frac{T_m}{12 \text{ in/ft}} = 30,000 \text{ ft} + \frac{8.89 \text{ in}}{12 \text{ in/ft}} = 30.74 \text{ ft} \]

9-135
**APPRAOCH:**

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 draft fore and aft)

![Diagram of waterplane](image)

**SOLUTION:**

**WEIGHT OF SHIP BEFORE**

= WEIGHT OF SHIP AFTER - 200 LT

WEIGHT BEFORE = 15,500 LT

VOLUME BEFORE = 15,500 x 35.0 \(\frac{ft^3}{ton}\) = 556,450 ft³

LESS F O BURNED = -200

WEIGHT AFTER = 15,300 LT

VOLUME AFTER = 15,300 x 35.0 \(\frac{ft^3}{ton}\) = 535,500 ft³

CHANGE IN VOLUME, \(\delta V\) = -20,950 ft³

CHANGE IN DRAFT, \(\delta T = \frac{\delta V}{A_{wp}} = \frac{-20,950}{21,760} ft^2\)

\(\delta T = .756 \text{ ft} = 9.06"\)

\(T_m_1 = 24' - 0"\)

\(\delta T = .9"\)

\(T_m_2 = 23' - 3"\)

**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:

\[ \text{Volume Before} = \text{Volume After} \]

Solution:

\[
\begin{align*}
\text{Weight Before} & = \Delta_1, \text{ LT} \\
\text{Volume Before} & = \Delta_1 \times \frac{2240 \text{ LB}}{63 \text{ LB/FT}^3} = \Delta_1 \times 35.56 \text{ FT}^3 \\
\text{Weight After} & = \Delta_1 + 175 \text{ LT} \\
\text{Volume After} & = (\Delta_1 + 175) \times 35.0 \text{ FT}^3
\end{align*}
\]

Then:

\[
35.56 \Delta_1 = 35.0 (\Delta_1 + 175)
\]

\[
35.56 \Delta_1 - 35.0 \Delta_1 = 35.0 \times 175
\]

\[
0.56 \Delta_1 = 6125
\]

\[
\Delta_1 = \frac{6125}{0.56}
\]

\[
\Delta_1 = 10,938 \text{ LT}.
\]
Unit Number: 10
Title: Dimension, form and flotation - 4
Tape Running Time: 42M 30S
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 symbols 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.


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

\[ y = \frac{1}{2} x^2 \]

\[ \text{SLOPE} = \frac{dy}{dx} = \frac{\text{RISE}}{\text{RUN}} \]
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)

SLOPE = \frac{\text{RISE}}{\text{RUN}}

y = \frac{1}{2} x^2

\text{TANGENT TO CURVE AT } x = 2, y = 2

\text{RISE} = 2 \text{ UNITS}

\text{RUN} = 1 \text{ UNIT}
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
\[ \int_{x=2}^{x=4} \frac{1}{2} x^2 \, dx = \left[ \frac{1}{2} \frac{x^3}{3} \right]_{x=2}^{x=4} = \left( \frac{1}{2} \frac{4^3}{3} \right) - \left( \frac{1}{2} \frac{2^3}{3} \right) = \frac{64}{6} - \frac{8}{6} = 6 \]
INTEGRATION (CON'T)

GRAPH OF THE FUNCTION $y = x$:

$y = x$

AREA UNDER $y=x$
FROM $x=2$ to $x=4$,
AREA = 6
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:

\[
\text{AREA} = h \left[ \frac{1}{2} Y_0 + \frac{1}{2} Y_1 \right]
\]
TRAPEZOIDAL RULE (CON'T)

CONSIDER SEVERAL TRAPEZIODS

FOR CONSTANT STATION SPACING, \( h \):

\[
\text{AREA} = h \left[ \frac{1}{2} Y_0 + \frac{1}{2} Y_1 \right] + \left( \frac{1}{2} Y_1 + \frac{1}{2} Y_2 \right) + \left( \frac{1}{2} Y_2 + \frac{1}{2} Y_3 \right) + \left( \frac{1}{2} Y_3 + \frac{1}{2} Y_4 \right)
\]

\[
\text{AREA} = h \left[ \frac{1}{2} Y_0 + Y_1 + Y_2 + Y_3 + \frac{1}{2} Y_4 \right]
\]
TRAPEZOIDAL RULE (CON'T)

FOR CONSTANT STATION SPACING, h AND

n ORDINATES FROM n=0 TO n=n,

\[
\text{AREA} = h \left[ \frac{1}{2} Y_0 + Y_1 + \ldots + Y_{n-1} + \frac{1}{2} Y_n \right]
\]

MULTIPLIERS:

\[
\frac{1}{2}, 1, 1, 1, \ldots, 1, 1, \frac{1}{2}
\]
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:

\[
\frac{1}{4} \rightarrow \frac{1}{4} \rightarrow \frac{1}{4} \rightarrow \frac{1}{4} \rightarrow \frac{1}{2} \rightarrow \frac{1}{2} \rightarrow \frac{1}{2} \rightarrow \frac{1}{2} \rightarrow \frac{1}{4} \rightarrow \frac{1}{4}
\]

MULTIPLIERS NOW CHANGE TO:

\[
\frac{1}{4} \rightarrow \frac{1}{2} \rightarrow \frac{1}{2} \rightarrow \frac{1}{2} \rightarrow \frac{3}{4} \rightarrow 1 \rightarrow 1 \rightarrow \frac{3}{4} \rightarrow \frac{1}{2} \rightarrow \frac{1}{4}
\]
SIMPSON'S (FIRST) RULE

REFERENCE: APPENDIX B OF MODERN SHIP DESIGN

THE AREA UNDER A SECOND ORDER (PARABOLIC) CURVE IS:

NOTE:
THREE ORDINATES

\[ \text{AREA} = \frac{h}{3} \left[ y_0 + 4y_1 + y_2 \right] \]

MULTIPLIERS: \[ \frac{h}{3} \left[ 1, 4, 1 \right] \]
CONSIDER SEVERAL SIMPSON'S INTERVALS

\[
\text{AREA} = \frac{h}{3} \left[ (y_0 + 4y_1 + y_2) + (y_2 + 4y_3 + y_4) + (y_4 + 4y_5 + y_6) \right]
\]

MULTIPLIERS: \[ \frac{1}{3}, 4, 2, 4, 2, 4, 1 \]
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

\[ \frac{h}{2} \quad \frac{h}{2} \quad h \quad h \quad h \quad \frac{h}{2} \quad \frac{h}{2} \]

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)

<table>
<thead>
<tr>
<th>STA</th>
<th>AREA FT²</th>
<th>SM</th>
<th>f(V)</th>
<th>LVR</th>
<th>f(LM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>½</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>½</td>
<td>65</td>
<td>2</td>
<td>130</td>
<td>4½</td>
<td>585</td>
</tr>
<tr>
<td>1</td>
<td>135</td>
<td>1½</td>
<td>202.5</td>
<td>4</td>
<td>810</td>
</tr>
<tr>
<td>2</td>
<td>290</td>
<td>4</td>
<td>1160</td>
<td>3</td>
<td>3480</td>
</tr>
<tr>
<td>3</td>
<td>405</td>
<td>2</td>
<td>810</td>
<td>2</td>
<td>1620</td>
</tr>
<tr>
<td>4</td>
<td>475</td>
<td>4</td>
<td>1900</td>
<td>1</td>
<td>1900</td>
</tr>
<tr>
<td>5</td>
<td>500</td>
<td>2</td>
<td>1000</td>
<td>0</td>
<td>8395 F</td>
</tr>
<tr>
<td>6</td>
<td>492</td>
<td>4</td>
<td>1968</td>
<td>1</td>
<td>1968</td>
</tr>
<tr>
<td>7</td>
<td>430</td>
<td>2</td>
<td>860</td>
<td>2</td>
<td>1720</td>
</tr>
<tr>
<td>8</td>
<td>283</td>
<td>4</td>
<td>1132</td>
<td>3</td>
<td>9396</td>
</tr>
<tr>
<td>9</td>
<td>133</td>
<td>1½</td>
<td>199.5</td>
<td>4</td>
<td>798</td>
</tr>
<tr>
<td>9½</td>
<td>70</td>
<td>2</td>
<td>140</td>
<td>4½</td>
<td>630</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>½</td>
<td>5</td>
<td>5</td>
<td>25</td>
</tr>
</tbody>
</table>

\[
\Sigma f(V) = 9507
\]

\[
S = 36.0 \text{ ft}
\]

\[
\nabla = \frac{36.0}{8} (9507) = 114,084 \text{ ft}^2
\]

\[
\Sigma f(LM) = 142 \text{ A}
\]

\[
\Delta = 3260 \text{ lt}
\]

\[
\text{LCB} = 36.0 \times \frac{142}{9507} \text{ A} = 0.54 \text{ ft A}
\]
SECTIONAL AREA CURVE @ DWL

396-FT OCEANOGRAPHIC SHIP

Loa = 396' - 0"  Cb = 528
Lpp = 360' - 0"  Cd = 1.633
B = 38' - 9"  Cm = 1.855
T = 15' - 6"  STATION
Δ = 3254 LT
COMPARISON OF INTEGRATION METHODS

ASSUME: SIMPSON'S RULE WITH 20 STATIONS AND 4 HALF STATIONS IS MOST ACCURATE

<table>
<thead>
<tr>
<th>Method</th>
<th>Δ</th>
<th>DIFF</th>
<th>LCB</th>
<th>DIFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simpson's (20 and 4)</td>
<td>3254</td>
<td>-</td>
<td>0.95'A</td>
<td>-</td>
</tr>
<tr>
<td>Simpson's (10 and 2)</td>
<td>3260</td>
<td>.18%</td>
<td>0.54'A</td>
<td>.11%</td>
</tr>
<tr>
<td>Trapezoidal (20 and 4)</td>
<td>3249</td>
<td>.15%</td>
<td>0.89'A</td>
<td>.02%</td>
</tr>
<tr>
<td>Trapezoidal (10 and 2)</td>
<td>3236</td>
<td>.55%</td>
<td>0.73'A</td>
<td>.06%</td>
</tr>
</tbody>
</table>
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 compute \( A_N \) 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.

<table>
<thead>
<tr>
<th>Station</th>
<th>Half-breadth</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 - 0 - 0</td>
</tr>
<tr>
<td>1</td>
<td>6 - 2 - 4</td>
</tr>
<tr>
<td>2</td>
<td>12 - 2 - 0</td>
</tr>
<tr>
<td>3</td>
<td>16 - 4 - 3</td>
</tr>
<tr>
<td>4</td>
<td>18 - 3 - 0</td>
</tr>
<tr>
<td>5</td>
<td>18 - 9 - 0</td>
</tr>
<tr>
<td>6</td>
<td>19 - 0 - 5</td>
</tr>
<tr>
<td>7</td>
<td>18 - 7 - 5</td>
</tr>
<tr>
<td>8</td>
<td>17 - 5 - 6</td>
</tr>
<tr>
<td>9</td>
<td>15 - 2 - 6</td>
</tr>
<tr>
<td>10</td>
<td>4 - 6 - 3</td>
</tr>
</tbody>
</table>
### Area of Waterplane

**Longitudinal Centroid of Waterplane (LCF)**

<table>
<thead>
<tr>
<th>Station</th>
<th>Half-Breadth</th>
<th>Simpson's Mult.</th>
<th>Functions of Half-Breadths</th>
<th>Lever Arm (Stations)</th>
<th>Functions of Long'1 Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP 0</td>
<td>1</td>
<td>5</td>
<td>F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>4</td>
<td>F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>2</td>
<td>F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>1</td>
<td>F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>0</td>
<td>Sum F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>1</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>2</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>3</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>4</td>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP 10</td>
<td>1</td>
<td>5</td>
<td>A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
f(A) = \sum A \\
\]

**Station Spacing** = \( s = \) 

**Total Area (both sides)** = \( 2 \times f(A) \times \frac{s}{3} = \) 

**Moment of Waterplane about** \( s^2 \) = \( 2 \times f(M) \times \frac{s^2}{3} = \) 

**Centroid of Waterplane about** \( f(M) \times s = \) \( f(A) = \) 

F or A
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 ft².

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:

<table>
<thead>
<tr>
<th>Height above W. P.</th>
<th>Tank W.P. Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom of Tank</td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>0.0</td>
</tr>
<tr>
<td>2.00</td>
<td>52.5</td>
</tr>
<tr>
<td>3.00</td>
<td>92.1</td>
</tr>
<tr>
<td>4.00</td>
<td>101.7</td>
</tr>
<tr>
<td>5.00</td>
<td>101.7</td>
</tr>
<tr>
<td>6.00</td>
<td>101.7</td>
</tr>
<tr>
<td>Top of Tank</td>
<td>101.7</td>
</tr>
</tbody>
</table>

Use the Trapezoidal Rule to calculate the molded capacity of the tank:

(a) \(\text{in ft}^3\)
(b) \(\text{in long tons}\)
(c) \(\text{in gallons}\)


**NOTES**

1. The table "Decimals of a Foot" in the appendix is a convenient way to convert feet-inches-eighths.

<table>
<thead>
<tr>
<th>STA</th>
<th>FEET-INCHES-EIGHTHS</th>
<th>DECIMAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0-0-0</td>
<td>0.000</td>
</tr>
<tr>
<td>1</td>
<td>6-2-4</td>
<td>6.203</td>
</tr>
<tr>
<td>2</td>
<td>12-2-0</td>
<td>12.167</td>
</tr>
<tr>
<td>3</td>
<td>16-4-3</td>
<td>16.365</td>
</tr>
<tr>
<td>4</td>
<td>18-3-0</td>
<td>18.250</td>
</tr>
<tr>
<td>5</td>
<td>18-9-0</td>
<td>18.750</td>
</tr>
<tr>
<td>6</td>
<td>19-0-5</td>
<td>19.052</td>
</tr>
<tr>
<td>7</td>
<td>18-7-5</td>
<td>18.552</td>
</tr>
<tr>
<td>8</td>
<td>17-5-6</td>
<td>17.479</td>
</tr>
<tr>
<td>9</td>
<td>15-2-6</td>
<td>15.229</td>
</tr>
<tr>
<td>10</td>
<td>4-6-3</td>
<td>4.531</td>
</tr>
</tbody>
</table>

(b) From pp 2

\[ A_w = 7,459.99 \text{ ft}^2 \]

\[ LCF = 12.67 \text{ ft at } x \]
### Area of Waterplane

**Longitudinal Centroid of Waterplane (LCF)**

<table>
<thead>
<tr>
<th>Station</th>
<th>Half-Breadth</th>
<th>Simpson's Mult.</th>
<th>Functions of Half-Breadths</th>
<th>Lever Arm (Stations)</th>
<th>Functions of Long'1 Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP 0</td>
<td>0.000</td>
<td>1</td>
<td>0.000</td>
<td>5</td>
<td>0.00 F</td>
</tr>
<tr>
<td>1</td>
<td>6.203</td>
<td>4</td>
<td>24.812</td>
<td>4</td>
<td>99.25 F</td>
</tr>
<tr>
<td>2</td>
<td>12.167</td>
<td>2</td>
<td>24.334</td>
<td>3</td>
<td>73.00 F</td>
</tr>
<tr>
<td>3</td>
<td>16.365</td>
<td>4</td>
<td>65.460</td>
<td>2</td>
<td>130.92 F</td>
</tr>
<tr>
<td>4</td>
<td>18.250</td>
<td>2</td>
<td>36.500</td>
<td>1</td>
<td>36.50 F</td>
</tr>
<tr>
<td>5</td>
<td>18.750</td>
<td>4</td>
<td>75.000</td>
<td>0</td>
<td>0.00 F</td>
</tr>
<tr>
<td>6</td>
<td>19.952</td>
<td>2</td>
<td>36.104</td>
<td>1</td>
<td>36.10 A</td>
</tr>
<tr>
<td>7</td>
<td>16.552</td>
<td>4</td>
<td>74.208</td>
<td>2</td>
<td>146.42 A</td>
</tr>
<tr>
<td>8</td>
<td>17.479</td>
<td>2</td>
<td>34.958</td>
<td>3</td>
<td>164.87 A</td>
</tr>
<tr>
<td>9</td>
<td>15.229</td>
<td>4</td>
<td>60.916</td>
<td>4</td>
<td>243.66 A</td>
</tr>
<tr>
<td>AP 10</td>
<td>4.531</td>
<td>1</td>
<td>4.531</td>
<td>5</td>
<td>22.66 A</td>
</tr>
</tbody>
</table>

$$f(A) = 438.823$$

Station Spacing = \( s = 25.50 \)

Total Area (both sides) = \( 2 \times f(A) \times \frac{s}{3} = 7459.99 \text{ ft}^2 \)

Moment of Waterplane about = \( 2 \times f(M) \times \frac{s^2}{3} = 94520.34 \text{ ft}^3 \)

Centroid of Waterplane about = \( \frac{f(M)}{f(A)} \times s = 12.67 \text{ ft or A} \)
<table>
<thead>
<tr>
<th>STA</th>
<th>AREA (BOTH SIDES) PT²</th>
<th>SM</th>
<th>FUNCTIONS OF VOLUME $f(V)$</th>
<th>LVR (STA)</th>
<th>FUNCTIONS OF LONG. YMT $f(LM)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>50</td>
<td>4</td>
<td>200</td>
<td>9</td>
<td>1800</td>
</tr>
<tr>
<td>2</td>
<td>115</td>
<td>2</td>
<td>230</td>
<td>8</td>
<td>1840</td>
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<td>340</td>
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<td>680</td>
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<td>4620</td>
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<td>2</td>
<td>840</td>
<td>2</td>
<td>1680</td>
</tr>
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<td>445</td>
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<td>1780</td>
<td>1</td>
<td>1780</td>
</tr>
<tr>
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<td>460</td>
<td>2</td>
<td>920</td>
<td>0</td>
<td>EF = 28,276</td>
</tr>
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<td>11</td>
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<td>8</td>
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<td>208</td>
<td>9</td>
<td>1872</td>
</tr>
<tr>
<td>20</td>
<td>5</td>
<td>1</td>
<td>50</td>
<td>10</td>
<td>50</td>
</tr>
</tbody>
</table>

$\Sigma f(V) = 16,261$

$Z_A = 27,914$

CONTINUED
\( \Xi A = 27.914 \)
\( \Xi' F = 28.776 \)

\( \Xi' f(v) = 16.281 \)
\( \Xi' f(LM) = 362 \text{ FWD} \)

**Station Spacing:**

\( s = \frac{400}{20} = 20.40 \text{ FT} \)

**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.):**

\[ \frac{\nabla}{35} = \frac{110,711}{35} \text{ FT}^3/\text{TON} \]

\[ \Delta = 3163 \text{ LT} \]

**Long. Ctr. of Buoy.:**

\( LCB = \frac{f(LM)}{f(v)} \times s \)

\[ = \frac{362}{16.281} \times 20.40 \]

\[ LCB = 0.46 \text{ FT FWD} \]

**Note:** The areas taken from Bonjeau's Curves include the shell plating, but do not include rudders, propellers, shafts, struts, rolling fins, and other appendages.

From the curves of Form

\[ \Delta = 3263 \text{ LT} \]

\[ LCB = 0.0 \text{ FT FWD} \]
<table>
<thead>
<tr>
<th>STA.</th>
<th>AREA $\text{FT}^2$</th>
<th>TM</th>
<th>$f(v)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>½</td>
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<td>7</td>
<td>101.7</td>
<td>$\frac{1}{2}$</td>
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</table>

$\sum f(v) = 500.55$

**Station spacing, $S$, = 1.00 FT.**

**Volume** = \(\sum f(v) \cdot S = 500.55 \times 1.00\)  \(\text{VOL} = 500.55 \text{ FT}^3\)

**The ballast tank will be filled with salt water at 35.0 FT$^3$/TON. Also 1 FT$^3$ = 7.48 GALS.**

**MID. CAPACITY OF TANK (at 100%)** = \(\frac{500.55}{35} = 14.30 \text{ LT}\)

= \(500.55 \times 7.48 = 3744 \text{ GALS.}\)

**RECAP: HOMOEO CAGNITY OF TANK**

(a) 500.55 FT$^3$
(b) 14.30 LT (SW)
(c) 3744 GALS.
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 $G_2$ 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. $G_2$ 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 $BM = I/\Delta$ 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
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-

$G_{M_L}$, $B_{M_L}$ AND $K_{M_L}$ 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

[Diagram of a boat showing the weight force, buoyant force, and the righting arm GZ]
STATIC STABILITY (CON'T)

RIGHTING MOMENT

THE RIGHTING MOMENT IS

\[ \text{RM} = \triangle \ GZ \]

\[ GZ \text{ IS DEFINED OVER THE FULL RANGE OF ANGLES OF INCLINATION, } \phi \]
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)

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-

\[ \triangle GG = w \cdot gg_1 \]

\[ GG_1 = \frac{w \cdot gg_1}{\triangle} \]
STATIC STABILITY (CON'T)

SHIFT OF WEIGHT ON BOARD

VERTICAL SHIFT: \[ G_{G_1} = \frac{wv}{\triangle} \]

LONGITUDINAL SHIFT: \[ G_{1G_2} = \frac{wl}{\triangle} \]

TRANSVERSE SHIFT: \[ G_{2G_3} = \frac{wt}{\triangle} \]
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 \( \theta = \text{TRIM ANGLE} \)
STATIC STABILITY (CON'T)

METACENTRIC RADIUS, $BM$

STUDENT SHOULD STUDY DERIVATION ON PP 57, MODERN SHIP DESIGN

THE IMPORTANT RESULTS ARE

$$BM = \frac{I}{\triangle} \quad \text{(TRANSVERSE)}$$

AND

$$BM_L = \frac{I_L}{\triangle} \quad \text{(LONGITUDINAL)}$$
STATIC STABILITY (CON'T)

METACENTRIC RADIUS, BM

\[ I = \text{TRANSVERSE MOMENT OF INERTIA OF WATERPLANE} \]

\[ I_L = \text{LONGITUDINAL MOMENT OF INERTIA OF WATERPLANE} \]

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:

\[ I = 2 \int_{0}^{L} \frac{r^3}{3} \, dx \]

THE 2 IS TO ACCOUNT FOR BOTH SIDES OF THE SHIP

THIS INTEGRATION IS DONE NUMERICALLY

SEE TABLE 3-1 IN MODERN SHIP DESIGN
\[
\frac{I_y}{I_x} = \frac{I_{xx}}{I_{yy}} = \frac{I_l}{I_l} = \frac{I_y}{I_y}
\]

**Moments of Inertia**

**Static Stability**

**Waterplane**
STATIC STABILITY (CON'T)

EXAMPLE

FIND GM OF RECTANGULAR BARGE IN SALT WATER

GIVEN

\[ L = 120' - 0'' \]
\[ B = 35' - 0'' \]
\[ T = 10' - 0'' \]
\[ KG = 6.00 \text{ FT ABOVE K} \]
STATIC STABILITY (CON'T)

EXAMPLE

1. **FIND $\Delta$ AND $\nabla$:**

   \[ \nabla = 120.0 \text{ ft} \times 35.0 \text{ ft} \times 10.0 \text{ ft} = 42,000 \text{ ft}^3 \]

   \[ \Delta = \frac{120.0 \text{ ft} \times 35.0 \text{ ft} \times 10.0 \text{ ft}}{35 \text{ ft}^3/\text{ton}} = 1,200 \text{ ton} \]

2. **FIND I:**

   \[ I = \frac{(35.0 \text{ ft})^3(120.0 \text{ ft})}{12} = 428,750 \text{ ft}^4 \]

3. **FIND BM:**

   \[ \text{BM} = \frac{I}{\nabla} = \frac{428,750 \text{ ft}^4}{42,000 \text{ ft}^3} = 10.21 \text{ ft} \]
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

\[
\begin{align*}
BM &= 10.21 \text{ ft} \\
\frac{KB}{KM} &= \frac{5.00 \text{ ft}}{15.21 \text{ ft}} \\
KM &= 15.21 \text{ ft} \\
KG &= 6.00 \text{ ft} \\
GM &= 9.21 \text{ ft}
\end{align*}
\]
Basic Naval Architecture

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 ft³/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)
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".

\[
\begin{align*}
\Delta & \quad \text{TPI} & \quad K_{M_t} \\
\Delta_{fW} & \quad \text{MTI} & \quad C_{B} \\
KB & \quad \text{CD1"TA} & \quad C_{P} \\
LCB & \quad \text{Wetted Surface, S} & \quad C_{M} \\
LCF & \quad K_{M_L} & \quad C_{WP}
\end{align*}
\]
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 C 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:

\[ T_f = 12' - 0" \]
\[ T_a = 13' - 6" \]
\[ KG = 19.50' \text{ above } B_L \]

Find the following:

Displacement
LCG
TPI
MTI
LCF
\( G'_t \)
BASIC NAVAL ARCHITECTURE

Problem 23

Problem Level: Basic

A rectangular barge has the following dimensions, drafts, and KG:

L \(_{pp}\) = 175'-0"

B = 35'-0"

Tf = 10'-0"

Ta = 10'-0"

KG = 8.00 ft above \(\Phi\)

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 \(\phi\))
(d) Transverse Metacentric Radius, \(BM_t\)
(e) \(KG\)
(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.
**Problem 25**

**Problem Level:** Basic

a) A rectangular barge has the dimensions shown below. Find $\triangle$, $\triangle_{FW}$, $KB$, $BM_t$, $KM_t$, $TPI$.

![Diagram of rectangular barge](image1)

b) The barge shown below has similar dimensions to that shown above, except that bow and stern rake have been added. Find the new $\triangle_{FW}$, $KB$, $KM_T$.

![Diagram of barge with bow and stern rake](image2)

c) If $KG = 8.00'$ above the keel, find $GM_T$ of the barge in (b) above.
(a) Decompose the figure into a rectangle and a triangle:

**Rectangle:**
- Area, \( A_1 = B \cdot l_1 = 30.0 \times 75.0' \)
- \( A_1 = 2250.0 \text{ ft}^2 \)
- Centroid, \( x_1 = \frac{l_1}{2} - 25.0' \)
- \( x_1 = 12.5' \) AFT X
- Moments of Inertia:
  - \( I_{xx1} = \frac{B^3 l_1}{12} = \frac{30.0^3 \times 75.0}{12} \)
  - \( I_{xx1} = 168,750 \text{ ft}^4 \)
  - \( I_{yy1} = \frac{B l_1^3}{12} = \frac{30.0 \times 75.0^3}{12} \)
- Centroid of D = \( \frac{1}{3} \times 25.0' = 8.3' \)
- \( I_{yy1} = 1,054,687.5 \text{ ft}^4 \)

**Triangle:**
- Area, \( A_2 = \frac{1}{2} B l_2 \)
- \( A_2 = 375.0 \text{ ft}^2 \)
- Centroid, \( x_2 = 25.0' + 8.3' \)
- \( x_2 = 33.3' \) AFT X
- Moments of Inertia:
  - \( I_{xx2} = 2 \left( \frac{B}{2} \right)^3 \frac{l_2}{12} = 2.15 \frac{3.0^3 \times 25.0}{12} \)
  - \( I_{xx2} = 14,062.5 \text{ ft}^4 \)
  - \( I_{yy2} = \frac{B l_2^3}{36} = \frac{30.0 \times 25.0^3}{36} \)
  - \( I_{yy2} = 13,020.8 \text{ ft}^4 \)

**Note on Axes:**
- Use 2 triangles
- For \( I_{xx} \), use formula for x-axis on base, \( \frac{B}{2} \) from center.
- Then, \( I_{xx} = 2 \left( \frac{B}{2} \right)^3 \frac{l_2}{12} \)
- For \( I_{yy} \), the axis is through the centroid, then
  - \( I_{yy} = \frac{B l_2^3}{36} \)

**Note:** Refer to "Properties of Geometric Section" in Appendix for formulas for areas, centroids, and moment of inertia.
Find centroid of combined areas, use tabular format

<table>
<thead>
<tr>
<th>ITEM</th>
<th>AREA $\text{ft}^2$</th>
<th>LVR $\text{ft}$</th>
<th>MOM $\text{ft}^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_1$</td>
<td>2250</td>
<td>+12.5</td>
<td>+281250</td>
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<tr>
<td>$A_2$</td>
<td>375</td>
<td>-38.3</td>
<td>-12487.5</td>
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<tr>
<td>$A_1 + A_2$</td>
<td>2625</td>
<td>+5.95</td>
<td>+15637.5</td>
</tr>
</tbody>
</table>

Centroid = $\frac{+15637.5}{2625} = +5.95$

Signs: $+$ = AFT $\times$

$-$ = FWD $\times$

The moments of inertia of each area, $I_{xx}$ and $I_{yy}$, 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

$I_{xx} = 168.750 \text{ft}^4 + 14.062.5 \text{ft}^4 = 182.812.5 \text{ft}^4$

For $I_{yy}$, moments of inertia for both the rectangle and the triangle must be transferred to the centroid of the combined area $5.95\text{ ft}$.
(a) (cont')

Then

\[ d_1 = 12.50' - 5.95' = 6.55' \]
\[ A_1 d_1^2 = 2250 \times 6.55^2 = 96,530.6 \text{ \text{ ft}^4 } \]
\[ I_{yy_1} = \text{(From PP 1)} = 1,054,687.5 \text{ \text{ ft}^4 } \]
\[ I_{yy_1} = I_{yy_1} + A_1 d_1^2 = 1,151,216.1 \text{ \text{ ft}^4 } \]

\[ d_2 = 33.3' + 5.95' = 39.25' \]
\[ A_2 d_2^2 = 375 \times 39.25^2 = 577,710.9 \text{ \text{ ft}^4 } \]
\[ I_{yy_2} = \text{(From PP 1)} = 13,020.8 \text{ \text{ ft}^4 } \]
\[ I_{yy_2} = I_{yy_2} + A_2 d_2^2 = 590,731.7 \text{ \text{ ft}^4 } \]

Finally

\[ I_{yy} = I_{yy_1} + I_{yy_2} = 1,151,216.1 + 590,731.7 \]
\[ I_{yy} = 1,741,949.8 \text{ \text{ ft}^4 } \]

(a) Recap:

\[ A = 2625 \text{ \text{ ft}^2 } \]
Centroid, \[ \bar{x} = 5.95 \text{ \text{ ft} \text{ aft} x } \]
\[ I_{xx} = 162,812.5 \text{ \text{ ft}^4 } \]
\[ I_{yy} = 1,741,949.8 \text{ \text{ ft}^4 } \]
(b) The solution to this problem will be worked by the tabular method. The triangular area A1 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 "Ac^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.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>AREA FT^2</th>
<th>LVE FT</th>
<th>MOM FT²</th>
<th>TRANS. LCOMX FT⁴</th>
<th>MOM' OF INERTIA</th>
<th>LONG'L MOM' OF INERTIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_1</td>
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<td>+17.50</td>
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<td>-86,343</td>
</tr>
</tbody>
</table>

\[ \sum (23.25) + 6.07 \sum (14.123) \sum 165,729 \sum (26,653) \sum 714,792 \sum 644,823 \]

\[ \Lambda = 23.25 \text{ ft}^2, \quad \chi = 6.07 \text{ ft} \]

\[ I_{xx} = 139,076 \text{ ft}^4 \]

\[ I_{yy} = 1,359,615 \text{ ft}^4 \]
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, \[ \nabla = 2325 \times 12.50 \text{ ft}^3 \]
\[ \nabla = 29063 \text{ ft}^3 \]
\[ \Delta = \frac{29063}{35} \text{ ft}^3/\text{ton} \]

(a) \[ \Delta = 830 \text{ LT} \]

(b) \[ \Delta_{fw} = \frac{29063}{36} \text{ ft}^3/\text{ton} \]

(b) \[ \Delta_{fw} = 807 \text{ LT} \]

(c) From 8(b) \[ A_{wp} = 2325 \text{ ft}^2 \]

(d) From 8(b) \[ LCF = 6.07 \text{ ft} A.B \]

(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.

\[ KB = 6.25 \text{ ft} A.B \]
\[ LCB = 6.07 \text{ ft} A.B \]

<table>
<thead>
<tr>
<th>ITEM</th>
<th>READING SCALE IN INCHES</th>
<th>VALUE</th>
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<td>KB</td>
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</tbody>
</table>
KEY RELATIONSHIPS:

1. \( BM_T = \frac{I_T}{V} \); \( BM_L = \frac{I_L}{V} \)

2. \( BM_T = KM_T - KB \); \( BM_L = KM_L - KB \)

3. \( TPI = \frac{A_{wp}}{420} \)

\( \therefore A_{wp} = 420 \cdot TPI \)

4. \( C_m = \frac{A_m}{BT} \)

\( \therefore A_m = C_m \cdot B \times T \)

SOLUTION:

\( KM_T = 20.08 \text{ ft A.K.} \)

\( KB = 8.13 \text{ ft A.K.} \)

\( KM_L = 502 \text{ ft A.K.} \)

\( KB = 8.13 \text{ ft A.K.} \)

\( BM_T = 11.95 \text{ ft} \)

\( BM_L = 493.87 \text{ ft} \)

\( \Delta = 1633 \text{ lt} \)

\( V = 1633 \times 35 \frac{\text{ft}^3}{\text{lt}} = 57,155 \text{ ft}^3 \)

\( I_T = 11.95 \times 57,155 \text{ ft}^4 \)

\( I_L = 493.87 \times 57,155 \text{ ft}^4 \)

\( I_T = 663,002 \text{ ft}^4 \)

\( I_L = 26,227,140 \text{ ft}^4 \)

\( A_{wp} = 420 \cdot TPI = 420 \times 17.60 \)

\( A_{wp} = 7392 \text{ ft}^2 \)

\( A_m = C_m \times B \times T = 0.760 \times 38.00 \times 13.60 \)

\( A_m = 375 \text{ ft}^2 \)
"BEAR" CLASS CUTTER

$T_f = 12' - 0''$

$T_o = 13' - 6''$

$T_m = 12' - 9'' = 12.75'$

$T_{trim} = 1' - 6'' = 18''$ BY STERN

$T_{m} = 12.75$, $\Delta_{o} = 1582$ LT (SW)

CDTA = 0.90 LT/INCH TRIM.

$\text{CORRECTION} = +0.90 \times 18'' = +16.2$ LT

$\Delta_{i} = 1598.2$ 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 $\Delta$.

The trim must be caused by a trimming moment ~

Trimming Moment $= MTI \times trim \text{ in inches}$

$MTI = 25.30 \times 20 = 506$ FT-FT/IN

$\text{Trimming Moment} = 506 \times 18'' = 9108$ FT-FT

The shift in the Center of Gravity will be ~

$\frac{G_o \Delta}{G_i \Delta} = \frac{\text{trim. Moment}}{\Delta}$

$G_o \Delta = \frac{9108}{1598} = 5.70$ FT AFT

Since LCG$_{o} = 1.35$ FT AFT $\Delta$

Then LCG$_{i} = \frac{5.70}{1.35} = 7.05$ FT AFT $\Delta$
FROM THE CURVES OF FORM

\[ \text{LCF} = 13.60 \text{ ft aft} \]

**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

\[ KM_b = 20.14 \text{ ft A.K.} \]

**GIVEN** \[ KG = 19.50 \text{ ft A.K.} \]

\[ GTM_T = 0.64 \text{ ft} \]
REF: GILLMER, pp 53-58

\[ L_{pp} = 175' - 0" \]
\[ B = 35' - 0" \]
\[ T = 10' - 0" \]
\[ KG = 8.00 \text{ a. d.} \]

(a) \[ \Delta = \frac{V}{35} = \frac{(175)(35)(10)}{35} \text{ ft}^3 \]
\[ V = 61,250 \text{ ft}^3 \]
\[ \Delta = 1,750 \text{ lb} \]

(b) \[ I_t = \frac{B^3 L}{12} = \frac{(35)^3(175)}{12} \text{ ft}^4 \]
\[ I_t = 625,260 \text{ ft}^4 \]

(c) \[ BM_t = \frac{I_t}{V} = \frac{(35)^3(175)}{(12)(175)(35)(10)} \text{ ft}^4 \]
\[ BM_t = 10.21 \text{ ft} \]

(e) Since the hull form is completely wall sided:
\[ KB = \frac{T}{2} = \frac{10.00}{2} \text{ ft} \]
\[ KB = 5.00 \text{ ft a. b.} \]

(f) \[ KM_t = KB + BM_t = 5.00 + 10.21 \]
\[ KM_t = 15.21 \text{ ft a. b.} \]

(g) \[ GM_t = KM_t - KG = 15.21 - 8.00 \]
\[ GM_t = 7.21 \text{ ft} \]
<table>
<thead>
<tr>
<th>STA</th>
<th>HALF-BREADTH, FT</th>
<th>CUBES OF HALF-BREADTHS, FT^3</th>
<th>TM</th>
<th>FUNCTIONS OF CUBES, f(I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.000</td>
<td>0.00</td>
<td>1/2</td>
<td>0.00</td>
</tr>
<tr>
<td>1</td>
<td>6.203</td>
<td>238.67</td>
<td>1</td>
<td>238.67</td>
</tr>
<tr>
<td>2</td>
<td>12.167</td>
<td>1801.15</td>
<td>1</td>
<td>1801.15</td>
</tr>
<tr>
<td>3</td>
<td>16.365</td>
<td>4382.76</td>
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</tr>
<tr>
<td>4</td>
<td>18.250</td>
<td>6078.39</td>
<td>1</td>
<td>6078.39</td>
</tr>
<tr>
<td>5</td>
<td>16.750</td>
<td>6591.80</td>
<td>1</td>
<td>6591.80</td>
</tr>
<tr>
<td>6</td>
<td>19.052</td>
<td>6915.47</td>
<td>1</td>
<td>6915.47</td>
</tr>
<tr>
<td>7</td>
<td>18.552</td>
<td>6385.17</td>
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<tr>
<td>8</td>
<td>17.479</td>
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<tr>
<td>9</td>
<td>15.229</td>
<td>3531.95</td>
<td>1</td>
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</tr>
<tr>
<td>10</td>
<td>4.531</td>
<td>93.02</td>
<td>1/2</td>
<td>46.51</td>
</tr>
</tbody>
</table>

\[ \sum f(I) = 41,311.97 \]

**STATION SPACING**, s = 25.50 FT.

\[ I_t = \frac{2}{3} \times s \times \sum f(I) = \frac{2}{3} \times 25.50 \times 41,311.97 \text{ FT}^4 \]

\[ I_t = 702,303 \text{ FT}^4 \]
(a) \[ \Delta = (140.0 \text{ ft})(36.0 \text{ ft})(10.0 \text{ ft}) = 50,400 \text{ ft}^3 \]
\[ \Delta = \frac{\Delta}{35} = \frac{(140.0)(36.0)(10.0) \text{ ft}^3}{(35 \text{ ft})^3/\text{ft}^3} \]
\[ \Delta_{fw} = \frac{\Delta}{36} = \frac{(140.0)(36.0)(10.0) \text{ ft}^3}{(36 \text{ ft})^3/\text{ft}^3} \]
\[ \Delta_{fw} = 1,440 \text{ ft}^3 \]

KB FOR WALL-SIDED BARGE = \[ \frac{T}{Z} = \frac{10 \text{ ft}}{2} = 5 \text{ ft} \]
KB = 5.00 ft

BM_t = \frac{I_1}{V} = \frac{B^3L}{12BLT} = \frac{3 \times 36^2 (140)}{(12)(36)(140)} \]
BM_t = 10.80 ft

KM_t = KB + BM_t = 5.00 + 10.80 = 15.80 ft

TPI = \frac{A_{wp}}{420} = \frac{(140)(36)}{420}
TPI = 12.0 \text{°/o}

(b) CALCULATE KB, USE TABULAR FORMAT.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>CALC’D</th>
<th>VCL</th>
<th>VCB</th>
<th>MOM’T.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RECT BARGE</td>
<td>140 x 36 x 10</td>
<td>50,400</td>
<td>5.00</td>
<td>252,000</td>
</tr>
<tr>
<td>EOTH END RAKES</td>
<td>2 x 1/2 x 10 x 10 x 36</td>
<td>- 3,600</td>
<td>3.33</td>
<td>- 11,988</td>
</tr>
<tr>
<td></td>
<td>46,800</td>
<td>5.13</td>
<td>240,012</td>
<td></td>
</tr>
</tbody>
</table>

\[ \Delta = \frac{46,800}{35} \text{ ft}^3/\text{ft}^3 \]
\[ \Delta = 1,337 \text{ ft}^3 \]

KB = 5.13 ft

BM_t = \frac{I_1}{V} = \frac{(36^3)(140)}{(12)(46,800)} = 11.63 ft

KM_t = 16.73 ft

KG = 8.00 ft

GM_t = 8.76 ft