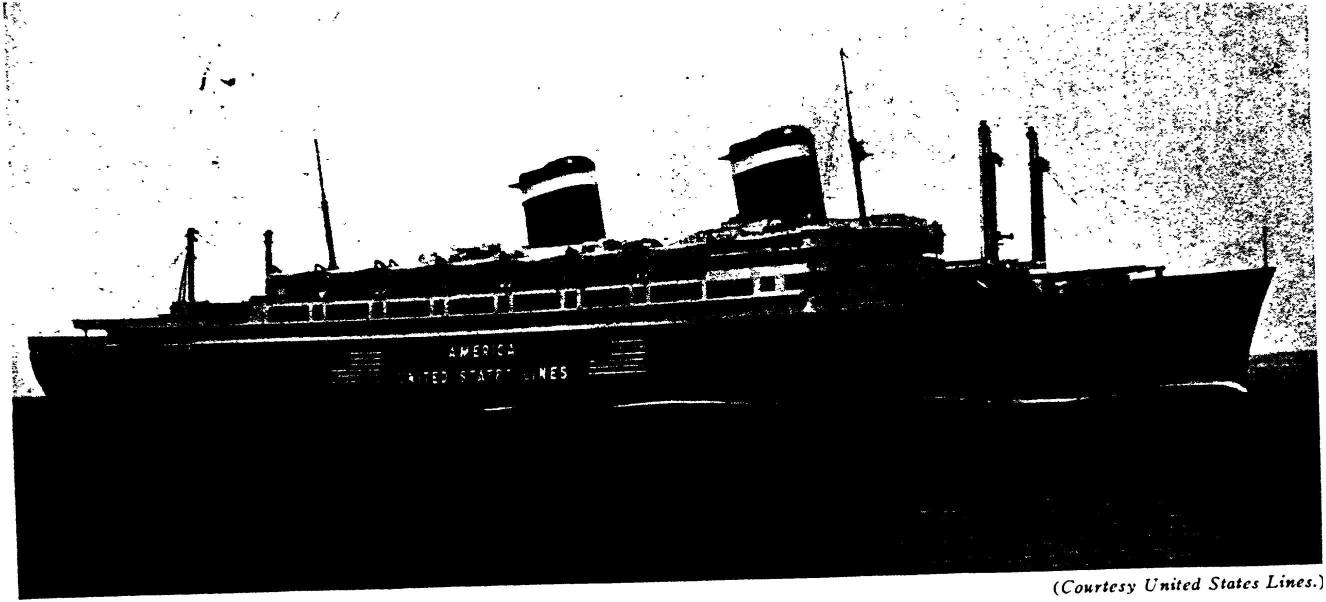

(*Courtesy United States Lines.*)

Frontispiece

PLATE A. Passenger vessel.

Principal Dimensions

Length overall	723 ft.	Net tonnage (approx.)	14,300	Service speed, designed	22 knots
Length between perpendiculars	660 ft. 6¾ in.	Shaft horsepower	34,000 tons	Passengers	1202
Breadth, molded	93 ft. 3 in.	Displacement (approx.)	35,400 tons	Officers and crew	639
Draft, loaded	32 ft. 6 in.	Bale cubic capacity including refrigeration (approx.)	293,500 cu. ft.		
Gross tonnage (approx.)	26,500 tons				

MANUAL OF
SHIP CONSTRUCTION

THE FUNDAMENTAL PRINCIPLES OF NAVAL ARCHITECTURE FOR THE OPERATING PERSONNEL OF THE MERCHANT SERVICE PARTICULARLY THOSE WHO ARE OR DESIRE TO BECOME OFFICERS.

by

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THIRD PRINTING

LONDON
CHAPMAN & HALL, LTD.
11 HENRIETTA STREET, W.C. 2

First Published December 1942
Reprinted, February 1943, June 1943

PRINTED IN THE UNITED STATES OF AMERICA

PREFACE

This book was written at the suggestion of the U. S. Maritime Commission for the instruction of cadets. The author hopes that this work will assist the serious student to improve his efficiency as a member of the operating personnel of the merchant marine. Questions covering the subject matter of the text are given at the end of each section. If a student finds that he cannot give a correct and complete answer to all of the questions at the end of a section, further study of the text is required. It is, of course, out of the question to reduce all parts of the subject to the same level of simplicity but particular attention has been given to the subjects with which students generally have the most trouble.

The effort has been made to treat the subject in such a way as to appeal to the practical operating officer for whom it has been prepared and to give him the fundamental principles. These if thoroughly learned will give him a correct basis for decisions in an emergency. It is also hoped that a study of the text will lead the student to a study of the ship on which he is serving. The author hopes in this way to contribute his mite to improving the safety of all those who " go down to the sea in ships."

In the preparation of the manuscript material assistance was received from Lieut. Peder Gald, U.S.N.R., Educational Assistant, Educational Unit, U. S. Merchant Marine Cadet Corps, U. S. Merchant Marine Academy, Kings Point, N. Y. and from Lieut. Comdr. Lauren S. McCready, U.S.M.S., now Lieutenant Commander, U.S.M.S., Senior Engineer Officer, U. S. Merchant Marine Academy, Kings Point, N. Y., who were good enough to read the first draft of the manuscript and to make numerous specific suggestions regarding improvements in the presentation.

The author also desires to express his appreciation to the individuals named for material used in the illustrations, from the sources indicated in each case.

Rear Admiral D. W. Taylor (C.C.) U. S. Navy (deceased) for Figs. 901, 902, 903 and 908 which were taken from *Speed and Power of Ships.*

The Society of Naval Architects and Marine Engineers and Messrs. John W. Hudson and T. M. Jackson for Figs. 225, 226 and 227, which were taken from the latters' paper, "Welding of Oil Tankers," in the Proceedings of the Society, Vol. 45. The above mentioned Society and Mr. Harold F. Norton for Fig. 524 which was taken from *Principles of Naval Architecture,* Vol. I, Chap. II. The foregoing Society and Dr. Karl E. Schoenherr for Figs. 705 to 710, inclusive, which were taken from *Principles of Naval Architecture,* Vol. II, Chap. IV. The Society for Fig. 801 which was taken from *Principles of Naval Architecture,* Vol. II, Chap. I.

The United States Naval Institute and Captain T. L. Schumacher, U. S. Navy, for Figs. 217, 218, 219, 220, 221, 231, 237, 319 and 321, which were taken from *Principles of Warship Construction and Damage Control.*

Marine Engineering for Figs. 202, 203, 213, 214, 216, 234, 301, 302, 303, 310, 311, 312, 313, 322, 323 and 324.

The *Nautical Gazette* for Figs. 209 and 316.

And most of all to Mr. John T. MacIsaac, Ensigns Richard S. Lovelace and Calvin S. Morser, the author's assistants at the Massachusetts Institute of Technology, who prepared most of the new illustrations.

GEORGE C. MANNING

August 1942
WINCHESTER, MASS.

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CHAPTER 1

SHIP LANGUAGE

A ship, boat, or vessel is a floating structure capable of motion. As such, it must be strong enough to support the loads it carries. The marked differences between the shape and arrangements of ships and fixed structures on shore are caused largely by the fact that ships do not rest solidly on the ground, but on the contrary float freely in the water. There is an entirely different set of words to designate the parts of a ship — ship terms. A lower deck in a ship, for example, is the same as a floor in a shore structure, but a floor in a ship has no relation to a floor in a house. It follows, therefore, that the first thing necessary in the study of ship architecture, is to learn the language.

In this chapter the most important ship terms are defined. Others are defined as we come to them and at the back of the book a complete list of these terms and their meanings are given. Failure to use these terms correctly or the use of a shore word for a ship term brands one as a " landlubber " on board ship. The true seaman is most particular in this respect.

Seagoing people never speak of the " front " end of a ship. The front of the ship is called the **bow** (rhymes with cow), or **forward end.** The structural member at the extreme forward end of the ship is called the **stem.** The back end of the ship is called the **stern** or **after part.** Anything which extends the full length of the ship is said to extend from stem to stern. The structural member at the extreme after end is called the **sternpost.** When one goes toward the bow, he is said **to go forward;** when he goes toward the stern, he **goes aft.**

The deck which forms the roof of the ship is called the **weather deck.** If a man on the weather deck goes down into the ship he **goes below** — not downstairs. If he goes to a higher deck, **he goes above** — not upstairs. If he climbs a mast **he goes aloft.** The horizontal partitions in a ship are called **decks,** the vertical partitions are called **bulkheads.** Openings in the deck are called **hatches.**

Fore and aft bulkheads are called **longitudinal bulkheads.** Bulkheads which extend across the ship are called **transverse bulkheads.** In general, the adjective **longitudinal** means fore and aft, and **transverse** means **athwartships** or crosswise.

The structural member which is in the middle of the bottom of the ship and extends from stem to stern is called the **keel.** The keel is the backbone of the ship. Extending athwartships from it on both sides, like ribs, are the **transverse frames.** The steel plates which form the skin of the ship compose the **shell plating.** Many ships have a second bottom about three feet above the outer shell. This is called the **inner bottom** or **tank top.** The space between is called the **double bottom** space. The space above the inner bottom (or bottom in single bottom ships) is called the **hold** or **lower hold.** The space between the lowest deck and that one next above is called the **lower 'tween deck space.** The space between the second and third decks from below is called the **upper 'tween deck space.** A structure at the extreme forward end of the ship above the highest complete deck is called a **forecastle,** pronounced like "foaksel." A similar structure at the extreme stern is called the **poop.** An elevated structure near the midlength is called a **bridge.**

The vertical plane which separates the ship into two equal halves is called the **centerline** plane. The transverse section midway between the stem and stern is called the **midship section** or **dead flat** and designated by the symbol ⊗. The right-hand half of the ship looking forward is called the **starboard** side; the left-hand side is called the **port** side.

A vertical line where the water touches the stem when a ship is floating at its designed position is called the **forward perpendicular.** A similar line where the water touches the sternpost is called the **after perpendicular.** The length of the ship measured between these two lines is called the **length between perpendiculars.** It will be seen that it is the length of the part of the ship which is below water. The length of the ship from the extreme point of the stem to the extreme point of the stern is called **length over all,** see Fig. 601. The width of the midship section at the waterline is called the ship's **breadth** or **beam,** see Fig. 419. The line on the side of the ship made by the surface of the water is called a **waterline.** When a ship floats at its designed waterline the vertical distance from the bottom of the ship to the waterline is called the **draft.** If the draft at the stem is more than that at the stern the ship is said to be **down by the head** or **trimmed by the head.** Similarly, if the draft aft is greater than the draft forward, the ship is **down by the stern** or **trimmed by the stern.** The mean or average of the draft forward and the draft aft is called the **mean draft.**

The **depth** of the ship is the vertical distance from the bottom to the highest complete deck at the side at the midship section, see Fig. 419. The vertical distance between the surface of the water and the edge of the highest complete deck at the side at the midship section is called the **freeboard.** The freeboard is therefore numerically equal to the difference between the depth and the draft. The highest complete deck is usually not flat but is higher at the centerline than at the edges and higher at the ends than at the midship section. The transverse curvature of the deck is called **camber,** see Fig. 419. The longitudinal curvature is called **sheer,** see Fig. 601. Numerically the camber is equal to the difference between the depth of the ship at the centerline and the depth at the side. The **sheer forward** is equal to the difference between the freeboard at the bow and the freeboard at the midship section. Similarly, the **sheer aft** is equal to the difference between the freeboard at the stern and that at the midship section.

The transverse frames which support the deck plating are called **deck beams,** see Fig. 201. Fore and aft rows of plating are called **strakes.** The ends of plates or planks are called **butts;** the edges, **seams.** The strake of shell plating next to the keel is called the **garboard strake;** that at the top of the side plating the **sheer strake.** The strake of deck plating which is farthest outboard is called the **deck stringer.** Plating above the level of the deck is called **bulwarks.** The section where the side joins the bottom is called the **bilge.** The strake of plating in this vicinity is called the **bilge strake.** Water in the bottom of a ship due to leakage is called **bilge water.** When a hole is made in a ship below the water, it is said to be **bilged.**

The size of the members forming the ship's structure are called its **scantlings.** If the scantlings are greater than required by the loads imposed, i.e., if the structure is stronger than it needs to be, it is said to have **redundant strength.** When one plate is fitted over another, either for the purpose of extra strength or protection, the plate on top is called a **doubling plate,** see Fig. 257. Vertical columns in a ship which support the decks are called **pillars** or **stanchions.** When a ship works in a seaway, the ends move up and down with reference to the midship section. When the ends are up the ship is said to be **sagged** or in **sagging condition.** When the ends are down the condition is called **hogging** and the ship is said to be **hogged,** see Figs. 248 to 251.

Openings in the side of a ship for light and air are called **side scuttles** or **air ports.** They correspond to the windows in a house.

The compartments at the extreme ends of the ship are called the **forward** and **after peak tanks.** They are generally used for ballasting the ship in case greater draft at either end becomes desirable. If the bottom of the midship section is not horizontal but slopes upward from keel to bilge, the ship is said to have **dead rise** or **rise of floor,** see Fig. 420.

Most ships are driven by a **screw propeller** (frequently called simply a propeller or " wheel "). The **propeller shaft** extends from the propelling machinery through the shell of the ship to the propeller. Where the shaft goes through the skin of the ship some device is required to prevent the leakage of water. This device is known as the **stern tube** and **gland.**

The size of ships is given by their **tonnage.** A **ton** may be either **2240 pounds** or **100 cubic feet,** depending on what kind of tonnage one is talking about. Displacement and deadweight are given in tons of 2240 pounds. Gross and net tonnage refer to tons of 100 cubic feet. These terms are discussed and explained more fully in the text.

There are many other ship terms which one must learn to be recognized as a member of the seagoing profession, but the addition to one's vocabulary of the words indicated in this chapter by bold-faced type will give a start to the learning of the rest.

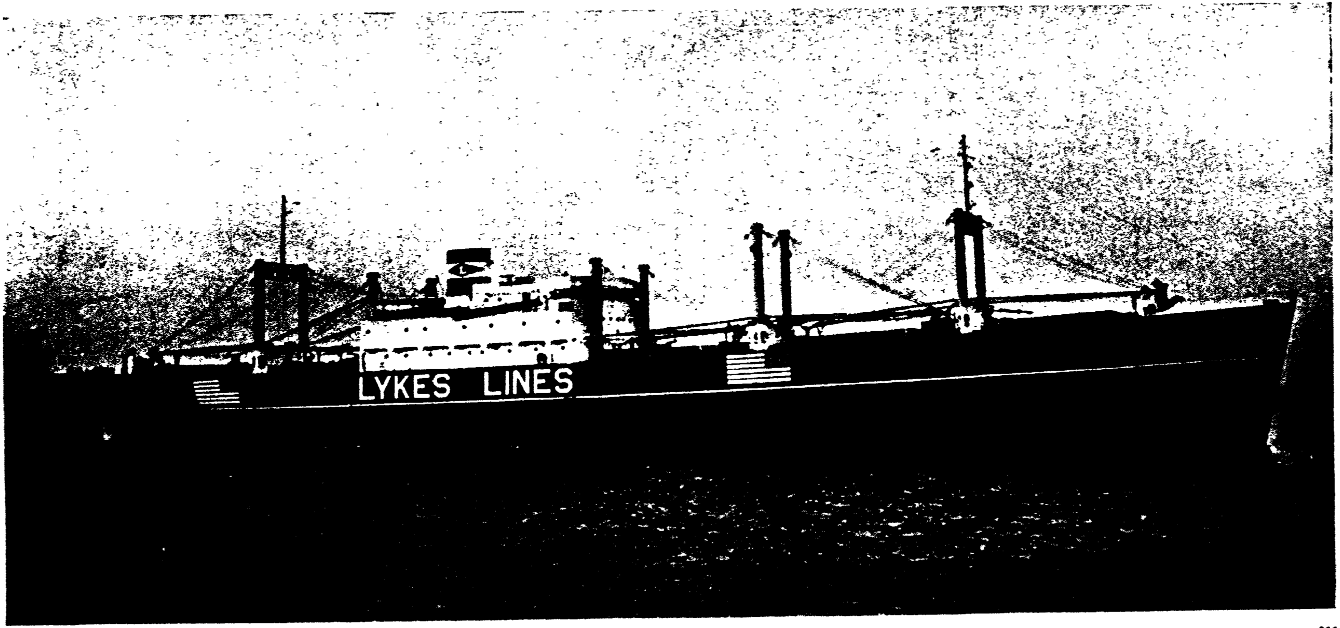


PLATE B. Cargo Vessel, C 1 Type. Suitable in all services not requiring excessive speed and for which large cargoes will not be continuously available.

PRINCIPAL DIMENSIONS

Length overall	417 ft. 9 in.	Gross tonnage (approx.)	6800 tons	Service speed	14 knots
Length between perpendiculars	395 ft.	Net tonnage (approx.)	4000 tons	Cruising radius (approx.)	16,600 miles
Breadth, molded	60 ft.	Shaft horsepower	4000	Passengers	4
Draft, loaded	27 ft. 6 in.	Displacement (approx.)	12,900 tons	Officers and crew	43
Deadweight	9290 tons	Bale cubic capacity (approx.)	447,700 cu. ft.		

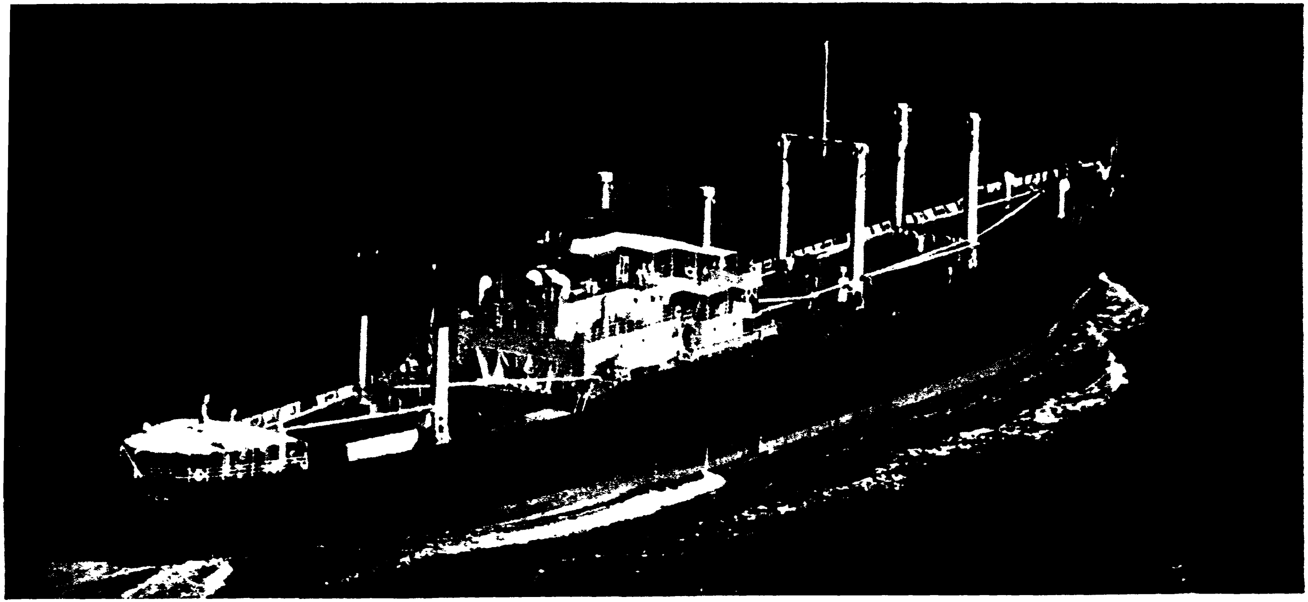


PLATE C. Cargo Vessel, C 2 Type. A balance of speed, cargo capacity, and economical operating characteristics have been attained in this type of vessel.

PRINCIPAL DIMENSIONS

Length overall	459 ft.	Gross tonnage (approx.)	6000 tons	Service speed	15½ knots
Length between perpendiculars	435 ft.	Net tonnage (approx.)	3600 tons	Cruising radius (approx.)	17,200 miles
Breadth, molded	63 ft.	Shaft horsepower	6000	Passengers	none
Draft, loaded	25 ft. 10 in.	Displacement (approx.)	13,900 tons	Officers and crew	41
Deadweight	9274 tons	Bale cubic capacity (approx.)	558,300 cu. ft.		

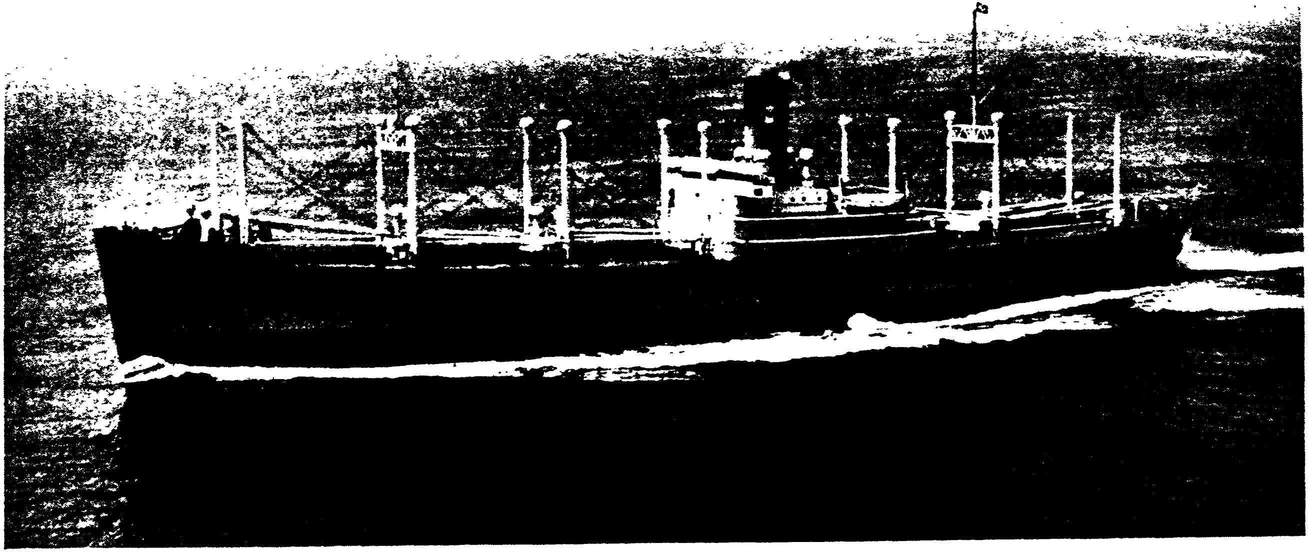


PLATE D. Cargo Vessel, C 3 Type. This design was made to satisfy the need for a vessel of greater deadweight cargo capacity and greater speed than the C 2 design.

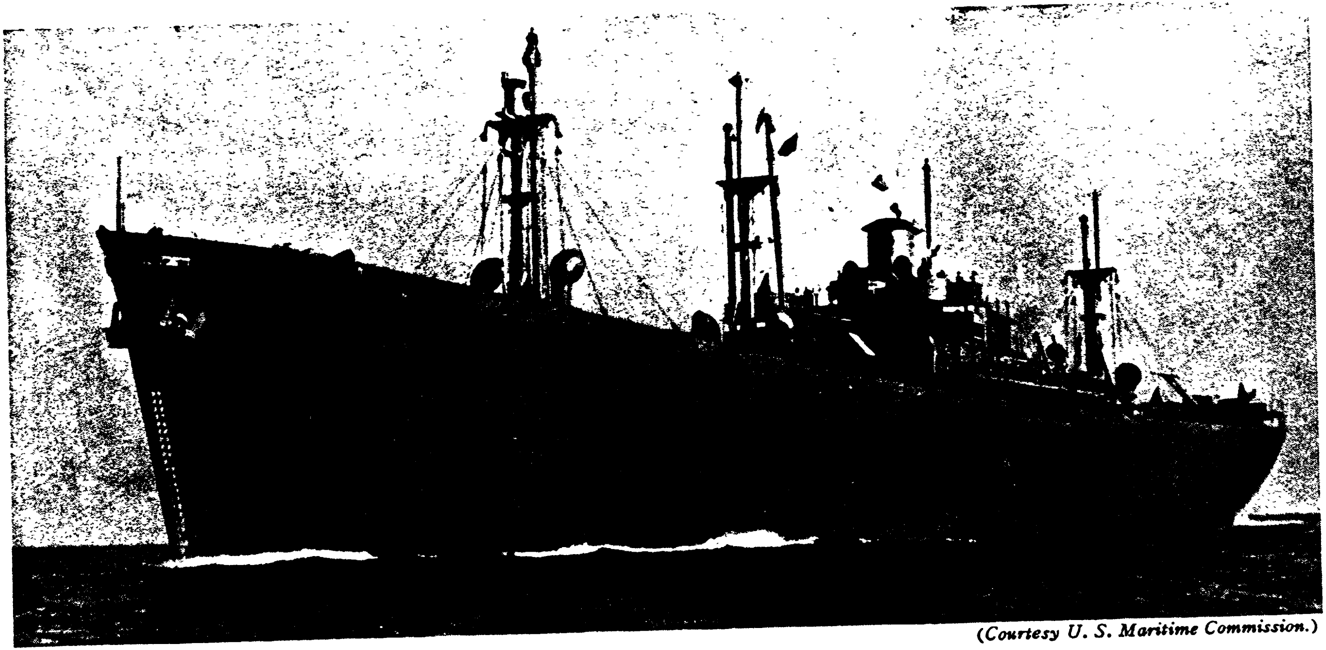
PRINCIPAL DIMENSIONS

Length overall	492 ft.	Gross tonnage (approx.)	7900 tons	Service speed	16½ knots
Length between perpendiculars	465 ft.	Net tonnage (approx.)	4700 tons	Cruising radius (approx.)	12,000 miles
Breadth, molded	69 ft. 6 in.	Shaft horsepower	8500	Passengers	12
Draft, loaded	28 ft. 7 in.	Displacement (approx.)	17,600 tons	Officers and crew	43
Deadweight	12,510 tons	Bale cubic capacity (approx.)	685,600 cu. ft.		

PLATE E. Combination Type, Cargo and Passenger Vessel, C 3 Type. This C 3 type was designed for the Round the World service of the American President Lines. Ship trimmed by the stern to keep propellers below water.

Principal Dimensions

Length overall	492 ft. 6 in.	Net tonnage (approx.)	5200 tons	Service speed	16½ knots
Breadth, molded	69 ft. 6 in.	Shaft horsepower	8500	Cruising radius (approx.)	20,300 miles
Draft, loaded	26 ft. 6 in.	Displacement (approx.)	16,200 tons	Passengers	96
Deadweight	9937 tons	Bale cubic capacity including refrigeration (approx.)	521,600 cu. ft.	Officers and crew	111
Gross tonnage (approx.)	9300 tons				



(*Courtesy U. S. Maritime Commission.*)

PLATE F. Liberty Ship.

Principal Dimensions

Length overall	441 ft. 6 in.	Deadweight	10,500 tons	Service speed	10 to 11 knots
Length between perpendiculars	416 ft.	Shaft horsepower	2500	Cruising radius (approx.)	17,000 miles
Breadth, molded	56 ft. 10¾ in.	Displacement (approx.)	14,100 tons	Officers and crew	54
Draft, loaded	27 ft. 8 in.	Bale cubic capacity (approx.)	500,200 cu. ft.		

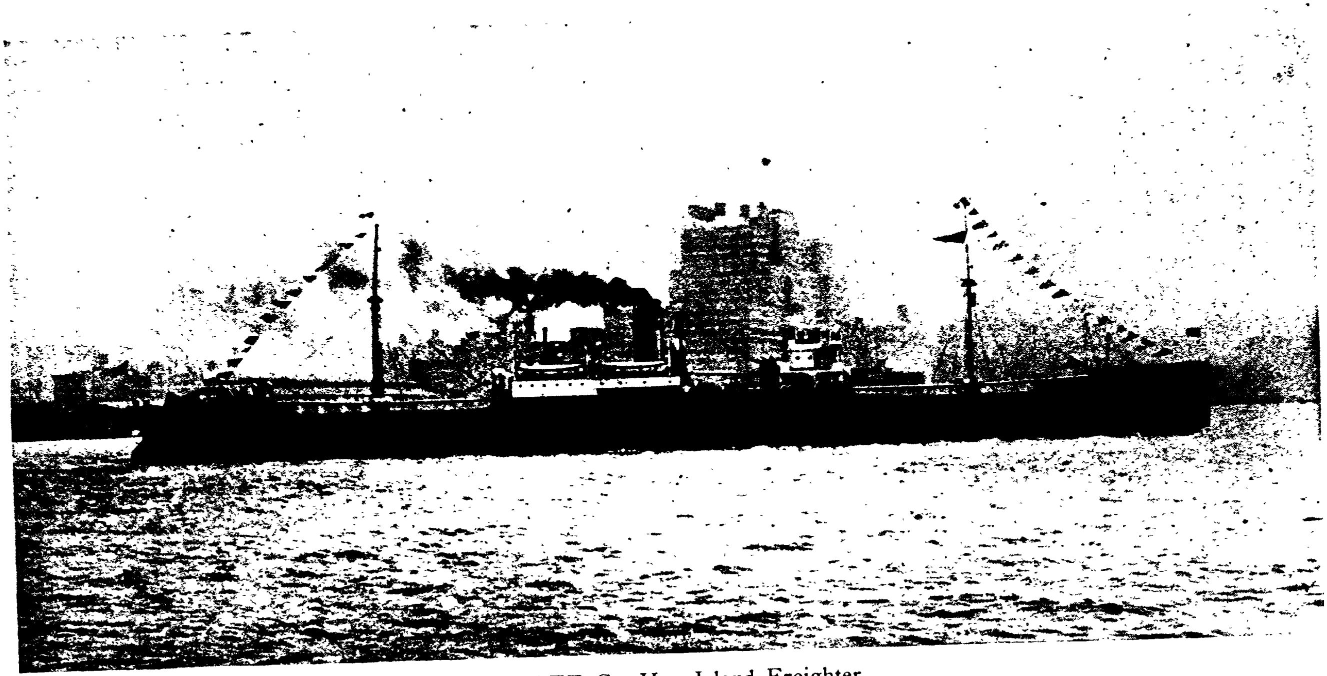


PLATE G. Hog Island Freighter.

Principal Dimensions

Length overall	401 ft.	Draft, loaded	27 ft. 6 in.	Net tonnage (approx.)	3453 tons
Length between perpendiculars	390 ft.	Cargo deadweight (approx.)	7500 tons	Officers and crew	41
Breadth, molded	54 ft.	Gross tonnage (approx.)	5590 tons		

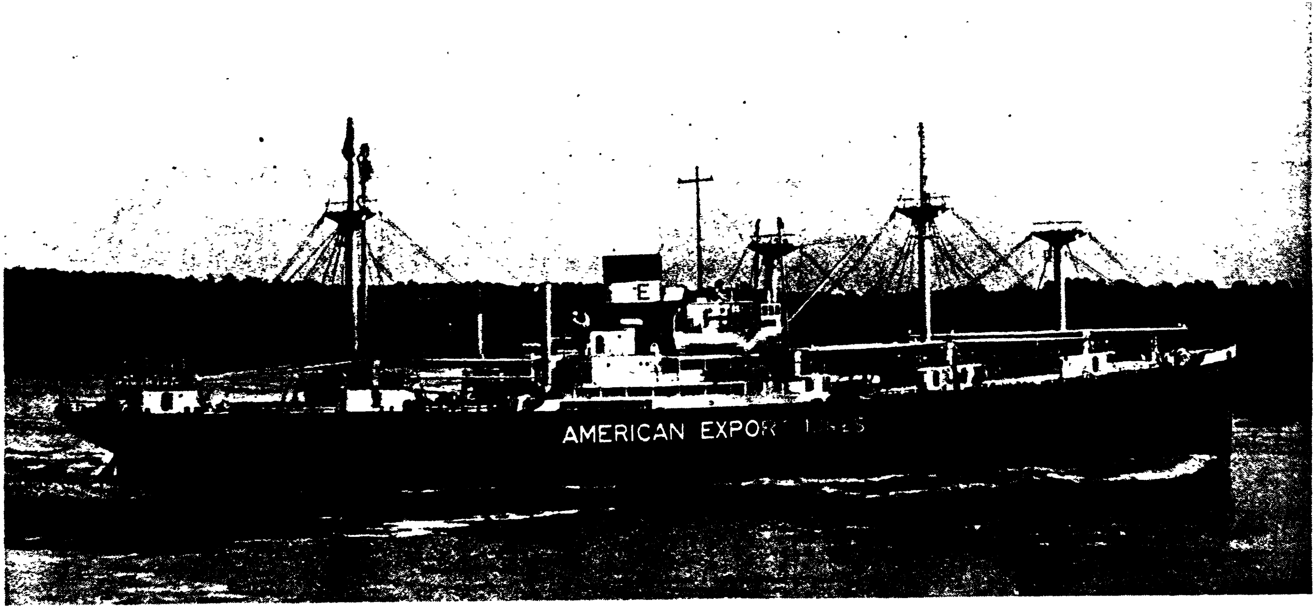


PLATE H. Cargo Vessel. This steamer illustrates the departure from the standard types, like the C 1, C 2, and C 3. In other words, ships of this type are being built to meet the requirements of a particular service, in this instance, the Mediterranean and Indian trade routes.

PRINCIPAL DIMENSIONS

Length overall	420 ft.	Deadweight	8150 tons	Bale cubic capacity (approx.)	396,400 cu. ft.
Length between perpendiculars	400 ft.	Gross tonnage (approx.)	6600 tons	Service speed	16½ knots
Breadth, molded	60 ft.	Shaft horsepower	7500	Cruising radius (approx.)	14,600 miles
Draft, loaded	27 ft. 7 in.	Displacement (approx.)	12,000 tons		

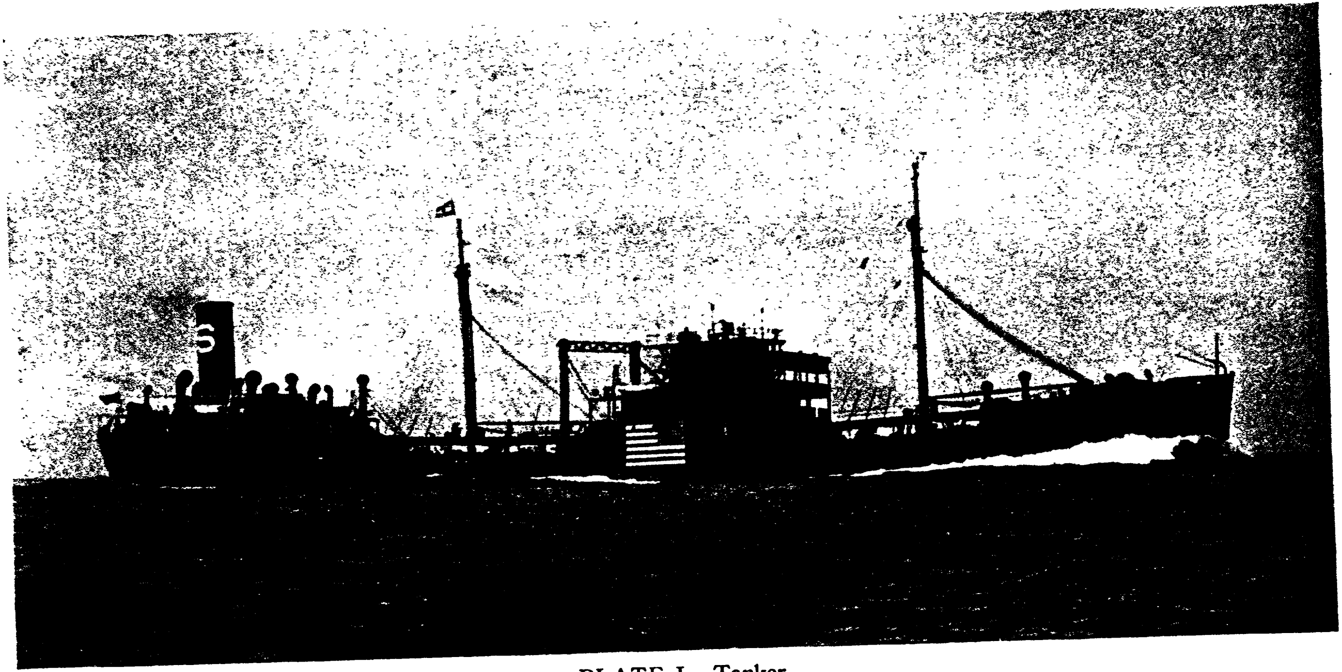


PLATE J. Tanker.

Principal Dimensions

Length overall	501 ft. 7½ in.	Deadweight	15,910 tons	Service speed	16½ knots
Length between perpendiculars	488 ft. 6 in.	Shaft horsepower	9600	Cruising radius (approx.)	9000 miles
Breadth, molded	68 ft.	Displacement (approx.)	21,000 tons	Officers and crew	65
Draft, loaded	29 ft. 8½ in.	Tank capacity	132,609 barrels		

CHAPTER 2

SHIP STRUCTURE

201. Structural members of a hull. A ship is many things to many people, but to the naval architect, it is before everything else a structure. It differs from structures on land in many respects. In the first place it is mobile and in the second place it has for its support, not the solid foundations of a shore structure, but the fluid pressure of the water on its bottom. These two facts lead to major differences in the structural arrangements of ships and fixed structures ashore.

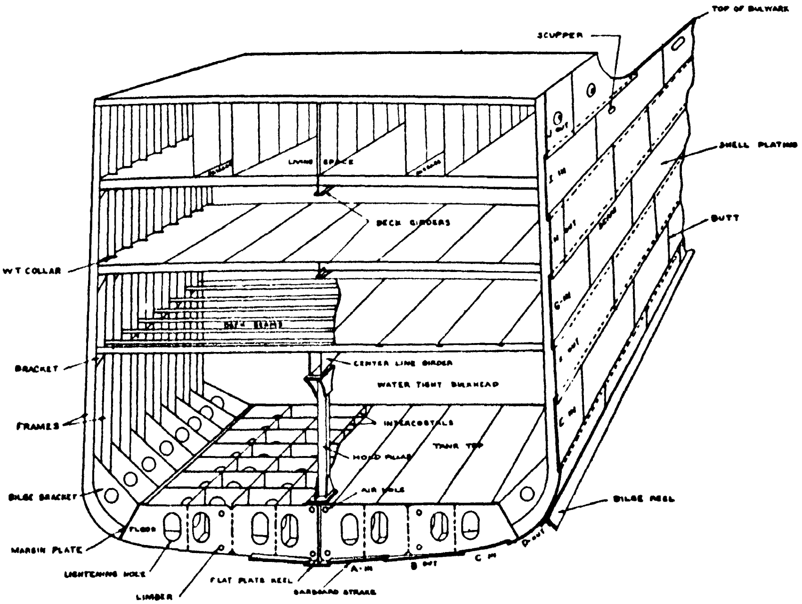


FIG. 201. Ship Structure

The structural members of a hull are the framing, including the stem and sternpost, the shell and inner bottom plating, bulkheads and decks. See Fig. 201. Each of these is discussed in some detail in this chapter. The framing is the skeleton to which the shell plating is attached. In appearance and function it is not unlike the framework of a large hotel or office building. The shell plating must exclude the water, but it is also a very important member of the hull structure, contributing materially to its strength. The shell plating forms three sides of the hull; the top or fourth side is formed by the deck. Structurally the deck is a continuation of the shell. The bulkheads and intermediate decks act as webs to stiffen the entire hull structure, which otherwise would be too flexible.

Structural members should be just as big as necessary to withstand the stresses to which they are subjected in service, and no bigger. The cost of a hull structure for a given type of ship is directly proportional to its weight. The initial cost of a properly designed hull is therefore less than one which is unnecessarily strong and heavy. Excess hull weight also reduces the paying deadweight on a given displacement and thus constitutes a tax on the owners and operators during the entire lifetime of the ship. Inadequate strength is likely to lead to failure of the structure and the loss of the ship. From the foregoing, it is apparent that the choice of the sizes of structural members requires the use of careful judgment founded on study and experience.

The form of structural members as distinguished from their strength is influenced by economic as well as technical considerations. The necessary strength may be obtained in a wide variety of ways. The particular type of construction to be adopted should be that of least total cost. This will not be the same in shipyards in different localities owing to many differences, including those in wage rates, efficiency of labor, cost of material and transportation. These are problems for the individual shipbuilder and account in large measure for differences in methods in various yards. It is impracticable in this discussion to do more than to invite attention to the material nature of economic considerations in ship construction and operation. The complete study of these constitutes a wide field in itself, but correct decision cannot be made without knowledge of the economic as well as the technical factors involved.

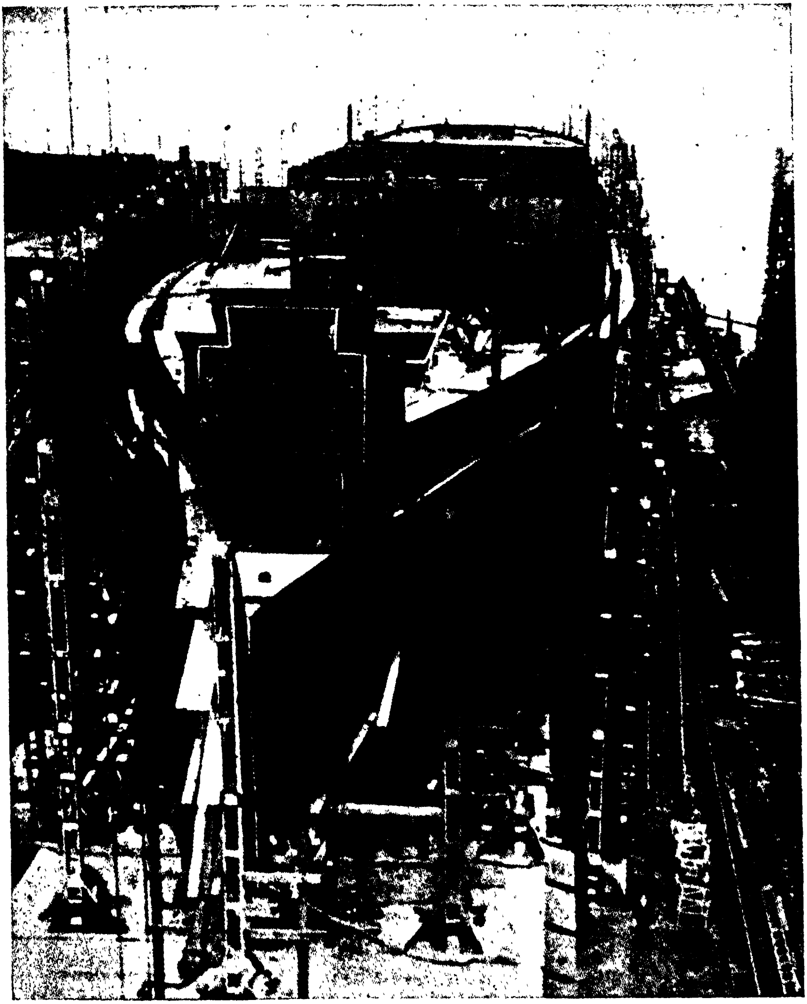


Fig. 202. Ship Structure

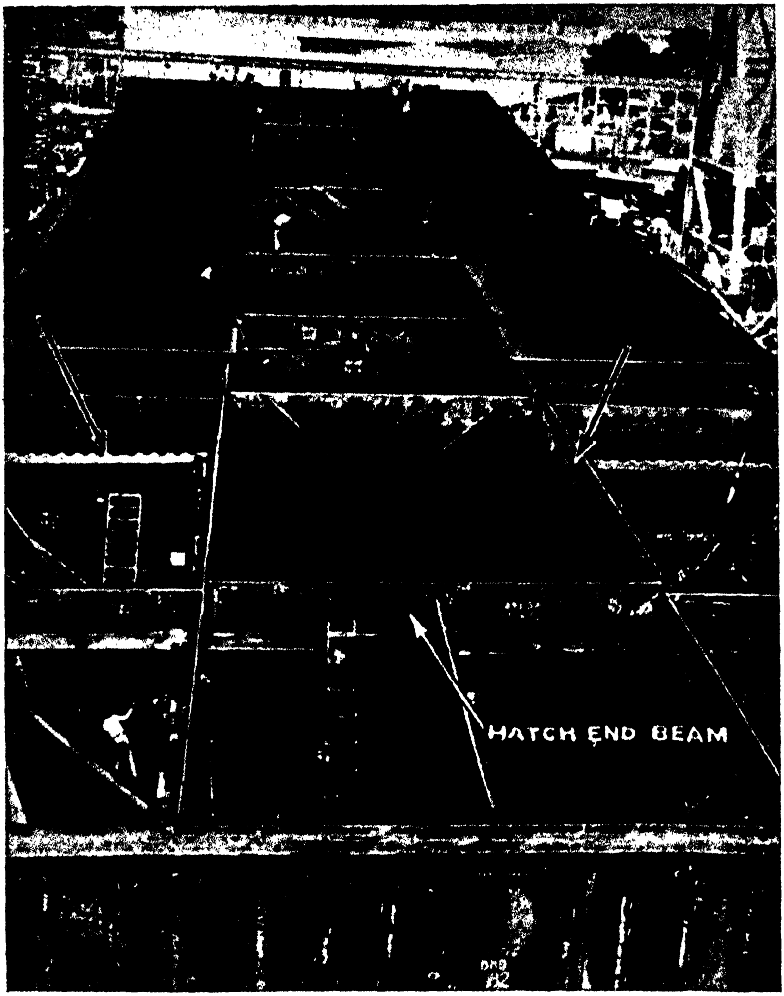


Fig. 203. Ship Structure

Section 21. Framing. *Arts.:* 211. Functions of framing. 212. Framing systems. 213. Keel structure. 214. Structure of frames. 215. Stem. 216. Sternpost.

211. Functions of framing. The most important function of the framing is to stiffen the shell plating and compel it to retain its proper form against the pressure of the water outside. The shell plating alone is somewhat flexible and were it not for the support of the framing, would collapse. The framing also transfers weights from the deck to the bottom structure, where they are neutralized by the ship's buoyancy. In the double bottom space, some of the frames form partitions between the individual tanks.

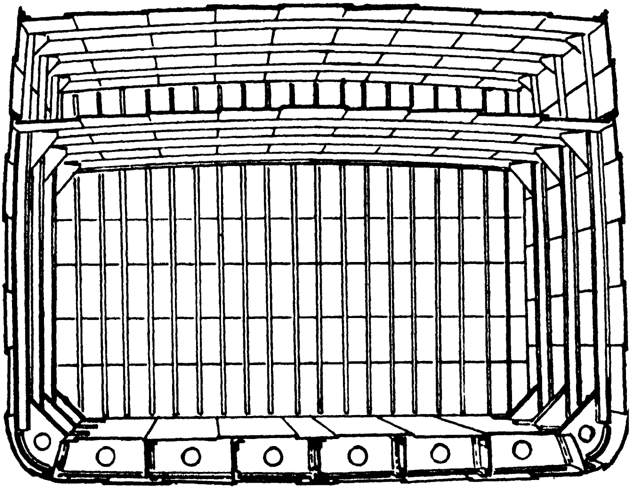


Fig. 204. Transverse Framing System

212. Framing systems. A ship may be built around any one of several different types of framing. These systems are illustrated in Figs. 204, 205 and 206 and defined below. Any system of ship framing consists basically of members at right angles to each other. Where these members meet, one may continue through but the other must be interrupted. The member which continues through is called a **continuous** member; the one which is interrupted to fit between the continuous members is said to be **intercostal.** This term was originally an anatomical word, meaning between the ribs and was applied to ship frames because of their similarity to ribs in the body. The rigidity of an intercostal girder is much less than that of a continuous one, no matter how much care is taken to secure a good connection. The most important frames of a ship are therefore made continuous.

The three framing systems in current use are called the **transverse, web,** and **Isherwood** systems. These are illustrated in Figs. 204, 205 and 206, respectively.

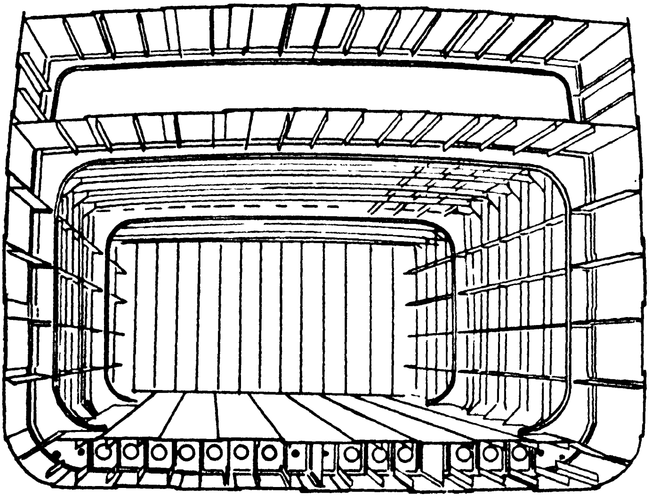


Fig. 205. Web Framing System

The transverse system of framing consists of a large number of closely spaced continuous transverse frames, usually referred to simply as frames and a much smaller number of more widely spaced longitudinal frames called **intercostal keelsons** and **side stringers.** The web system of framing consists of heavy plate web frames spaced about six ordinary frame spaces with continuous light frames between them and heavy intercostal longitudinal frames called **stringers.** The Isherwood system, which is patented, consists of a large number of closely spaced continuous **longitudinals** and more widely spaced, deeper frames, called **transverses.** The latter are continuous also except where notched out next to the shell plating to permit the longitudinals to pass through.

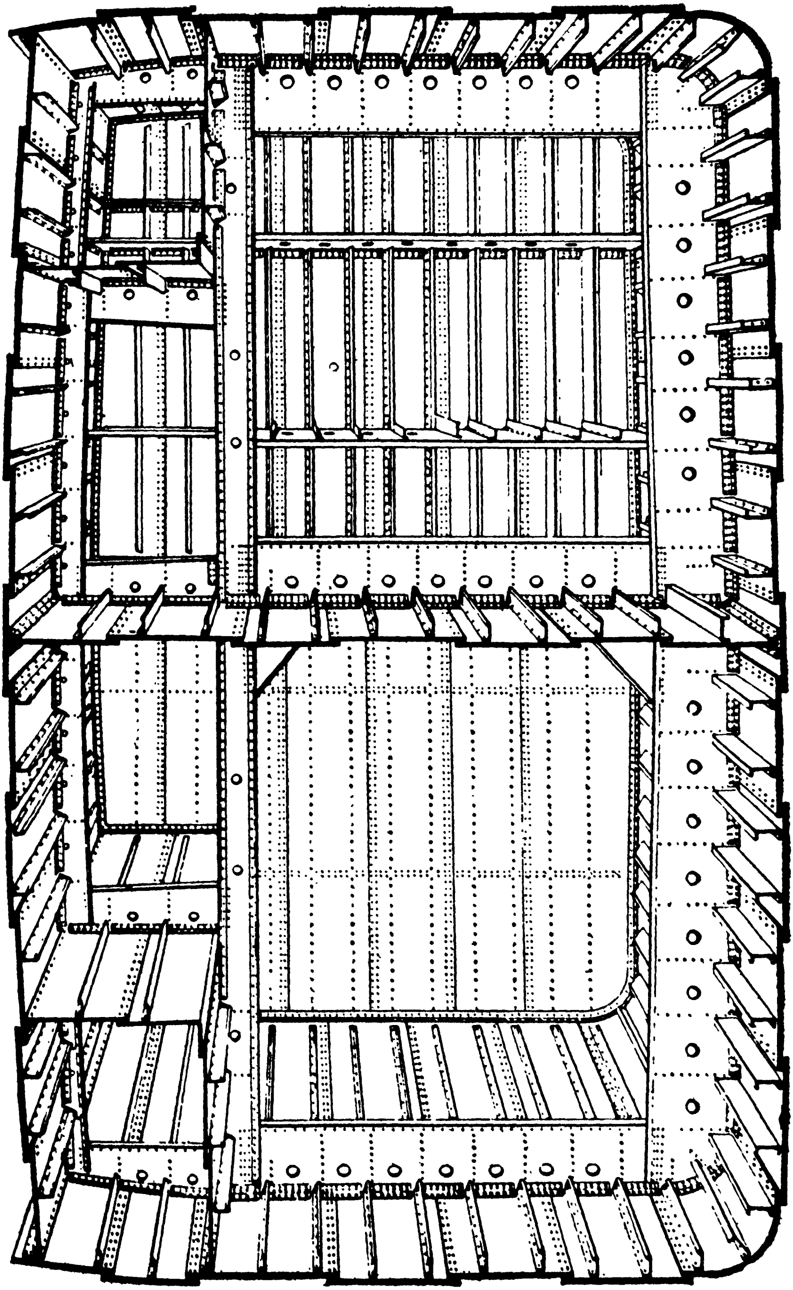


FIG. 206. Isherwood System of Framing

213. Keel structure. The most important frame on any ship is the centerline longitudinal, known as the **keel.** Fig. 207 shows the usual type of keel construction for all classes of ships. The angles against the shell and inner bottom plating are both double, i.e., on both sides of the **vertical keel** which is a solid plate. The **flat keel plate** and centerline strake of the inner bottom plating are usually considered as part of the keel structure. Sometimes ships have a bar keel below the flat keel plate and secured to the latter by double angles on the outside. **All members of the keel structure are continuous from stem to sternpost.**

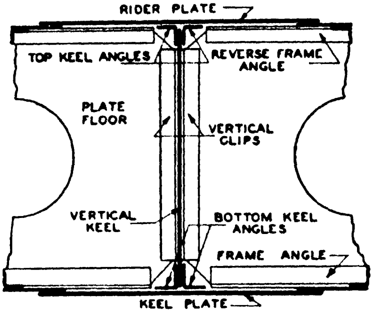


FIG. 207. Keel Structure

214. Structure of frames. Frames may be formed of a simple rolled bar, known as a **shape,** such as the angle, Z-bar, channel, I-beam or T-bar, illustrated in Fig. 208, or they may be built up of plate and angles. The simple rolled shapes are used for side framing; built-up frames are found in the bottom structure. Z-bars, channels, T-bars and I-beams are used up to the strength deck. Light framing above the strength deck is usually formed of angles which are also extensively used for deck beams. Z-bars are used in riveted work where the web is too shallow to permit holding on.

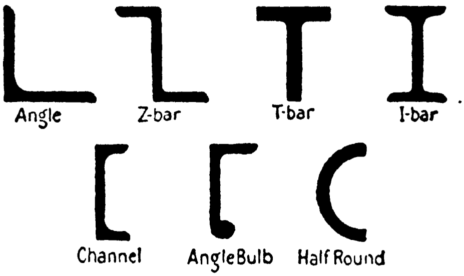


FIG. 208. Shipbuilding Shapes

A **built-up frame** usually consists of a plate standing at right angles to the shell plating with an angle connecting it to the shell and another making the other flange. The angle connecting to the shell is known as the **frame bar,** the other angle is the **reverse bar** and the plate is a **floor;** see Fig. 210. The floor may be formed of a number of small rectangular plates called **brackets.** This is the

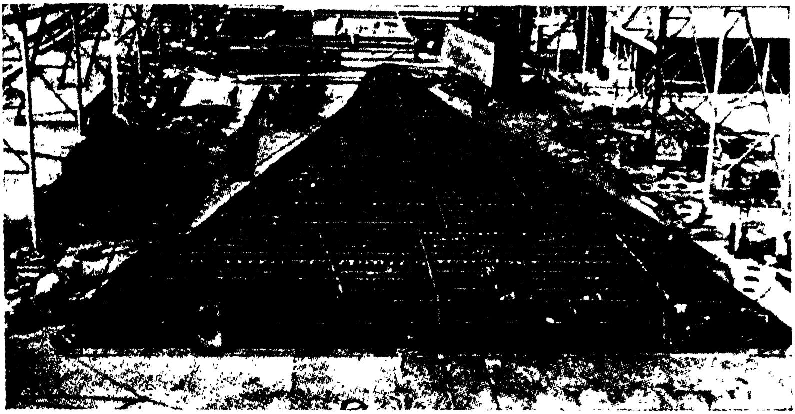


Fig. 209. Bottom Structure

cheapest kind of construction and therefore used whenever permitted by the rules of construction. Most floors have large holes for access to the various cells or pockets. These holes are called **lightening holes.** Where the frame serves as the boundary of a tank or where there are load concentrations, the floor is formed of a solid plate. This is the heaviest and most expensive type of floor.

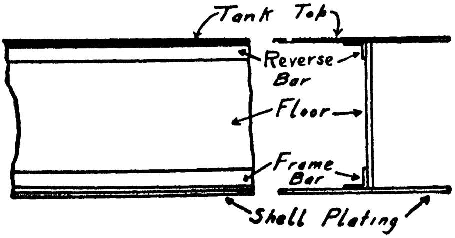


Fig. 210. Built-up Frame

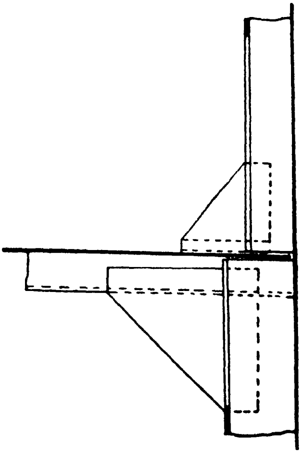


Fig. 211. Bracket

When there is a change in the size of a frame, a bracket should be fitted as shown in Fig. 211 to prevent concentration of stress which always occurs when there is an abrupt change in the size of a structural member. The longitudinals in the bottom, which are also called

side keelsons or intercostal girders, are of the built-up type. They are intercostal between the transverse frames, but may be given a measure of continuity by continuous upper angles. The longitudinals above the turn of the bilge, called **side stringers,** are of the built-up type, similar in construction to those in the bottom but of less depth. In ships having a double bottom, the tank extends to the turn of the bilge where it is terminated by a **margin plate,** which is a continuous watertight longitudinal, see Fig. 201. Frames both transverse and longitudinal are more closely spaced in the ends, particularly forward, see Figs. 214 and 216.

Web frames are built-up frames similar to those in the double bottom space of a ship framed on the transverse system. The web frames are continuous to the strength deck. The floors may be solid or bracket type, but when of the latter type, they must be stiffened at the edge to prevent buckling under load. The frames between web frames are simple one-piece frames, usually angles, continuous from keel to strength deck. The side stringers are built-up longitudinal frames against the side plating. They are intercostal between web frames and notched out for the intermediate light frames.

Sir Joseph Isherwood developed and patented a longitudinal system of framing ships. This system of framing is now accepted by the maritime authorities as equal in strength to the transverse system of. framing. It is used almost exclusively for tankers, and to a certain extent for other bulk carriers and general cargo ships. This system of framing is shown in Fig. 206. The longitudinals are of the one-piece type, usually channels. They are continuous through the transverses, the floors of which are cut out to allow the longitudinals to pass through. The longitudinals are interrupted at the transverse bulkheads. Their continuity is provided for at this location by brackets or other reinforcement. The transverses are of the built-up type. They have more stiffness than the longitudinals because of their greater depth.

215. Stem. The stem is usually a forged steel bar. It is one of the end members of the ship structure and the other structural members which extend to the extreme ends of the ship must be well secured to it. As shown in Fig. 212, the stem is recessed along its after edge to receive the shell plating so that the outside will present a smooth surface to cut through the water. This recess is called a **rabbet.** The keel structure is securely fastened to the lower end of the stem by

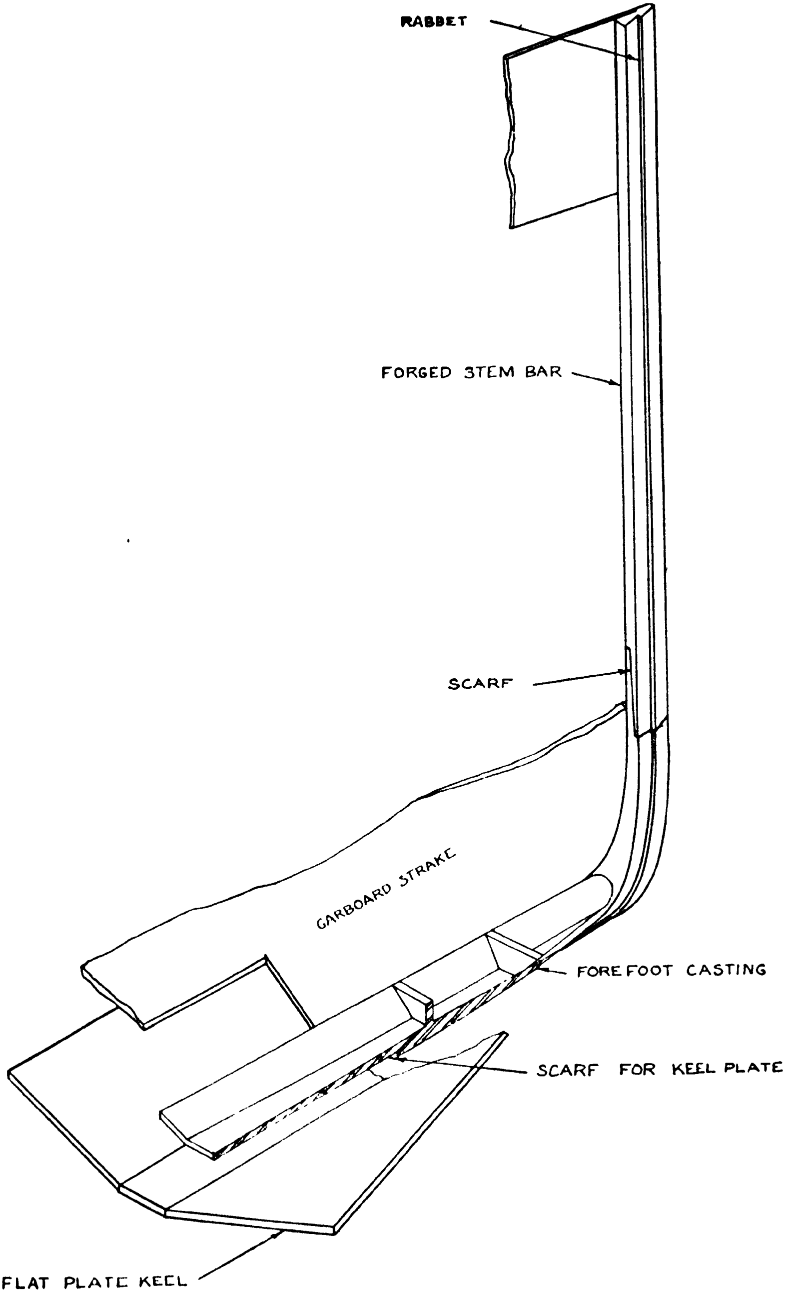

RABBET
FORGED STEM BAR
SCARF
GARBOARD STRAKE
FORE FOOT CASTING
SCARF FOR KEEL PLATE
FLAT PLATE KEEL

Fig. 212. Stem

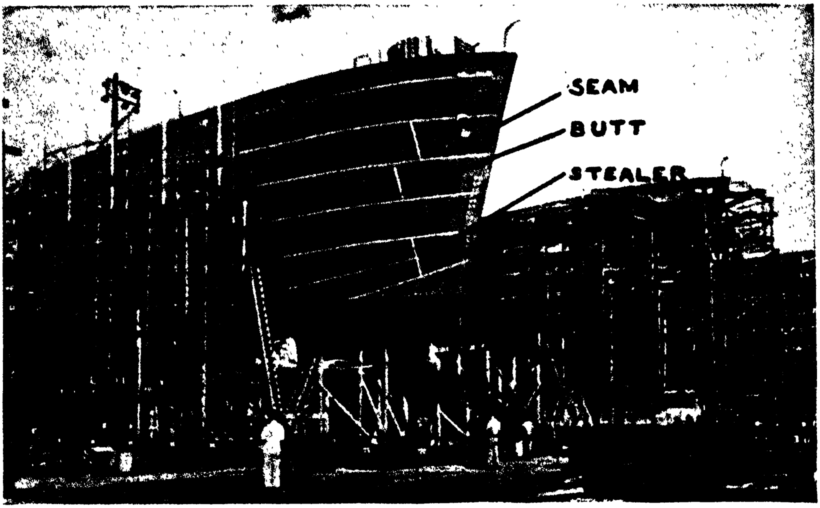


Fig. 213. Bow Structure

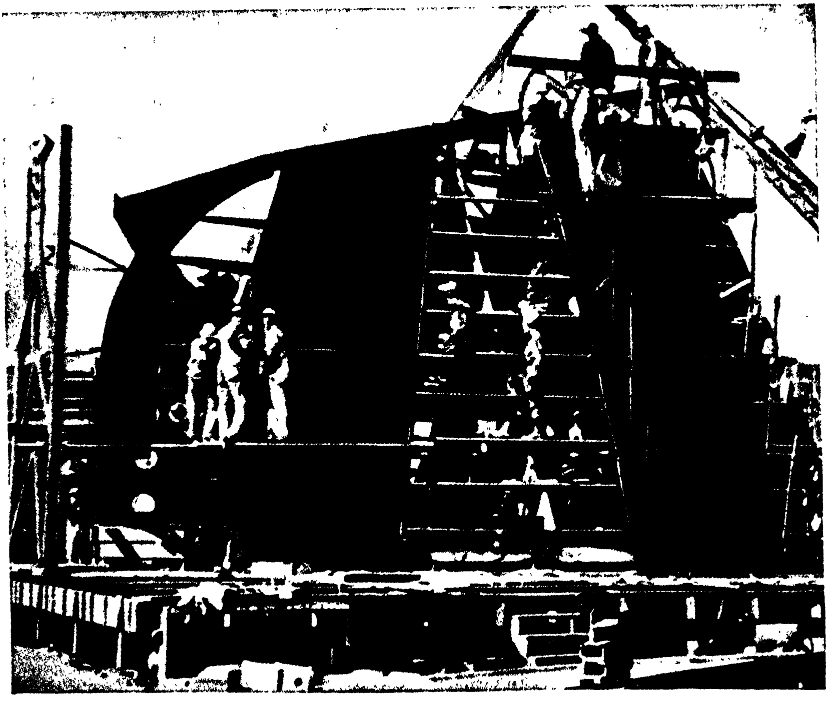


Fig. 214. Bow Structure

scarfing and overlapping as shown in Fig. 212. The decks support the stem at various intermediate points and at the top. The stem shown in Fig. 212 is a type often seen on older merchant ships. It is spoken of as a plumb stem to distinguish it from the raked clipper stem, shown in Fig. 213, which slopes forward and upward. The latter type has recently come into more common use and was formerly used a great deal on sailing ships.

216. Sternpost. Fig. 215 shows the type of sternpost usually fitted on single screw ships, and Fig. 216, the structure at the stern. The sternpost for twin screw ships is simpler because no aperture for the propeller is necessary. On account of its intricate form, the sternpost is usually a large steel casting. It is the aftermost member of the ship structure and must be rigidly secured to the keel, shell plating and decks. As shown in Fig. 215 the shell plating is rabbeted to the sternpost to give a smooth finish. A sternpost, like Fig. 215, furnishes the outboard bearing for the propeller shaft which passes through a swelling or boss on the sternpost provided for that purpose. The sternpost also furnishes the support for the rudder. The vertical part of the sternpost aft of the propeller aperture is called the **rudder post.** There are three or more projections on the rudder post which are known as **gudgeons.** Through these project pins, called **pintles,** which are fastened to the rudder. When the rudder is put over, the pintles turn in the gudgeons. See Fig. 309.

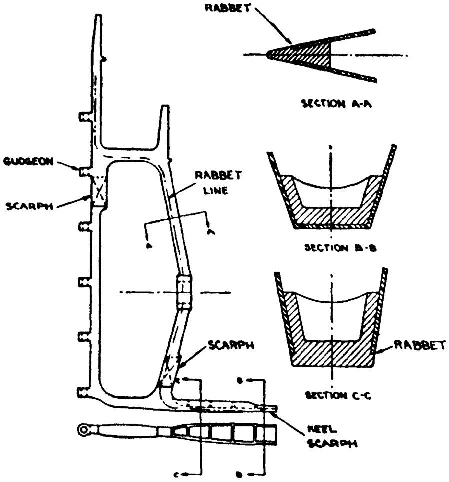


FIG. 215. Stern Frame

QUESTIONS

211. Name the structural parts of a ship and tell the general functions which they fulfill.

212. Give the specific functions of the framing.

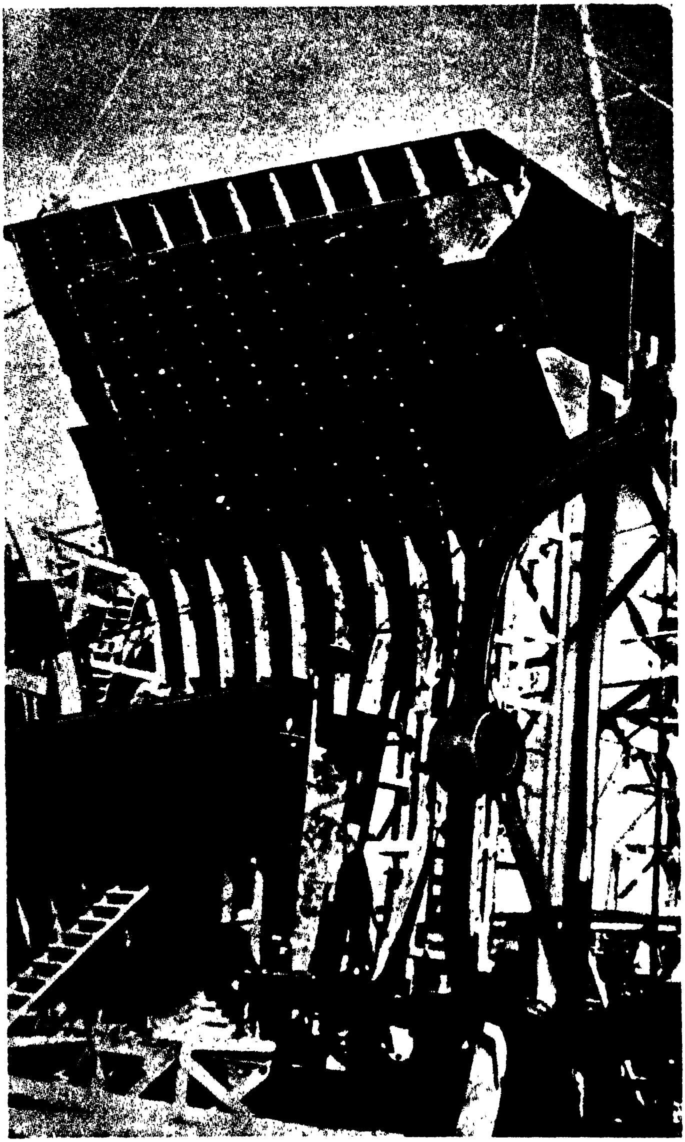


FIG. 216. Stern Structure

213. Describe two framing systems in common use.

214. What is a built-up frame? Illustrate by sketch. Name and define the parts.

215. Sketch a typical keel structure for a large steel ship and name the parts of which it is composed.

216. Sketch the sternpost of a single screw ship and mark and name the different parts.

217. What are the functions of the stem and sternpost?

Section 22. Shell and inner bottom. *Arts.:* 221. Functions of shell plating. 222. Plating systems. 223. Structure of shell plating. 224. Inner bottom.

221. Functions of shell plating. The shell plating is the " skin " of the ship. It is important that this skin should be thoroughly watertight, for the ship derives its buoyancy from the ability of the shell to hold its shape against the water pressure and exclude the water. In addition, as stated in Art. 201, the shell plating is one of the most important strength members of the hull, contributing materially to the strength of the entire structure.

The shell plating is subject to tension or compression due to the tendency of the ship to bend longitudinally. This is explained in Section 28 and indicated in Figs. 248 to 251. In addition, each shell plate below water is stressed by the load of the external water pressure. The thickness of shell plating is based on these stresses plus a margin for loss of thickness by rusting. In certain localities on the ship, such as in way of the anchors where the shell plating is subject to damage, doubling plates must be provided.

222. Plating systems. As shown in Fig. 201, the shell plating is worked in fore and aft rows, which are called **strakes.** These strakes are designated by letters beginning with the one next to the flat keel plate. The strake next to the keel is known as the **garboard** or **A strake** and the topmost strake on the side of the ship as the **sheer strake.** The connection between plates in adjoining strakes is called a **seam** connection; that between adjoining plates in the same strake is called a **butt** connection. These terms are an inheritance from the planking of wooden ships.

There are three systems of plating: the **flush system** shown in Fig. 217, the **clinker system** shown in Fig. 218, and the **raised and**

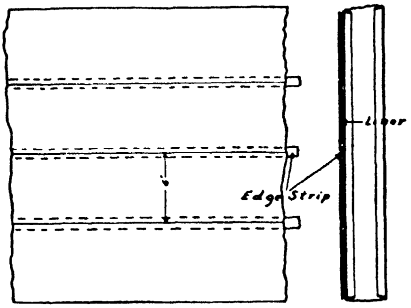


FIG. 217. Flush System of Plating

sunken system (also called the in and out system) shown in Figs. 219, 220 and 221.

223. Structure of shell plating. In the flush system of plating, the seam connections are made by **edge strips** or **seam straps** on the inside of the plating. This sets the plating away from the frame bar a distance equal to the thickness of the edge strips. Where the plates cross the transverse frames a strip of plate whose length is equal to the distance between edge strips and whose width is that of the flange of the frame bar must be inserted in order to fasten the plate to the frame. Such strips are called **liners.** See Fig. 217. In the clinker system of plating, **tapered liners** are required under each plate as shown in Fig. 218. In the raised and sunken systems, liners may be required under the outside or raised strakes. Recent practice is to avoid the use of liners altogether by offsetting the plate edges or frame bar an amount equal to the thickness of the plate. This latter process is known as **joggling.** See Figs. 219, 220 and 221. The raised and sunken system of plating is in more general use than any other.

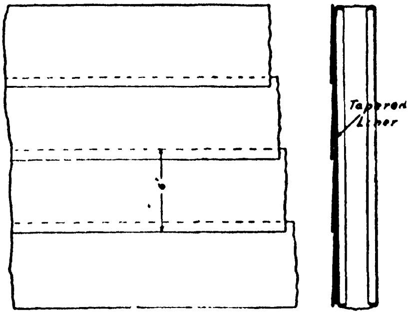
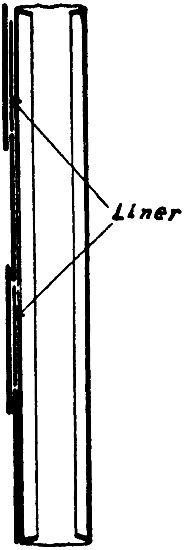
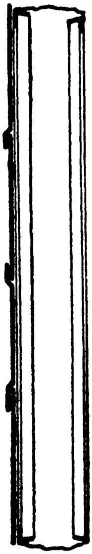


FIG. 218. Clinker System of Plating

The plates in a strake may be joined together by butting them together and fitting a **butt strap** over the ends of the two plates, as shown in Fig. 222, or they may be lapped over one another to form a **butt lap** as shown in Fig. 223. These connections may be made by either riveting or welding. A riveted butt joint is not as strong as the unbroken plate. From this it follows that in riveted construction the butts in adjacent strakes of plating should be separated by several frame spaces, and that there should be as few butts as possible in any frame space. The rules of the American Bureau of Shipping require





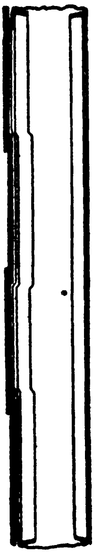


FIG. 219. Raised and Sunken System of Plating with Parallel Liner
FIG. 220. Raised and Sunken System of Plating with Joggled Plate Edges
FIG. 221. Raised and Sunken System of Plating with Joggled Frame Bar

that there shall be not less than two frame spaces between butts in adjoining strakes within the midship three-fourths length, and that plates shall be arranged to provide the best possible shift of butts. All connections of shell plating both at seams and butts must be watertight. The methods of obtaining tightness are explained in Section 27.

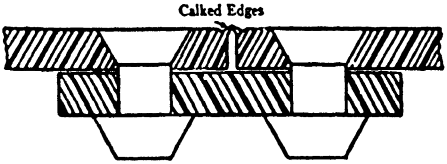


FIG. 222. Butt Strap

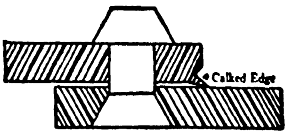


FIG. 223. Butt Lap

224. Inner bottom. The inner bottom or tank top is a watertight covering laid on top of the bottom framing. With the shell plating and framing, it forms the spaces known as the **double bottoms,** which may be used for the stowage of fresh water or fuel oil or for ballasting. It is a **second skin** inside the bottom of the ship which prevents flooding of the hold spaces in event of damage to the outer bottom due to grounding or other cause. It also acts as a strength member of the ship. Practically all ships except tankers have an inner bottom which usually extends from the turn of the bilge on one side to the turn of the bilge on the other side; see Fig. 201. The longitudinal extent of the inner bottom in ships over 330 feet long is from the fore peak tank to the after peak tank. In the case of shorter ships the regulations of the Convention on Safety of Life at Sea allow a reduction in the length of the inner bottom; see Art. 252. The outboard boundary of the double bottoms is the margin plate; see Fig. 201. The regulations of the Convention on Safety of Life at Sea limit the vertical position of the connection of the margin plate to the shell plating as shown in Fig. 233. The tank top plating in most ships is laid with the plate edges joggled, unless there is considerable dead rise, in which case it is clinker laid. In bulk carriers, the tank top plating is usually laid flush.

QUESTIONS

221. What are the functions of the shell and inner bottom plating?
222. Describe the various plating systems.
223. Define strake, butt, lap, liner, seam, margin plate.
224. What is the usual transverse and longitudinal extent of the tank top?

Section 23. Bulkheads. *Arts.:* 231. Functions of bulkheads. 232. Kinds and names of bulkheads. 233. Bulkhead structure.

231. Functions of bulkheads. Bulkheads in a ship correspond to the walls in a shore building and serve pretty much the same purposes. Their first and most obvious function is to separate different activities, such as machinery space from holds and holds from crew space, etc. Fig. 224 shows the principal bulkheads in a cargo ship. In the second place, certain bulkheads are very important strength members of the ship. They stiffen the hull structure, compelling the shell to retain its shape against the external water pressure. They also help to distribute topside weights and the forces of buoyancy throughout the hull structure. When the ship is in dry dock and supported on a comparatively narrow strip of its bottom, practically all of the weight of the side plating and framing hangs on the outboard edges of the main transverse bulkheads. At such times these bulkheads act like beams supported at the middle (where the ship is in contact with the keel blocks) and loaded at both ends by the weight of the side structure. In addition, bulkheads serve as a flooding boundary in case the ship is bilged. Further, certain bulkheads form the boundaries of oil or water tanks. Continuous longitudinal bulkheads, such as are found in tankers, also assist the side structure in resisting the tendency of the hull to bend longitudinally.

232: Kinds and names of bulkheads. Bulkheads are classified as **structural** or **strength bulkheads** and **non-structural** or **partition bulkheads.** The former, as their name suggests, are strength members of the hull, the latter simply serve to separate diverse activities. Bulkheads are also classified as **transverse** or **longitudinal,** depending upon whether their plane is athwartships or fore and aft. The bulkhead at the after end of the fore peak tank is called the **fore peak** or **collision bulkhead.** It gets the latter name from the fact that in event of a head-on collision, opening the forward end of the ship to the sea, it is expected that this bulkhead will remain intact and restrict the length of ship flooded. The bulkhead at the forward end of the after peak tank is called the **after peak bulkhead.** The bulkheads at the ends of the machinery space are designated as the forward and after **machinery space bulkheads.** A

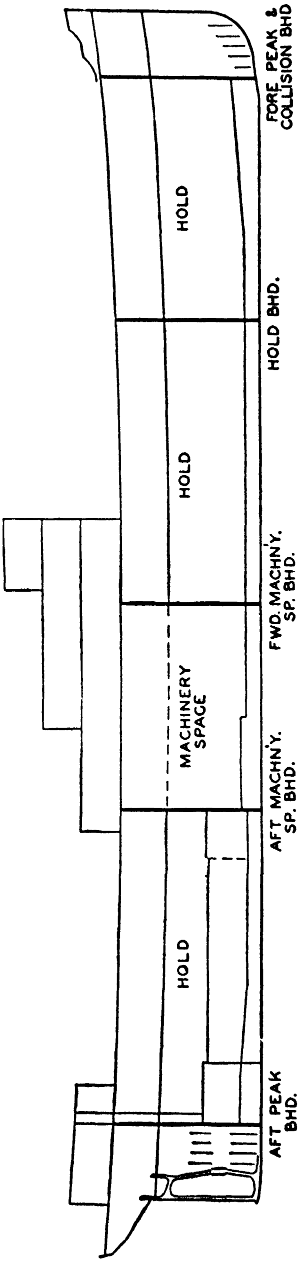


Fig. 224. Principal Bulkheads

longitudinal bulkhead on the centerline of the ship is called a **centerline bulkhead.**

233. Bulkhead structure. The main structural bulkheads are designed to serve as flooding boundaries in case the ship is damaged below the load line and water enters the ship. To make these bulkheads strong enough to stand up against the pressure of the water in an adjacent flooded compartment, the plating must be stiffened in the same manner as the shell plating is stiffened by the framing. The stiffening members of a bulkhead are called **bulkhead stiffeners.** They are of many different types, one of which is shown in Fig. 225. The strakes of plating of a bulkhead are usually horizontal because the pressure is greatest at the bottom and, if horizontal strakes are used, they can be made progressively thinner as they go up, while if the strakes are vertical, the plating has to be of the same thickness throughout. In any case, the stiffeners are at right angles to the strakes. In the case of large bulkheads, auxiliary stiffeners of smaller section are frequently worked at right angles to the main stiffeners. The main stiffeners are usually secured at the top and bottom by brackets, as shown in Fig. 225.

Structural bulkheads are worked continuously through all decks. Where they pass through a deck, the stiffeners are usually bracketed to the deck. To obtain watertightness at the edges of a bulkhead, an angle is worked continuously around the boundary. One leg of the angle is fastened to the bulkhead and the other leg to the deck, bottom, and side plating. Such an angle is called a **bulkhead bounding angle.**

Tankers are required to have either one centerline bulkhead or two longitudinal bulkheads each about one-fourth of the beam from the centerline plane. These bulkheads extend vertically from the bottom of the ship to the weather deck and longitudinally the full length of the space in which oil is carried. See Fig. 227. In the oil-carrying space, transverse bulkheads must be not more than 30 feet apart. At the ends of the oil-carrying space are additional transverse bulkheads forming a **cofferdam** at least 3 feet in length. The bounding bars are double, i.e., on both sides of bulkheads. Light bulkheads with large openings are usually fitted in oil-carrying spaces to prevent the oil from sloshing too much when the ship rolls and pitches. These are known as **swash bulkheads**; see Fig. 521.

Non-structural bulkheads or partitions may be of light plate, wood,

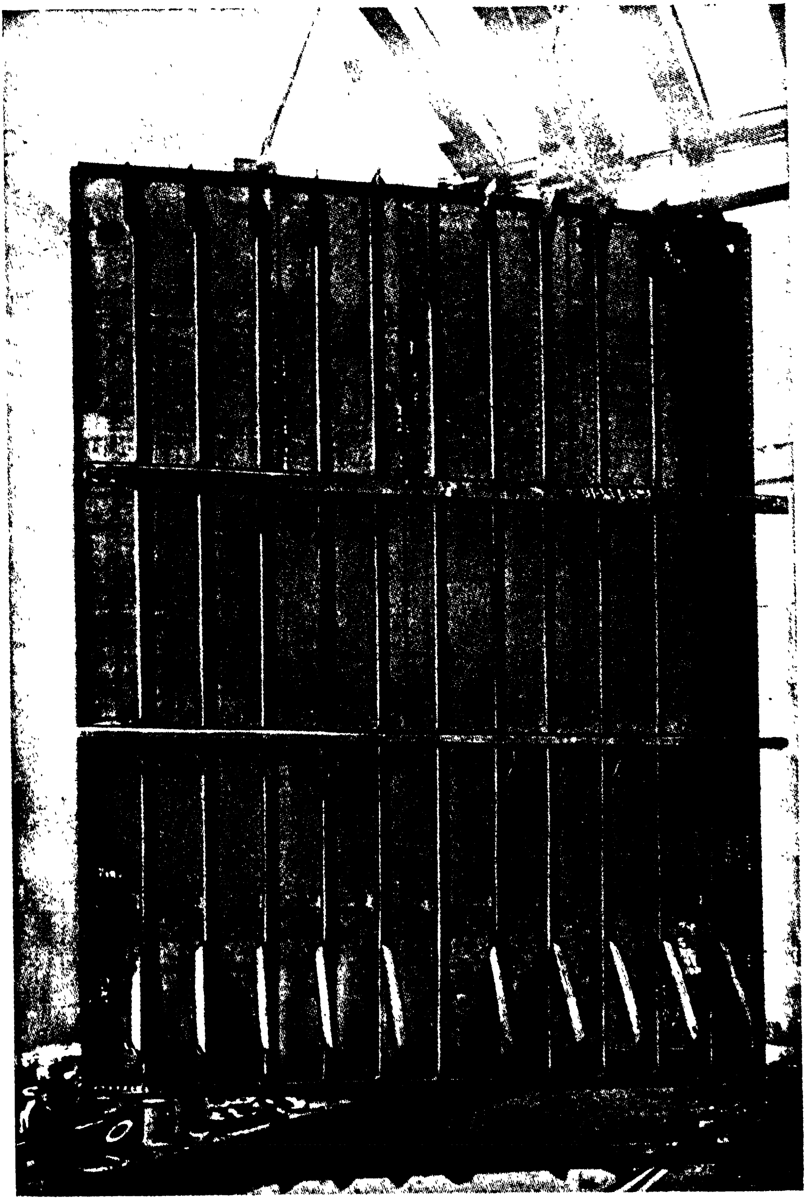


FIG. 225. Transverse Bulkhead, Riveted Structure

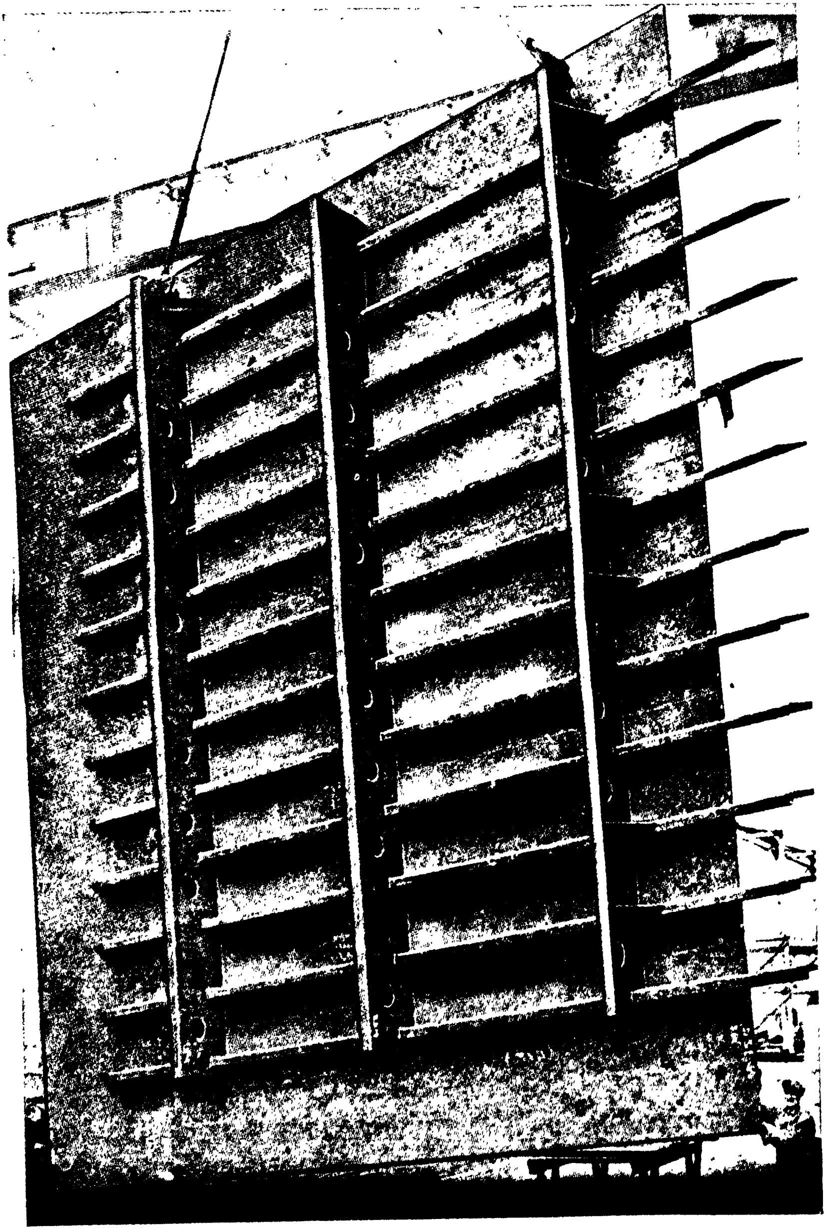


FIG. 226. Transverse Bulkhead, Welded Structure

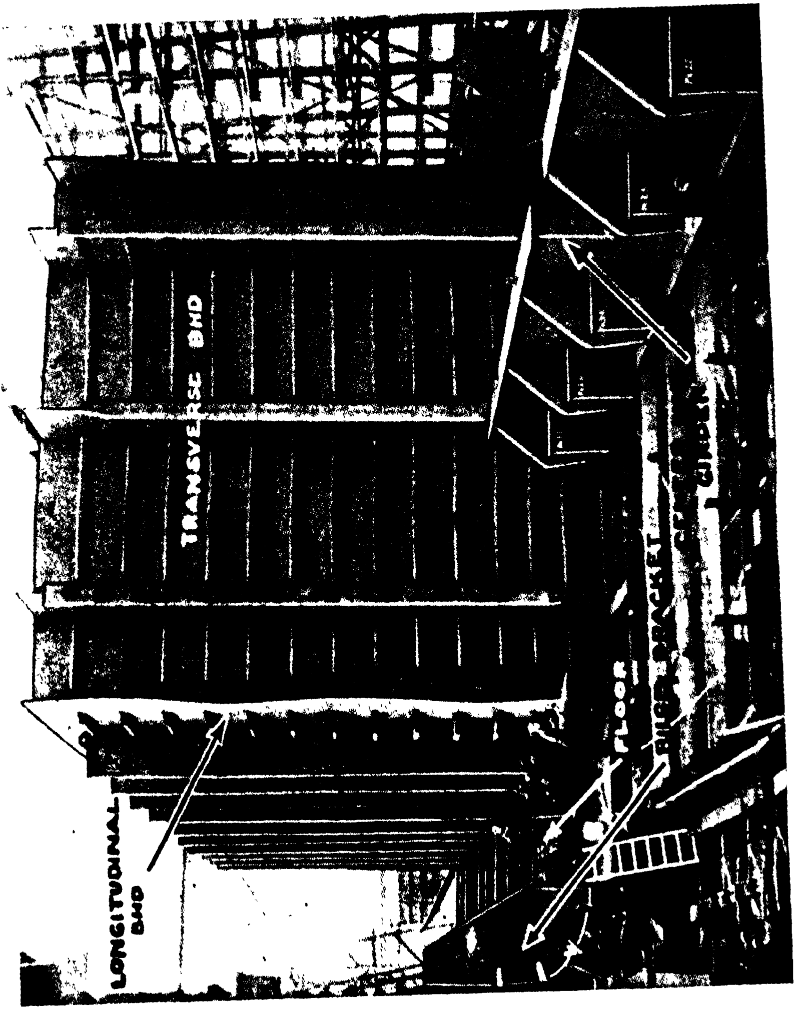


FIG. 227. Longitudinal Bulkhead

wire mesh, or corrugated sheet steel. They are used simply to separate the quarters of one person from another or from galleys, washrooms, etc. They have no stiffeners and extend only one deck height. They are not watertight.

QUESTIONS

231. What are the structural functions of a bulkhead?
232. What are the other functions of bulkheads?
233. Sketch the longitudinal view of a ship and mark the names of the main transverse bulkheads.
234. Describe the structure of a main transverse bulkhead.
235. Describe the bulkheading arrangements on a tanker.

Section 24. Decks. *Arts.:* 241. Functions of decks. 242. Names and location of decks. 243. Deck structure. 244. Deck coverings.

241. Functions of decks. The decks correspond to the floors in a shore structure. They divide the space inside the hull into a number of layers. This makes it easier to stow the cargo, quarter the crew and passengers, and in general to make good use of all spaces. The upper deck is usually the strength deck. It is a most important strength member since it is subject to the same stresses as the bottom structure, due to the ship's tendency to longitudinal bending. The deck is supported by the deck beams and in turn supports these against wracking. Other decks contribute to the structural sufficiency of the ship but not to the same extent as the upper deck.

242. Names and location of decks. Figs. 228 and 229 indicate the manner in which decks are named. On a completed passenger ship the decks are designated by the letters of the alphabet, the highest being the " A " deck, next " B " deck, and so on. In the rules of the classification societies and rules for tonnage measurements, other terms are used which are likely to be somewhat confusing.

The deck from which the freeboard is computed is the **freeboard deck.** This is frequently the highest complete structural deck and therefore also the **strength deck** and the **upper deck.** If it is also the deck at which the bulkheads terminate, it is the **bulkhead deck.** The upper deck is always the highest complete structural deck, but it is not always the bulkhead deck; the bulkheads may be run a deck

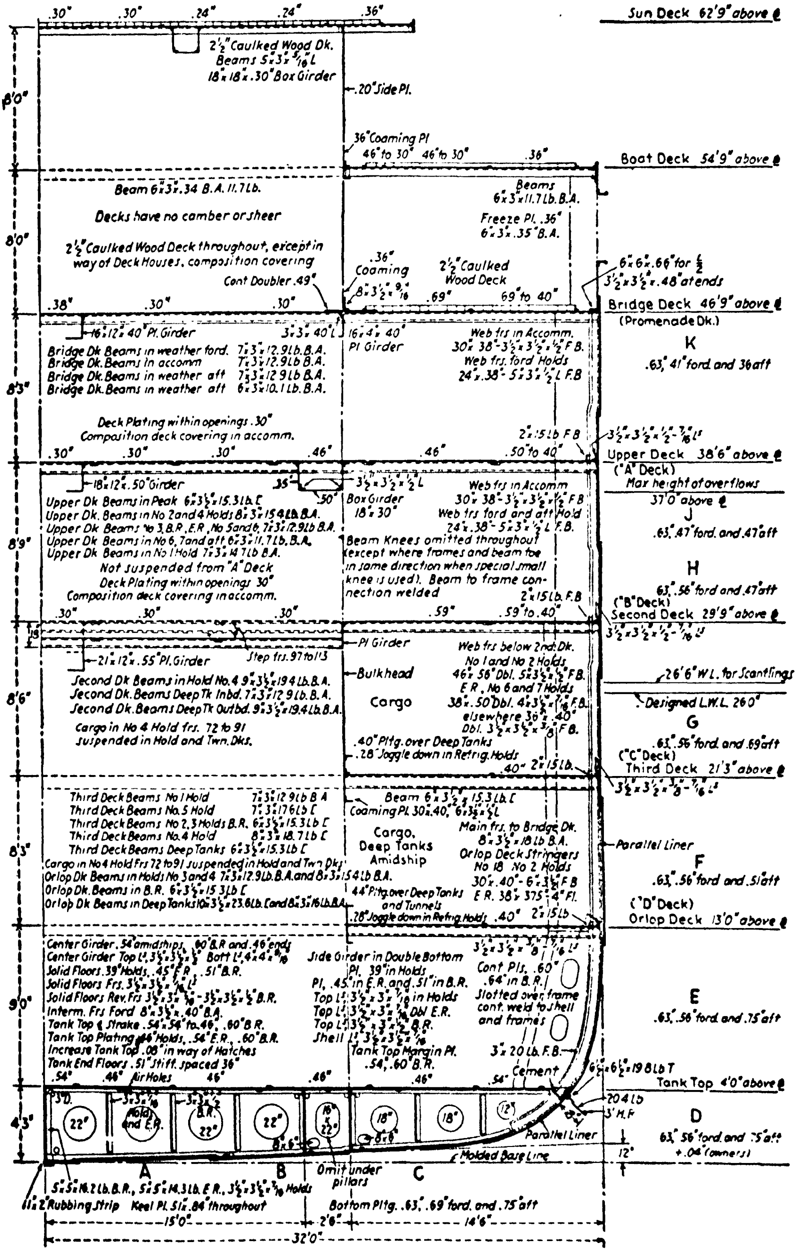


FIG. 228. Nomenclature of Decks, Passenger Ships

height higher. Also, the upper deck, while always a strength deck, may not be the only strength deck.

In the record book of the classification societies, the decks below the upper deck are the **second deck, third deck,** and so on, and the deck above the upper deck is the **superstructure deck** or **shelter deck.** A partial deck at the bow is a **forecastle deck,** and at the stern a **poop deck.** Partial decks below the upper deck are called **platforms** or **orlop decks.** The deck below the upper deck is sometimes called the **main deck.** A partial superstructure deck amidships is sometimes called the **bridge deck.** On passenger ships the deck on which the lifeboats are carried is frequently called the **boat deck.** The deck below which the under-deck tonnage is measured is called the **tonnage deck;** in ships having three or more complete decks it is the second deck from below. Other special names are used sometimes, such as spar deck, awning deck, shade deck, promenade deck, etc.

243. Deck structure. The

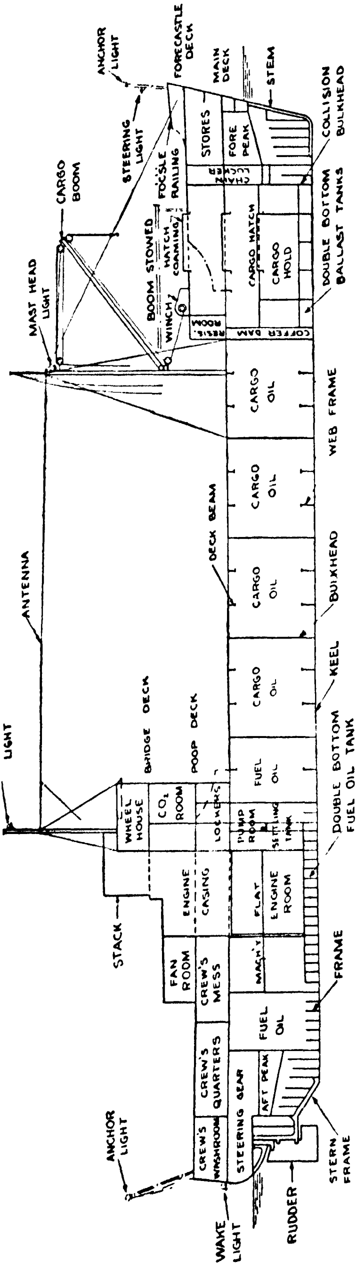


FIG. 229. Nomenclature of Decks, Coastwise Tanker

rules of the American Bureau of Shipping require that vessels of 400 feet and longer have the strength deck completely plated. In shorter vessels omission of some deck plating at the ends is permitted. The deck plating is laid in fore and aft strakes like the shell plating and fastened to transverse deck beams, which in turn are secured to the frames by triangular brackets; see Fig. 230. In addition to the transverse deck beams, longitudinal beams under the deck, called deck girders, are sometimes worked where necessary to give the deck structure adequate longitudinal stiffness. The outboard strake of deck plating, known as the **deck stringer,** is heavier than the other strakes as explained in Art. 287.

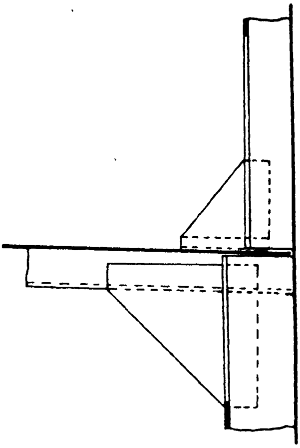


Fig. 230. Beam Bracket

Wherever a frame goes through a deck, a hole has to be cut for the frame to pass through. This destroys the watertightness of the deck, which is generally restored in the following manner. The deck bounding angle, known as the **stringer angle,** is worked at the inner edge of the frame, and the space between the stringer angle and the shell plating is filled with close fitting chocks of wood or plate secured in position and covered with a good body of cement.

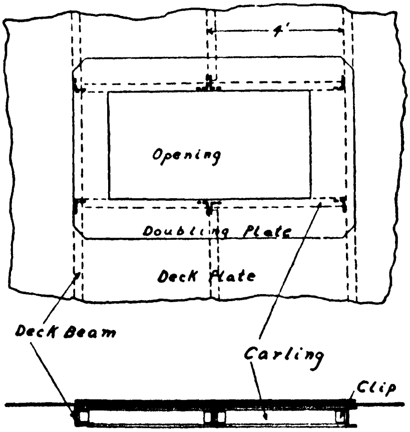


Fig. 231. Carling

Where openings are made in the plated portion of a deck structure, arrangements must be made to compensate for the material lost. Usually this takes the form of doubling plates at the corners; see Fig. 257. When hatches are so long as to require the cutting of deck beams, the interrupted beams are riveted to a fore and aft frame, called a **hatch side**

girder or **carling,** which extends between the uncut beams, and transmits the loads from the cut beams to the adjacent uncut ones; see Figs. 231 and 257.

In addition to support by the frames, deck beams are supported by stanchions or pillars. These are fitted in vertical lines to the highest deck and spaced about 18 feet athwartships. When a stanchion is not fitted to each beam, the intermediate beams are carried by runners or deck girders under the beams.

244. Deck coverings. The deck covering for weather decks over living spaces, used earliest and still the most satisfactory, is wood. Oregon fir, yellow pine, and teak are satisfactory woods for this purpose. The specifications for deck planking are very strict, because only the best is satisfactory for this purpose. The portions of weather decks, which under the rules are not required to be completely plated, are covered with wood. Fir and pine deck planking should be laid edge-grain, as otherwise it is likely to sliver off. Margin pieces are laid along the waterways around hatches and foundations for deck machinery. As shown in Fig. 232, the planking is secured to the steel deck or deck beams by galvanized bolts and nuts. The bolt heads are sunk below the level of the planking and the space above filled by wood plugs or dowels dipped in white lead. The bolts have grommets under the head and above the nut to prevent leakage through the deck. Recently it has been found feasible to weld deck bolts to the top of the deck plating. The thickness of all planks must be not less than 2 inches if teak and 2½ inches if pine or fir. The edges of individual planks are given a slight bevel and the space between them is filled with oakum and the latter then covered or " payed " with marine glue. A little space is also left between the ends of planks and similarly calked and payed. This is to prevent moisture from getting onto the steel deck (when such is fitted) and attacking it from the top, which is hidden, and to keep the spaces below free of water when no watertight steel deck is fitted. It also prevents moisture from attacking and rotting the wood at the ends of planks.

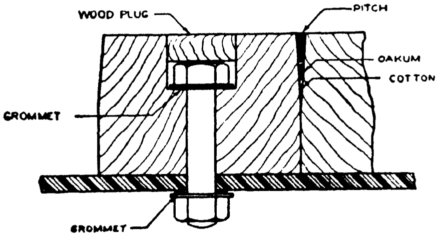


FIG. 232. Method of Fastening Deck Planking

Below decks in living spaces, linoleum and patented mastic deck coverings are in general use. In washrooms, toilets, and galleys, the deck is usually covered by tiling. The use of proprietary deck coverings on steel decks not exposed to the weather, moisture, or heat is permitted only if (1) the material has no destructive action against steel, and (2) is insulated from the steel deck by an approved protective covering.

QUESTIONS

241. What are the functions of decks?

242. How are the decks designated on a passenger ship?

243. What is the freeboard deck? Strength deck? Upper deck? Bulkhead deck?

244. Describe the structure of the strength deck.

245. How is the strength of a structural deck maintained where an opening must be cut?

246. Name two deck coverings, tell where they are used, and state their advantages and disadvantages.

Section 25. Subdivision of ships. *Arts.:* 251. Types of subdivision. 252. Subdivision regulations. 253. Openings in watertight members.

251. Types of subdivision. Watertight subdivision of a steel ship is essential to its safety in event of damage. It also influences the cost of building and operating the ship. The best form of such subdivision for merchant ships is by transverse watertight bulkheads extending vertically from the shell or inner bottom to the bulkhead deck. Subdivision by longitudinal bulkheads, which is called longitudinal subdivision, is inherently dangerous because if such a ship is damaged on one side, water enters on that side only, and is likely to capsize the ship. This actually happened in the cases of the *S.S. Empress of Ireland* and the *S.S. Lusitania.* The listing of the ship makes it impossible to lower the lifeboats on the high side and large loss of life frequently occurs.

252. Subdivision regulations. The requirements of the 1929 Convention on Safety of Life at Sea, regarding the spacing of bulkheads, are based largely on the "floodable length" and "factor of subdivision," which are defined and explained in Chapter 6. In addition, this Convention gives the following subdivision requirements.

(*a*) There must be a collision or fore peak bulkhead between 5 percent of the ship's length and 5 percent of the ship's length plus 10 feet from the forward end of the ship.

(*b*) There must be a similar after peak bulkhead.

(*c*) There must be bulkheads at the ends of the machinery space.

(*d*) There must be bulkheads enclosing the propeller shafts to prevent flooding of the machinery space in event of damage to the propeller or shaft, and the stern gland must be enclosed in a watertight space.

(*e*) Ships over 330 feet long must be fitted with an inner bottom extending transversely across the ship and longitudinally the entire length; ships 200 to 249 feet long must have a similar inner bottom between the forward machinery space bulkhead and the collision bulkhead; ships 249 to 330 feet long must also have such an inner bottom from the after machinery space bulkhead to the after peak bulkhead. The inner bottom must be at such a height that at no place does the intersection of the margin plate with the shell plating lie below a horizontal plane passing through the point of intersection of the molded line at the midship section and a line making an angle of 25 degrees to the horizontal drawn from the intersection of the base line and a vertical line tangent to the molded line at the midship section. See Fig. 233.

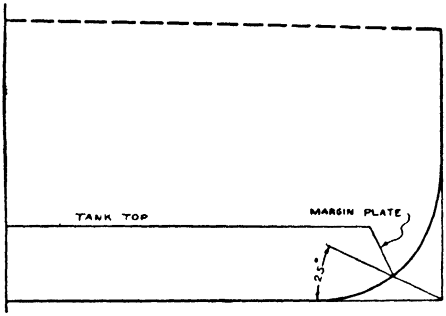


Fig. 233. Vertical Position of Margin Plate

The requirements of the American Bureau of Shipping in regard to location of watertight transverse bulkheads are as follows:

(*a*) No compartment may exceed 100 feet in length.

(*b*) There must be a collision bulkhead not less than 5 percent of the ship's length from the stem.

(*c*) There must be a similar after peak bulkhead, so fitted as to shut off the stern tubes, through which the propeller shafts enter the water, in a separate watertight compartment.

(*d*) There must be bulkheads at the ends of the machinery space. If the machinery space exceeds 15 percent of the length of the ship, the end bulkheads must be increased in height or an intermediate bulkhead provided.

(*e*) Intermediate bulkheads in the cargo space are required as follows:

Length of ship	*Location of machinery space*	*Additional bulkheads*
Over 285 feet	Amidships	One forward
Over 285 feet	Aft	Two forward
Over 335 feet	Amidships	One forward, one aft
Over 335 feet	Aft	Three forward

The bulkhead next aft of the collision bulkhead must not be more than 20 percent of the ship's length from the stem. If the freeboard is less than 15 percent of the load draft in ships over 335 feet long, or less than 20 percent in ships 435 feet long, or the sheer is less than the standard sheer, the height of these bulkheads must be increased or an additional bulkhead fitted.

Lloyd's requirements are similar.

253. Openings in watertight members. Experience has taught that only intact watertight boundaries of watertight compartments can be depended upon at all times. For this reason the 1929 Convention on Safety of Life at Sea does not permit any access opening in the collision bulkhead below the bulkhead deck and permits only one pipe connection, which must have a screw-down valve operated from above the bulkhead deck. While those who represented the regulatory authorities of the various nations at the 1929 Convention were anxious to eliminate all openings in watertight partitions, except such as necessary for vertical access, the representatives of the ship owners and operators were able to convince the delegates of the necessity of permitting, subject to regulation, the following types of openings in watertight partitions: cargo, coaling, and gangway ports, watertight doors, and opening side scuttles or air ports. Fig. 234 shows a cargo port in use and Fig. 235 shows an air port in a passenger stateroom.

Coaling, cargo, and gangway ports do not seriously reduce the

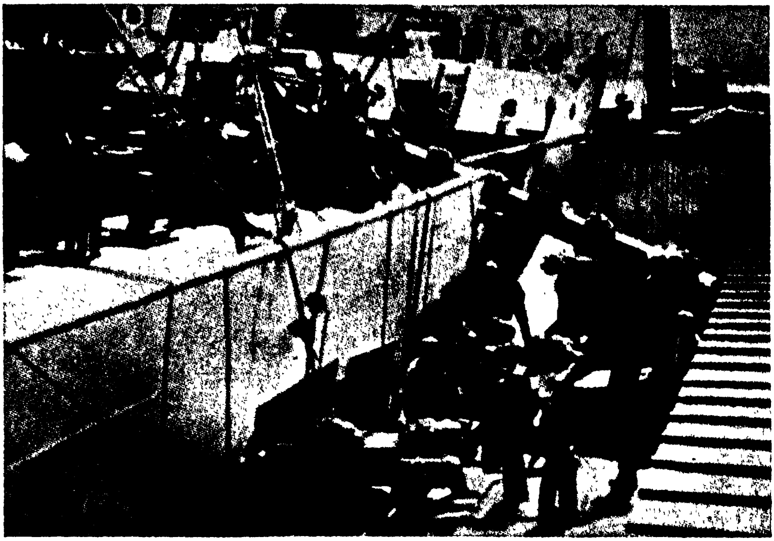


FIG. 234. Cargo Port

watertight integrity of the ship, because they are closed or " secured " before the ship is out of the harbor and remain secured until the ship makes port again. Any lack of tightness is indicated by leakage when seas hit the ship. This creates a sufficiently unpleasant situation to demand a remedy at once. The regulations regarding these simply state that the design, materials, and construction shall be to the satisfaction of the governmental regulatory authority (Bureau of Marine Inspection in the United States), and that they shall be effectively closed and secured watertight before the ship leaves port, and kept closed during navigation.

Watertight doors through main transverse bulkheads constitute a serious menace to the watertight integrity of the ship, because they are frequently neglected and usually kept open. Unless power operated, they are not likely to be closed at the time of a serious casualty and, in any case, due to neglect, they may not close watertight. They are, however, distinctly superior to archways with no means of closing, because even if not watertight, they do retard the spread of water from one space to another. There are two types of watertight doors in common use: sliding doors, which may be power operated, and hinged doors which are operated by hand. Sliding doors are of two types: those which close by moving horizontally and those which move vertically. When power operated, they may be

Fig. 235. Side Scuttle

closed either at the door or from a remote control station, such as the pilot house. Hinged watertight doors are lighter and cheaper than sliding doors and consequently are installed except where the regulations of the 1929 Convention require sliding doors. The regulations on this subject may be summarized as follows:

(*a*) Hinged doors are permitted only above a deck, the lowest point of which is at least 7 feet above the deepest subdivision loadline.

(*b*) Power operated sliding doors are required in practically all other cases.

Side scuttles or air ports, particularly those which may be opened at sea, are an even greater source of danger to the safety of the ship than watertight doors, because they are so widely scattered throughout the ship and that they may be in locked cabins or other spaces difficult of access and where power operation from a remote control station has not been developed. The side scuttle regulation of the Convention is illustrated by Fig. 236.

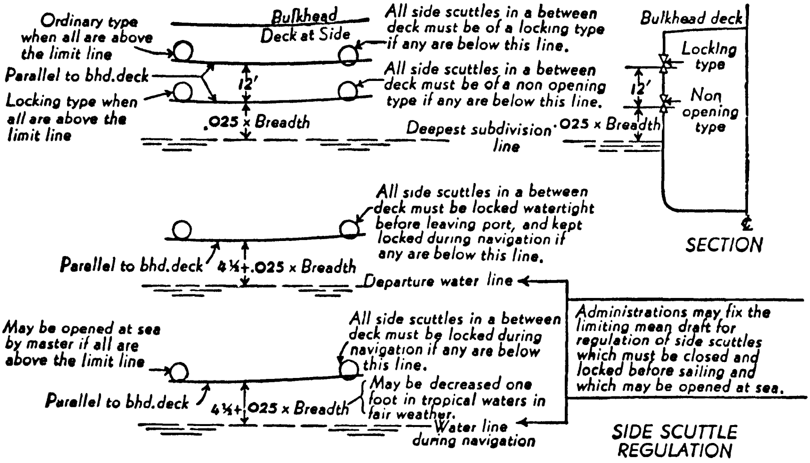


FIG. 236. Side Scuttle Regulation

Where access through a watertight deck is required, a watertight hatch or bolted plate may be fitted. The former is like a hinged watertight door except that it is horizontal instead of vertical. As shown in Fig. 237, a bolted plate manhole consists simply of a plate bolted instead of riveted or welded to the deck. A reinforcing ring is fitted underneath the deck around the opening for stiffening and the plate is set in a gasket

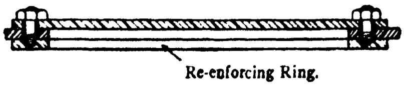


FIG. 237. Bolted Plate Manhole

of canvas soaked in red lead. Access to the tanks in the double bottom is usually obtained through such bolted plate manholes.

The main cargo hatchways of a ship usually go right through all decks. These hatchways are required to have coamings extending from the bottom of the deck beams to a height of at least 24 inches above the freeboard deck or superstructure deck forward of the midship half-length and 18 inches above other superstructure weather decks. These coamings must be adequately stiffened and braced and provided with fixtures for securing the tarpaulins which are hauled over the hatch covers to protect the cargo. Hatch beams must be provided to subdivide the hatchway sufficiently to keep the hatch covers small enough for easy handling. Hatch covers were formerly wooden but now are usually metal. Hatchways on the forecastle deck are frequently closed by hinged steel plate hatch covers. This type of hatch cover is occasionally used for other cargo hatches also. Wedging or other battening arrangements must be provided. Locking bars across cover boards should be provided to seal hatches for customs and prevent pilferage of cargo.

Engine and boiler hatchways are required to be protected by superstructures enclosed by plate trunks extending at least 6 feet above the superstructure deck.

Permanent companionways in exposed positions on weather decks are required to be covered by steel hoods fastened to the deck plating. Deck openings for masts must have coamings equal in height to one-third the diameter of the mast, or 9 inches, whichever is less.

QUESTIONS

251. What are the two systems of subdividing a ship? Which is the better and why?

252. Give the requirements of the 1929 Convention on Safety of Life at Sea regarding subdivision of merchant ships.

253. Give the classification of doors used on board ship and tell where each kind is used.

254. Discuss the advisability of openings in main bulkheads.

Section 26. Materials of ship construction. *Arts.:* 261. Structural materials. 262. Non-structural materials.

261. Structural materials. The hull structure of ships has in the past been built of wood, wrought iron, steel, and even concrete. Wood was the earliest shipbuilding material. It is fairly abundant; the source of supply is widespread; it is easy to work. Large ships cannot be built of wood because connections between the individual pieces cannot be devised to develop the full strength of the material. Rigid connections between members of wooden hulled vessels are practically impossible so that such vessels, unless small, frequently give evidence of working and hog or sag excessively, i.e., up to 5 or 6 feet. Wood is not uniform in structure or strength; it has a plane (parallel to the grain) of very little strength; it is subject to organic decay and injury by worms, insects and marine worms (teredoes); for equal strength it is heavier than steel; lastly, it will burn.

Wrought iron was the first metal used for shipbuilding but has not been used to any extent since about 1880. It is almost non-corrosive but not as strong as steel. Furthermore, steel can now be made more cheaply than wrought iron. Some of the early wrought iron ships remained afloat for half a century; steel hulls thirty years old are a rarity.

By far the vast majority of ships are built of steel. Steel can be produced which is practically uniform in strength, structure and composition; it is fairly cheap; it can be easily worked into shapes to give the greatest strength for weight; joints can be made to develop the full strength of the piece joined. The principal disadvantage of steel is its susceptibility to rusting and corrosion, which is generally kept under control by painting.

Reinforced concrete was first used during the first World War when the demand for ships was well-nigh insatiable. Not many have been built since. In these the tensile strength is provided by the steel reinforcing rods. The principal objections to this material of construction are the low value of the deadweight-displacement ratio of concrete hulls due to their excessive weight and the susceptibility of concrete to cracking.

Steel used for shipbuilding is inspected and tested at the steel works by a representative of the classification society. It comes in the following forms: plates, shapes, rivets, castings, and forgings. Plates are pieces of rectangular cross section which are thin compared to their length and width. The thickness is specified in hundredths of an inch or in weight per square foot. A steel plate 1 foot square and an inch thick weighs 40.8 pounds. Thin plates, i.e., those less than about 0.12 inch thick, are called sheets. Shapes are straight pieces of special cross section. Some of the common shapes are shown in Fig. 208.

Rivets and welding are used for joining together individual plates, shapes, etc. The common forms of rivets are shown in Fig. 238 and the common forms of riveted joints in Figs. 239, 240 and 241. The most used types of welded joints are shown in Fig. 242.

FIG. 238. Common Forms of Rivets

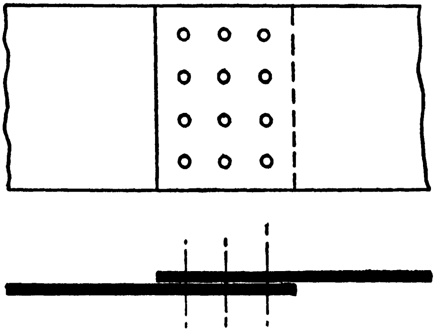


FIG. 239. Butt Lap

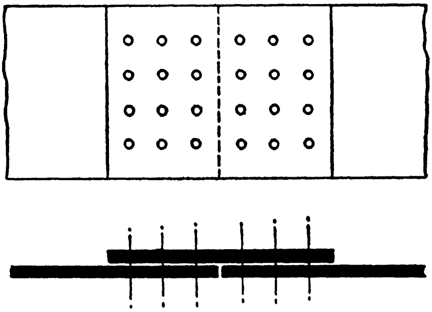


FIG. 240. Single Butt Strap

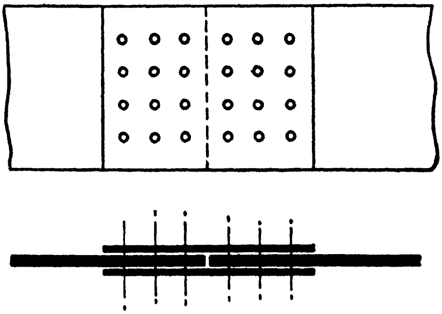


FIG. 241. Double Butt Strap

Castings and forgings are made of a special form to suit a particular requirement such as the stem and sternpost. Castings are used where the part is complicated in form; forgings where it is simple, but neither are used where the part can be built up of plates and shapes because they are both more expensive than built-up structures.

262. Non-structural materials. In addition to the material which is worked into and becomes an integral part of the ship's structure, there is a great deal of material required for specific purposes. Such materials include:

(*a*) Non-ferrous metals, particularly non-corrosive alloys, such as the brasses and bronzes for piping and fittings; lead, copper, etc.

(*b*) Cast iron for fittings not subject to shock.

(*c*) Steel and iron pipes.

(*d*) Wood (on steel ships) for weather decks, gratings, ceiling and sparring.

(*e*) Concrete for filling pockets inaccessible for proper preservation.

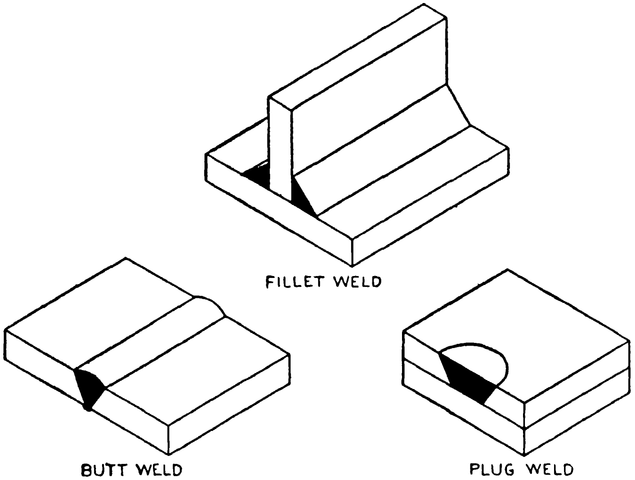


FIG. 242. Common Forms of Welded Joints

(*f*) Deck coverings, such as linoleum or patented mastic coverings, in crew and passenger spaces, and tiling in galleys, pantries, and toilet spaces.

(*g*) Materials for insulating spaces against heat or noise such as cork, felt, asbestos, etc.

(*h*) Paint as a preservative of iron, steel, and wood surfaces and for decorative and sanitary purposes.

(*i*) Rubber for making watertight joints on doors, hatches, and air ports.

(*j*) Glass for windows, air ports, skylights, etc.

(*k*) Cordage.

In fact there is at least a little of nearly every material in a large ship.

QUESTIONS

261. Why are most ships built of steel?

262. Sketch five commonly used shipbuilding shapes and give their names.

263. Sketch the common forms of rivets and give their names.

264. Name ten non-structural materials used in shipbuilding and tell what they are used for.

Section 27. Joints and connections. *Arts.: 271.* Types of joints and connections. *272.* Strength of joints. *273.* Tightness of joints.

271. Types of joints and connections. The hull structure of a ship is composed of a large number of individual pieces, so that the strength and tightness of the structure as a whole depends quite as much on the strength and tightness of the connections between these pieces as it does on the materials forming them. Up to about 1915, riveting was used exclusively to joint the steel plates and shapes of a hull. Since then, electric welding has been used more and more and is now entirely acceptable to the classification societies as a means of joining structural as well as non-structural members. This increase in the use of welding for joints in structural members has come about largely due to improvements in welding technique, welding apparatus, and welding electrodes. It appears probable that welding will ultimately entirely supersede riveting, but this has not yet occurred and at the present time both are used extensively. The relative cost of riveting and welding is still a matter of dispute.

Many of the complications which formerly plagued shipbuilders were caused by necessity of making a riveted connection between individual pieces and the difficulty of designing such a connection which was nearly as strong as the uncut material. Welding has tremendously simplified hull structural design. With welding it is no problem at all to make connections which have the same strength as the uncut plate. Furthermore, the application of welding to shipbuilding permits methods of assembly which greatly reduce the time required to erect a hull on the building ways. In a word, it may be said that welding is producing more profound changes in shipbuilding methods than anything that has happened since wood was superseded by iron and steel.

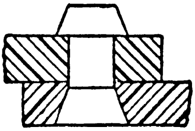


FIG. 243. Elementary Riveted Joint

Fig. 243 shows the elementary riveted joint, from which all types of riveted joints are obtained. Figs. 239, 240 and 241 show the more common types of riveted joints and Fig. 242 the more common types of welded joints.

Connections may be plate to plate, plate to shape or plate to casting, and the connection may be along the long or short dimension of plate and either dimension of other member. The connection may be square or at an angle. There are therefore a great variety of connections in shipbuilding. Some of the more common ones will be described. The connection between two plates is a **seam** if along the long dimension, and a **butt** if along the short dimension. If one plate is lapped over the other, as in Fig. 239, it forms a **seam** or **butt lap.** If the edges of the joined plates are butted together and they are connected by a third part, as in Fig. 240, the connection is a **strapped seam** or **butt** and the piece making the connection is a **strap.** If there is a strap only on one side of the plates joined, it is a **single strap;** if on each side, a **double strap.** Similarly, connection may be made between angles by lapping or strapping. Two shapes meeting at right angles may be joined by an angle, called a **clip,** or a piece of plate (usually triangular) called a **bracket** or **gusset;** see Figs. 244 and 245.

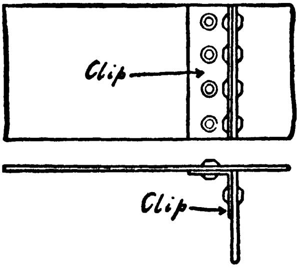


FIG. 244. Clip

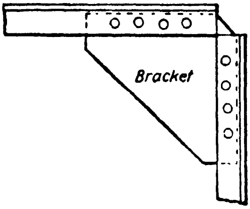


FIG. 245. Bracket

272. Strength of joints. The strength of a riveted connection depends upon (*a*) the material of the parts joined and the rivets, (*b*) thickness of parts joined, (*c*) diameter of rivets, (*d*) distance or pitch between rivets in same row, (*e*) number of rows of rivets, (*f*) distance from rivet to edge of part joined, (*g*) distance between rows of rivets. The strength of a welded joint depends upon (*a*) the material of the parts joined, (*b*) the material, diameter and covering of the electrode, (*c*) the cross-sectional area and form of the weld and its position relative to the line of stress at the joint, (*d*) the number of welds between the pieces and the degree of continuity of each weld, (*e*) the position of the pieces when the weld was made, i.e., flat, overhead, or vertical, (*f*) the welding technique and skill of the welder, (*g*) the sequence followed in making the various individual welds of the joint.

273. Tightness of joints. Joints are classified regarding tightness as **non-watertight, watertight,** and **oiltight.** In obtaining tightness, a welded joint has a distinct advantage over a riveted joint because the weld has only to be made continuous to produce a tight joint. Regardless of how closely the rivets in a riveted joint are spaced, such a joint must be calked to be oil or watertight. The greatest number of joints are non-watertight. Certain deck and bulkhead connections and all shell connections must be watertight. Ships that carry oil have some boundaries which must be oiltight. The difference between oiltightness and watertightness is one of degree rather than kind. Oil is more searching than water and consequently requires a little closer rivet spacing and more skilled workmanship in making the joint. Figs. 222 and 223 show the methods of calking riveted joints in plating to secure tightness. The effects of calking are somewhat exaggerated to make them clear. A joint may appear to the unaided eye to be "metal to metal," but unless calking is done the joint is not likely to be tight. The parts must be forced into very intimate contact to eliminate the possibility of leakage. Generally speaking, if the workmanship is good, watertightness and oiltightness can be obtained by calking. Packing a joint for this purpose is evidence of inferior workmanship and should be permitted only where, due to the nature of the work, tightness cannot otherwise be secured.

QUESTIONS

271. What are the two methods used for joining parts of a ship together?
272. Sketch three common forms of joints and give their names.
273. What does the strength of a riveted joint depend on?
274. What does the strength of a welded joint depend on?
275. How are joints classified as regards tightness?
276. How are riveted joints made tight? Illustrate by sketch.
277. What is a clip? A bracket? Illustrate by sketches.

Section 28. Stresses in ship structure. *Arts.*: 281. Classification of stresses. 282. Stresses due to longitudinal bending. 283. Transverse stresses. 284. Local stresses. 285. Dynamic stresses. 286. Continuity of strength members. 287. Nature of stresses in important structural members.

281. Classification of stresses. The term **stress** is properly used to indicate the load within a structural member. For example, if we say that the stress on a certain frame is 5 tons per square inch tension, we mean that the number of tons pull on the material of the frame is equal to its cross-sectional area in square inches multiplied by 5. Stresses are of four kinds: tension, compression, shear, and torsion or twisting. The last is of little importance in hull design and will not be further discussed. Tension and compression are spoken of as direct stresses because they act along the member being stressed. For example, if we have a bar of steel in a tensile testing machine and fasten one end securely to a fixed structure and fasten the other end to a head which can be moved in the direction of the bar's length, we can exert a pull upon the bar. When the bar is undergoing such a pull, it is said to be " under stress " or " to be stressed " in tension. If now, we reverse the direction of motion and exert a pressure on the free end of the bar, the stress is compression. These two stresses are illustrated in Figs. 246 and 247. Shearing stress may be explained by reference to Fig. 243. Suppose that on the upper plate a pull is exerted to the left, while an equal pull to the right is exerted on the lower plate. The rivet connecting the two plates is then subjected to a stress at right angles to its length. Such a stress is called shear or shearing stress.

When a member is subject to tension, it grows longer. The most common illustration of this is the ordinary rubber band. Steel subject to tension is also lengthened but sensitive instruments are required to measure the increase in length. Similarly, when a member is subject to compression, it is shortened. A change in length due to stress is called **strain.** In other words, stress and strain have the same relation as cause and effect, and are not the same thing. Some people loosely use the word strain when they mean stress. These words should be used in their correct meaning.

There are two general ways of classifying the stresses to which a ship is subject: first with regard to the type of load which produces the stress, and second with regard to the extent of the stress. Under the first heading we have, (1) what are known as static loads and (2) dynamic loads. When a ship is floating at rest in the water, the pressure on the bottom due to height of the head of water is spoken of as a static pressure. When the ship is moving ahead through the water, there is on the forward plating, in addition to the pressure due to its distance below water, another pressure component caused by pushing the water aside. This is spoken of as a dynamic pressure force because it is due entirely to motion. It does not exist when the ship is static, i.e., stationary.

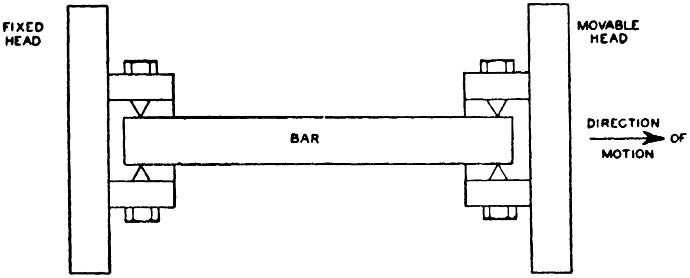


FIG. 246. Bar in Tension

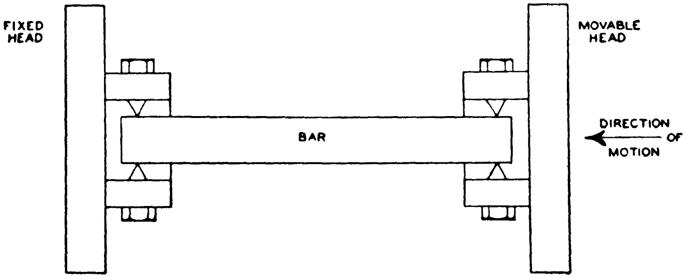


FIG. 247. Bar in Compression

When the stress is of such a nature as to affect the entire ship structure, it is spoken of as a **structural stress.** A stress which affects only a few members of the structure is called a **local stress.** These stresses are discussed in somewhat greater detail in the following articles and figures.

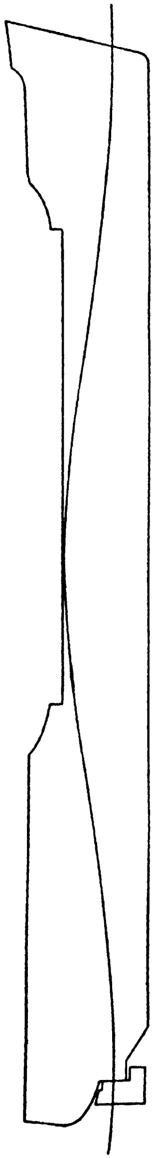


Fig. 248. Ship in Hogging Condition

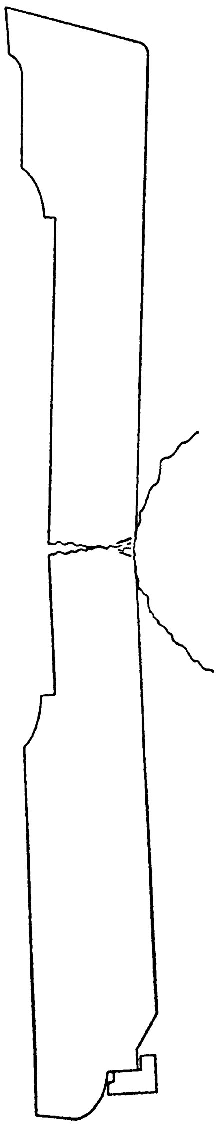


Fig. 249. Ship in Hogging Condition

282. Stresses due to longitudinal bending. When a ship is floating freely in still water, the total weight is equal to the buoyancy, but generally speaking, the distribution of the weight along the length of the ship is not the same as that of the buoyancy. In the case of a fully loaded ship, the weight of the ends is usually greater than the buoyancy and the buoyancy of the middle is greater than the weight. The result is pretty much the same as if we had a ship of less weight, supported at the middle; the ends tend to droop, see Fig. 249. The ship has a tendency to bend in the fore and aft plane. Such bending is called **longitudinal bending.** This particular type of longitudinal bending is known as **hogging.** When the ship is light, the weight at the midlength may exceed the buoyancy there, and this deficiency of buoyancy is made up by excess buoyancy at the ends. In this case, conditions are very much the same as if the ship were supported only at the ends. The ship, therefore, tends to bend in the form of a curve concave up, see Fig. 251. This type of longitudinal bending is called **sagging.**

The tendency to longitudinal bending is less in still water than when the ship is among waves. When the waves are of the same length as the ship, the tendency to hogging will be greatest when the wave crest is at the midship section and the ends are in the hollows. This is therefore called the **hogging condition,** see Fig. 248. Similarly, the tendency to sagging will be greatest when the ends are in wave crests and the trough is at the midlength, see Fig. 250. This latter condition is therefore known as the **sagging condition.** For strength calculations the ship is assumed to be floating in a stationary standard wave. The standard wave has the same length as the ship and a height of one-twentieth of its length.

The tendency to longitudinal bending of the ship results in stresses in the ship structure. In hogging condition the deck is in tension and the bottom in compression; in sagging condition, the reverse is true. If the ship is properly constructed, the actual deflection is small, but stresses are set up in the ship structure. The only reason that the deflection is not greater or that structural failure does not occur is because the structural members are strong enough to carry the stresses without excessive deflection or failure. As a matter of experience, it has been found that the maximum stresses due to longitudinal bending occur in the strength deck and bottom structure at the midship section

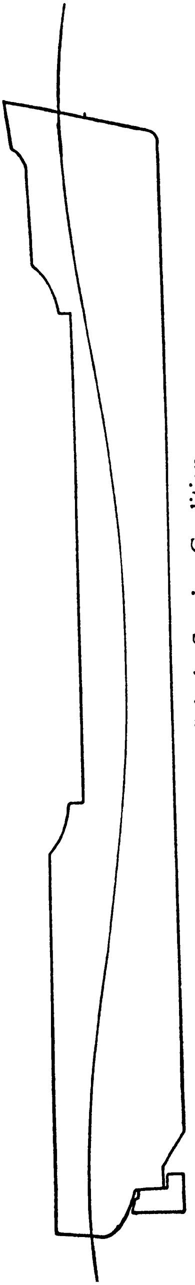


FIG. 250. Ship in Sagging Condition

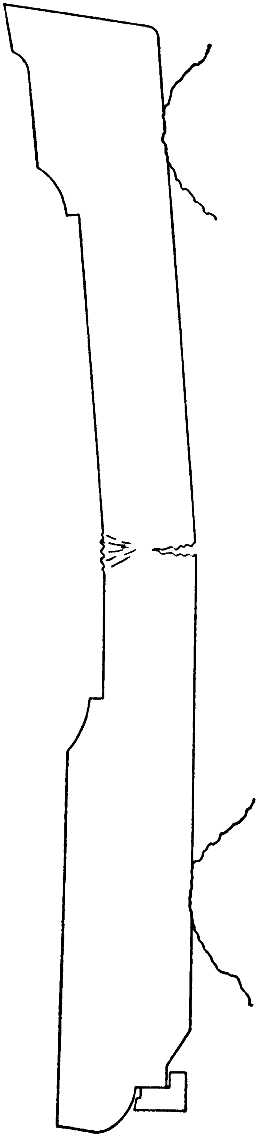


FIG. 251. Ship in Sagging Condition

when the ship is fully loaded and has its ends in wave hollows and its midship section in a wave crest.

From a structural point of view, the ship is not unlike a box girder, and in structural design, the term **ship girder** is often used to designate the structural part of the hull. The structural parts of the hull, i.e., those parts which contribute to its strength as a girder, are the shell plating, decks, tank top, framing, both transverse and longitudinal, and bulkheads. The functions of each of these have been discussed at greater length in Sections 21, 22, 23, and 24, but it is desired to emphasize the fact that there are many flats, partitions, and other structures, which do not contribute to the strength of the ship as a whole and are not, therefore, parts of the ship girder. Any changes in the structural members of the ship should be made only after approval of a naval architect versed in structural design. No change should be made in a non-structural member unless it is known for a certainty that it is not a structural member. Disregard of these principles may lead to serious consequences to the ship.

283. Transverse stresses. The pressure of the water on the ship's sides is a static load which subjects the transverse framing, deck beams, and shell plating below water to stresses similar to those due to longitudinal bending. See Fig. 252. The stresses due to this source are usually moderate in amount, however, because the ship is so much narrower than it is long. Grounding or docking result in stresses as indicated in Fig. 253. It is desirable at this point to emphasize the fact that structurally the deck beams are a continuation of the transverse frames and form with the latter what is frequently spoken of as a "frame ring." When a ship is rolling, it is subject to a wracking action which tends to distort the entire frame ring; see Fig. 254. This is a dynamic stress, since it is caused by the rolling motion of the ship. It is seldom serious in amount. Tankers having a centerline bulkhead are sometimes ballasted by filling tanks alternately on the

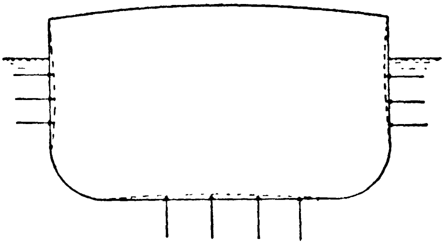


Fig. 252. Transverse Stress Due to Water Pressure

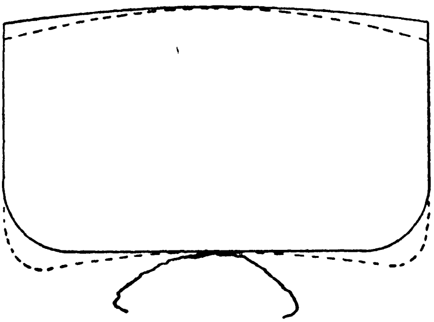


FIG. 253. Transverse Stress in Docking or Grounding

port and starboard sides. This puts a twist on the hull but the stresses resulting are seldom great.

284. Local stresses. There are numerous sources of local stresses in a ship. Where these are present, the structure must be suitably strengthened in that vicinity, so that these stresses will be transmitted to and absorbed by the ship structure as a whole. Several types of local stresses are discussed in this article. The most common sources of local stresses are heavy weights, such as masts, kingposts, anchor engine and windlass, deck winches, etc. Inspection of the structure in the immediate vicinity of such weights will usually disclose that the deck plating underneath is thicker than on the rest of the deck, the deckbeams are deeper or have been reinforced, and the decks on which the weight rests is supported by a bulkhead or stanchions on the lower deck. Other sources of local stresses occur in dry docking and cases of grounding. In such cases the ship is supported in whole or in part

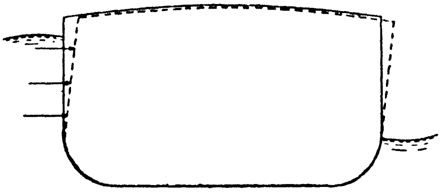


FIG. 254. Transverse Stress Due to Waves

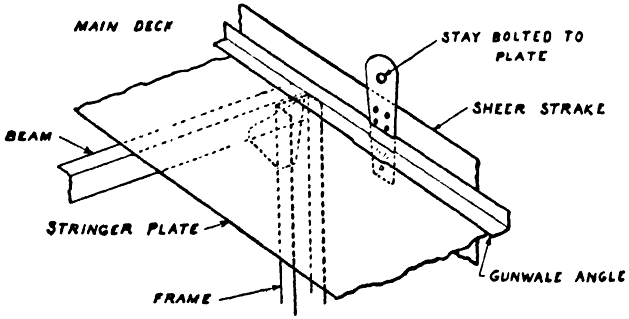


FIG. 255. Local Reinforcement for Stays, etc.

at comparatively small areas of the bottom and severe stresses are likely to occur in the areas of contact. This is one reason for making the keel structure stronger than the other longitudinal frames. It carries a large part of the ship's weight when the ship is in dry dock.

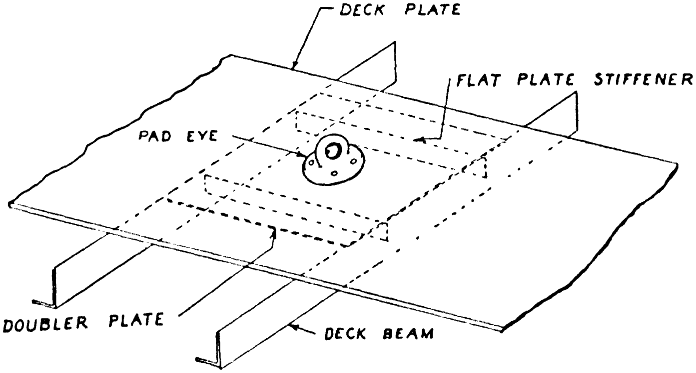


FIG. 256. Local Reinforcement for Stays, etc.

The point of attachment of shrouds and stays for masts and smokestacks are areas of high local stresses as a rule. Figs. 255 and 256 show the method of providing local strengthening of the ship structure at rigging attachments. The stresses on rigging attachments are greater when the ship is rolling and strong winds are blowing. In other words, these stresses are increased by dynamic action and therefore are a combination of dynamic and static local stresses.

285. Dynamic stresses. When a ship is among waves of length equal to its own, it changes from hogging condition to sagging condition and vice versa in the time required for the wave to advance one-half a wave length. This is a very short period of time. That is, when a ship is operating other than in still water the deck and bottom structure are subjected to very rapid reversal of stresses (from tension to compression and vice versa). The maximum stresses may be considerable (five or more tons per square inch of sectional area). The effect of this rapid reversal of stresses on the structure is equivalent to that of a static stress of greater amount. The effect of the dynamic action of the waves, therefore, is to produce a virtual increase in the stress computed on the assumption that the wave is stationary.

Another source of dynamic stress has already been mentioned, viz., pressure loads forward due to the ship's motion ahead. The thrust of the propeller also produces local dynamic stresses in the vicinity of the thrust bearing. The variation of pressures forward when a ship is pitching may set up panting in the plating forward. Panting is a small in-and-out working of the plating at the bow. The method of preventing panting is shown in Fig. 213. Stresses due to rolling and pitching have already been mentioned. The important thing to remember is that while the stress due to longitudinal bending is usually the greatest single and therefore most important structural stress, it is not the whole stress by any means.

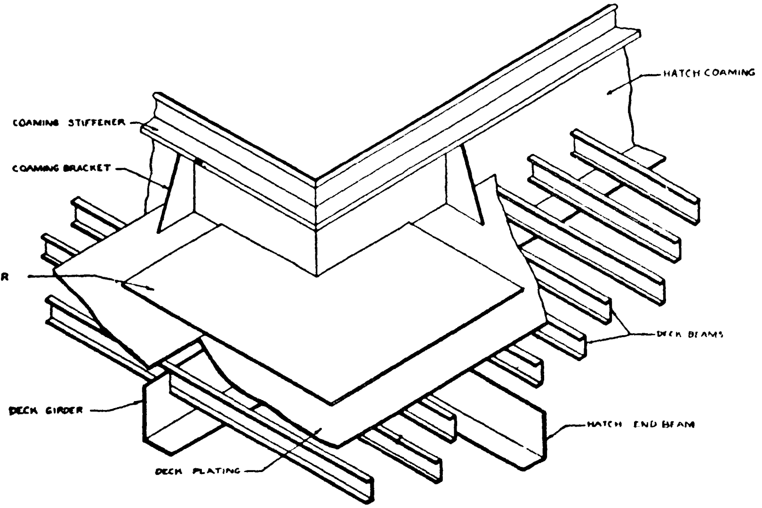


Fig. 257. Hatch Structure

286. Continuity of strength members. In order that the strength members of a hull should perform their function, it is essential that they should form continuous closed rings. There must be no break in their continuity. Where there is any discontinuity in the member, such as due to hatchways in the deck, measures must be taken to carry the stress in some other way. Compensation for a hatchway often consists of doubling the plating at the corners, as shown in Fig. 257.

In addition to avoidance of discontinuity in any structural member, it is important to proportion such members to the stresses they must carry. The variation of stress intensity in the side plating of a ship in hogging condition is indicated in Fig. 258. It is almost as important to avoid giving a member too much strength as too little, because redundant strength may be a positive source of weakness. A disproportionately strong member shirks its load and throws it upon the adjacent relatively weak member, which may reach the point of failure before the strong member is subject to any appreciable stress. Considerations of economy as well as good structural design both dictate the proportioning of the size and weight of strength members to the loads they must carry in service.

287. Nature of stresses in important structural members. Although the stress in the deck and bottom structure is subject to rapid reversals, the stress across any particular section at any instant is fairly uniform. This is not true of the side plating, however. At an instant when the ship is in hogging condition, the tension in the upper half varies from that in the deck plating to zero, while the compression in the lower half varies from zero to that of the bottom plating; see Fig. 258. In other words, the stress on the side plating, at any instant, varies uniformly from top to bottom. Further, the stress at any point changes its nature, i.e., from tension to compression, etc., in the same intervals of time as the deck and bottom. The uniform variation of stress in the side plating, resulting in a tendency of one strip of plating to slide past the next, is called **longitudinal shear,** and constitutes the severest stress in the sides of a ship. Maximum values occur at about the half depth of the ship at the quarter lengths. Most classification societies require additional riveting in these regions.

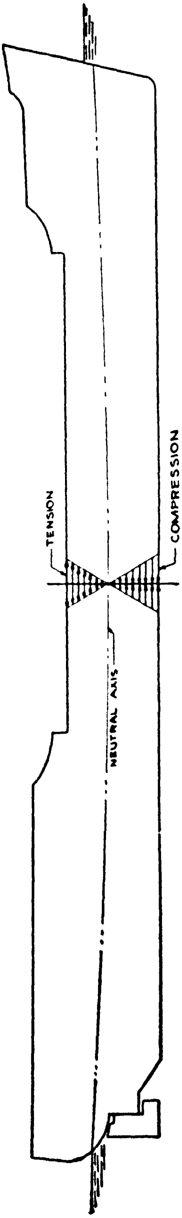


Fig. 258. Variation of Stress in Side Plating

The plating, which transmits the tensile stresses in the bottom and deck to the side plating and converts these tensile stresses into shear stresses, is itself subject to considerable intensification of stress and, therefore, is usually heavier than adjoining plating. The plating involved is the outside strake of deck plating (called the deck stringer), the top strake of side plating (called the sheer strake), and the strongly curved strake of plating at the turn of the bilge (known as the bilge strake). Fig. 259 shows the method of providing adequate continuity at the end of a superstructure.

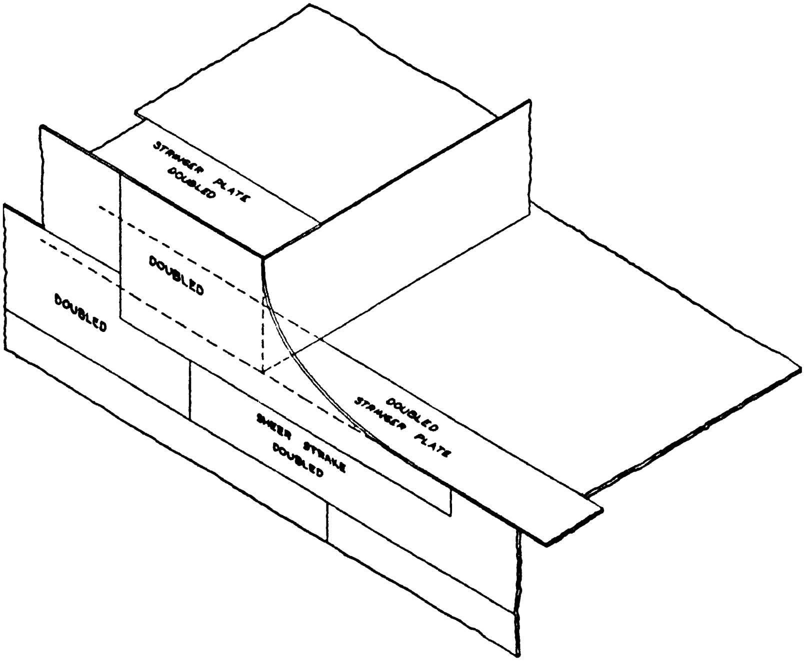


FIG. 259 Strengthening at End of Superstructure

QUESTIONS

281. Define stress, strain, tension, compression, shear.

282. How are the stresses to which a ship is subject classified?

283. Define longitudinal bending, hogging, hogging condition, sagging, sagging condition.

284. State the nature of stresses in the deck and bottom; at what point in the ship's length do they have their greatest value?

285. State the nature of stresses in the side plating and the areas of maximum stress.

286. Discuss continuity of strength members and proportioning the size of structural members to the computed stress.

CHAPTER 3

HULL EQUIPMENT AND SYSTEMS

Section 31. Hull equipment and fittings. *Arts.:* 311. Equipment required. 312. Anchor gear. 313. Steering gear. 314. Cargo handling gear. 315. Boats and boat handling gear. 316. Mooring, warping, and towing gear. 317. Hull fittings.

311. Equipment required. The equipment which must be carried by merchant ships includes: (1) the anchors, anchor chain, hawse pipes, compressors, stoppers, and anchor windlass or capstan. (2) steering gear, steering engine, control gear and rudder; (3) boats and boat handling gear; (4) mooring, warping and towing gear; (5) compasses and other navigational equipment. The capacity of the various items of equipment and the number of units which must be provided is based on the equipment tonnage, which may be simply defined as the volumetric capacity of the ship in tons of 100 cubic feet. Equipment tonnage is a measure of the size of the ship. Only equipment which has been approved as to capacity and design by the Bureau of Marine Inspection and the American Bureau of Shipping may be installed. Before installation, all equipment is inspected at the place of manufacture. It is subsequently tested on the ship either before or during the trial trip. There is a considerable range in the price and quality of equipment which may be installed. In making a choice, the first cost must be balanced against service life, ruggedness and liability to breakdown.

312. Anchor gear. The anchor gear is composed of the anchor engine, the anchor capstan or windlass, the anchors, anchor chain, hawse pipes, compressors, stoppers, pelican hooks, chain pipes and chain locker. Fig. 301, 302 and 303 are general views of the forecastle showing this gear. Fig. 301 shows the usual arrangement of housing the anchors. Fig. 304 shows an anchor capstan driven by a steam engine, and Fig. 305 an anchor windlass driven by an electric motor. Gasoline or Diesel engines or man power may also be used for this purpose, but on large ships steam or electric drive is usual. As shown in Figs. 304 and 305 the difference between a windlass and a capstan is in the direction of the axis of rotation. A windlass has a horizontal axis, a capstan a vertical axis.

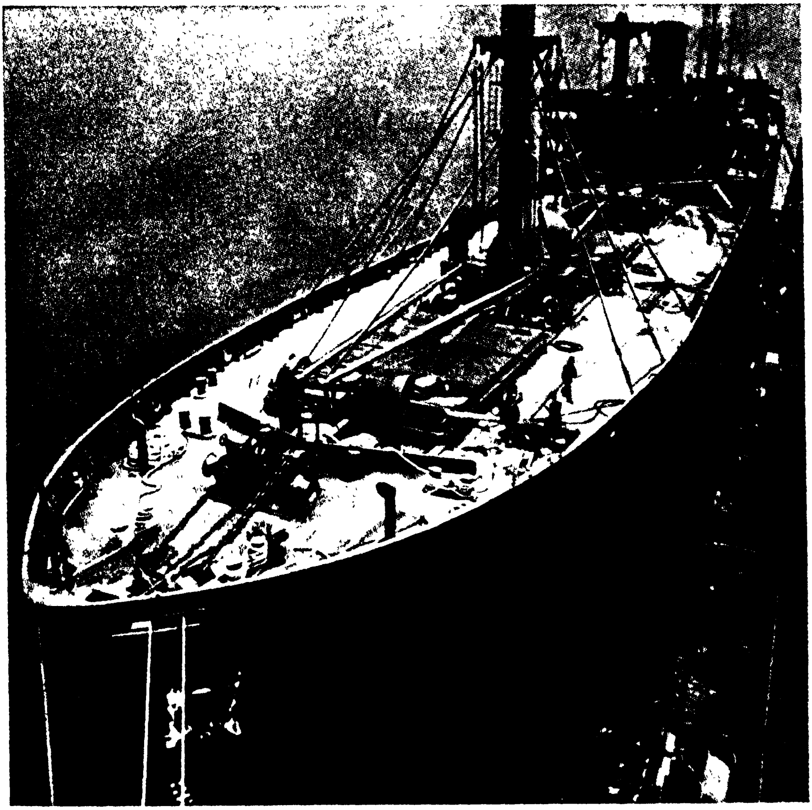


FIG. 301. General View, Forward Deck, Liberty Ship

The anchor windlass on merchant ships is usually installed on the forecastle deck as shown in Fig. 301. The drums over which the chain cable passes are known as wildcats. They have projections known as whelps which fit the links as they come over. By means of a clutch, the wildcats may be made to revolve with the shaft driven by the anchor engine or allowed to turn freely. Brakes are fitted to control the speed of the wildcats when they are disconnected by means of the clutch. When the anchor is dropped, the clutch is disconnected and the wildcat controlled by the brake. When hoisting the anchor, the clutch is connected up and the wildcat turned by the shaft. When it is desired to pay out only a few links, the engine can be walked back. The windlass must be securely bolted down and the deck beams below it are required to be of extra strength and adequately supported.

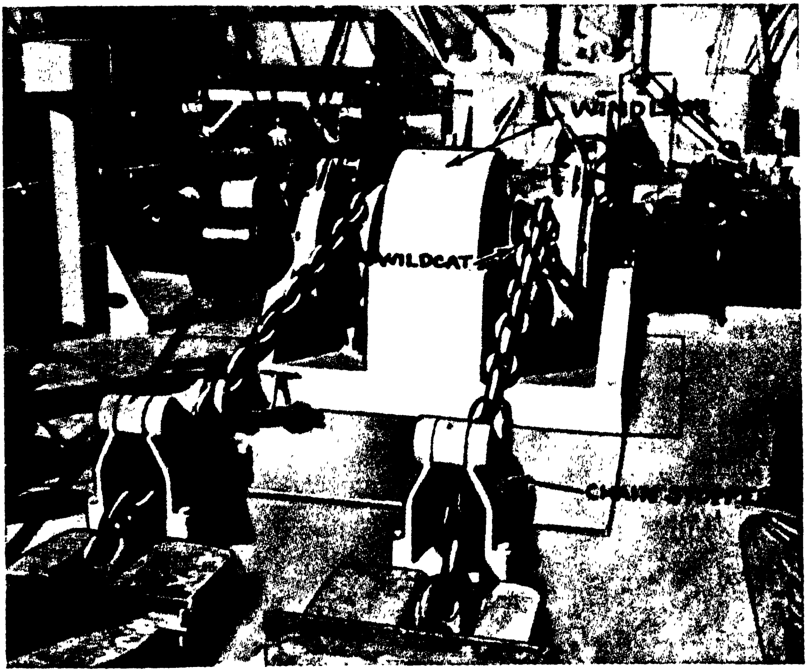


Fig. 302. General View of Anchor Gear

The number and weight of anchors which a ship must carry are given in a table of the Rules of the American Bureau of Shipping based on the equipment tonnage, defined in Art. 311. In general, a ship must carry two bower anchors, one spare bower and a stream anchor. The anchors may be ordinary anchors with stocks or patent stockless anchors. If an ordinary anchor is used, the tabular value of the weight is without the stock, but the stock must weigh 25 percent of the tabular weight. Weights of stockless anchors are in general the

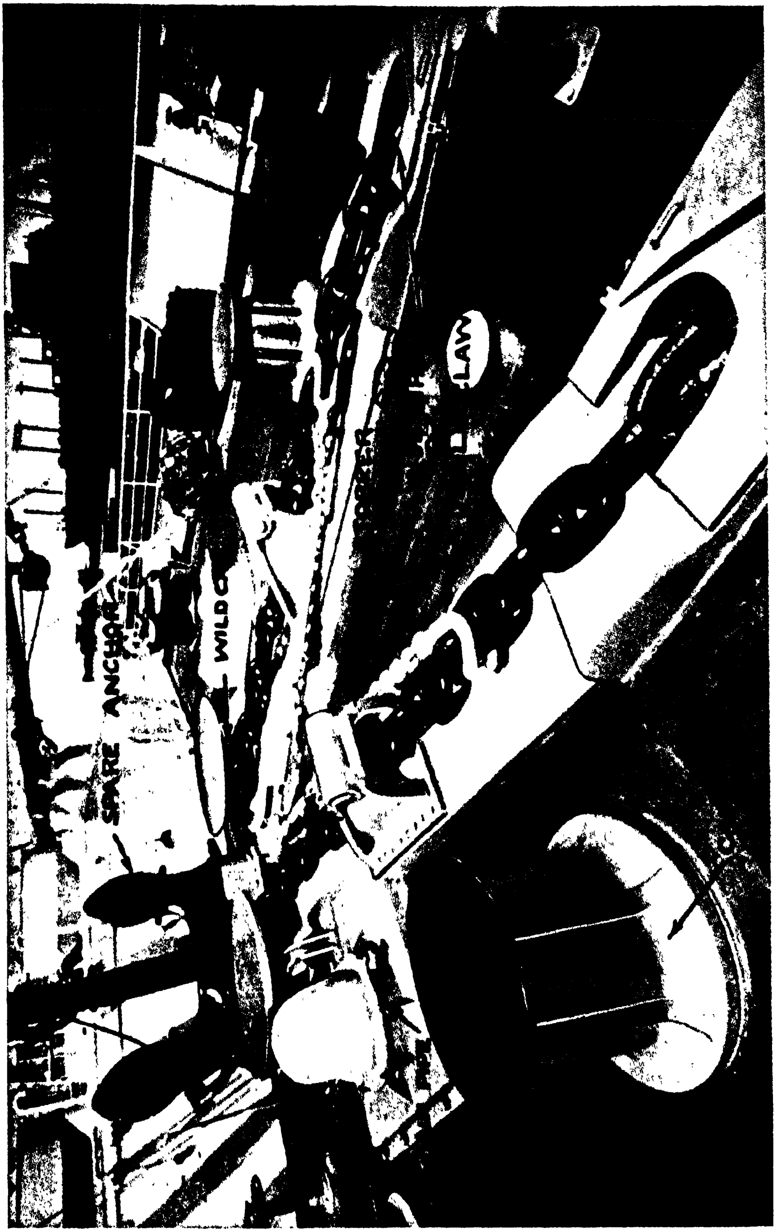


Fig. 303. General View of Anchor Gear

same as ordinary anchors including the stock so that there is no advantage from a weight standpoint in either one. Sixty percent of the weight of a stockless anchor must be in the head.

The anchor chain is frequently called the anchor cable, probably because with early sailing ships a cable laid rope was used to secure the anchor. Until a generation ago anchor chains were almost universally wrought iron, hand welded links. During the last 25 years, first cast steel, and later alloy steel, di-lok anchor chain were developed and are now in use and have almost completely taken the place of wrought iron chain. The sizes of the chain cables and their lengths are based on the equipment tonnage. The dimensions of the various types of links and cable fittings, the proof and breaking stresses, and details of manufacture are covered fully in the American Bureau Rules.

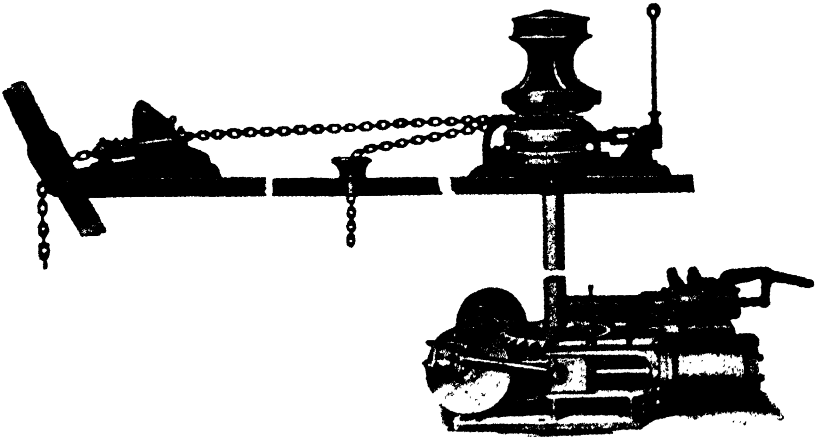


FIG. 304. Steam Driven Anchor Capstan

The pipe through which the anchor chain passes from the anchor windlass to reach the water is called the **hawse pipe.** The compartment in which the anchor chain is stowed is the **chain locker.** The pipe through which the chain passes between the windlass and the chain locker is called the **chain pipe.** Chain pipes are similar to hawse pipes but need not be as strong, particularly since the chain has a vertical drop from the windlass to the chain locker. Hawse pipes are required to be of ample size and strength. If they are used for stowing stockless anchors, the latter must be shipped and unshipped in the presence of a surveyor to demonstrate the certainty that they will not jam and fail to drop when released. The hawse pipes must have full round flanges and an easy lead to avoid probability of nipping the anchor chains. The securing to the hull must be ample and the hawse pipes must be tested for watertightness.

The ends of the anchor chains are usually made fast in the top of the chain locker in such a way that the securing will part before the tension on the chain will be great enough to part it or wreck the structure. The chain locker is like a deep tank.

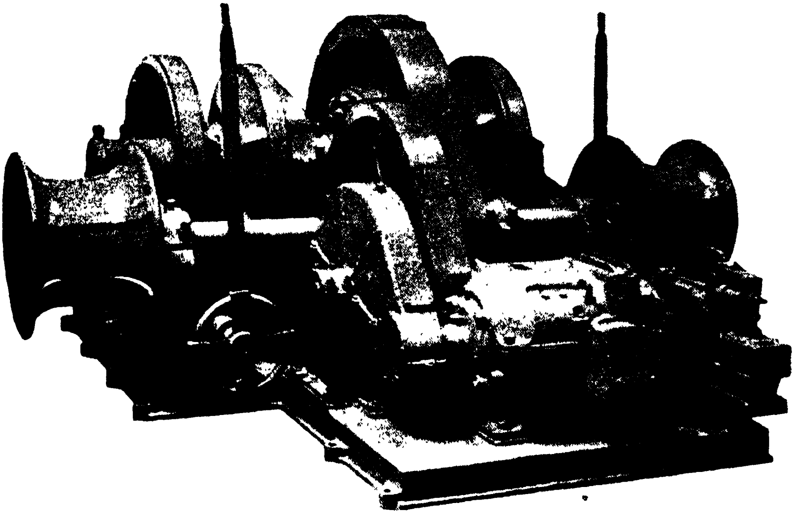


FIG. 305. Electric Driven Anchor Windlass

An anchored ship may ride to her anchor simply with the chain over the wildcats and brakes set up hard. This, however, is not usual on account of the possibility of damage to the windlass or capstan. It is more general either to take a turn with the cable over the drum of the windlass or capstan or riding bitts installed for that purpose, or to make the chain fast to lugs on the deck by means of short lengths of chain and pelican hooks. The latter method makes it possible to release the anchors very quickly.

For the purpose of controlling the cable in veering or heaving in, various devices known as stoppers or compressors are frequently installed on the forecastle; see Figs. 302 and 303.

313. Steering gear. The steering gear consists of the control gear, steering engine, steering mechanism and rudder. The control gear is the device for starting and stopping the rudder movement. The steering engine supplies the power for putting the rudder over and the steering mechanism moves the rudder. Movement of the rudder causes the ship to change heading.

The regulations of the Bureau of Marine Inspection and Navigation require that the steering gear is to be constructed and inspected in accordance with the rules of the American Bureau of Shipping; also that all ships more than 250 feet long must have a power operated main steering gear and a power or manually operated auxiliary steering gear. The main steering gear must be capable of moving the rudder from hard over to hard over in 30 seconds with the ship at full speed ahead. The auxiliary gear must be capable of moving the rudder from hard over to hard over in 30 seconds with the ship moving ahead at half speed or 7 knots, whichever is greater.

Other requirements regarding the steering gear are: the main steering gear is to be under cover on ocean-going vessels and the auxiliary gear sufficiently protected to permit operation in bad weather; the steering gear is to be thoroughly tested after installation, preferably on the trial trip.

The control gear includes that wide range of devices by means of which the movement of the rudder is controlled, i.e., those by which the ship is steered. Originally, and even today in small boats, the control gear was a tiller fastened to the rudder at its upper end. Later the steering wheel was introduced. Turning the steering wheel takes up on a rope leading to one side of the tiller and at the same time pays out on a rope leading to the other side, thereby turning the rudder. When the size and speed of ships reached a point that hand steering was no longer practicable, wheels and wheel ropes continued for a long time to be used to actuate the steering engine, primarily because seamen were used to them. Other types of control gear which have been, or are, in use are: shafting and gears, hydraulic telemotor, electric switch gear and, most recently, the gyro pilot, sometimes called metal mike.

It is now required on ships of United States registry that the steering wheel, rudder indicator, and tell-tale all turn in the same direction as the ship's head. Formerly, practice varied widely in this respect and was very confusing. All mechanical leads are required to be as direct as possible and protected against mechanical damage. The means of shifting from one steering gear to another must be capable of quick operation and clearly indicated and so interlocked that one gear cannot be operated while another is being used. The steering wheel at the forward station is required to be so located that the helmsman can see ahead and on both bows. The emergency steering wheel is located aft on the weather deck with the helmsman facing forward.

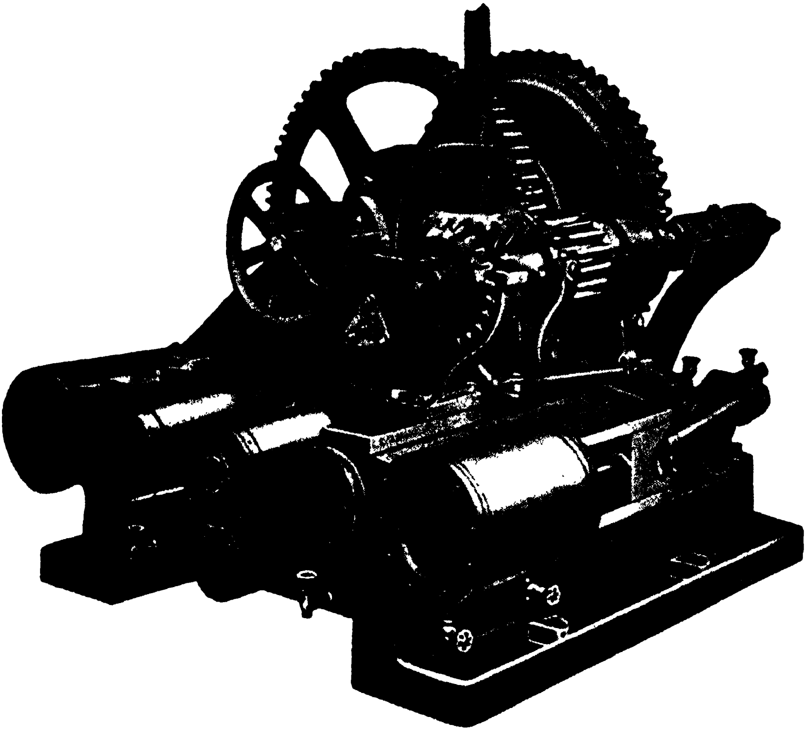


Fig. 306. Steam Steering Engine

The first steering engines were steam engines. In the last 25 years, electric motors have come into common use for operating the steering mechanism and recent installations have been mostly of the electric hydraulic type. Fig. 306 shows a steam steering engine and Fig. 307 an electric hydraulic mechanism. In the latter type, an oil pump is driven by a constant speed electric motor. Operation of the control gear causes this oil pump to force oil into one end of the hydraulic ram and suck it out of the other end. In this way the hydraulic ram is made to move. Other types of prime movers occasionally employed for the steering mechanism are air motors and steam turbines, or power from a nearby winch. The regulations of the Bureau of Marine Inspection require that the steering engine be housed below decks or in a substantial deck house. It must be fitted with stops to shut off the power before the rudder comes against the limit stops.

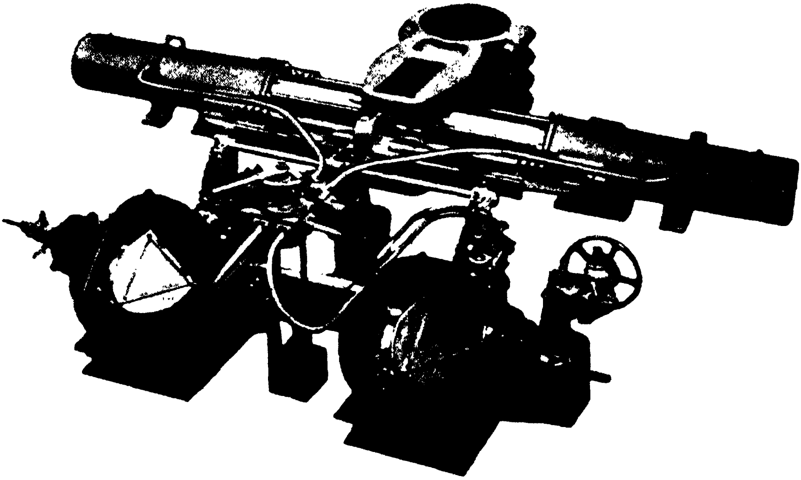


FIG. 307. Electric Hydraulic Steering Gear

The steering mechanism is the device for transmitting the energy of the steering engine to the rudder. The earliest type of steering mechanism, still used widely, is rope or chain secured to a tiller or quadrant on the rudder stock. The action of the steering engine takes up on one rope and pays out on the other. By means of sheaves and fairleads, this motion is transmitted to the tiller or quadrant, thereby turning the rudder stock. Strong buffer springs must be placed in the line near the tiller to relieve the ropes or chains of sudden pulls which might break them. This type of steering mechanism is shown in Fig. 308. One of the hydraulic ram types of steering mechanism is shown in Fig. 307. There are many other variations of the electric hydraulic gear. On some ships the steering engine is mounted at the quadrant on the rudder stock which it turns by means of worm or spur gearing.

The shapes of rudders which are likely to be found on any ship are shown in Figs. 309 and 705 to 710. Fig. 309 is the usual shape for single screw cargo ships. From the standpoint of strength we may consider that a rudder is composed of the stock, frame, pintles and crosshead, tiller or quadrant. The stock is the heavy steel shaft, usually vertical, which turns the rudder on its pintles. The stock is made in two parts joined by a bolted flange just outside the hull, so that the rudder can be "unshipped" or removed in dry dock. The frame consists of the lower stock, arms and blade. If the rudder is a simple plate rudder, the arms are simple forgings, keyed to or shrunken on the rudder stock and fastened to the blade, usually alternately on opposite sides. If the rudder is streamlined, the arms are shaped so that when the plating is secured to them it will have the desired thickness and contour. Unless the rudder has sufficient thickness to allow a man to get inside, only the plating on one side can be riveted, that on the other side must be secured by screws called tap rivets, or by weld-

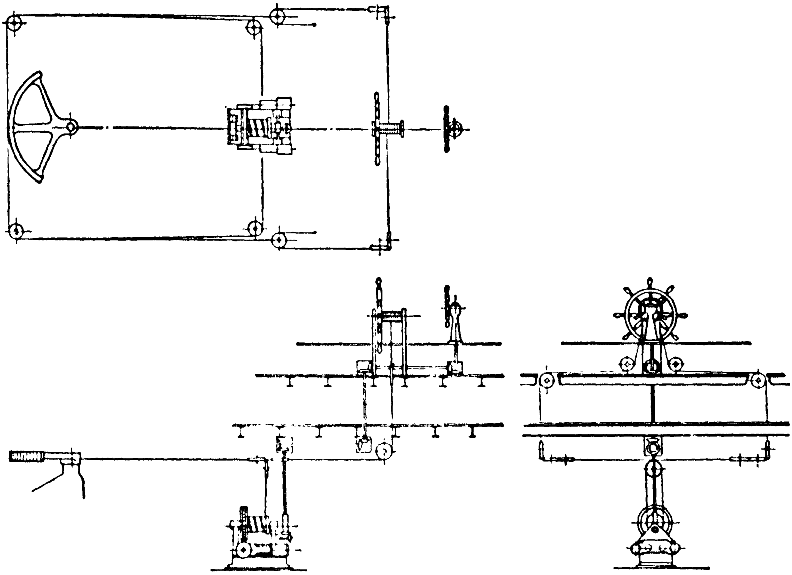


FIG. 308. Tiller Ropes

ing. In some cases an all-welded rudder may be used. The interior of hollow rudders must be well coated with paint or other preservative. The space inside a double plate rudder may be filled with some material which is lighter than water, such as soft pine or paraffin wax. The pintles are the pivots on which the rudder turns and must be strong enough to stand the pressure loads when turning with full rudder at full speed. Stops to limit the rudder angle must be fitted on the hull. The weight of the rudder is usually carried by a bearing in the hull.

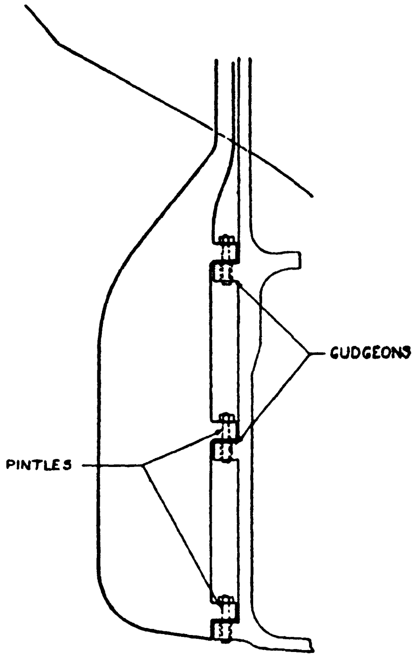


Fig. 309. Unbalanced Rudder

Means must be provided for holding the rudder amidships if the steering engine breaks down. A substantial band brake is generally provided for this purpose. Electric contacts are provided on the quadrant to indicate to the helmsman the exact angle of the rudder at all times.

314. Cargo handling gear. The cargo handling gear of a general cargo carrier consists of: (1) cargo winches, (2) masts or derrick posts and booms, (3) fittings for masts and booms, (4) running and standing rigging, and (5) cargo nets, slings and platforms. The Bureau of Marine Inspection requires that cargo handling gear shall be adequate in power; that the power leads shall be protected against mechanical injury and damage from water and freezing; and that the devices shall be designed to prevent injury to personnel or equipment in event of power failure or dropping of the load.

Cargo winches are installed convenient to the hatches; see Figs. 310 and 311. On recent ships, electric driven winches are the rule, although up to a short time ago the winches were usually steam driven. Fig. 312 shows a typical electric cargo winch. The lift is raised and lowered by winding up the hoisting line on the winch drum. Brakes are provided for holding the load. Electric winches have to have grid resistors. These are usually installed in resistor houses under the derrick tables.

Fig. 310. Arrangement of Cargo Handling Gear

Masts or derrick posts are required for cargo handling. These are shown in Fig. 310. They are usually made of steel plates rolled into cylindrical form. Derrick booms may be either steel plate or wood, depending largely on the lift and outreach. Derrick tables are arranged to give a convenient arrangement of booms for working cargo in and out of the various cargo hatches and over the side. The masts

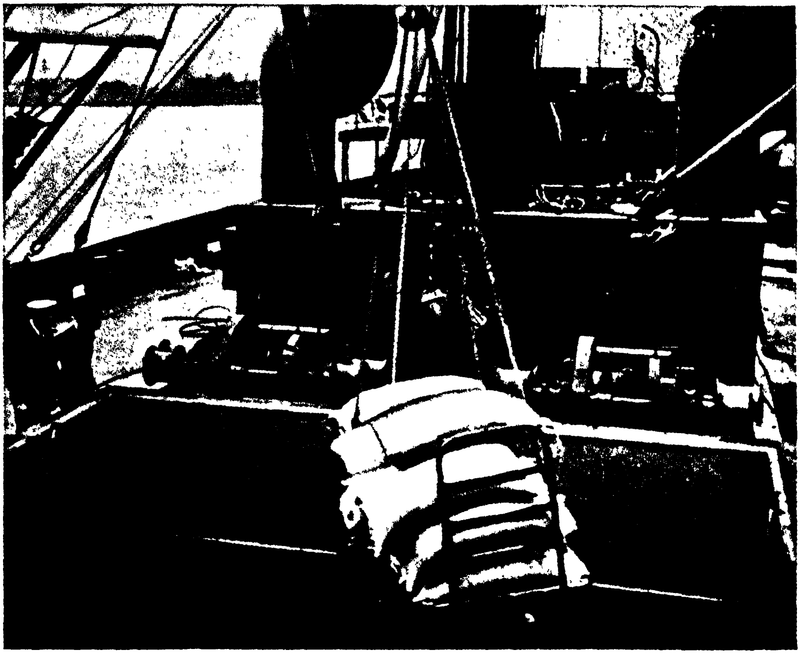


FIG. 311. Arrangement of Cargo Handling Gear

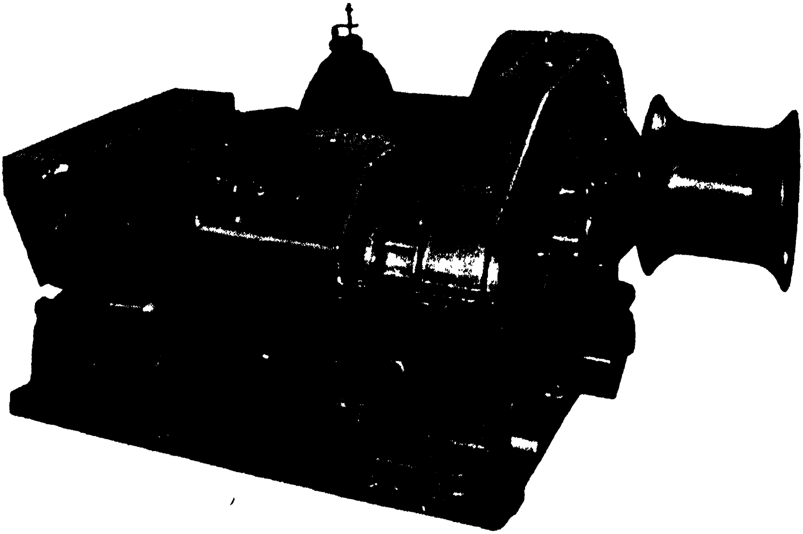


FIG. 312. Electric Driven Cargo Winch

and derricks must be properly stayed to meet load conditions and the deck structure near them must be adequately stiffened.

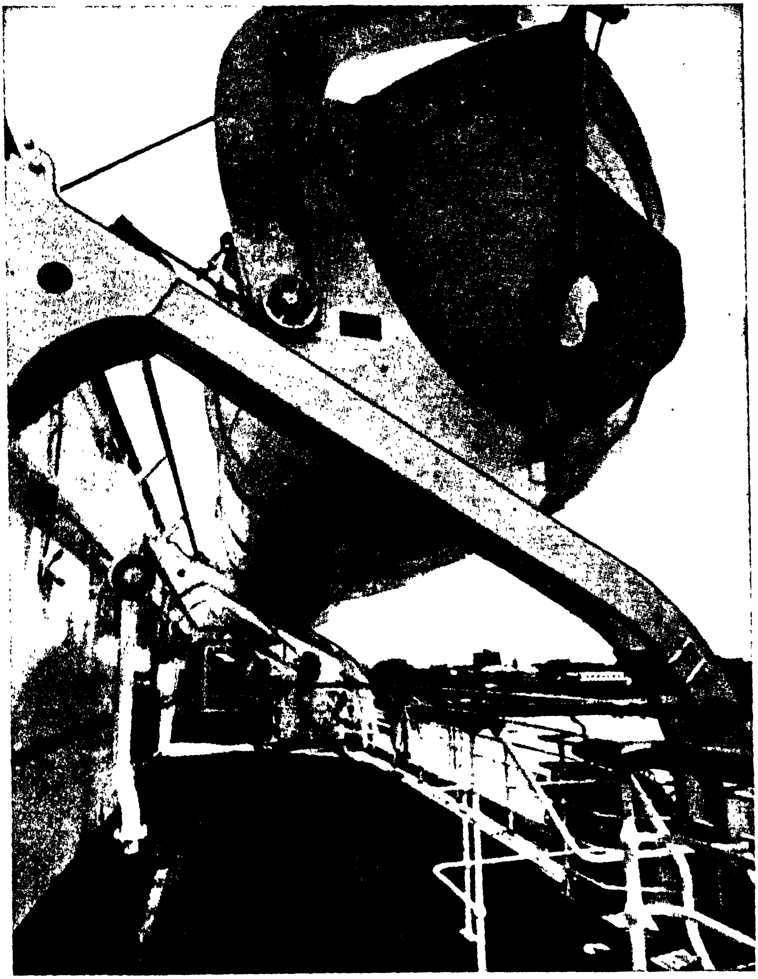


FIG. 313. General View of Boat Gear

315. Boats and boat handling gear. Cargo ships are required by the regulations of the Bureau of Marine Inspection and Navigation to have sufficient lifeboats on each side for all persons on the ship. Sea-going passenger ships are required to have a total lifeboat capacity for all passengers and crew, and other floating equipment (such as liferafts) for 25 percent of the total number on board. Each boat must be secured to its own set of davits, except that in the case of passenger ships, if all boats cannot be under davits, a second line of boats may be stowed below the boats attached to davits. If this does not meet the requirements for lifeboats, a third boat may be carried inboard, but must be capable of being lowered over the side without first being lifted.

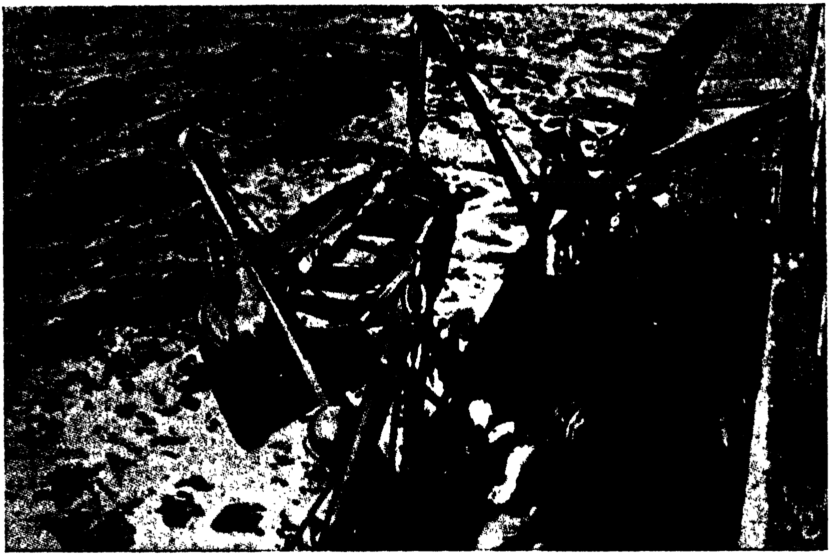


FIG. 314. Launching a Lifeboat

The capacity of open life boats is based on 10 cubic feet per person. Boats having a capacity of more than 60 persons are required to be driven by a hand-operated propeller instead of oars. Ships carrying more than 13 lifeboats must have one motor propelled. The details of construction and outfit are given at considerable length in the regulations. Tests of the equipment are conducted after installation and before the ship goes into service and periodically thereafter. The davits must be capable of hoisting out the boats when the ship is listed 15 degrees or has a 4-degree trim by head or stern. Figs. 313 and 314 give a good idea of this equipment.

316. Mooring, warping and towing gear. Warping capstans and winches come in a wide variety of forms. Two types are shown in Figs. 315 and 316. They are, as their name suggests, for the purpose of warping a ship alongside a pier, wharf, or quay wall. They may be hand, steam, or electric driven and if power driven may have the driving unit at the barrel or under the deck. Sometimes, drums

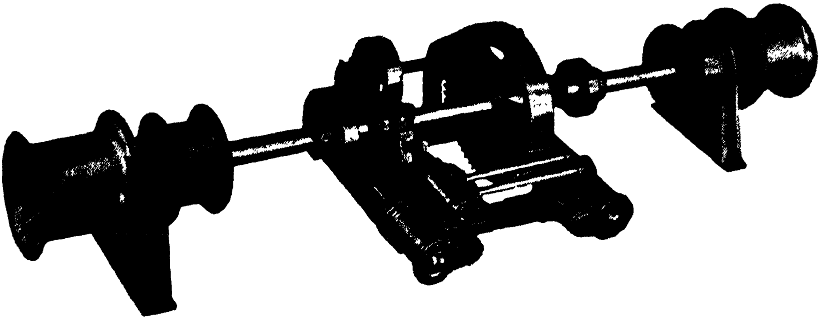


FIG. 315. Warping Winch

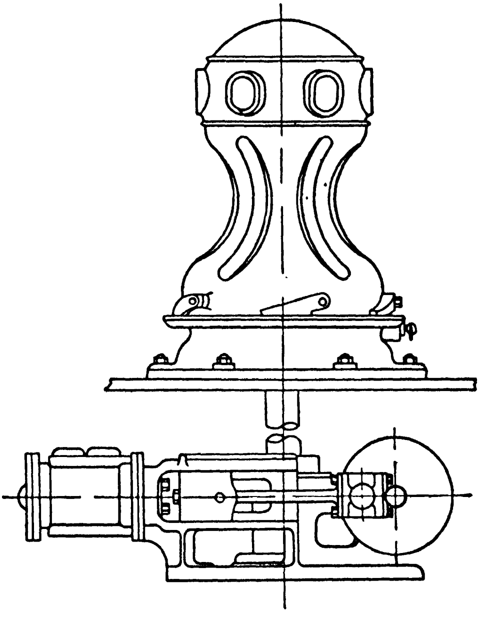


FIG. 316. Warping Capstan

are provided on an extension shaft of a cargo winch for this purpose.

Bitts for securing mooring lines and chocks for giving them a fairlead over the side should be provided along the ship's length. In very high-sided ships the chocks are simply openings in the side with a round beading to prevent chafing the lines. Those set on a weather deck consist usually of two horns with an opening between; see Fig. 317. Fig. 318 shows a pair of bitts of ordinary form. It is essential that they have no sharp edges to chafe the lines.

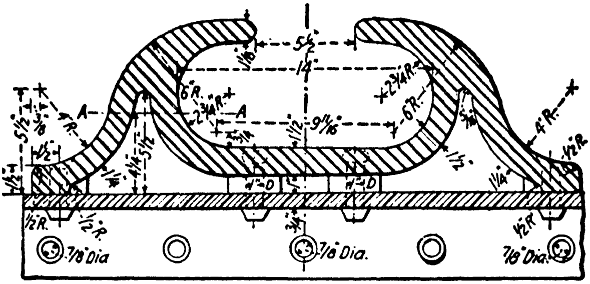


FIG. 317. Chock

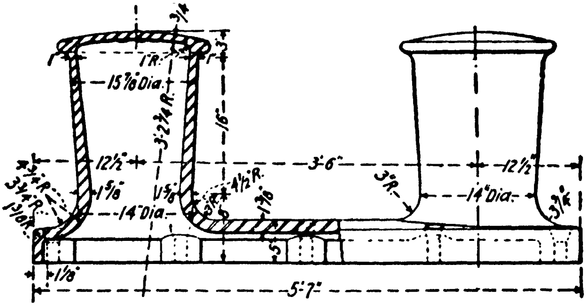


FIG. 318. Bitts

The chock and bitts shown in Figs. 317 and 318 are castings. Recently, weldments have also been used for this purpose. The general appearance is similar to that shown in the figures. Chocks are sometimes fitted with rollers, horizontal, vertical, or both, to reduce chafing. The regulations of the Panama Canal require that ships desiring transit must have closed roller chocks at the bow and stern for towing, and bitts conveniently located.

Towing vessels, such as sea-going tugs, frequently have towing engines either steam or electric operated. All ships should have towing bitts and chocks, because no one can tell when he may be called upon to take a disabled ship in tow, or may have to make port on the end of a towline himself. Automatic towing engines pay out or haul in the towline as the tension varies and under steady conditions keep out a constant scope of towline.

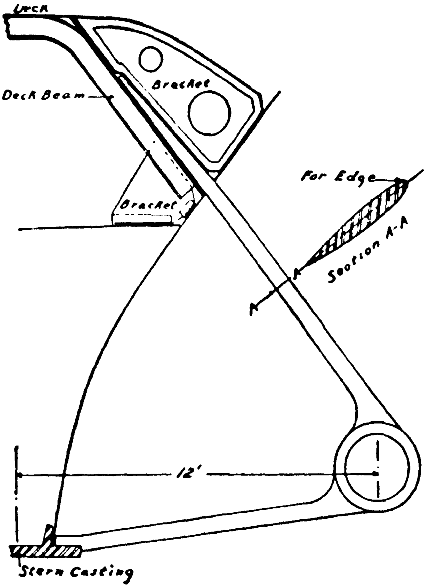


FIG. 321. Propeller Shaft Struts

317. Hull fittings. On ships with single bottoms, close ceiling, 2 to 2½ inches thick, must be laid on top of the floors on the flat part of the bottom, capable of easy removal for inspection of the bottom. In double bottom ships, ceiling is required only under the hatchways.

Sparring about 10 inches wide and 2 inches thick must be fitted on the sides of all holds carrying general cargo. It is usually installed in cleats attached to the reverse face of the frame. No sparring is required in coal bunkers or in the holds of bulk carriers.

Ships having two screws cannot have both of the propeller shafts on the centerline. These shafts must be supported after they leave the fairline of the hull. Merchant ship practice has been to build out a bossing called the spectacle frame to carry these shafts. Naval practice has been to fit cast steel struts. Spectacle frames show less resistance to the water flowing past and permit ready access to the shafts but are heavier than shaft struts, which are shown in Fig. 321.

The ability of bilge keels to reduce rolling has been thoroughly proved. They are therefore fitted on practically all ships at the turn of the bilge extending from 50 to 75 percent of the length of the hull; see Fig. 201. Bilge keels usually consist of a plate about 12 or more

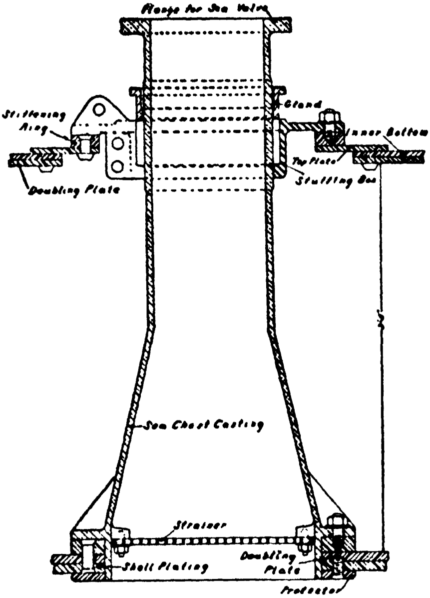


FIG. 319. Sea Chest

inches deep standing at right angles to the shell plating and secured to it by double angles.

Sea valves must be so placed as to be easily worked from the engine-room platforms. When they make connection with the sea through the double bottom or otherwise so that they would require a long neck if fastened directly to the shell, they are attached to sea chests which are secured on the inside of the shell plating. Frequently a strainer is provided over the opening in the shell to prevent the entry of foreign matter. Sea cocks and valves fitted direct to the shell must be secured with tap bolts or bolts with countersunk heads tapped through the plating. This is to eliminate the possibility of some object striking the head of a bolt and starting a leak through the shell. Fig. 319 shows a sea connection through the inner bottom; those outside the double bottom space are similar but simpler.

QUESTIONS

311. What are the component parts of the steering apparatus and what are the functions of each?

312. Describe the rudder structure of a single plate unbalanced rudder.

313. Tell what each of the following is: stockless anchor, hawse pipe, chain locker, chain pipe.

314. Describe the anchor engine and windlass.

315. Describe the cargo handling gear on a cargo carrier, including derricks, booms and cargo winches.

316. Tell briefly the functions of each of the following: boat davits, bitts, and chocks, and give a brief description of each.

317. Name and describe briefly the outboard fittings of merchant ships.

Section 32. Hull systems. *Arts.:* 321. General. 322. Fire protection systems. 323. Water systems. 324. Oil systems. 325. Ventilation and air conditioning systems. 326. Engineering systems outside of machinery space.

321. General. The hull systems of a ship include the systems for the detection and extinguishing of fires, the drainage and ballasting of the ship, the sanitary systems, cargo oil system, and air conditioning and ventilation systems. In addition, in this chapter there is given a brief discussion of the fuel oil system and the communicating systems, but the systems having solely to do with the operation of the propelling machinery are not described or discussed.

There are three general forms of systems, known respectively as the loop, herringbone, and multiple types. Each of these forms has certain advantages as well as certain drawbacks. The choice of type depends, therefore, upon the service to be furnished and consequently the relative importance of the advantages and disadvantages. A loop installation consists usually of one main on each side of the ship with cross connections at the ends, forming a closed loop. The advantages of this form are its ability to withstand damage, its extreme flexibility and comparatively low cost. The principal drawback is the large number of watertight partitions which must be pierced. It is widely used where penetration of watertight members does not forbid it.

The herringbone (also called Christmas tree) installation consists of one main in the center of the ship with branches to various connections. This type is generally somewhat cheaper to install than a loop system and the main (being well removed from the sides of the ship) is better protected against damage. Its principal drawbacks are its inflexibility and the fact that damage to the main puts a large part of the system out of commission.

The multiple installation consists of a number of small systems of limited extent and relatively small capacity, each serving only a particular part of the ship. The advantages of this type are in the small number of watertight members which must be penetrated and the fact that damage affects only a small part of the entire system. Its disadvantages are that it is heavier and more costly than the loop or herringbone types, it is inflexible in operation, and damage to a part results in complete discontinuance of service in the damaged location.

On account of its greater weight and cost, it has relatively little application on merchant ships, but because of its ability to survive damage and the freedom from passage through watertight partitions, it finds considerable application on naval ships.

Spaces for the carriage of liquids must have overflows. Overflow pipes have their discharges above the load waterline where they can be plainly seen.

To permit the escape of air when a tank is filled and to admit the air when it is emptied, a vent from the top of each tank is provided. The overflow pipe may generally be used as an air escape. Vents from tanks containing gas-forming liquids terminate in return bends well above the weather deck where there is little chance of ignition, and they are generally covered by wire gauze.

All compartments below the load waterline should be capable of being sounded, especially those designed for the carriage of liquids. Sounding pipes should have a vertical lead from the lowest part of the tanks and the upper end should be above the bulkhead deck. The sounding pipe is usually closed by a pipe plug at the top and a striking plate is required in the tank under its lower end.

322. Fire protection systems. Passenger ships are required to maintain a fire patrol between 10 P.M. and 6 A.M. The interval between visits of the patrolman is one hour if automatic detecting devices are installed in the public spaces, otherwise 20 minutes.

Passenger ships are required to have bright red fire-alarm boxes at various locations in the ship. Both passenger and cargo ships are required to have general alarm gongs. The sounding of the alarm gongs is a signal for all the crew members to repair to their stations and the passengers to proceed to their embarkation stations.

The fire extinguishing systems on passenger ships include the usual water system, automatic sprinklers, and smothering systems. The water system consists of the fire pumps, fire mains and risers, fire hydrants and fire hose and nozzles. The number and capacity of the fire pumps depend upon the size of the ship. The requirements are that every place on the upper decks must be within reach of hose from two hydrants; one hose to be not over 50 feet long. Fire hose is not to be used for any other purpose. Smothering systems for oil fires and other highly inflammable material may use steam, carbon dioxide gas, or foam. Smothering is the most effective means of extinguishing such fires. Fig. 322 shows the smoke detector cabinet; Fig. 323 the controls; and Fig. 324 the gas supply for the smothering system.

Cargo ships are required to have a water system with pumps, mains, and hydrants but the capacity of the pumps does not have to be as great as on passenger ships. All cargo spaces, machinery spaces, oil tanks, and spaces containing inflammables must be provided with a smothering system using steam or carbon dioxide.

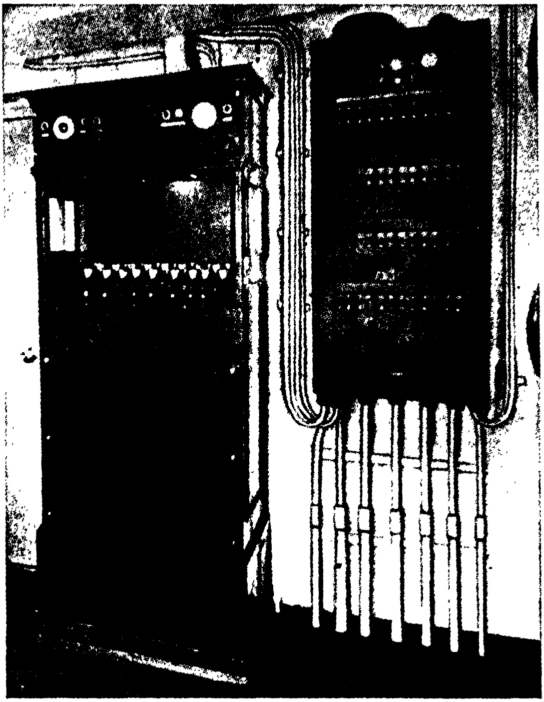


Fig. 322. Smoke Detector

In addition, all ships are required to have portable fire extinguishers and fire axes distributed throughout the occupied spaces of the ship. Boiler rooms of oil burning ships and machinery spaces of Diesel ships must have a supply of sand handy. Ships must also carry rescue breathing apparatus and flame safety lamps.

323. Water systems. The water systems of a ship comprise the bilge system for drainage below decks, the gravity drainage system, the ballast system, and the sanitary systems. The purpose of the bilge system is to rid the ship of small amounts of water which find their way to the bilges from leakage through the shell or deck plating, steam and water pipes, etc.

In accordance with the regulations of the 1929 Convention on Safety of Life at Sea, all ships must be provided with such a bilge system which can drain any watertight compartment whether the ship be erect or listed. Not so long ago certain compartments were not required to have any means of drainage at all. In ships over 300 feet long, two independent power-operated bilge pumps must be provided, one of which must be a submersible pump having a source of power above the bulkhead deck. Formerly, hand pumps, which were seldom actually used, were permitted for this purpose. Power-operated pumps must be located in separate compartments which are not liable to be flooded by one under-water damage. The main circulating pumps must have bilge suctions direct from the lowest drainage level of the

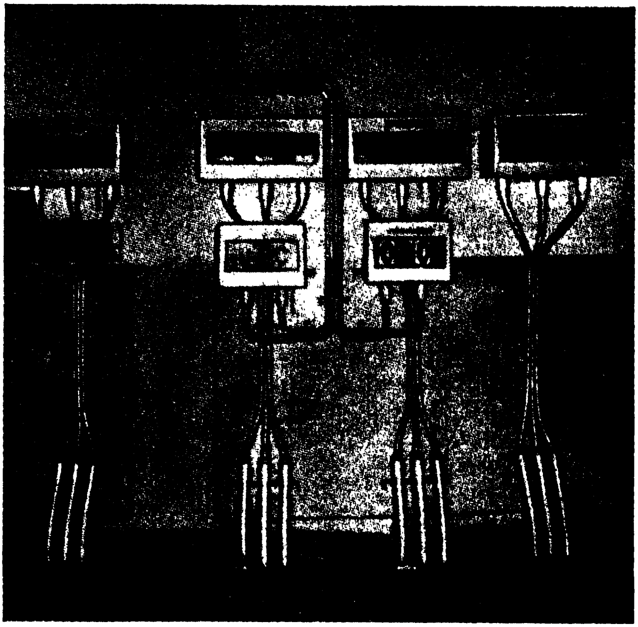


FIG. 323. Smothering System Controls

machinery space. The arrangements of the drainage piping and valves must make it impossible for water to pass from the sea or ballast tanks into cargo or machinery spaces, or from one compartment to another. The drainage system must be entirely separate from systems used for filling and emptying oil, and for water-carrying spaces.

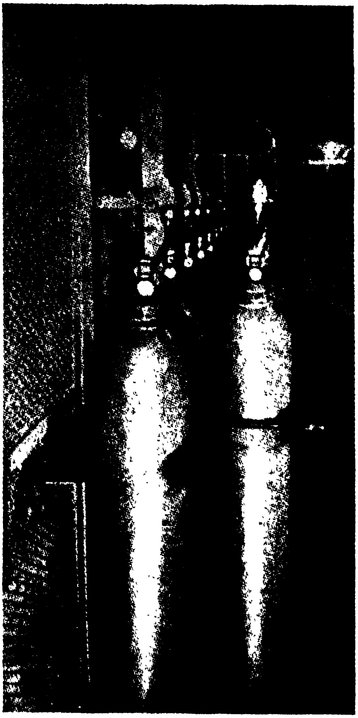


FIG. 324. Gas for Smothering System

The drainage from flat surfaces, such as tank top, machinery spaces, tunnels, etc., is from bilge wells, illustrated in Fig. 325. The rules of the 1929 Convention require that the bottom of bilge wells in the double bottom space must be at least 18 inches from the outer bottom and the inner edge of the margin plate so that they will probably not be damaged if the ship grounds.

Watertight decks, particularly weather decks, usually have a gutter or waterway to take the drainage from these decks and discharge it overboard through scuppers. Scuppers are castings which have openings in the waterway, usually protected by strainers. They discharge to pipes leading overboard through storm valves. The last is simply a flapper hinged at its upper edge, which permits the drainage water to flow out but closes when struck by seas on the outside. The number of such discharges over the side should be kept to a minimum.

Wells which are enclosed by bulwarks must have freeing ports to get rid of the large volumes of water which may fill them to a depth as great as 5 feet. Such freeing ports must have an area equal to 5 percent of that of the bulwarks. These freeing ports may be open railings or holes cut in the bulwark plating.

Most ships are provided with a system for admitting sea water to the fore and after peak tanks and double bottom tanks for the purpose of ballasting the ship to improve either stability or the trim. The ballast system may use the same pumps as the bilge drainage system but the piping must be separate from the bilge suctions.

The staterooms of officers and passengers, and washrooms of crew, galleys, hospital, etc., must be supplied with fresh water, hot and cold. The usual system is to have a small fresh-water pump operating continuously or a tank located high in the ship to keep a pressure on the system and supply cold fresh water to the various taps. Hot water is obtained by passing cold water through a heater operated by steam or electricity.

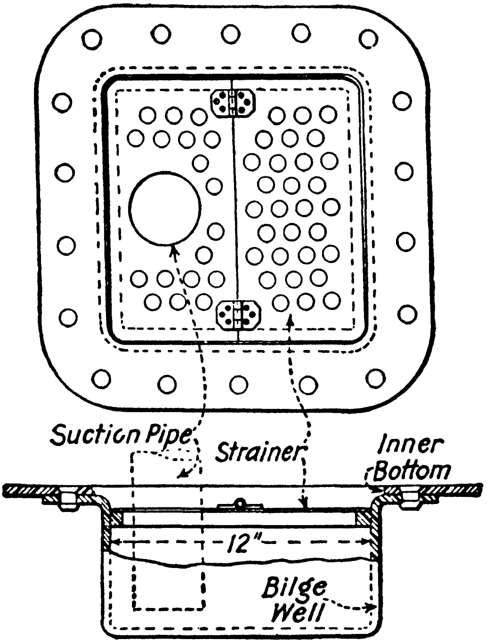


FIG. 325. Bilge Well

Potable water must be provided in the accommodations of passengers and crew, galleys, pantries and bar. The regulations require that the entire system must be approved by the U. S. Public Health Service before the ship goes into commission. On large passenger ships, cold drinking water is sometimes distributed throughout the ship; other ships have small unit coolers for providing drinking water. The tanks for drinking water must not be located next to the shell of the ship because of the danger of contamination. The tanks, pumps, and piping must be thoroughly washed out before being put into use and never used for any other purpose.

Salt water must be supplied for flushing water closets, for washrooms, galleys, etc. The usual system is to have a small pump operating continuously keeping a pressure on the system at all times.

The plumbing system discharges refuse and water from water closets, washrooms, galleys, etc. It consists of gravity drains overboard through scuppers. Special provision must be made for clearing these scuppers and cleansing them by steam.

324. Oil systems. The oil systems on a ship using oil fuel and carrying oil include the fuel oil filling and transfer system, the fuel oil service system, the fuel oil heating system, and the cargo oil system. The fuel oil filling and transfer system is the piping system (with its pumps and valves) through which the fuel is taken onto the ship, distributed to the various oil tanks, and transferred from tank to tank or overboard as required in the operation of the ship. The fuel oil heating system is used to heat the oil in the tanks and before burning. The fuel oil service system conveys the oil to the boilers or engine manifolds. The last two are strictly engineering systems and will not be further discussed here.

The fuel oil filling and transfer system has a filling connection on each side of the upper deck for taking oil from an oil barge or shore line. This leads to a manifold in the machinery space from which the oil is distributed to the various tanks. The service oil pumps take suction from the oil tanks and pump the oil through the heaters to the burners on the boilers. The spaces most commonly used as fuel oil tanks are the double bottom compartments. Occasionally, deep tanks are also used for this purpose. Oil may not be carried in a space next to a fire-room. An empty space, called a cofferdam, must be provided separating oil tanks from other spaces.

The cargo oil pumping system on tankers is the principal cargo and oil system on the ship. It consists of high-capacity centrifugal main cargo pumps, stripping pumps, and the piping and venting system. Large tankers can discharge about 15,000 tons of oil in about 10 hours. The pumps are either steam driven or if motor driven have the motors in another compartment. When the amount of oil in a tank is reduced to a small amount, the stripping pump is put into use. The stripping pumps can pump the tanks dry.

The venting system is very important and every precaution against fire must be taken in its construction. The vents from a group of tanks are usually led to a common pipe which extends to almost the top of the mast and has a flame arrester at its upper end.

General cargo carriers which have deep tanks in one or more cargo holds frequently carry oil in bulk. This is usually edible oil for making butter substitutes or soap and must be kept clean. Such ships sometimes have entirely independent cargo oil systems for handling this material. Sometimes the customer supplies portable pumps and hose for handling it to prevent possibility of contamination.

325. Ventilation and air conditioning systems. Ventilation and air conditioning systems are required in all living, working, and cargo spaces. The purposes of these systems are to supply fresh air for breathing and to keep cargo and other supplies in good condition, to supply or remove heat and moisture, to get rid of unpleasant odors, gases and vapors, and to prevent formation of mold.

There are two general methods of ventilating spaces: natural and forced. **Natural ventilation** is ventilation by the natural air currents. **Forced ventilation** is when the air currents are created by a fan. When air is forced into a compartment, the ventilation system is called a **supply system.** When a fan sucks the air out of a compartment, the system is called an **exhaust system.** Spaces in superstructure usually have only natural ventilation; passenger spaces below decks usually have forced ventilation. Forced ventilation, except for galleys, toilets, and hospital spaces, is usually of the supply type. The draft for the operation of the boilers is generally sufficient for the ventilation of fire-rooms. Machinery spaces frequently have forced, supply, and exhaust ventilation. All holds, 'tween decks, and bunkers are required to have two ventilators placed as nearly as possible at the ends of each compartment. A ventilator must also be led into peak tanks, tunnels and other watertight compartments where gas may accumulate.

Air conditioning may be applied to a large compartment such as a cargo hold, dining saloon, lounge, etc. A few passenger ships have individual air conditioning units installed in the staterooms.

Quarters for crew and passengers must be provided with means of heating. Such heating may be by means of ordinary radiators or in combination with forced supply ventilation by passing the fresh air over heated coils.

326. Engineering systems outside machinery spaces. Formerly, all deck machinery was steam driven. The recent trend is towards electric drive on all ships except tankers. Hull auxiliaries which may be steam driven include the anchor windlass, cargo winches, steering engine, and towing engine.

The electrical systems outside of the machinery space are the power system, lighting system, communication system and emergency system. The power system operates the anchor windlass, cargo and mooring winches, boat hoisting equipment, ventilating fans, radio transmitter, steering engine, refrigerating machinery, elevators, galley, bake shop and laundry. The lighting system provides for the general illumination of the ship, individual electric fans and radio receivers and navigation lights, also usually the gyro compass. The communication system operates the fire detection and general alarm systems, telegraphs, call bells and telephones. The emergency system consists of the emergency generator, switchboard and wiring. It supplies current for emergency operation of essential illumination, radio, and navigation lights, and sometimes the steering engine in event of failure of primary source of electricity.

QUESTIONS

321. State the requirements of the 1929 Convention on Safety of Life at Sea for drainage systems below decks.

322. Describe the system for ridding of water spaces above the load waterline. What are air escapes and sounding tubes?

323. Discuss the ventilation and heating of merchant ships.

324. State the requirements of the United States for fire detection and extinguishing equipment of ships.

325. What are the sanitary systems of a ship?

CHAPTER 4

CALCULATION OF BUOYANCY AND TONNAGE

Section 41. Calculation of buoyancy. *Arts.:* 411. Principle of flotation. 412. Line drawing of ship. 413. Architectural definitions. 414. Rules of mensuration. 415. Calculation of areas. 416. Calculation of displacement. 417. Tonnage definitions. 418. Tons per inch immersion. 419. Difference in draft in salt and fresh water.

411. Principle of flotation. When a body floats in still water without any vertical motion, the force which supports the body must be equal to the weight. The force which supports a floating body is called buoyancy. By the law of Archimedes the buoyancy of a floating body is equal to the weight of the fluid displaced. Applying this law to a floating ship, we have the principle of flotation: the weight of the ship with everything on board is equal to the weight of the water displaced by the ship. From this it follows that in order to determine the weight which a ship can carry on a given draft, we must determine the weight of the water displaced at that draft and the weight of the empty ship. The weight of the water displaced by the ship is equal to the immersed volume of the hull in cubic feet multiplied by the weight of a cubic foot of water. In ship calculations the unit of length is the foot, the unit of area is one square foot, the unit of volume one cubic foot, and the unit of weight the long ton of 2240 pounds. Sea water has an average weight of 64 pounds per cubic foot and, therefore, it requires 35 cubic feet to weigh one ton. Fresh water at maximum density weighs 62.4 pounds per cubic foot, which is equivalent to 35.90 cubic feet per ton. If a ship has a volume to the load waterline of 612,500 cubic feet, it displaces $612{,}500 \div 35 = 17{,}500$ tons in sea water. Or to put it the other way, if this ship is loaded so that the total weight is 17,500 tons, it will float at the load waterline.

412. Line drawing of ship. If a ship had the form of any of the usual geometric solids, such as the sphere, cylinder, cone, prism, or pyramid, the computation of the volume of displacement would be very

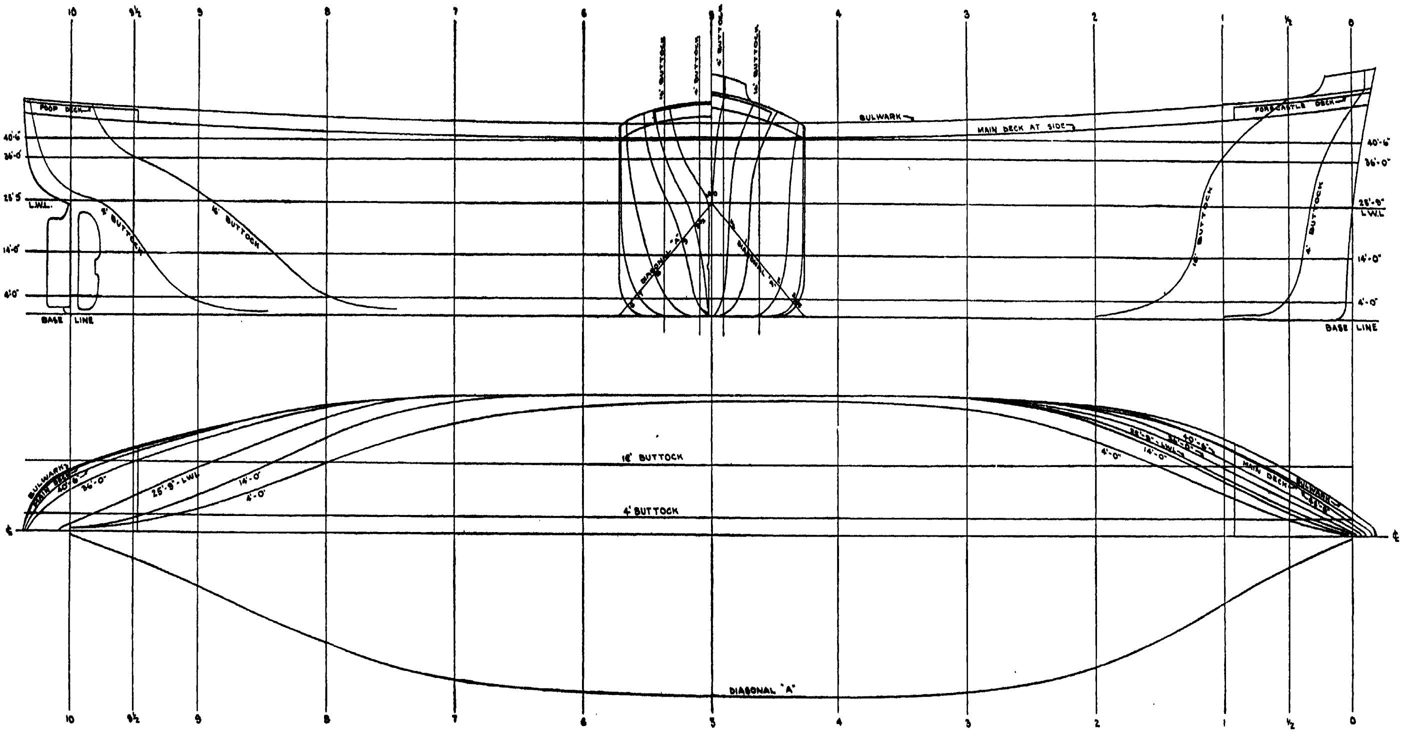


Fig. 401. Line Drawing of Cargo Ship. U. S. Maritime Commission Design C2

simple. The form of most ships is such, however, that it can only be described by a drawing. The drawing which shows the form of a ship is called the **line drawing.** Fig. 401 is the line drawing of a cargo ship, United States Maritime Commission design C-2. Fig. 402 is the photograph of a model of this ship. This model has been marked with lines and cut and photographed to show how the lines, shown in Fig. 401, are obtained for a full-size ship.

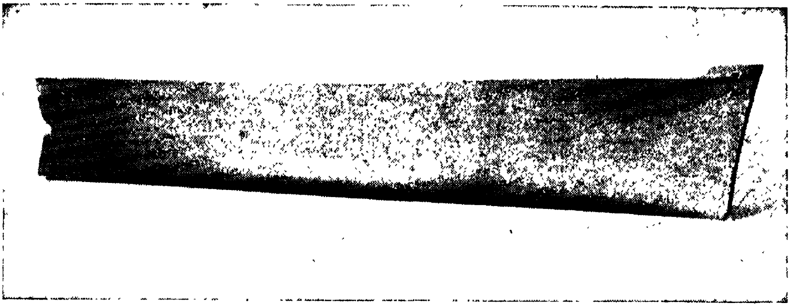


FIG. 402. Half-Model of C2 Cargo Ship

In making the line drawing of a ship, the three views usually shown for structures on shore and machine parts are not sufficient because there are large curved areas of the hull which are not adequately defined by a bow or stern view, deck plan, and profile. The ship's lines, therefore, include the shape of plane intersections of the hull at intermediate points. These may be imagined to have been obtained in the following manner. Let us first saw the wooden model, shown in Fig. 402, into pieces by cuts at right angles to the centerline. Each of these cuts will give us the shape of a plane intersection of the hull at a certain point in the ship's length. Fig. 403 is a head-on view of the model showing the saw cuts outlined in black ink and Fig. 404 is a drawing of these sections. Similarly, Fig. 405 is a stern view of the model with the saw cuts marked on it, and Fig. 406 a drawing showing the shape of the sections at these cuts. The entire series of curves for the ship are as shown in the middle of Fig. 401. It will be noted that only half of each section (except the midship section) is shown. The forward sections are drawn on the right, and after sections on the left, of the centerline plane of the ship which appears in this view simply as a vertical line. This series of curves shows how the transverse

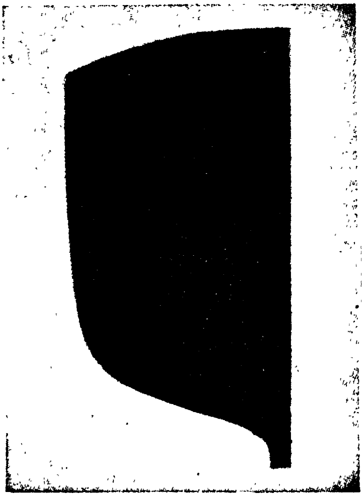


FIG. 403. After Sections (Photograph)

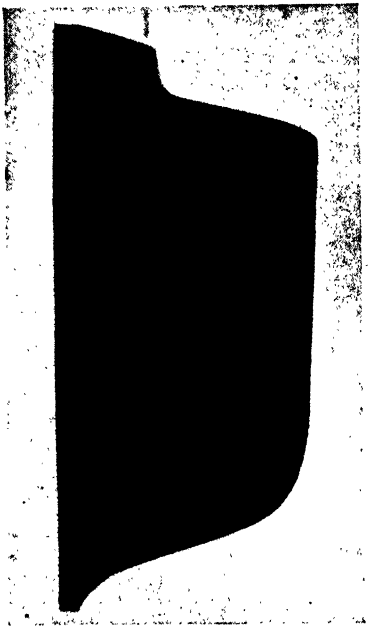


FIG. 404. Bow Sections (Photograph)

FIG. 405. After Sections (Drawing)

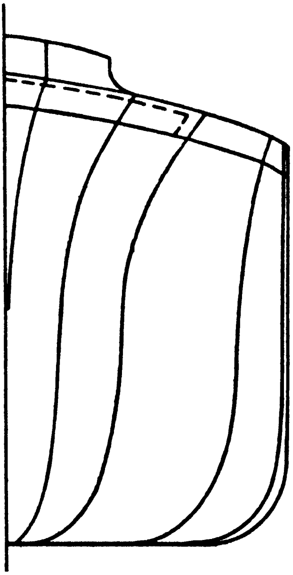


FIG. 406. Bow Sections (Drawing)

sections of the ship change shape from stem to stern and thereby give definite information of the ship's form. These curves constitute what is known as the **body plan** of the line drawing. The individual curves are called **stations.** For the purpose of this drawing, the length on the load waterline is divided into any convenient number of equal parts. The stations are numbered consecutively from forward aft; the forwardmost station, that is, the one at the forward end of the load waterline, is designated station 0 in the United States and station 1 in Great Britain. In the United States, the use of 10, 20, or 40 stations has become practically standard practice. The station at the forward end of the load waterline is called the **forward perpendicular,** abbreviated **F.P.,** and that at the after end, the **after perpendicular,** abbreviated **A.P.** See Fig. 401. The station midway between these perpendiculars is sometimes known as the **middle perpendicular,** but more commonly as the **midship section,** and is designated by the symbol ⋈ . The distance between the end perpendiculars is the **length between perpendiculars.**

Many merchant ships, particularly cargo carriers, have no change of section for an appreciable part of the length on each side of the midship section. This part of the ship is known as the **parallel middle body.** The center of length of the parallel middle body may or may not be at the midship section but in any case is not far from the midship section. The distance of the midlength of the parallel middle body from the midship section and the length of the parallel middle body are usually expressed as a percentage of the length of the ship.

Let us now assume that we can glue our model together and saw it up again, this time making cuts parallel to the load waterline, i.e., cuts perpendicular to those which gave the stations. Fig. 407 shows one such cut and the two parts of the model separated. The trace of such a cut on the hull is called a **waterline.** Fig. 408 is another photograph of the model with the traces of several similar cuts shown in black ink. Fig. 409 shows the outlines of the waterlines obtained by the cuts shown in Fig. 408. The complete set of waterlines is shown in the lower part of Fig. 401. Such a series of curves, as shown in Fig. 409, make up the **half breadth plan.** The individual curves are called **waterlines** and designated by their distance above the **base line,** (which is the zero waterline), by such designations as 14 ft. W.L. The distance between the load waterline and the base line is divided into any convenient number of equal intervals. The reason for using equal intervals is that the areas of waterlines and stations are subsequently used in calculating the volume of the ship and most of the formulas for such calculations require that the areas be equally spaced. This phase of the matter is discussed more fully in Art. 416. As in the case of the body plan, only half of the waterlines are drawn in the half breadth plan. If the entire waterline is wanted, it can be plotted by setting off the same distance on the opposite side of the centerline.

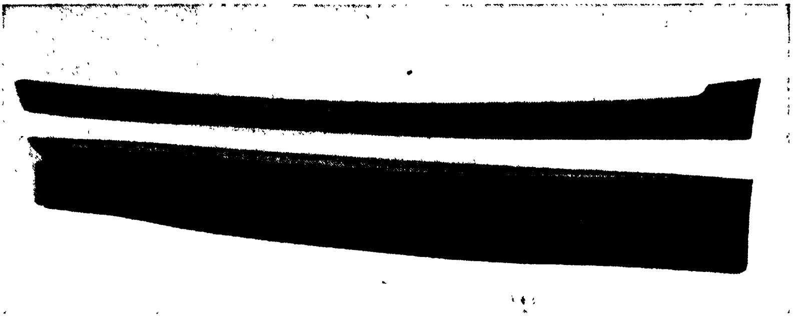


FIG. 407. Model cut to show Waterline (Photograph)

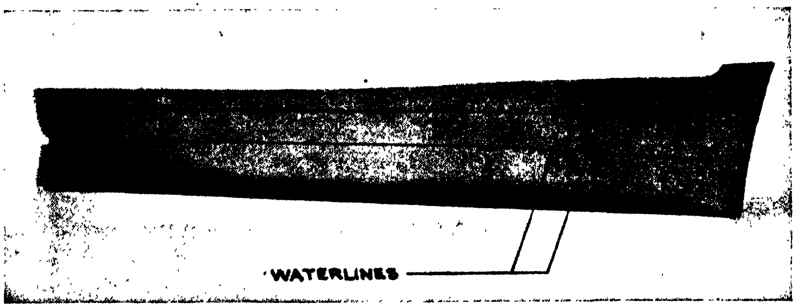


FIG. 408. Waterlines (Photograph)

The number of waterlines above the load waterline depends largely on how many are required to show adequately the shape of the hull above water, since such waterlines are seldom used in calculations. The stations appear as straight lines (planes seen on edge) in the half breadth plan and the waterlines appear as straight lines in the body plan. These two views give sufficient information to ascertain the shape of the ship in most places, but usually a third view and some other curves are added to complete the picture and fair up certain areas.

The third view which is developed as shown in Fig. 410 is called the **sheer plan.** It may be considered to have been obtained from the ship model by vertical cuts parallel to the centerline plane of the ship, as indicated in Fig. 410. Fig. 411 is the photograph of the model after one such cut has been made, showing the part cut off and moved slightly aft to show clearly the shape of the curve produced by the cut. Fig. 412 is another photograph of the model with two cuts outlined in black, and Fig. 413 is a drawing showing the shape of the curves on the hull made by these cuts. The complete set of curves is also shown in the upper part of Fig. 401. These curves are called **buttocks** or **bow and buttock lines** and designated by their distance from the centerline plane which is, therefore, the zero buttock. Since the areas of these planes are not used in the subsequent calculations,

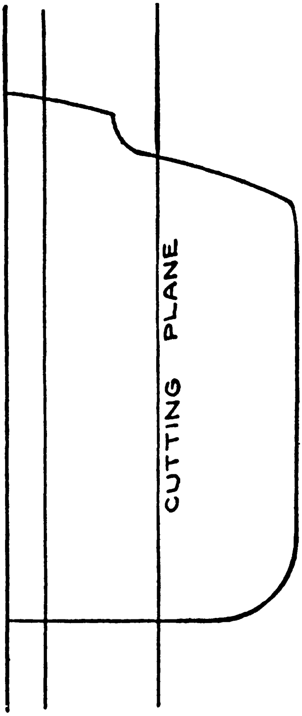


Fig. 410. Buttock Planes

their spacing need not be uniform and is chosen by the designing naval architect so as to show up any humps or hollows in the forward and after quarters of the ship. The buttocks appear as straight lines in the body and half breadth plans and in their true shape only in the sheer plan. Similarly, the waterlines and stations appear as straight lines in the sheer plan.

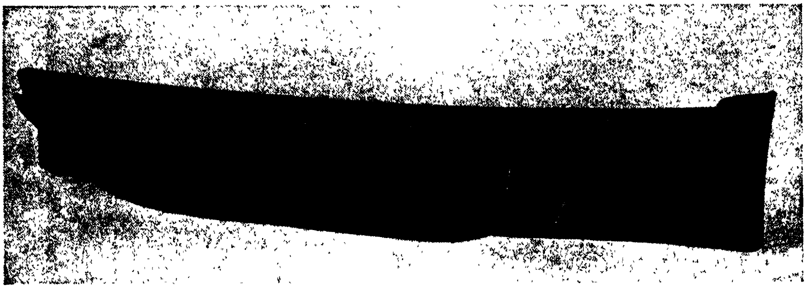


Fig. 411. Buttock Line (Photograph)

These three views shown in Fig. 401 make up what is known variously as the **ship's lines, line drawing, sheer drawing** or **sheer draft.** Its purpose is to show the shape of the hull and to supply distances from which volume of the latter can be computed. A complete set of ship's lines contains several other curves in addition to the stations, waterlines, and buttocks. The **diagonals** may be conceived to result from cutting the hull in a plane perpendicular to the stations but inclined to the waterlines and buttocks. Fig. 414 shows the relative locations of a diagonal plane and a waterline plane. Fig. 415 is a photograph of the model after having been cut by a diagonal plane

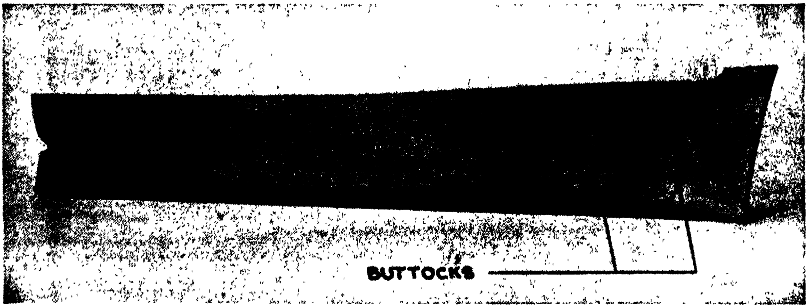


Fig. 412. Buttock Lines (Photograph)

with the upper part of the hull removed and the vertical and diagonal planes shown by vertical and diagonal hatched lines. Fig. 416 shows the trace of this diagonal on the surface of the hull. Fig. 417 is a drawing showing the relative shapes of the outline of a diagonal and a waterline. Similar curves may be found in the lower part of Fig. 401.

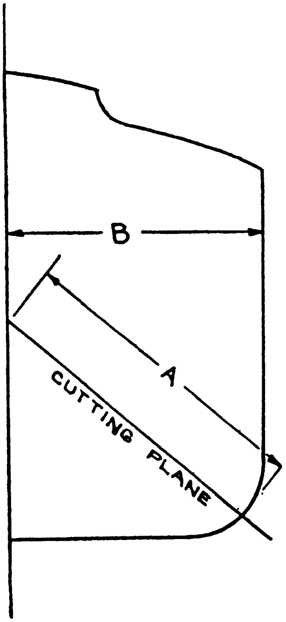


FIG. 414. Diagonal Plane (Drawing)

The **bilge diagonal** is shown and marked in the body plan and half

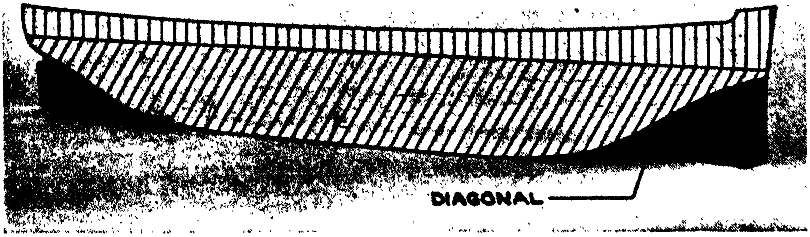


FIG. 415. Diagonal Plane (Photograph)

breadth plan of Fig. 401. The purpose of the diagonals is similar to that of the buttocks, viz., to show up regions of possible unfairness, i.e., unevenness of curvature in the hull, which are not shown by the stations and waterlines. They are particularly useful in showing up any humps or hollows in the bilge line.

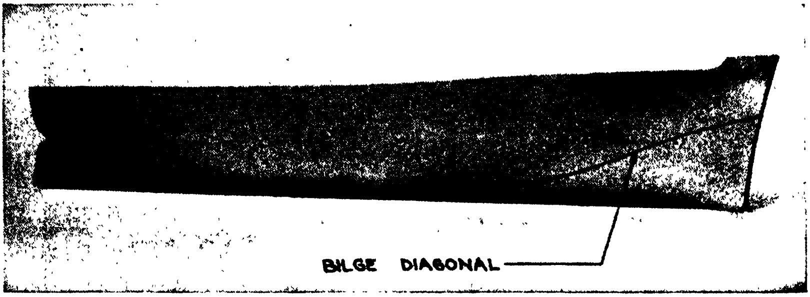


FIG. 416. Diagonal Line (Photograph)

Fig. 418 is a photograph of the model showing the curves made on the surface of the hull by the traces of the various cutting planes.

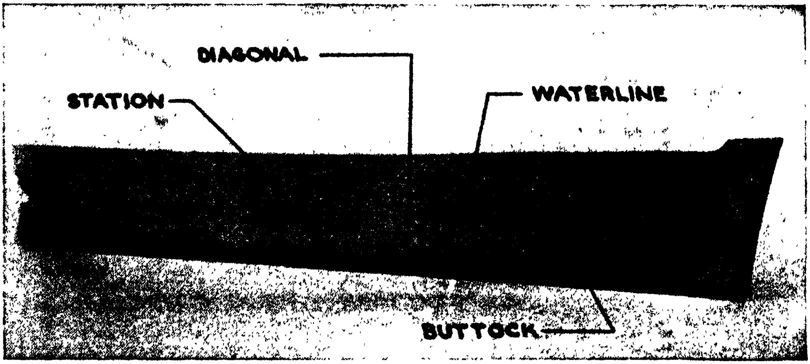


FIG. 418. Ships Lines

From Figs. 402 to 418 inclusive, the method of obtaining the line drawing of the ship, Fig. 401, should be clear.

The upper boundary of the hull is the weather deck, which is seldom flat, but has curvature fore and aft as well as athwartships. The trace of the deck at the side is plotted in all three views. It appears as a curve in each of these, since it is a three-dimensional curve and there-

Fig. 409. Waterlines (Drawing)

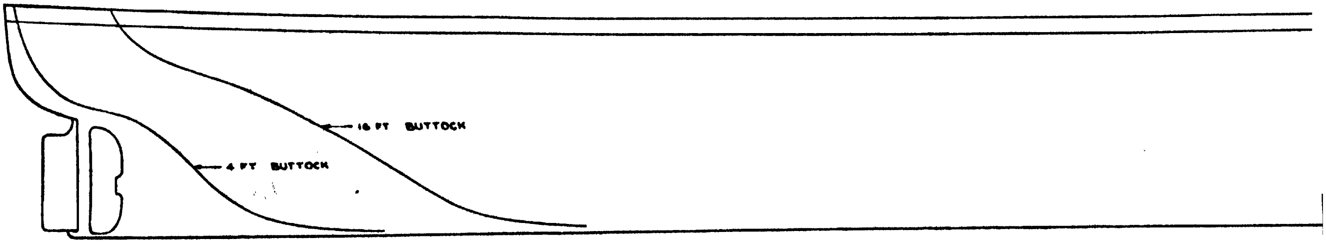


Fig. 413. Buttock Lines (Drawing)

Fig. 417. Diagonal and Waterline (Drawing)

fore its true shape cannot be shown in a plane drawing. The trace of the deck at the centerline is also frequently drawn in the sheer plan.

413. Architectural definitions. The curves of the line drawing show the molded shape of the ship. An all-inclusive definition of the term "molded" as applied to naval architecture is practically impossible but, generally speaking, **molded dimensions** and **molded lines** define smooth surfaces, i.e., surfaces which have continuous curvature without jogs or other abrupt changes. For example, in the case of ships which have the usual type of frames, the molded surface of the ship is that defined by the outside surface of the frame bars. If cloth or thin paper is stretched over such a figure, it presents a smooth surface having continuous curvature. The actual plated surface of a ship is seldom smooth, particularly if it is plated on the raised and sunken system. Fig. 401 shows the molded lines of a hull.

The **base line** has been mentioned in Art. 412. Here again a definition covering all cases is difficult. In the case of most commercial ships which are designed with the keel line straight and the same draft forward and aft, the base line is the molded line of the keel, i.e., at the top of the flat keel plate. In any case, it is the molded line from which vertical dimensions are taken. For ships which have the keel inclined to the load waterline or curved, the choice of the location of the base line is largely a matter for the judgment of the naval architect.

The **forward perpendicular** is a plane perpendicular to the base line through the intersection of the molded line of the stem and the designed load waterline. The location of the **after perpendicular** is similarly determined from the intersection of the molded line of the sternpost and the designed load waterline. The length of the load waterline between the forward and after perpendiculars is the **length between perpendiculars,** i.e., the **molded length** of the immersed part of the hull. So far as buoyancy, stability and propulsion are concerned, the immersed part of the ship is the ship. The rest is just upper works. **Length over all** is the distance parallel to the load waterline from the forwardmost part of the stem to the aftermost part of the stern. It is not a molded dimension. The general symbol for length is *L*. Where precision of expression is essential, length between perpendiculars is designated by L.B.P. and length over all, L.O.A.; see Fig. 601.

The **molded breadth** or **beam,** designated by the symbol *B*, is the breadth of the widest frame at the load waterline. In other words, it is the maximum **molded width** of the load waterline. This maximum width is usually found at the midship section. Beam, extreme, corresponds to length over all. It is not a molded dimension but the maximum actual breadth of the ship taken over plating fenders or any other permanent attachments to the hull.

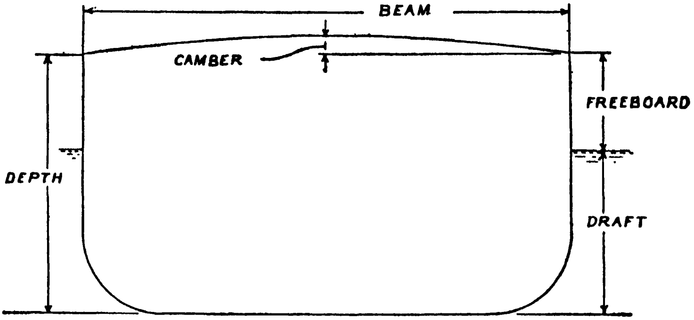


Fig. 419. Molded Dimensions

The **depth, molded,** (D) of a ship, is the vertical distance from the base line to the molded line of the highest deck to the hull **at the side** at the midship section; see Fig. 419. The **molded draft** is the vertical distance from the base line to the surface of the water. The actual draft is measured from the lowest part of the ship in that region. The symbol for draft is H. Draft at the stem, is **draft, forward;** that at the stern is **draft, aft;** that at the midship section is **draft, amidships.** The mean of the drafts, forward and aft, is termed **mean draft** and, if the keel line is straight, is the same as the draft, amidships. The difference between the draft, forward, and that aft is called **trim.** If the draft, forward, is greater, the ship has trim by the head or is said to be **trimmed by the head.** If the draft, aft, is greater, the corresponding terms are trim by the stern and **trimmed by the stern.** If, instead of being designed to have the same draft, forward and aft, at the load waterline, a ship is designed to have a greater draft, aft (as is usual with tugs), the ship is said to be designed with a **drag,** and the difference in the drafts when floating at the designed waterline is called the drag. We may say that a certain ship is designed with a drag of 3 feet, if it is designed to draw 3 feet more aft than forward. There is no corresponding term for ships designed with greater draft, forward, because this is unusual. When simultaneous changes of draft occur due to longitudinal inclination of the ship, it is said to **change trim.** The amount of change of trim is the **sum of the changes in draft** at the ends. For example, if on a ship drawing 25 feet forward and aft, weight changes are made to produce a draft of 24 feet forward and 26 feet aft, the change of trim is 2 feet. It is a very common error to call this a 1-foot change of trim.

Freeboard, F, is the vertical distance from the surface of the water in which the ship is floating to the deck at the side. The minimum freeboard is usually found amidships, where the curve of the deckline at the side has its lowest point. The freeboard at this point is equal to the molded depth minus the molded draft; i.e., $F = D - H$; see Fig. 419. In the case of ships having a continuous upper deck, the difference between freeboard forward and that amidships is the **sheer, forward,** and the difference between the freeboard aft and that amidships is the **sheer, aft.** When the term sheer as a dimension of the ship is used without any qualifying adjective, the sheer forward is meant; see Fig. 601. When the term freeboard is used without qualification, the freeboard at the midship section is meant. The term sheer of the ship also refers to the longitudinal curvature of the weather deck. When the height of the upper deck above the base line is considerably greater at the bow and stern than at the midlength, the ship is said to have much sheer. The Hog Island ships, famous but not very pretty (see Plate G), were built without sheer, i.e., the upper deck is parallel to the load waterline. Lines which show the longitudinal curvature of the deck at side, the deck at center, rail, etc. are known as **sheer lines.**

It is usual to construct the weather deck higher at the centerline than at the ship's side, so that it will clear itself of water from the sea, washing down, or rainfall. If the line joining the deck at the centerline to the side is straight, the deck is said to have a **pitch** of so many inches per foot. If, as is more usual, the line of the deck in any transverse section is a continuous curve, the deck is said to have **camber** or **round of beam;** see Fig. 419. The amount of camber is usually about one-fourth of an inch per foot of beam.

If the bottom of the ship is not flat at the midship section, the amount which the bottom rises in one-half the beam is called the **dead rise** or **rise of floor;** see Fig. 420.

While the above are architectural definitions, they are terms which are in common use by all who have anything to do with the operation of ships as well as with their construction, and therefore should be thoroughly understood by all licensed personnel.

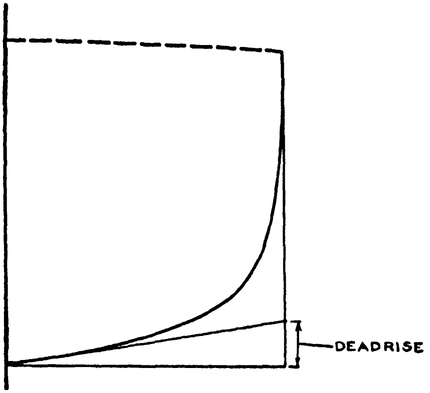


Fig. 420. Dead Rise

414. Rules of mensuration. As may be seen by careful consideration of Fig. 401, ships' curves are not simple ones. The ordinary rules of plane geometry for finding areas cannot, therefore, be used to find the areas of stations, waterlines and decks of a ship. Such areas are computed by formulas which have been developed for this purpose. These formulas are based on certain rules which are called rules of mensuration. In this part of the text, the rules are given simply as formulas which may be used, just like the formulas for the area of a triangle or rectangle.

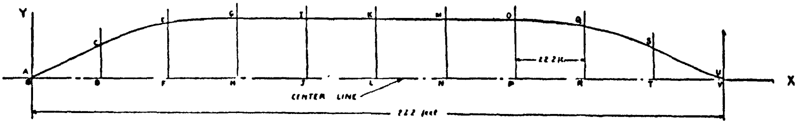


Fig. 421. Waterline for Calculations

To illustrate the use of the rules of mensuration, consider Fig. 421, which represents half of a waterline. Distances along or parallel to the line *BX* are called abscissae (plural of abscissa) and along or parallel to the line *BY* are called òrdinates. The location of any point on a curve is given by the abscissa and ordinate of the point. For example, the position of point *C* is known definitely when we know that its abscissa is 22.2 feet and its ordinate 10.6 feet. Since the length of a ship is divided into a specific number of equal parts, the shape of a waterline is defined when we have the ordinates at these abscissae.

In Fig. 421, the length of the waterline is 222 feet and there are 11 stations. The distance between stations is therefore 22.2 feet. If we know the half breadth of the waterline at each station, the curve can be reproduced. Waterline breadths are called ordinates; half-breadths, such as given in Fig. 421, are called half ordinates or semi-ordinates. Once we have calculated the area of half a waterline, it is only necessary to multiply the result by two to get the complete area. This is the way it is done in practice because the line drawing shows only half of each station and waterline.

The area between the curve *ACEGIKMOQSU* and the straight line *BV* by Simpson's First Rule is

$$A = \frac{BD}{3}(AB + 4\,CD + 2\,EF + 4\,GH + 2\,IJ + 4\,KL + 2\,MN + 4\,OP + 2\,QR + 4\,ST + UV)$$

Where $BD = DF = FH = HJ = JL = LN = NP = PR = RT = TV$

The usual way of expressing this formula is

$$A = \frac{s}{3}(y_0 + 4\,y_1 + 2\,y_2 + 4\,y_3 + \cdots 2\,y_{n-2} + 4\,y_{n-1} + y_n) \quad (401)$$

In this formula, s is the common interval and y_0, y_1, etc., are the values of the ordinates at equal distances apart. **The number of intervals must be even.**

Using the values given below, let us compute the area under the curve *ACEGIKMOQSU* of Fig. 421.

$BV = 222$

$BD = \frac{BV}{10} = \frac{222}{10} = 22.2 = s$

$AB = y_0 = 0.2$

$CD = y_1 = 10.6$

$EF = y_2 = 17.3$

$GH = y_3 = 18.5$

$IJ = y_4 = 18.5$

$KL = y_5 = 18.5$

$MN = y_6 = 18.5$

$OP = y_7 = 18.5$

$QR = y_8 = 17.9$

$ST = y_9 = 15.0$

$UV = y_{10} = 6.4$

$$A = \frac{22.2}{3}(0.2 + 4 \times 10.6 + 2 \times 17.3 + 4 \times 18.5 + 2 \times 18.5 + 4 \times 18.5 + 2 \times 18.5 + 4 \times 18.5 + 2 \times 17.9 + 4 \times 15.0 + 6.4)$$

$$= 7.4 \times 475.3 = 3518 \text{ square feet}$$

Simpson's First Rule is the most used rule of mensuration because it combines simplicity of application with a high degree of accuracy. Another rule, which is somewhat simpler but not as accurate as Simpson's First Rule is the Trapezoidal Rule. Using the same notations as previously, this rule may be expressed as follows:

$$A = s\,(\tfrac{1}{2}\,y_0 + y_1 + y_2 + y_3 + \cdots + y_{n-2} + y_{n-1} + \tfrac{1}{2}\,y_n) \qquad (402)$$

In this rule *n* may be any integer.

Now let us compute the area under the curve *ACEGIKMOQSU* of Fig. 421 by the Trapezoidal Rule, using the values previously given.

$$A = 22.2\,(\tfrac{1}{2} \times 0.2 + 10.6 + 17.3 + 18.5 + 18.5 + 18.5 + 18.5 + 18.5 + 17.9 + 15.0 + \tfrac{1}{2} \times 6.4)$$

$$= 22.2 \times 156.6 = 3477 \text{ square feet.}$$

It should be noted that the above value of this area is not the same as that obtained by the use of Simpson's First Rule. The reason for this is that neither of these formulas gives exact results. Generally speaking, the accuracy of a computation by Simpson's First Rule is about the same as that obtained by the Trapezoidal Rule using twice as many ordinates. The failure of these formulas to give exact results is not as serious as it may seem at first. In the first place, the ordinates are seldom known exactly. Therefore, an exact solution would be impossible even if we had a formula which was absolutely accurate. If we have a formula which is as accurate as the information on which the solution is made, it is sufficiently accurate because the result can not be more exact than the data on which it is based. Judged by this standard, the rules of mensuration are sufficiently accurate for ship calculations.

415. Calculation of areas. To illustrate the use of the rules of mensuration given in Art. 414 and to show the usual form of solution, let us compute the area under the curved line in Fig. 422, assigning the following values for the ordinates: $y_0 = 0$, $y_1 = 60$, $y_2 = 100$, $y_3 = 112$, $y_4 = 106$, $y_5 = 84$, $y_6 = 40$, and for the common interval, $s = 48$. M_1 and M_T are the multipliers for Simpson's First Rule and the Trapezoidal Rule respectively, and $f_1(A)$ and $F_T(A)$ are known as the "functions of areas," i.e., the values of the terms inside the parentheses of equations (401) and (402).

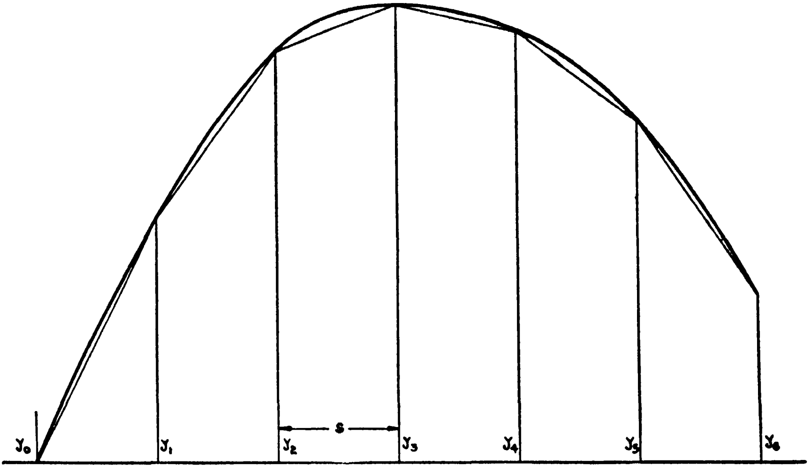


FIG. 422. Curve for Calculations

Ordinate	M_1	$f_1(A)$	M_T	$f_T(A)$
$y_0 = 0$	1	0	$\frac{1}{2}$	0
$y_1 = 60$	4	240	1	60
$y_2 = 100$	2	200	1	100
$y_3 = 112$	4	448	1	112
$y_4 = 106$	2	212	1	106
$y_5 = 84$	4	336	1	84
$y_6 = 40$	1	40	$\frac{1}{2}$	20
Sums		1476		482

If we designate the areas by Simpson's First Rule and the Trapezoidal Rule by A_1 and A_T, respectively, we have:

$$A_1 = \frac{s}{3} \times f_1(A) = \frac{48}{3} \times 1476 = 23{,}616 \text{ square feet}$$

$$A_T = s \times f_3(A) = 48 \times 482 = 23{,}136 \text{ square feet}$$

The outside area of the hull or **wetted surface** up to the designers waterline may be computed by one of the rules of mensuration using the lengths of equally spaced girths as ordinates. A formula developed by Rear Admiral D. W. Taylor (C.C.) U. S. Navy, requires less work, however, and gives a result which is close enough for most purposes.

This formula is:

$$S = C\sqrt{\Delta L} \tag{403}$$

where S = surface in square feet

C = factor varying with form of ship but having a value of about 15.60 for most merchant ships

Δ = displacement of ship in tons

L = length of ship in feet.

The ship of Fig. 401 is 222 feet long and has a displacement at load draft of 2660 tons. Let us compute the area of the wetted surface by equation (403).

$$\begin{aligned} S &= 15.60\sqrt{2660 \times 222} = 15.60 \times 768.4 \\ &= 11{,}990 \text{ square feet} \end{aligned}$$

If a gallon of ships' bottom paint covers 250 square feet, how many gallons will be required for one coat for the foregoing ship?

$$\text{Number of gallons of paint} = \frac{11{,}990}{250} = 48$$

416. Calculation of displacement. The capacity of a space may be computed in a manner similar to that for computing an area, using as the ordinates the areas of equally spaced planes instead of the lengths of lines. In preparing the line drawing, two series of equally spaced planes are drawn, the stations and the waterlines. The calculation of the volume of displacement may therefore be made using either the areas of the stations or those of the waterlines after these areas have been computed by the method explained in Art. 415. Usually, the volume of displacement is calculated using both the areas of the stations and those of the waterlines in order to get a check on the accuracy of the calculation. If the work is exact, the volume obtained by each of these calculations is the same. In the case of large ships, the volume of displacement corresponding to the designed load draft and to each of several lighter drafts is computed. With this information a curve of displacement against draft may be plotted (see Fig. 423) or a deadweight scale (similar to Fig. 424) prepared.

The principles given above may also be used to compute the volume of any space.

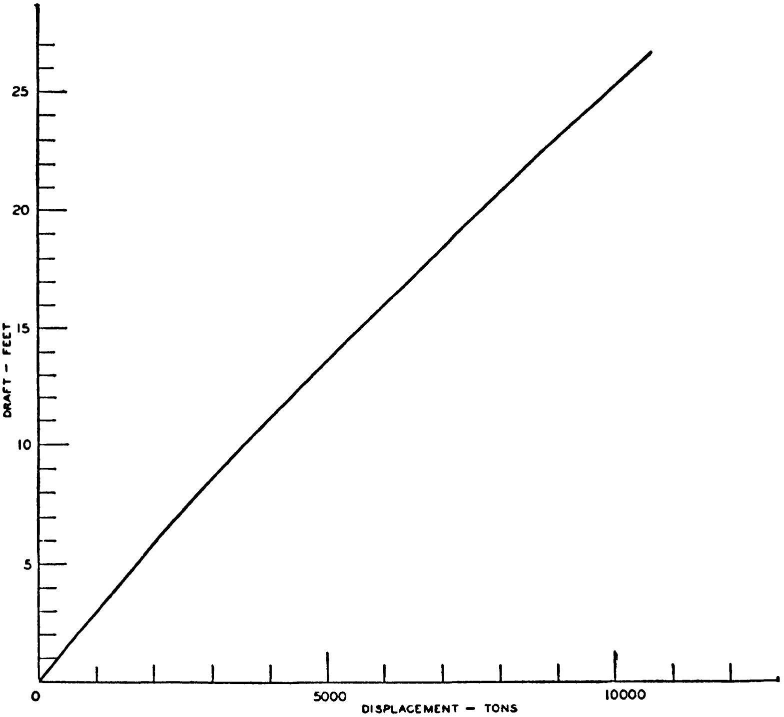


FIG. 423. Curve of Displacement

Example: Sections at 10-foot spacings of a cargo hold are found to have the following areas: 170, 218, 246, 248, 247, 225, and 180 square feet. Find the volume by Simpson's first rule.

Such problems are usually solved in tabular form, as follows:

Ordinate	Simpson's Multiplier	Function of Volume
170	1	170
218	4	872
246	2	492
248	4	992
247	2	494
225	4	900
180	1	180
Sum		4100

$$V = \frac{10}{3} \times 4100 = 13{,}667 \text{ cu. ft.}$$

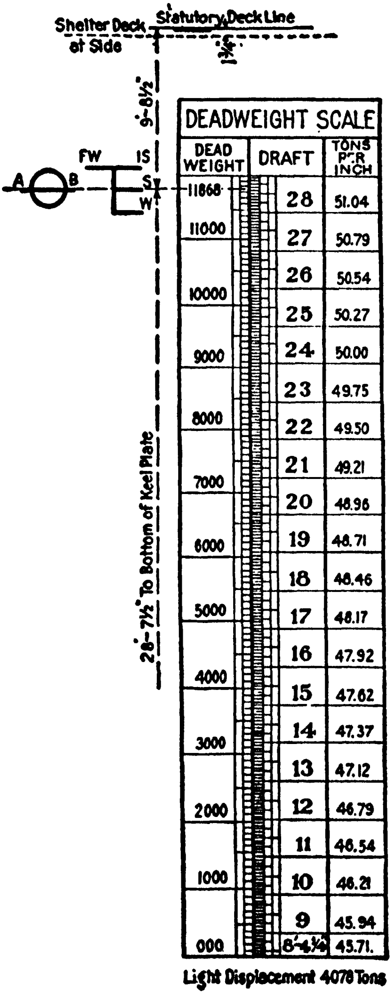


FIG. 424. Deadweight Scale

417. Tonnage definitions. The term displacement is derived from the conception that when the ship is placed in the water, it **displaces** or **takes the place of a certain amount of water.** The volume of displacement is therefore the volume in cubic feet of the immersed part of the hull. The displacement tonnage or simply the displacement is the weight in tons of this volume of water. For seagoing ships this is equal to the volume of displacement in cubic feet divided by 35, since 35 cubic feet of sea water weigh one ton. It is represented by the symbol Δ (delta). The displacement in tons is also the weight of the ship and is so used by seafaring people. To distinguish the weight of the ship at different conditions of loading, several different qualifying words are used in conjunction with displacement. The displacement of the ship when loaded to the load waterline is called the **load displacement.** The **light displacement** is the weight of the light ship, i.e., the ship with propelling machinery and equipment but without fuel and cargo. The difference between the load displacement and the light displacement is the **deadweight tonnage.** In other words, the deadweight is the number of tons of cargo, fuel, and the like, required to bring the light ship to the load draft. The **paying deadweight** is the part of the deadweight which is cargo and therefore pays freight.

There are two other tonnages which may be defined here, although they are discussed at greater length in Section 42. **Gross tonnage** is a measure of the cubical contents of the hull in tons of 100 cubic feet. **Net tonnage** is a measure of the revenue paying volume of the hull in the same unit. These tonnages are measures of cubic capacity, not measures of weight, and the use of the word tonnage, therefore, is somewhat misleading.

The watertight structure above the waterline provides a **reserve of buoyancy** in event of under-water damage which results in flooding. It is usual to express this reserve of buoyancy as a percentage of the displacement at load draft. Thus, if at load draft the volume of the watertight part of the ship above the waterline is half of the volume of displacement, the ship has a reserve buoyancy of 50 percent.

In comparing the form and fullness of different ships, several so-called **coefficients of fineness** are used. The most common of these is the **block coefficient,** designated by b. It is the ratio of the volume of displacement to the volume of a rectangular prism having the same length and breadth as the ship, and depth equal to the ship's draft; see Fig. 425. Using the symbols previously given, and V for the volume of displacement, we have

$$b = \frac{V}{L \times B \times H} \qquad (404)$$

This coefficient gives in a general way information of the ship's fullness. A block coefficient of 0.50 means that half of the block has been whittled away to make the model. High-speed ships have a lower block coefficient than low-speed ships. Cargo carriers and tankers generally have higher values of block coefficient than passenger ships and these in turn have greater block coefficients than yachts. Approximate values of the block coefficient of ships of various types are given below.

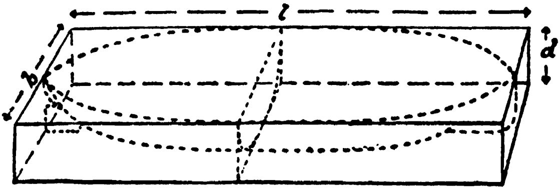


Fig. 425. Block Coefficient

Low-speed cargo carriers and tankers	0.65 to 0.80
Passenger ships	0.50 to 0.65
Yachts	0.35 to 0.50

A knowledge of the proper value of the block coefficient helps a designer to select the principal dimensions of a ship after he has determined the approximate displacement.

As an illustration of its use, let us compute the displacement of a ship which has the following principal dimensions: length 222 feet, breadth 37 feet, draft 15 feet, and a block coefficient of 0.731.

From equation (404)

$$V = bLBH$$

$$\Delta = \frac{V}{35} = \frac{bLBH}{35} = \frac{0.731 \times 222 \times 37 \times 15}{35} = 2575 \text{ tons}$$

The **prismatic,** also called the **cylindrical** and **longitudinal, coefficient** is the ratio of the volume of displacement to a figure having the same length as the ship and a constant section, the midship section; see Fig. 426. Using l as the symbol for this coefficient and $A_{\otimes}$ for the area of the midship section, we have

$$l = \frac{V}{A_{\otimes} \times L} \tag{405}$$

The longitudinal coefficient gives somewhat more exact information of a ship's fineness than the block coefficient. In particular, it tells how the displacement is distributed along the ship's length. A low value of longitudinal coefficient means that the displacement is largely concentrated near the midship section and the ship therefore has fine ends. On the contrary, a large value of longitudinal coefficient means that the displacement is more uniformly distributed along the length of the ship and may be associated with a finer midship section and fuller ends. Generally speaking, low-speed ships have higher values of longitudinal coefficient than high-speed ships as indicated below.

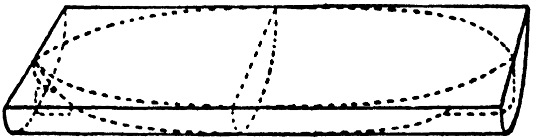


FIG. 426. Prismatic Coefficient

Cargo carriers and tankers	0.70 to 0.80
Passenger ships	0.60 to 0.70
Yachts	0.55 to 0.65

To illustrate the use of equation (405), let us compute the length of a ship if the displacement is 2575 tons, the area of the midship section 544 square feet, and the longitudinal coefficient 0.746.

$$L = \frac{V}{lA_{\otimes}} = \frac{35\Delta}{A_{\otimes}l} = \frac{35 \times 2575}{0.746 \times 544} = 222 \text{ feet}$$

The **midship section coefficient,** *m,* is the ratio of the area of the midship section to that of a rectangle having dimensions B and H, i.e.,

$$m = \frac{A\maltese}{B \times H} \tag{406}$$

The midship section coefficient measures the fullness of the midship section. It varies from about 0.70 in fine, high-speed yachts to 0.98 in low-speed cargo ships.

Example: A ship has a draft of 15 feet, a breadth of 37 feet, and a midship section coefficient of 0.98; what is the area of the midship section?

$$A\maltese = mBH = 0.98 \times 37 \times 15 = 544 \text{ square feet}$$

The **waterline coefficient,** p, is the ratio of the area of the waterline to that of a rectangle having dimensions L and B, i.e.,

$$p = \frac{A_{WL}}{L \times B} \tag{407}$$

A_{WL} represents the area of the waterline.

The waterline coefficient gives an idea of the fineness of the waterline. It varies from about 0.70 in fine, high-speed ships to 0.85 in low-speed cargo carriers.

Example: A ship has a waterline area of 7081 square feet, a length of 222 feet, and a breadth of 37 feet; what is the value of the waterline coefficient?

$$p = \frac{A_{WL}}{L \times B} = \frac{7081}{222 \times 37} = 0.851$$

418. Tons per inch immersion. It is desirable to know how much the draft will be increased or decreased by the addition or removal of a known weight. This information may be obtained from Fig. 424, which gives for any draft the weight addition necessary to increase the draft 1 inch or the weight removal to reduce the draft 1 inch. If the weight change is unknown but the drafts before and after are known, the amount of weight involved can be determined by multiplying the tons per inch by the number of inches change of draft. The tons per inch are obtained as follows. As may be seen from Fig. 408, the areas of two waterlines 1 inch apart are practically equal. The increase in the volume of displacement, in cubic feet, due to an increase in draft of 1 inch is equal to the area of the waterline in square feet times one-twelfth, i.e., $A_{WL}/12$. The weight of such a volume of sea water in tons is equal to this volume divided by 35, since 35 cubic feet of sea water weigh one ton. The increase in displacement corresponding to 1 inch increase in draft is therefore $A_{WL}/(12 \times 35) = A_{WL}/420$. Thus the tons per inch immersion, T, is obtained by dividing the waterline area in square feet by 420.

$$T = \frac{A_{WL}}{420} \tag{408}$$

Example: A ship has a waterline area of 7000 square feet. What are the tons per inch immersion? How much will the draft be increased due to taking on 50 tons of fuel? $T = 7000/420 = 16.67$ Increase in draft $= 50/16.67 = 3$ inches.

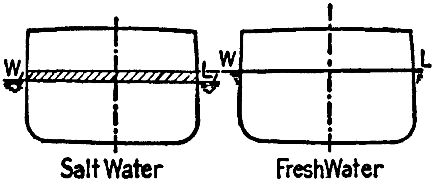


FIG. 427. Difference of Draft in F & S Water

419. Difference in draft in salt and fresh water. Since a cubic foot of fresh water weighs less than a cubic foot of salt water, it requires more cubic feet of fresh water to have the same weight as a given volume of salt water. If a ship comes from sea into a fresh-water harbor, the ship's weight does not change; but, since the buoyancy (which is equal to the weight) is equal to the weight of the displaced liquid, and the new liquid (fresh water) weighs less per cubic foot, the ship must displace more cubic feet of fresh water than it did of salt water. This increase in volume of displacement in passing from salt to fresh water involves an increase in draft; see Fig. 427. Formulas for this increase of draft are given in equations (409), (410), (411), and (412).

For pure fresh water

$$x = \frac{\Delta}{38.89\,T} \tag{409}$$

For brackish water which has a specific gravity intermediate between fresh water (1.000) and sea water (1.026)

$$x = \frac{\left(\frac{35.90}{w} - 35\right)\Delta}{35\,T} \tag{410}$$

The Load Line Regulations give the following formulas

$$x = \frac{\Delta}{40\,T} \tag{411}$$

$$x = \frac{H}{4} \tag{412}$$

In equations (409), (410), (411), and (412)

x = difference in draft in fresh and salt water in inches
Δ = displacement in tons
T = tons per inch immersion in salt water
w = specific gravity of brackish water (value lies between 1.000 and 1.026).
H = salt water draft in feet.

It will be noted that equations (409) and (411) are practically the same. Equation (409) is derived by the use of exact values of the specific gravity of fresh and salt water. It gives a rather awkward number in the denominator. In writing the Load Line Regulations, the equation has been simplified and the value obtained changed only slightly by substituting 40 for 38.89, as can be shown by a simple example.

Example: The load displacement of a ship is 15,950 tons, corresponding draft 28 feet 7½ inches, tons per inch immersion 51; how far above the load line should the fresh-water load line be?

From equation (409)

$$x = \frac{\Delta}{38.89\,T} = \frac{15{,}950}{38.89 \times 51} = 8.04 \text{ inches}$$

Using equation (411),

$$x = \frac{\Delta}{40\,T} = \frac{15{,}950}{40 \times 51} = 7.82 \text{ inches}$$

Equation (412) is used when either the displacement or the tons per inch at the load draft are not known. Using this equation to solve the problem given above, we get

$$x = \frac{28'7\frac{1}{2}''}{4} = \frac{28.63}{4} = 7.16 \text{ inches}$$

Frequently, a ship may be in water which is not pure fresh water nor as salty as sea water. Two sources of greater specific gravity than pure fresh water are salt and silt. For example, the water in Chesapeake Bay is not as salty as ocean water. In the spring of the year the water in most fresh-water rivers contains varying quantities of silt which gives it a varying specific gravity. The increase in draft in such water can be computed by equation (410) if we know its specific gravity.

Example: A ship is to be loaded in New Orleans to draw 24 feet in salt water. Displacement at this draft is 13,000 tons. Mississippi River water has a specific gravity of 1.007. What should the ship's load draft be in New Orleans, if the tons per inch immersion at 24 feet draft is 50?

$$x = \frac{\left(\frac{35.90}{w} - 35\right)\Delta}{35\,T} = \frac{\left(\frac{35.90}{1.007} - 35\right)13{,}000}{35 \times 50} = 4.83 \text{ inches}$$

The ship's load draft at New Orleans should therefore be 24 feet, 4¾ inches.

QUESTIONS

411. Sketch the line drawing of any ship, give the names of the views, and mark the following on all the views in which they appear: waterline, station, buttock, base line, forward perpendicular, after perpendicular, midship section, deck line.

412. Define freeboard, sheer, depth molded at side and draft, and draw sketch or sketches showing relation between these.

413. Define dead rise, camber, change of trim, diagonal, molded line, length between perpendiculars, beam extreme.

414. What are rules of mensuration and why are they used in ship calculations?

415. Write Simpson's First Rule and the Trapezoidal Rule.

416. How are volumes computed by rules of mensuration?

417. Tell briefly how to compute the displacement of a ship.

418. Define displacement, light displacement, load displacement, deadweight, paying deadweight, gross tonnage, net tonnage.

419. What is the weight in pounds of a cubic foot of sea water? Fresh water? How many cubic feet of each to the ton? How many pounds to the ton in naval architecture? What is the unit of length in naval architecture?

4110. What is meant by tons per inch immersion? How is the value of this obtained from the waterline area?

4111. Give the formula for the inches increase in draft of a ship in pure fresh water as compared with its draft in salt water.

4112. Give Taylor's formula for the wetted surface of a ship and explain the meaning of the symbols.

PROBLEMS

411. You are required to renew completely the insulation on a bulkhead whose half ordinates are 0.3, 6.0, 8.0, 10.0, 11.0, 11.8, 12.3, 12.7, and 12.9 feet, respectively, and common interval 2 feet. How many square feet of cork slabs would be required to do this job, allowing 10 percent for waste? NOTE: Percentage of waste is figured on the material supplied and not on the area to be covered.

Ans. 353.8, Simpson's First Rule; 350.7, Trapezoidal Rule.

412. You are required to renew completely the linoleum on a deck whose half ordinates are 0.2, 5.9, 10.5, 13.1, 14.12, 14.5, 14.5, 14.0, 12.6, 9.8, and 0.2 feet, respectively, and common interval 15 feet. How many square feet of linoleum will be required to do this job, allowing 10 percent for waste?

Ans. 3702.2, Simpson's First Rule; 3643.3, Trapezoidal Rule.

413. You are required to red lead a bulkhead whose half ordinates are 0.0, 2.75, 5.50, 8.20, 10.60, 13.20 feet, respectively, and common interval 2.5 feet. How many pounds of red lead would be required? One pound of red lead will cover 6 square feet of surface.

Ans. 28.04.

414. You are required to paint an engineroom bulkhead whose semi-ordinates are 26.6, 26.8, 26.8, 26.4, 25.4, 23.4, and 18.5 feet, respectively, the ordinates being 3 feet apart. How many gallons of paint would be required? One gallon of paint will cover 50 square yards of surface.

Ans. 2.02.

415. You are required to renew completely a wood deck whose semi-ordinates are 0, 5.0, 9.6, 12.6, 14.4, 14.5, 14.4, 13.5, 11.3, 6.5, and 0.5 feet,

respectively, with a common interval of 14.5 feet. How many square feet of decking will be required, allowing 25 percent for waste?

Ans. 3947.9.

416. You are required to renew completely the linoleum on a section of deck having ordinates at a common distance apart of 2.5 feet, the length of the ordinates being 3.50, 4.70, 5.60, 6.30, 7.00, 7.50, and 7.90 feet. How many square feet of linoleum will be required, allowing 10 percent for waste?

Ans. 102.5, Simpson's Rule; 101.9, Trapezoidal Rule.

417. The half breadths of frame number 135 of the *S.S. California* are 0.8, 2.0, 4.9, 9.1, 13.7, 17.9, 21.3, 23.6, and 25.1. The distance between ordinates is 4 feet. Find the area of a section of the ship at this point by Simpson's First Rule.

Ans. 843.

418. The sectional areas at alternate frames of a reserve feed-water tank are 19.4, 18.5, 17.2, 15.6, 13.6, 10.9, and 6.5 square feet, respectively. The frame space is 2 feet. Find the volume by Simpson's Rule. Find the capacity in gallons. One cubic foot = 7.48 gallons.

Ans. 2668 gal.

419. The areas of sections of a fuel oil tank on the *S.S. Mololo* measured at every fourth frame are 135, 170, 186, 200, and 212 square feet, respectively. The frame space is 4 feet. Find the volume, using the Trapezoidal Rule. How many gallons will the tank hold when filled to 95 percent of its capacity?

Ans. 83,000.

4110. A fuel oil tank has sectional areas of 19.4, 18.5, 17.2, 15.6, 13.6, 10.9, and 6.5 square feet, respectively, the distance between sections being 12.5 feet. How many gallons of fuel oil will it hold? One gallon measures 231 cubic inches.

Ans. 8337, Simpson's First Rule; 8302, Trapezoidal Rule.

4111. The half breadths of the midship section of a ship are 0.6, 24.7, 26.4, 26.9, 27.2, 27.3, 27.4, and 27.5. The distance between waterlines is 2 feet. Find the area by the Trapezoidal Rule. What is the coefficient of fineness of the midship section?

Ans. Area 696. $m = 0.904$.

4112. The areas of stations on the *U.S.S. Sacramento* in square feet are 0, 31, 66, 111, 163, 221, 281, 338, 385, 420, 428, 416, 387, 342, 288, 218, 170, 113, 61, 22, and 0. The distance between stations is 11.6 feet. Find the volume by the Trapezoidal Rule. What is the displacement in salt water?

Ans. 51,747.6 cubic feet; 1478 tons.

4113. Using the Trapezoidal Rule, find the measurement tonnage (100 cubic feet = 1 ton) of cargo hold 60 feet long having the following half breadths in feet.

Section	*Forward*	*Middle*	*Aft*
0-level line	12.8	14.2	14.4
5-foot level line	18.8	20.0	20.2
10-foot level line	20.6	21.6	21.6
15-foot level line	21.2	21.8	21.8
20-foot level line	21.4	21.8	21.8

Ans. Tonnage = 483.30.

4114. Find the volume of displacement of a 40-foot motor boat having breadths as follows:

Sections No.	1	2	3	4	5
Base Line	0.2	0.2	0.2	0.2	0.2
2-foot W. L.	0.2	2.0	7.6	2.6	0.3
4-foot W. L.	0.2	5.3	10.5	6.5	0.3
6-foot W. L.	0.2	7.4	11.0	9.3	2.0

Use Trapezoidal Rule.

Ans. 998 cubic feet.

4115. The half breadths of the 10-foot waterline of the *U.S.S. Converse* are 0.1, 2.4, 4.8, 7.2, 9.3, 11.3, 12.9, 14.1, 14.9, 15.3, 15.4, 15.3, 15.0, 14.6, 14.0, 13.1, 11.7, 9.8, 7.3, 4.0, and 0.3. The distance between ordinates is 15.5 feet. Find the area by the Trapezoidal Rule. What is the tons per inch immersion?

Ans. Area 6593.7; $T = 15.7$.

4116. The tons per inch immersion of the *U.S.S. Pennsylvania* is 101.5. What is the area of the designer's waterline?

Ans. 42,630.

4117. The area of a waterline is 9,648 square feet. Find the tons per inch immersion. If 200 tons of fuel are taken aboard, what will be the increase of draft?

Ans. $T = 22.97$; 8.7 inches increase in draft.

4118. A box-shaped vessel floats at a draft of 10 feet in fresh water, specific gravity 1.000; what will be the draft in Great Salt Lake, specific gravity 1.050?

Ans. 9.52 feet = 9 feet 6.25 inches.

4119. The *U.S.S. Raleigh* lying at League Island Navy Yard (fresh water) was drawing 14 feet 9 inches, corresponding displacement 7800 tons. Before departure, 15,000 gallons of shore water, 12,000 lbs. of fresh meat, 40,000 lbs. of fresh vegetables, and 25 tons of ammunition were taken on board. The tons per inch immersion is 50.8, and fresh water weighs 8.35 lbs. per gallon. What was the draft on reaching Delaware Breakwater (salt water)?

Ans. 14 feet 6.61 inches.

4120. The Cruiser *Seattle* is ordered to proceed to Portland, Oregon. Her mean draft taken in the Pacific just before entering the Columbia River is 28 feet, 4 inches, corresponding to a displacement of 14,800 tons. Tons per inch immersion is 75. Portland is 120 miles up the river and to get there it is necessary to cross a shoal spot 20 miles below the city where there is only 28 feet 3 inches of water. Between the entrance to the Columbia River and this shoal spot, 105 tons of coal, stores, etc., are consumed. Prove that the *Seattle* can or cannot pass the shoal and by what amount.

Ans. Cannot pass by 5.2 inches.

4121. The mean draft of the *S.S. Mololo* before fueling is 28 feet. After fueling, the mean draft is 29 feet 8 inches. If the tons per inch immersion is 101.5 and there are 300 gallons of oil to the ton, how many gallons of fuel did the ship take?

Ans. 609,000.

4122. A ship at load draft has a displacement of 13,000 tons. The length is 460 feet. If bottom paint has a spreading power of 30 square yards per gallon, how many gallons will be required per coat for this ship?

Ans. 141.3.

Section 42. Tonnage calculations. *Art.:* 421. Authority and basis.

421. Authority and basis. Merchant ships are subject to wide fluctuations in displacement, and the deadweight and load displacement of ships of the same light displacement may show considerable variation. In assessing charges for tolls, wharfage, pilotage, and the like, it was felt that there should be a factor which reflected the potential earning power of the ship regardless of its actual condition of loading. For example, a ship might come to a wharf fully laden and leave it empty, or vice versa. If wharfage is assessed on the loading, what loading should be used in such a case? Gradually there arose a body of opinion that the volume of a hull under the deck was a good measure of the ship's earning capacity and various rules were promulgated as to the method of determining this. The current regulations for determining the gross tonnage of ships are the result of progressive development of rules for measuring the volume of the hull under the deck.

In the case of sailing vessels, only a small part of the underdeck volume of the hull is not available for the stowage of cargoes or accommodation of passengers, but with the introduction of steam power for self-propulsion this condition was materially changed. The boilers, engines and fuel bunkers all occupy hold space which cannot be used for carrying freight. From this fact arose the conception that the earning power of a ship was more accurately measured by the hold space not required by activities essential to the operation of the ship and rules were framed defining the conditions to be fulfilled in order that a space should be classified as a non-revenue space. The current regulations for determining the net tonnage of ships are the result of progressive development of such rules.

It must be kept in mind that gross and net tonnage are measures of capacity, not weight. A measurement ton is 100 cubic feet. Tonnage measurement is a legal requirement of every merchant ship. No ship may be registered in the United States or any other maritime nation until, and unless, it has been measured for tonnage and the correctness of the calculations have been certified by some authorized agency of the government.

Owing to the diversity of conditions existing in the various maritime nations, a wide diversity of regulations for tonnage measurements arose and tonnage certificates of one nation were frequently not accepted in the port of another. During the past half century, this condition has been almost entirely corrected by means of international conferences and treaties on the subject, and, to-day, tonnage certificates of ships of United States registry are accepted at face value in practically all ports of the world and, similarly, the port authorities of United States ports give full credence to the tonnage certificates of practically all ships of foreign registry. This reciprocal acceptance of tonnage certificates, which was brought about by securing agreement in the methods of measurement and computation and the requirements for exempting or deducting compartments, is a matter of great convenience to ship owners and operators.

Like the load line regulations, the tonnage regulations of the United States are issued by the Department of Commerce under the authority of Acts of Congress. The regulations are based on the assumption that the measurements for calculating the tonnage are taken from the ship. In the vast majority of cases, the measurements are taken from the ship's plans, supplemented by checking a few important dimensions from the ship to insure the veracity and accuracy of the plans. Ship designers and builders must be thoroughly acquainted with the detail requirements of the tonnage regulations; the operating officer should at least have a working knowledge of the principles underlying them.

CHAPTER 5

PRINCIPLES OF STABILITY

Section 51. Equilibrium of floating bodies. *Arts.:* 511. Fundamental definitions. 512. Equilibrium and stability. 513. Conditions required for equilibrium. 514. Effect of the position of metacenter. 515. Conditions requisite for equilibrium in inclined position.

511. Fundamental definitions. Before starting a discussion of stability, the terms which are to be used should be defined. The **center of gravity** of a body is the point at which a force equal to the weight of the body may be applied to support the body without changing its position. For example, a string attached to this page where the lines connecting diagonally opposite corners meet, will hold it in the flat position in still air. This is because the center of gravity is at the intersection of the diagonals. Similarly, the center of gravity of a ship is the point where the ship balances and could be lifted without tipping. In stability discussions the ship is treated as if its whole weight were at its center of gravity, which is indicated in sketches by

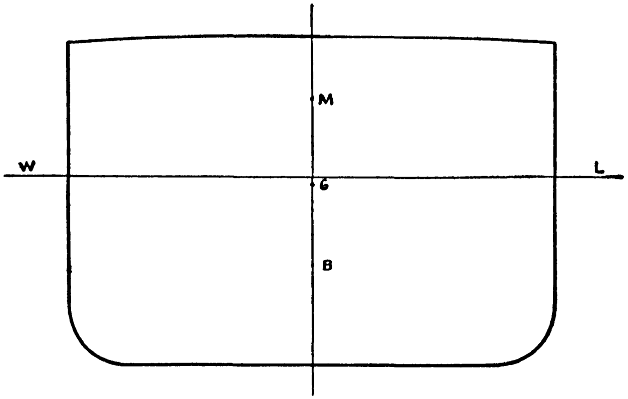


FIG. 501. Centers

the letter G. See Fig. 501. Since the weight of each half of a ship is the same, G must be in its centerline plane.

The force which actually supports a floating ship is its buoyancy. Since the buoyancy is equal to the weight of the displaced water, the center of gravity of the displaced water is called the **center of buoyancy.** The buoyancy of the ship may be treated as one force at the center of buoyancy. This point is indicated in sketches by the letter B. See Fig. 501. Like the center of gravity, the center of buoyancy of a ship floating erect lies in the centerline plane, since the buoyancy is equally distributed on both sides of it. The center of buoyancy is usually below the center of gravity because the displaced water is all below the waterline, but a large part of the ship is above that plane. Racing yachts with lead keels may have the center of buoyancy above the center of gravity. The methods of computing the positions of the center of gravity and center of buoyancy of a ship are not particularly difficult but are rather involved. They are not calculations in which an operating officer is particularly interested and therefore the methods of making these calculations are omitted here. They may be found in more advanced treatises on naval architecture.

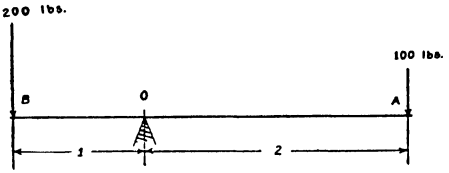


FIG. 502. Moment of Force

In the lever shown in Fig. 502, a force of 100 pounds exerted at A results in a force of 200 pounds at B. This is based on the principle of moments, which states that $F_A \times OA = F_B \times OB$; where F_A is the force at A and F_B is the force at B, and OA and OB are the distances of A and B, respectively, from O, the pivoting point. Therefore, if (as in Fig. 502) OA is twice OB, F_B will be twice F_A. The product of a force by the distance of its point of application from the pivot is called the **moment of the force.** That is, the moment of the force F_A is $F_A \times OA$; the moment of the force F_B is $F_B \times OB$. The distances OA and OB are called the **arms** of the forces F_A and F_B, respectively.

If we hang a weight of 100 pounds at A and 200 pounds at B, the lever AOB will be balanced, because $F_A \times OA = F_B \times OB$. In other words, the system of forces is in balance when the moments of these forces are equal. This is a very important principle in understanding the stability of a ship. A ship like the lever *AOB* will be in balance, i.e., will be in equilibrium if the moments acting upon it are equal in amount and tend to produce motion in opposite directions.

The product of a force by the distance between its point of application and any line of reference is known as the moment of the force. For example, if the weight of a ship 460 feet long is 12,500 tons and the center of gravity is at the middle of the length, the moment of the weight of the ship with reference to the forward perpendicular is 12,500 × 230 = 2,875,000 foot-tons. The distance between the point of application of the force and the line of reference is called the arm of the force. In the above example, the force is 12,500 tons and the arm is 230 feet.

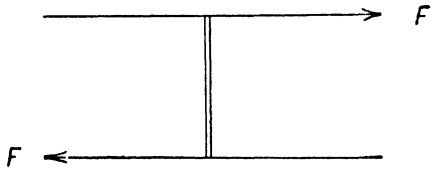


FIG. 503. Couple

Two forces which are equal in amount and opposite in direction and act along parallel lines, as in Fig. 503, form a **couple.** A couple is therefore equal to the moment of one of the forces about the other force. The perpendicular distance between the forces is called the **arm of the couple.** For example, the weight and the buoyancy of a ship are equal forces. The center of buoyancy of the ship of Fig. 504, as shown

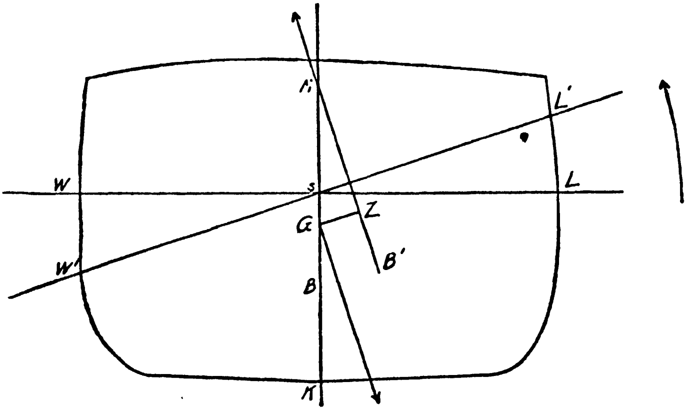


FIG. 504. Couple of Weight and Buoyancy

in the inclined position, is at B'. Therefore, the buoyancy acts vertically upward through B' and the weight acts vertically downward through G. We have then two equal and opposite forces which act in parallel lines. The perpendicular distance between their lines of action in Fig. 504 is GZ. These forces, therefore, form a couple. The magnitude of this couple is equal to the weight of the ship times the distance GZ.

When a ship is given a small inclination, provided there are no loose weights aboard, the center of gravity remains fixed. The center of buoyancy, however, changes position, moving out of the centerline plane towards the low side. From Fig. 504, it can be seen that the buoyant volume to the right of the centerline in the inclined position, represented by the areas under sL', is greater than the buoyant volume to the left of the centerline represented by the area under $W's$. The center of gravity of the buoyant volume under $W'sL'$ cannot, therefore, be in the centerline but must be on the side of the greater buoyancy. The force of buoyancy always acts vertically upward. Its direction when the ship is inclined is in the line $B'M$. The line of action of the buoyancy when the ship is erect is BGM. The intersection of the line of action of the buoyancy when the ship is in the erect position with the line of action of the buoyancy when the ship is given a **small inclination,** i.e., M in Fig. 504, is called the **metacenter.** Fig. 504 represents a transverse inclination and M is properly called the **transverse metacenter.** Fig. 505 represents a longitudinal inclination of the ship. The point M_L, the location of which is obtained in the same manner as was M, is called the **longitudinal metacenter.**

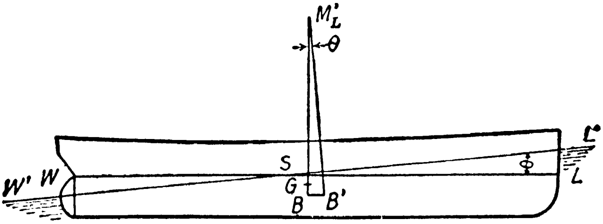


FIG. 505. Longitudinal Inclination

The distance between the center of buoyancy in the erect position and the transverse metacenter, i.e., the distance BM in Fig. 504, is called the **transverse metacentric radius.** Similarly, the distance BM_L in Fig. 505 is called the **longitudinal metacentric radius.** The distance between the center of gravity and the transverse metacenter, i.e., the distance GM in Fig. 504, is called the **transverse metacentric height.** Similarly, GM_L in Fig. 505 is the **longitudinal metacentric height.** Transverse inclinations are much more important than longitudinal inclinations; consequently, when there is no danger of confusion, the word " transverse " is frequently omitted and GM is called simply the metacentric height.

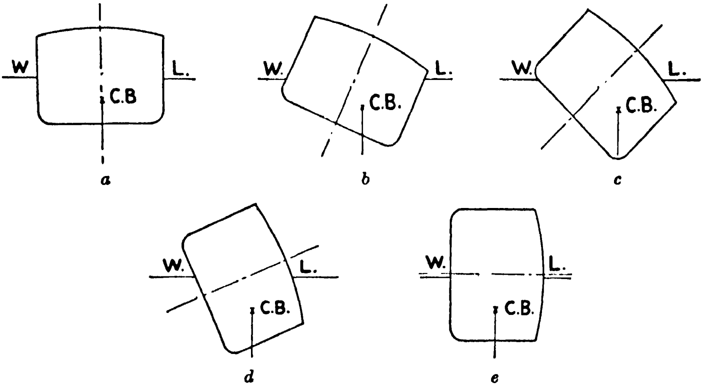


Fig. 506. Movement of Center of Buoyancy

In Fig. 506, a ship is shown upright and at inclinations of 22½°, 45°, 67½°, and 90°. The location and the direction of the force of buoyancy are indicated for each inclination. In Fig. 507, the inclined waterlines are shown drawn on the cross section of the erect ship. The force of buoyancy in each case is perpendicular to the corresponding waterline, since the waterline is always horizontal and buoyancy always acts vertically upward. The intersections of these verticals with the centerline plane of the ship are indicated by the points M_1, M_2, M_3, and M_4. The true metacenter is the location of the point M when the inclination is very small. If the transverse sections of the ship are circular, the shapes of the immersed sections are the same regardless of the inclinations, as shown in Fig. 508. Since by plane geometry, the perpendicular to the chord of a circular arc always passes through the center of the circle, for such ships, the line of action of the buoyancy always passes through the same point M, regardless of the inclination.

For ships of usual form, however, we have the condition shown in Fig. 507.

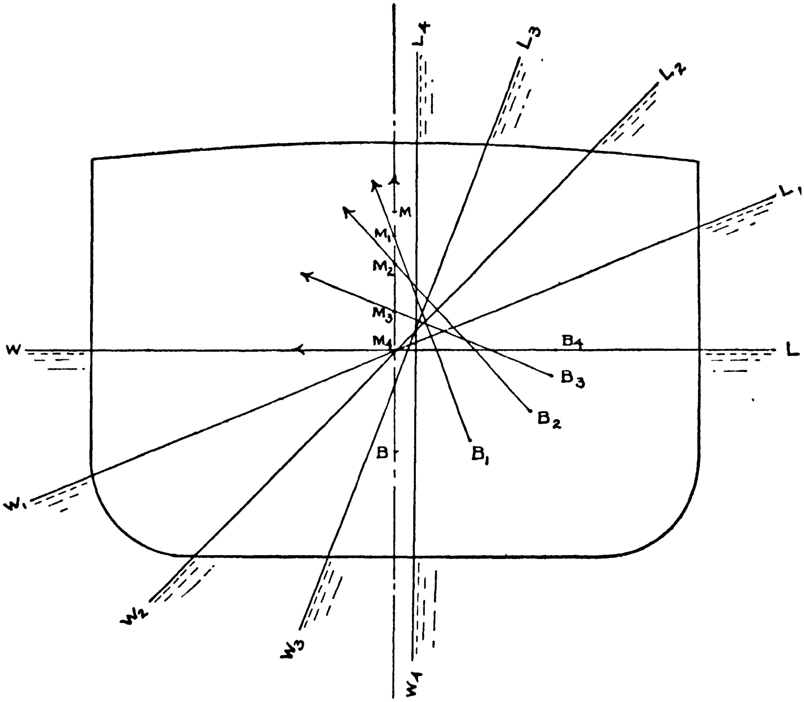


FIG. 507. Movement of Center of Buoyancy

If a man pumps 100 gallons of water from a well to a tank in the attic of his house, he does a certain amount of work. The amount of **work is equal to** the **weight** of the water **multiplied** by the **distance** it was lifted. In the foregoing example, if the tank is 20 feet above the surface of the well and the water weighs 7.5 pounds per gallon, he did 750 × 20 = 15,000 foot-pounds of work. The general expression for **work** is the **product** of **force times distance.** No matter how great the force, unless there is movement, no work is done. To obtain the amount of work done, we multiply the force by the distance through which it is exerted.

Now, when the water has been pumped to the attic tank, it can be made to run a water motor on the first floor of the house if we open a tap to the water motor. In other words, due to its elevation, the water is able to do some work. Any inanimate body which can do work is said to **possess energy.** If it has energy by reason of position, the energy is called **potential energy.** In the incident case, if we should locate a water motor at the water level of the well and allow the hundred gallons of water to run back into the well, we would find that the water motor would do 15,000 foot-pounds of work. But this is exactly the amount of work which was done to transfer the water from the well to the tank in the first place. It appears from the foregoing that work and energy are two aspects of the same thing. When work is done on a substance, it acquires energy and can do an amount of work equal to the energy it possesses.

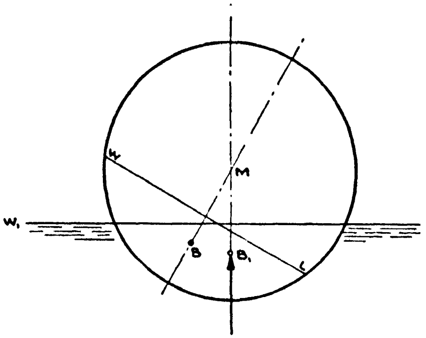


Fig. 508. Ship of Circular Section

If a man turns a crank, the amount of work done in one complete turn is equal to the force exerted multiplied by the length of the circumference of the circle through which his arm moves. The circumference of a circle is equal to the diameter multiplied by 3.14. Therefore, if the crank of a cream separator describes a circle 2 feet in diameter and a man has to exert a push of 50 pounds to keep it turning, he does 2 × 3.14 × 50 = 314 foot-pounds of work for each turn of the crank.

The rate of doing work is called power. The unit of power is the **horsepower.** A machine which does **33,000 foot-pounds of work every minute** is said to have a power of **one horsepower.** Suppose that our man operating the cream separator turns the crank at the rate of 15 revolutions per minute; how many horsepower is he developing? He does 15 × 314 = 3710 foot-pounds of work per minute. One horsepower is 33,000 foot-pounds of work per minute. The man is therefore developing 0.11 horsepower. If we know how many foot-pounds of work per minute any machine does, we determine its horsepower by dividing this amount by 33,000.

In trigonometry, the ratio of the side opposite one of the acute angles of a right angle triangle to the other short side is called the tangent of the angle. In Fig. 509, the tangent of the angle *BAC* (= angle *a*) is *BC*/*AC*. This is written tan $a = BC/AC$. Similarly, the ratio *BC*/*AB* is called the sine of the angle *BAC* and written sin $a = BC/AB$. The ratio *AC*/*AB* is called the cosine of the angle *BAC* and written cos $a = AC/AB$. Any angle is known when its sine, cosine, or tangent is known. That is, regardless of the size of the triangle, we have definitely determined the angle between two of its sides when we know the value of the sine, cosine, or tangent. From this it follows that if we know the value of the sine, cosine, or tangent of one angle of a right angle triangle and the length of one side, we can determine the length of all the sides. For example, suppose we know the value of tan *a* and the length of *AC*. We can then write $BC = AC \tan a$. These relations are used in the solution of certain problems in stability.

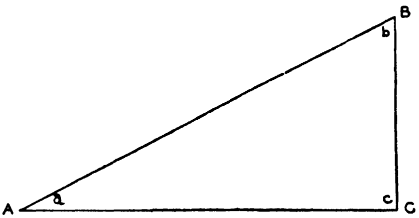


Fig. 509. Functions of Angle

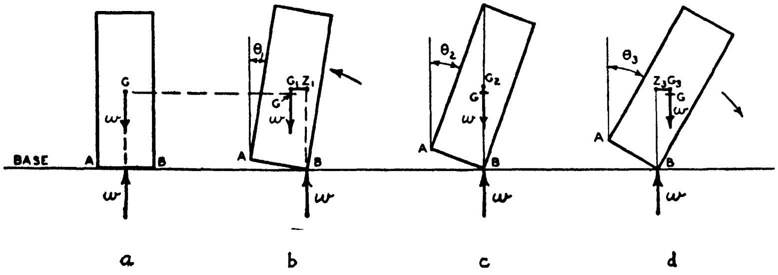


Fig. 510. Stability of Prism

512. Equilibrium and stability. Fig. 510*a* represents a square prism resting on a solid base. This body is in stable equilibrium. The weight acts vertically downward through *G*, its center of gravity, and the supporting force, which is equal to the weight, acts vertically upward through the center of the base. In algebra, if we call one direction positive, the opposite direction is negative. The sum of two equal quantities which have opposite signs is zero. Thus $x + (-x) = 0$. The weight of the prism and the force supporting it act in the same vertical line. These forces are opposite in direction and therefore of opposite signs and equal in amount; their sum is therefore zero. These are the necessary conditions for a body supported on a solid base to be in stable equilibrium.

In Fig. 510*b*, the prism has been tilted about one edge to an angle θ_1; (θ is pronounced theta). The supporting force now acts vertically upward through *B* and the weight acts vertically downward through its center of gravity, as it did in the erect position, Fig. 510*a*. The body in Fig. 510*b* is clearly not in stable equilibrium, because the weight and supporting force do not act in the same vertical line. There is a moment equal to *w*, the weight of the body, multiplied by G_1Z_1, the perpendicular distance between the line of action of the weight and that of the supporting force, tending to return the body to its position of stable equilibrium, Fig. 510*a*. Note, also, that the position of the center of gravity in Fig. 510*b* is above its position in Fig. 510*a*. The force tending to return the body to the erect position is the weight of the body. This does not change as the body is tilted. The righting moment is therefore measured by the magnitude of the perpendicular distance between the lines of action of the weight and supporting force. The body shown in Fig. 510*b* is said to **possess statical stability** because it tends to return to the erect position. The moment tending to right the object is the **moment of statical stability,** or the **righting moment.** Since the righting force, the weight of the body, is constant, the statical stability may be measured by the **righting arm,** G_1Z_1. The righting arm is numerically equal to the righting moment divided by the weight. In the case of ships where the weights are great (thousands of tons), it is frequently more convenient to express the statical stability in righting arms rather than in righting moments, but it should not be overlooked that the latter is the true measure of statical stability.

In tilting the body, it was noted that the center of gravity was raised. This is equivalent to saying that the body was lifted. If a weight, *w*, is lifted a distance, *d*, an amount of work equal to $w \times d$ is done. In Fig. 510*b*, we have a weight *w* lifted through a distance GG_1. Work equal to $w \times GG_1$ must therefore have been done in tilting the body to the angle θ_1 and in the position indicated by Fig. 510*b*, the body possesses an equal amount of potential energy to return it to the erect position. This work or energy is also a measure of the stability of the body and is specifically called the **dynamical stability.**

In Fig. 510*c*, the body has been tilted to an angle θ_2, such that the weight and supporting force act in the same vertical line. There is no righting moment, because the righting arm is zero. In Fig. 510*d*, the supporting force and weight do not act in the same vertical line, the moment is an **upsetting moment** and the body is **unstable;** if it is not restrained it will fall over. Fig. 510*c* represents the limiting condition between stability and instability of the body. The body in Fig. 510 is in stable equilibrium and possesses statical stability for inclinations less than θ_2; for greater inclinations, it is in **unstable equilibrium** or is **statically unstable.** θ_2 is therefore called the **range of stability** of this object. Some objects, such as a sphere on a plane surface, are in equilibrium regardless of their position. Such bodies are said to be in **neutral equilibrium.** The three kinds of equilibrium are illustrated by a cone in various positions. Upon its base, the cone is in stable equilibrium; on its apex, it is in unstable equilibrium; and on its side, it is in neutral equilibrium. **Only bodies which are in stable equilibrium possess statical stability.** Bodies which are in neutral or unstable equilibrium are statically unstable; they have no tendency to return to their initial position when disturbed therefrom.

513. Conditions required for equilibrium. A body is in equilibrium when it is acted upon by no unbalanced forces or moments of forces. We cannot say that a chair standing on the floor is not acted upon by **any forces,** because its weight is a force. It is acted upon by no **unbalanced forces** because the floor exerts a supporting force vertically upward which is exactly equal to the weight acting vertically downward. If, therefore, we call the weight a positive force, the supporting force is a negative force and the sum of the forces is zero. The **conditions for equilibrium** are frequently stated to be that: first, the sum of the horizontal forces must be zero; second, the sum of the vertical forces must be zero; and third, the sum of all moments of forces about any axis must be equal to zero. A ship floating at rest is in equilibrium. Regarding the horizontal forces, little need be said. If the ship is at rest, either there are no horizontal forces or the tension on the anchor chain or mooring lines is equal to the force exerted by the current.

The only vertical forces are the weight and buoyancy. These forces must be equal. The third condition of equilibrium requires that these forces act in the same line. If the force of buoyancy acting vertically upward through the center of buoyancy did not pass through the center of gravity of the ship, the point of application of the ship's weight, there would be a couple equal to the weight of the ship multiplied by the perpendicular distance between the lines of action of the weight and buoyancy to produce rotation of the ship until these two forces did act in the same line. It follows, then, that for equilibrium, a floating body must have the center of buoyancy and center of gravity in the same vertical line.

514. Effect of the position of metacenter. The metacenter has been defined in Art. 511. It is a mathematical point in a ship. It does not have the same kind of physical meaning as the center of buoyancy or center of gravity, but it is used because it facilitates and simplifies the discussion of stability. It and its derived terms are in such general use by maritime people that a proper understanding of these terms in the part of the operating officer is essential. The **metacenter** is the point of intersection of the vertical through the center of buoyancy in the erect position with the vertical through the center of buoyancy in the inclined position, **when the inclination is very small.** The metacenter, therefore, lies on the line containing *B* and *G* and consequently may be above *G*, below *G*, or coincident with it. These three cases are illustrated by Figs. 511, 512 and 513. In the first case, the metacenter, *M*, above the center of gravity: it may be seen from Fig. 511 that, when the ship is given an inclination, a righting moment, equal to the product of the weight of the ship multiplied by the perpendicular distance between the lines of weight and

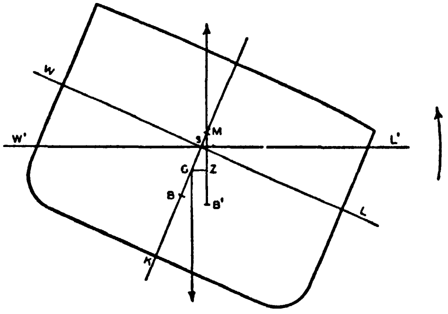


FIG. 511. Ship in Stable Equilibrium

buoyancy, is immediately created. Such a ship, therefore, is in **stable equilibrium** and **possesses statical stability.**

When *M* is below *G,* as illustrated in Fig. 513, the couple brought into existence by giving the ship an inclination is an upsetting couple. Such a ship is therefore in **unstable equilibrium** and **statically unstable.** When *M* coincides with *G,* as shown in Fig. 512, inclination of the ship produces no moment at all, neither to right or upset the ship. The vessel is in equilibrium in the inclined position as well as in the erect position. Such a ship is in **neutral equilibrium** and therefore also **statically unstable. In order that a ship may possess statical stability, the metacenter must be above the center of gravity.**

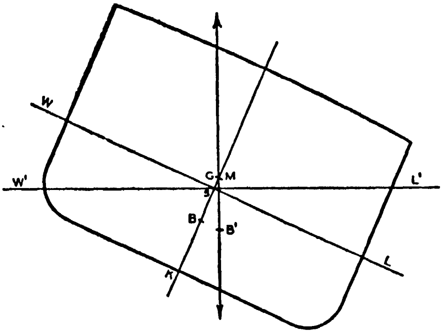


Fig. 512. Ship in Neutral Equilibrium

Figs. 511, 512 and 513 indicate transverse inclinations for the reason that, while ships may be unstable as regards such inclinations, the longitudinal metacenter is always above the center of gravity and ships are always statically stable for longitudinal inclinations.

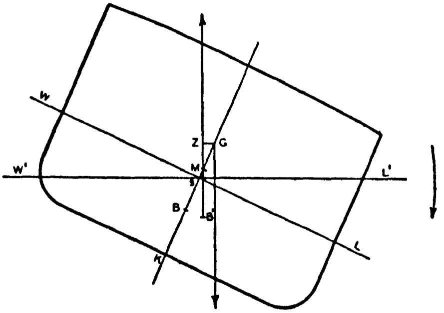


Fig. 513. Ship in Unstable Equilibrium

The transverse and longitudinal metacentric radii, *BM* and *BM*$_L$, and the transverse and longitudinal metacentric heights, *GM* and *GM*$_L$, have previously been defined in Art. 511. Metacentric height is regarded as positive if *M* is above *G;* therefore, a **stable ship has a positive metacentric height;** an unstable ship has a zero or negative metacentric height.

515. Conditions requisite for equilibrium in inclined position. The conditions necessary for equilibrium in an inclined position are the same as those for equilibrium in the erect position as stated in Art. 513. If, however, a stable ship is listed, a righting moment equal to $\Delta \times GZ$ immediately comes into being. (Δ is the displacement and GZ is the perpendicular distance between the lines of weight and buoyancy; see Fig. 511.) If a condition of equilibrium is reached, there must be an inclining moment acting on the ship which is equal in amount and opposite in direction to the righting moment at the inclination reached. This is the only way to comply with the third condition of equilibrium as given in Art. 513, that the sum of the moments of forces must equal zero.

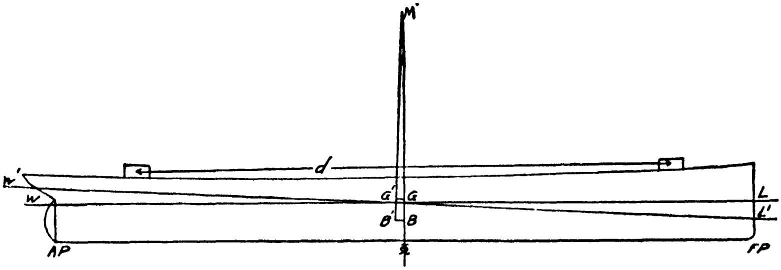


FIG. 514. Longitudinal Weight Movement

A common way of reaching a position of equilibrium in an inclined position is by moving a weight on the ship. Fig. 514 illustrates this for a longitudinal weight movement and Fig. 515 for a transverse weight movement. The latter is used in the following discussion because the points are better separated and the angles easier to see, but the discussion is applicable to both transverse and longitudinal inclinations.

Let Δ = the weight of ship
w = weight moved (w is part of Δ)
d = transverse distance weight w is moved.
θ (theta) = angle of inclination when equilibrium is established after weight w has been moved transverse distance d
B' is the center of buoyancy at inclination θ
$W'L'$ is the waterline at inclination θ
B, G, M, and WL have their usual meaning
GZ is a perpendicular from G on $B'M$

The reason that the ship reaches a position of equilibrium in the inclined position is that the ship's center of gravity travels parallel to the weight movement. When the weight movement is complete, the ship's center of gravity lies in the line *B'M* in Fig. 515 and $B'M_L$ in Fig. 514. This must be so, since for equilibrium, the center of gravity and center of buoyancy must lie in the same vertical line.

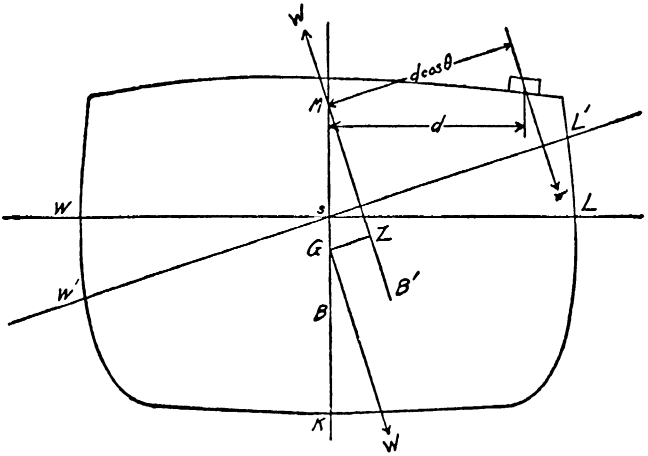


FIG. 515. Transverse Weight Movement

Equating the righting moment and inclining moment, we have

$$\Delta \times GZ = w \times d \cos \theta$$

$$GZ = GM \sin \theta$$

$$\therefore \Delta \times GM \sin \theta = w \times d \cos \theta \qquad (501)$$

and

$$\Delta \times GM_L \sin \phi = w \times d \cos \phi \qquad (502)$$

where ϕ (phi) is the longitudinal inclination corresponding to θ.

Equations (501) and (502) each contain five quantities; if any four are known, the fifth may be computed from the applicable equation.

QUESTIONS

511. Define center of gravity and center of buoyancy.
512. Define metacenter, metacentric radius, and metacentric height.
513. Name and define the three states of equilibrium.

514. Explain with sketches, statical stability, dynamical stability, range of stability, righting moment, righting arm, upsetting moment.

515. What are the conditions required for equilibrium of a floating body?

516. Explain with sketches the effect of the position of the metacenter on the stability of a ship.

517. What is the necessary condition for a ship to assume a position of equilibrium in an inclined position? Express this in an equation.

Section 52. Stability calculations. *Arts.*: 521. Inclining experiment. 522. Moment to change trim one inch. 523. Stability curves.

521. Inclining experiment. The location of the metacenter can be computed from the ship's offsets in a manner somewhat similar to that of computing the volume of displacement. The calculation is not difficult but is long and is done by the ship designer and not the operating officer. The details of how this calculation is made are therefore omitted. If, however, the position of the metacenter is known and is above the ship's center of gravity, the vertical position of the latter point may be computed from equation (501) if we know, w, d, Δ and θ. If, therefore, we give the ship a small inclination by moving a known weight a known distance, and determine from the draft diagram or deadweight scale the displacement of the ship at that time, we can, solve equation (501) for the value of GM, the metacentric height: Also, if we already know the height of the metacenter and the ship's behavior shows that it is in stable equilibrium so that this point must be above the ship's center of gravity, we can determine the vertical position of the center of gravity. In Fig. 515, if we know KM and compute GM by equation (501), then $KG = KM - GM$.

Inclining the ship for the purpose of determining the position of its center of gravity is known as the **inclining experiment.** All operating officers should know the fundamental principles involved and how to use the information obtained from it. The experiment itself is simple and, if properly planned and carried out, takes little time. The preparations are of utmost importance in the success of the experiment. These preparations include the following:

(*a*) Preparation of the inclining weight. Using equation (501), the inclining weight is computed from the known displacement, width of deck, the inclination desired (about 3°) and the estimated value of GM.

(*b*) Preparation of the arrangements for handling the inclining weight. The weight may be either skidded across the deck or swung from a cargo boom.

(*c*) Removal or securing of all loose articles around ship and estimate of the weight of stores, fuel, etc. on board.

(*d*) Preparation of schedule for experiment and drilling of all personnel concerned in their duties during experiment.

(*e*) All fuel and water tanks should be run up full into the sounding tubes or pumped dry. Bilges should be pumped dry and boilers, excepting steaming boiler, run full or emptied.

(*f*) Soundings should be taken to insure that the ship is afloat.

(*g*) The members of the crew should be sent ashore or stationed on the centerline with instructions to remain there until the completion of the experiment.

(*h*) During the taking of readings of inclination, all lines should be slacked except the headline and check made to insure that ship is not resting against piling or wharf.

For measuring the inclinations, pendulums made by plumb bobs are hung at hatchways or other places where a good length of pendulum can be obtained. Frequently, two or three pendulums are used as a check on the accuracy of the experiment.

To determine the displacement, the draft is carefully read from a boat.

The inclining weights are carefully weighed before the experiment. The centerline of the ship is accurately determined and marked on the ship. The value of d is then obtained by carefully measuring the distance from the centerline of the ship to the center of the weight at each weight movement.

At the beginning of the experiment the ship should be erect. Any list in excess of 1° should be removed by weight changes on board before the experiment is begun.

If the precautions given above are carefully observed, the preparations carefully made, and the experiment conducted without loss of time, reasonably accurate results can be expected. Otherwise the time and energy expended on the experiment may be wasted.

Example: A ship is inclined by moving a weight of 35 tons a distance of 22 feet from the centerline. A 16-foot pendulum shows a deflection of 10 inches. The displacement of the ship is 7475 tons. What is the metacentric height? If the metacenter is 27.83 feet above the base line, what is the height of the center of gravity?

Equation (501) may be rewritten

$$GM = \frac{w \times d \cos \theta}{\Delta \times \sin \theta} = \frac{w \times d}{\Delta \tan \theta} \tag{503}$$

since it will be seen from Art. 511 and Fig. 509 that

$$\frac{\sin a}{\cos a} = \frac{\frac{BC}{AB}}{\frac{AC}{AB}} = \frac{BC}{AC} = \tan a$$

$$\tan \theta = \frac{10}{16 \times 12} = 0.0521$$

$$GM = \frac{35 \times 22}{7475 \times 0.0521} = 1.98 \text{ feet.}$$

If we designate by KM the height of the metacenter above the base line, we have

$$KM = 27.83 \text{ feet}$$
$$KG = KM - GM = 27.83 - 1.98 = 25.85 \text{ feet.}$$

522. Moment to change trim one inch. Equation (502) of Art. 515 may be rewritten as follows:

$$w \times d = \Delta \times GM_L \tan \phi \tag{504}$$

When a change of trim of one inch is produced, the longitudinal inclination is the angle whose tangent is $\frac{\frac{1}{12}}{L}$, i.e., in Fig. 514,

$$\tan \phi = \frac{\frac{1}{12}}{L} = \frac{1}{12\,L},$$

where L is in feet. If we let $MT1$ be the value of $w \times d$ which produces this longitudinal inclination, i.e., let $MT1$ be the moment required to change the trim one inch, we have from equation (504),

$$MT1 = \frac{\Delta \times GM_L}{12\,L} \tag{505}$$

The moment to change trim one inch is used to compute the number of inches change of trim caused by the fore and aft movement of a known weight. Change of trim is equal to the product of the weight by the distance it was moved divided by the moment to change trim one inch. For example, if we pump 50 tons of water from the forepeak tank to the after peak tank a distance of 400 feet and the moment to change trim one inch is 1000 foot-tons, a change of trim of $(50 \times 400)/1000 = 20$ inches by the stern is produced.

Example: Compute the moment to change trim one inch for a ship of 10,000 tons displacement, 460 feet long, having a longitudinal metacentric height of 641 feet.

$$MT1 = \frac{10{,}000 \times 641}{12 \times 460} = 1161 \text{ foot-tons}$$

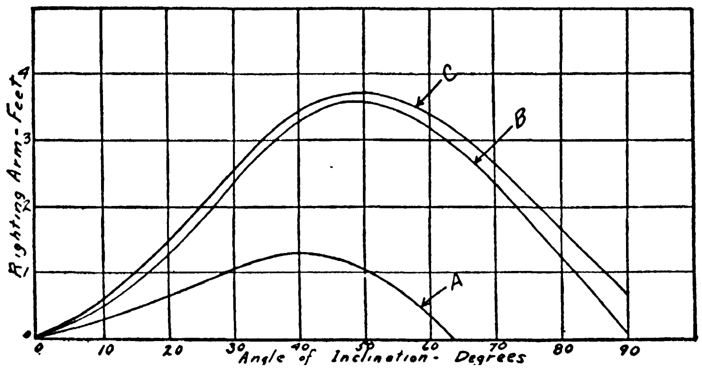


FIG. 516. Statical Stability Curves

523. Stability curves. Curves which show how the righting arm of a ship changes as the angle of heel increases are known as curves of statical stability. A typical curve is shown in Fig. 516.

The features of a curve of statical stability from which the stability characteristics of the ship in that condition of loading may be judged are (1) the slope at the origin, (2) the angle of heel at which the maximum righting arm is obtained, (3) the value of the maximum righting arm, (4) the angle at which the righting arm becomes zero, and (5) the area under the curve. The slope of the curve at small inclinations depends upon the metacentric height. In other words, the metacentric height exercises the major influence on the righting arm at small inclinations. This is usually expressed by saying that the **initial stability** of a ship **depends upon** the **metacentric height.** A formula in common use for the righting arm, R, at small angles of inclination is

$$R = GM \sin \theta \qquad (506)$$

The angle of maximum righting arm is the angle at which the deck edge goes under the water. This angle depends directly upon the freeboard. The greater the freeboard, the greater the angle. For example, if the freeboard is equal to one-half the breadth, the angle of deck edge immersion is 45°; if the freeboard is only one-fourth the breadth, this angle is only 26½°. The angle at which the righting arm becomes zero is approximately equal to twice the angle of deck edge immersion. For all inclinations up to that at which the righting arm becomes zero, the ship has a positive righting moment. That is, within this range of inclinations the ship is statically stable. For this reason, the angle of zero righting arm is called the **range of stability.** Since the range of stability is about twice the angle of deck edge immersion and since the latter angle depends directly upon the freeboard, it may be stated that the **range of stability depends** largely **upon** the **freeboard.** This is one of the reasons for using the freeboard as a measure of the safety of a ship, as exemplified in the Load Line Regulations.

The maximum righting moment gives the value of the inclining moment which will capsize the ship if the upsetting moment is slowly applied. Actually, since inclinations are due to waves or damage which are what is known as dynamic forces, no ship will stand an inclining moment as great as the maximum righting moment. All ships actually become unstable before the theoretical range of stability is reached. There is no way for a ship to attain a steady inclination in the region represented by the part of the curve of statical stability between the angle of maximum righting arm and zero righting arm. If the inclining moment is less than the maximum righting moment, the inclination of the ship will be less than that of the angle of maximum righting moment. If the inclining moment is greater than the maximum righting moment, the ship will continue on past the angle of maximum righting moment until it capsizes. **From a practical**

point of view the angle of maximum righting arm is the range of stability.

In Art. 512, dynamical stability was defined as the work done in producing a definite inclination. This is equal to the energy absorbed by the ship in reaching this inclination. The area under the curve of statical stability is the dynamic stability of the ship and therefore a measure of the ability of the ship to absorb the energy of an inclining force.

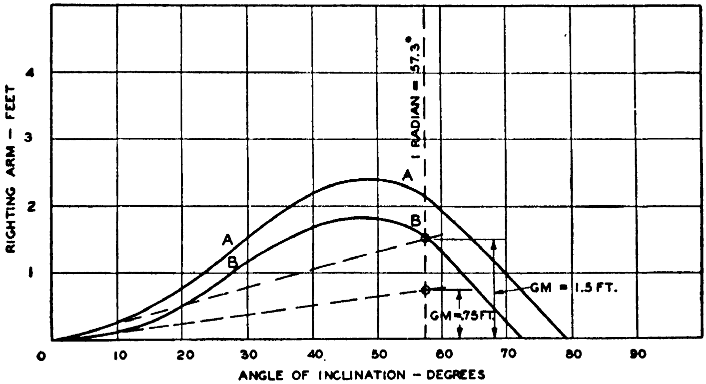


FIG. 517. Effect of *GM* on Stability

Curves *A* and *B* of Fig. 517 are for the same ship but the metacentric height for curve *B* is one-half that of curve *A*. This results in reduced slope at the origin, smaller righting arms throughout, and smaller range of stability for curve *B*. But of equal importance, it reduces very materially the **area** under this curve. This area represents the dynamical stability of the ship. Since the inclining forces actually met in service are dynamic forces, not static forces, it is essential that a safe ship should have a good value for its dynamic stability. For a ship in a given condition of loading, the **dynamic stability depends** almost entirely **on** the **metacentric height.**

From the foregoing, it may be seen that the **stability characteristics of a ship are determined by the metacentric height and the freeboard.** Since the metacentric height depends partly on the freeboard, the importance of the freeboard as a measure of the safety of the ship may be seen. The value of the metacentric height depends upon the relative values of the height of the ship's center of gravity and metacenter. The height of the center of gravity in a ship of given depth depends upon the loading and the freeboard. The height of the metacenter depends upon the height of the center of buoyancy and the value of BM, the metacentric radius. The former depends upon the form of the underwater body; the latter depends almost entirely on the breadth of the ship.

Application of the principles developed in this section to the practical operation of cargo ships are given in Art. 534.

QUESTIONS

521. Describe the inclining experiment including purpose, preparations, precautions and method of performance.

522. Define moment to change trim one inch and tell how it is computed.

523. What are curves of statical stability?

524. What are the five features of a curve of statical stability from which the stability characteristics of a ship may be judged?

525. Discuss the effect of metacentric height and freeboard on the stability characteristics of a ship.

526. What ship characteristics have the greatest influence on the height of the ship's center of gravity?

PROBLEMS

521. A tanker is inclined in the light condition, displacement 6700 tons, by moving a weight of 60 tons a distance of 25 feet from the center line. In the inclined position the deflection of the 21-foot plumb bob is $4\frac{3}{8}$ inches. What is the transverse metacentric height in this condition? If the transverse metacenter is 26 feet above the base line, what is the height of the center of gravity?

Ans. $GM = 12.91$ feet; $KG = 13.09$ feet.

522. You are required to conduct an inclining experiment on a vessel whose displacement is 8500 tons. The only weight available is 40 tons and the width of the deck where it can be moved is 50 feet. You know that GM is not over 4 feet. How long a pendulum will you use in order that it will not swing more than 6 inches in each side of the middle position?

Ans. 17 feet.

523. A small passenger vessel 280 feet long has a displacement of 3100 tons and a longitudinal metacentric height of 326 feet. Compute the moment to change trim one inch.

Ans. 301.

524. A scout cruiser is 550 feet long, $GM_L = 480$ feet, $\Delta = 7000$ tons; compute $MT1$.

Ans. 509.

525. Your vessel is to go in dry dock. She has a list of 3° to port. Her displacement is 30,000 tons and GM is 5 feet. How many gallons of fuel oil will you pump from No. 4 fuel oil tank to No. 3, the distance between centers of these tanks being 60 feet, in order to bring her to an even keel? One gallon of fuel weighs 8 pounds.

Ans. 36,680 gals.

526. Plot the statical stability curve of a ship which has the following righting arms in feet at 10° intervals beginning with zero and extending to 90° inclination: 0, 0.25, 0.75, 1.62, 2.29, 2.41, 1.96, 0.96, −0.13, −1.23. $GM = 1.50$ feet. Determine the maximum righting arm, the angle at which it occurs, and the range of stability.

Ans. Maximum righting arm = 2.46 feet at 47.2° inclination. Range of stability = 78.8°.

Section 53. Stability in operation.

Arts.: 531. Adding, removing, and moving weights. 532. Docking and grounding. 533. Free surface. 534. Loading.

531. Adding, removing, and moving weights. The addition, removal, or movement of a weight in any structure afloat or ashore produces changes in the stability and supporting forces. In the cases of structures ashore, such changes become apparent only when there is danger of failure. With a ship, however, a comparatively small weight movement may produce an appreciable change of trim and list, because the **center of buoyancy must be in the same vertical line as the center of gravity.** The addition or removal of a weight also produces a change in the mean draft. In other words, weight changes on a ship may cause not only a change in the location of the center of gravity but changes in the location of the center of buoyancy, metacenter, and all of the characteristics such as tons per inch, moment to change trim, etc., which depend upon the volume of displacement. When the weight change is of large amount all of these must be taken into consideration and the calculation is very involved. When, however, the weight does not exceed about 5 percent of the displacement, it is possible to simplify the solution without impairing the accuracy, provided the ship is of normal form. This is usually the case to be dealt with by operating officers. The method of making the calculations for such cases will be given herein and the more complex calculations left to the naval architects. These methods may be used to get an approximate solution, even if the weight exceeds 5 percent of the displacement, provided the solution does not indicate a list which causes the bottom to come out of the water or the deck edge to go under it, or a trim which exposes the bottom or immerses the deck at the ends of the ship. Even in such extreme cases the error rarely exceeds 10 percent. Very often in operation, particularly in case of damage, a prompt solution which is 10 percent in error is better than a solution which is only 1 or 2 percent in error but takes all day to make.

The explanation is simplified by taking a specific case.

Example: A ship draws 24 feet forward and 23 feet aft in salt water, displacement 12,813 tons. There is a list of 3° to starboard. How much water ballast must be taken into a tank having its center of gravity 20 feet to port of the centerline, 180 feet aft of the midship section and 1.5 feet above the base line to correct the list, and what will the draft of the ship at the ends then be? The metacentric height of the ship from inclining experiment data is known to be 3.50 feet. Moment to change trim one inch = 1260 foot-tons; tons per inch immersion = 50.4.

From equation (501)

$$w = \frac{\Delta \times GM \tan \theta}{d} = \frac{12{,}813 \times 3.50 \times 0.0524}{20} = 117.8 \text{ tons}$$

$$\text{Trimming moment} = 117.8 \times 180 = 21{,}180 \text{ foot-tons}$$

$$\text{Change of trim} = \frac{21{,}180}{1{,}260} = 16.8 \text{ inches, divided evenly}$$

forward and aft.

$$\text{Increase in draft} = \frac{117.8}{50.4} = 2.34 \text{ inches}$$

Before ballasting, draft forward	=	24 ft. 0.00 in.	aft 23 ft. 0.00 in.
Increase in mean draft	=	(+)2.34 in.	(+)2.34 in.
Change in draft due to change of trim	=	(−)8.40 in.	(+)8.40 in.
Final drafts	=	23 ft. 5.94 in.	23 ft. 10.74 in.
Final drafts	=	23 ft. 6 in.	23 ft. 10¾ in.

On a floating ship, changes in draft, trim, and list become apparent during the weight change and a serious condition is not likely to arise because the change be stopped in time. A ship in dry dock is like a structure ashore supported on foundations. The effects of any weight changes do not become apparent until the ship is floated, when a serious list or trim may occur. It is desirable, therefore, that no weight changes be made in dry dock. If any changes are made, they should be equal on both sides of the ship. Raising of weights without change of transverse or longitudinal location may also be dangerous because of the rise of the ship's center of gravity and consequent reduction of metacentric height which occurs. This may cause the ship to be unstable when floated. Many ships have been damaged on undocking due to ill-considered and indiscriminate weight changes in dry dock.

532. Docking and grounding. From the point of view of stability the only difference between docking and grounding is that the former is carefully planned and carried out; the latter is usually accidental or an emergency operation to prevent something worse. The stability changes in a ship grounded all along the keel are the same as those of a ship dry docked. In dry docking, the ship comes out of the water entirely; this is seldom the case in grounding. The stability changes on a ship grounded either in a dry dock or on the bottom are most easily explained as a case of weight removal.

Let us first consider the transverse stability of the grounded ship. It is no longer a floating body; part of the weight is taken by the direct pressure of the ship's bottom on the docking blocks or the ground. This pressure is equal to the difference between the weight and the buoyancy of the ship. This in turn is equal to the difference between the weight of the water displaced by the ship when floating and when grounded. The pressure at the bottom of the ship has exactly the same effect on the ship's stability as if that much weight were removed from the location. This would leave a floating ship of smaller weight, which was touching the ground but did not rest on it. If a **weight below** the **center of gravity** of the ship is **removed,** the **center of gravity rises;** see Fig. 518. The **effect of grounding** is therefore **equivalent** to a **rise** of the **ship's center of gravity,** and the **greater the pressure** on the bottom the **greater this rise.** In dry docking, a stage is always reached when this **virtual rise** of G is equal to GM. At this point, the metacentric height is zero; the transverse stability vanishes. Before this condition arises, shores must be set up or blocks placed at the turn of the bilge to prevent the ship from falling over. Whether a grounded ship becomes unstable or not depends on how far the water falls after grounding. If the grounding occurs at or near low water, serious results are not probable unless the ship's structure is badly damaged. If the bottom at the point of grounding is

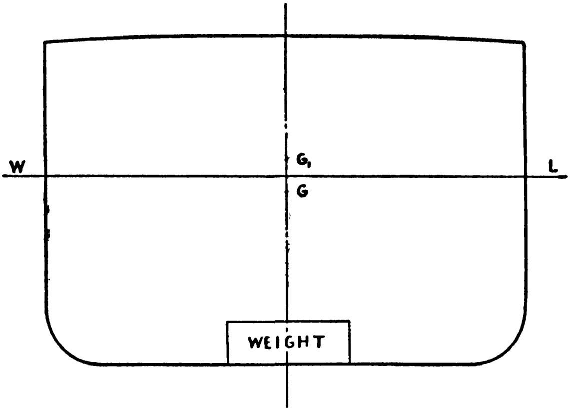


FIG. 518. Effect of Removing Low Weight

soft, the ship usually makes a cradle and comes afloat when the tide arises. When a ship grounds at or near high water, it may become unstable at low water and lie over on its side. In such case, it may fill up when the tide rises and becomes a case for salvage.

To determine the probability of instability in any specific case, the following calculation may be made. Refer to Fig. 519.

Let Δ = displacement to waterline WL

Δ_1 = displacement to waterline $W'L'$

$$\Delta \times KG = \Delta_1 \times KG'$$

$$\therefore KG' = \frac{\Delta \times KG}{\Delta_1} \qquad (507)$$

When $KG' = KM_1, G'M_1, = 0$

Example: A ship drawing 16 feet 9 inches grounds all along the keel during ebb tide. The center of gravity is accurately estimated at 24.50 feet above the base line. The tide tables indicate a 3-foot fall of tide. At 16 feet 9 inch draft, $KM = 26.50$ feet; at 13 feet 9 inch draft, $KM =$

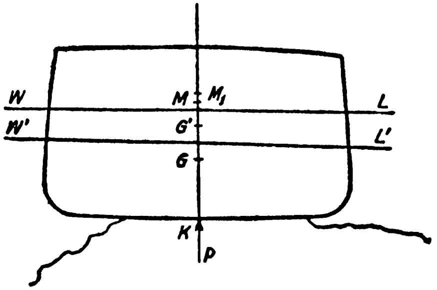


FIG. 519. Stability When Grounded

28.20 feet. Determine the metacentric height at the turn of the tide, neglecting any settling of the ship into the bottom.

$$
\begin{aligned}
\text{At 16 feet 9 inch draft, } \Delta &= 8825 \text{ tons} \\
\text{At 13 feet 9 inch draft, } \Delta &= 7100 \text{ tons} \\
\text{At 16 feet 9 inch draft, } KM &= 26.50 \text{ feet} \\
KG &= 24.50 \text{ feet} \\
KG' = \frac{8825 \times 24.50}{7100} &= 30.45 \text{ feet, from equation (507).} \\
\text{At 13 feet 9 inch draft, } KM &= 28.20 \text{ feet} \\
G'M_1 &= -2.25 \text{ feet}
\end{aligned}
$$

This calculation indicates that the ship will become unstable during the fall of the tide, and will therefore take a list and may roll over on its side. To prevent this, prompt action should be taken to reduce the height of the center of gravity. Steps to accomplish this are the emptying of high tanks and lowering the boats into the water. When the ship grounds on a limited area only, the pressure may cause both a list and change of trim. The calculation in this case is considerably more complicated and one which an operating officer could hardly be expected to make.

533. Free surface. In Fig. 520, *wl* is the level of liquid in a partially filled tank having the section shown. As the ship rolls, some of the liquid on the high side runs to the low side because the surface of a liquid always tends to remain horizontal. If the ship reaches an inclination θ, waterline $W'L'$, a wedge of liquid wsw' is transferred to the low side causing the center of gravity of the liquid in the tank to shift from b in the centerline plane to b', which is off-center. In other words, due to its mobility, the liquid now exerts an upsetting moment equal to its weight times *bb′*. The effect of this upsetting movement is to reduce the righting moment which the ship would otherwise have at this inclination. It can be shown mathematically that the effect on the stability of the ship of the liquid's freedom to move from side to side is exactly the same as if the liquid were lifted a distance *bm*, as given by equation (508).

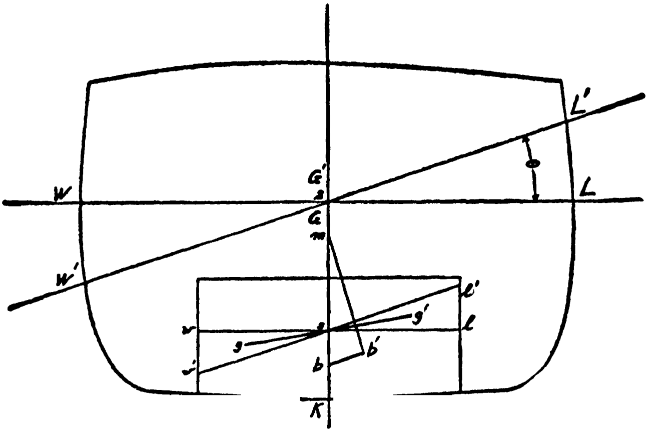


Fig. 520. Free Surface

$$bm = \frac{lb^3}{12\,v} \tag{508}$$

l = length of tank in feet

b = breadth of tank in feet

and v = volume of liquid in tank in cubic feet.

Since the effect of the mobility of the liquid surface is the same as if the liquid were raised, the **effect of free surface is equivalent to a rise of the center of gravity of the ship.** The amount of this rise *GG′* is given by equation (509).

$$GG' = \frac{rlb^3}{12\,V} \tag{509}$$

where V = volume of displacement of ship and r = specific gravity of liquid with respect to the liquid in which the ship is floating. If the liquid in the tank is the same as that in which the ship is floating, $r = 1$.

It is seen from the above that the effect of a free surface is twofold. First, it is equivalent to a rise in the ship's center of gravity. This results in a reduction in metacentric height and, consequently, a reduction in the righting arms at all angles of inclination. Second, for each angle of inclination it produces a definite inclining moment. The effect of these two causes is that the angle at which equilibrium in the inclined position is obtained is always greater when the ship carries liquids having free surfaces. This is the reason that there must be no free surfaces when the inclining experiment is performed.

Example: The *S.S. California* of 30,000 tons displacement has a metacentric height of 3 feet without any free surface. What is the metacentric height if there are two slack fuel oil tanks, each 40 feet long and 60 feet wide (30 feet each side of the centerline)? What is the supsetting moment due to the transference of oil at an inclination of 10°? ($r = 0.92$.)

$$GG' = \frac{rlb^3}{12V} \text{ [equation (509)]}$$

$$= \frac{2 \times 0.92 \times 40 \times 60 \times 60 \times 60}{12 \times 30{,}000 \times 35}$$

There are two tanks. Since 35 cubic feet of sea water weigh one ton, we can compute the volume of displacement by multiplying the displacement in tons by 35.

From the above $GG' = 1.26$

$$G'M = GM - GG' = 3 - 1.26 = 1.74 \text{ feet.}$$

When the ship has an inclination of 10°, the angle wsw' = angle $lsl' = 10°$

$$ww' = ll' = 30 \tan 10° = 30 \times 0.1763 = 5.289 \text{ feet}$$

The area of the triangle $wsw' = lsl' = \frac{1}{2} \times 30 \times 5.289 = 79.34$ square feet. The volume of the liquid transferred from one side of the ship's centerline to the other is therefore

$$v = 2 \times 40 \times 79.34 = 6347 \text{ cubic feet.}$$

$$\text{Its weight, } w = 6347 \times \frac{0.92}{35} = 167 \text{ tons.}$$

Since the center of gravity of a triangle is two-thirds of the distance from the apex to the base, from the apex, the distance which the oil is transferred across the ship is $2 \times \frac{2}{3}$ of $30 = 40$ feet. The upsetting moment of this oil at 10° is therefore $40 \times 167 = 6680$ foot-tons.

Semi-liquid cargoes, such as grain, coal, and ore in bulk, may shift and produce an upsetting moment; they seldom follow the roll of a ship as a liquid does.

It should be noted from equation (509) that the loss of metacentric height caused by free surface does not depend upon the amount of liquid in the tanks but only on the dimensions of the surface. Generally speaking, it is impossible to avoid a free surface in all tanks, but by careful management on board ship the number of tanks having a free surface can be kept small. Equation (509) shows that the rise of the ship's center of gravity is proportional to the cube of the breadth of the free surface. Where liquid-carrying tanks must be wide, such as the cargo tanks of tankers, the effect of free surface on the metacentric height is reduced by fitting one or two oil-tight longitudinal bulkheads. If there is one bulkhead, the loss of metacentric height due to the free liquid in each of the narrower tanks so formed is only one-eighth of what it would be if the tanks extended the full width, and if both tanks have free surfaces, the reduction is only one-fourth of what it would be without the bulkhead.

534. Loading. The stability characteristics of a ship depend upon the freeboard and the metacentric height. The freeboard of any particular ship depends upon the deadweight, because the deadweight plus the light weight of the ship equals the total displacement. At any displacement near the load displacement, the **position of the center of gravity** of the ship depends in large measure on **where the cargo is stored.**

The displacement is measured by the mean draft. That is the principle of the curve of displacement and deadweight scale. If we measure the mean draft of the ship, we can read the displacement from either of these. Consequently, if we know how much deadweight we intend to put into the ship, we can read on the deadweight scale what the mean draft will be. This does not, however, tell us a number of things we need to know in order to have full knowledge of the stability and trim of the ship. It does not tell us whether the draft at the bow will be the same, greater, or less than that at the stern. It does not tell us whether the ship will be erect or listed port or starboard. It does not tell us whether or not the ship will be top heavy or whether it will roll fast or slowly. It does tell us what the mean draft will be and where the metacenter will be. All of these other things must be calculated using the principles of stability previously given in this chapter.

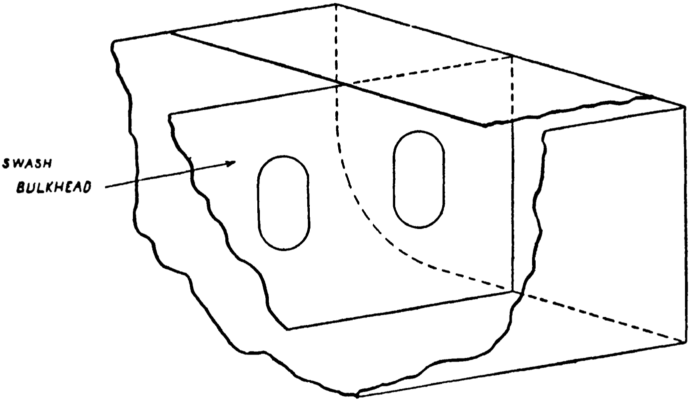


FIG. 521. Swash Bulkheads

Cargo should be well secured to keep it from shifting when the ship rolls. This is particularly important in the case of liquid and semi-liquid bulk cargoes and delicate cargoes, such as tropical fruits. Oil or water sloshing around in a tank creates a " water-hammer " when it strikes the under side of the deck. The deck may be damaged and leaks started. This has actually happened, although not recently. This is entirely independent of and in addition to the effect of the free surface on stability discussed in Art. 533. To prevent liquids from getting in violent motion, swash bulkheads are frequently provided; see Fig. 521. These are not tight bulkheads, since they have holes in them to allow the liquid to flow through, but they do stop it from crashing across the tank.

To prevent bulk cargoes from shifting and thereby listing the ship, shifting boards are installed on ships when carrying grain, ore, and coal in bulk. These are shown in Fig. 522. Delicate cargo must be secured to prevent damage to it. Locomotives, tanks, trucks and other heavy weights must be well secured to prevent them from coming loose and damaging the ship.

If the center of gravity of the ship is brought very low by the stowage of much heavy cargo in the bottom of the holds, the ship will have a large value of the metacentric height and be perfectly safe as regards stability, but may be a most unpleasant roller. This is not desirable in a cargo carrier and particularly bad in ships carrying passengers and cargoes of tropical fruit. The relation between the metacentric height and the rolling is discussed at more length in Chapter 8, but it may be stated here that the greater the metacentric height the faster the ship rolls. A ship of large *GM* is a quick roller. Fast rolling is more jerky than slow rolling and therefore makes more people seasick, is more liable to set cargo adrift, and strains the ship more. If cargo of different densities is being carried, the heavy cargo should be divided between the lower holds and 'tween decks in such a way as to avoid having the ship's center of gravity come too low or too high. The best guide in this respect is experience with the ship in different conditions of loading. It is better to err on the side of giving the ship a little bit too much *GM* than to start a voyage across the ocean with insufficient stability. There is a happy medium which is best arrived at by

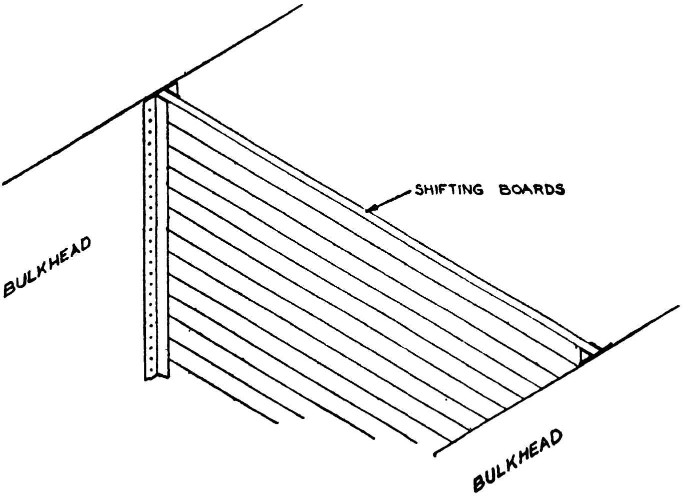


FIG. 522. Shifting Boards

a knowledge of the principles involved and experience with the specific ship. Problems illustrating this principle are given at the end of this article.

A ship should never begin an ocean voyage with an appreciable list as did the *Vestris* on her last ill-fated voyage. Fig. 523 shows how the righting arm and range of stability are reduced by initial list.

It is the duty of the operating officers to watch closely the stowage of the cargo, to see that it is properly secured and distributed so as to give proper metacentric height for the voyage. In cases where the ship carries cargo of only one kind, the ship's officers should see that the spaces are filled or, when partially filled, that substantial partitions are erected and shored to keep the cargo in place. Deck cargoes, such as lumber and cotton, should be given particular attention because it is not easy to secure such cargo against shifting, and shifting of deck cargoes is dangerous to both ship and personnel. When deck cargo of considerable amount is carried, it is well to check the metacentric height.

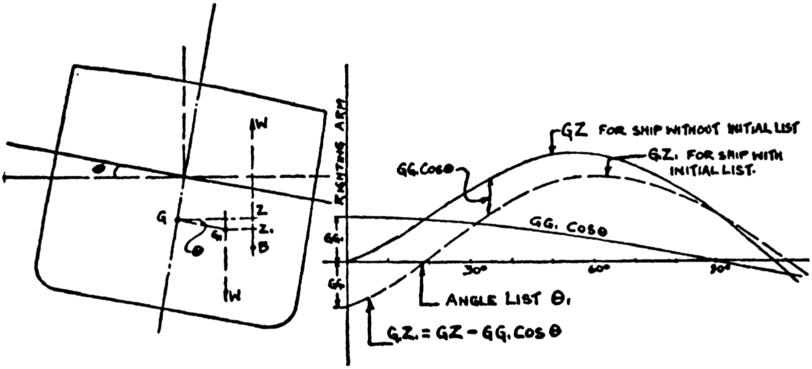
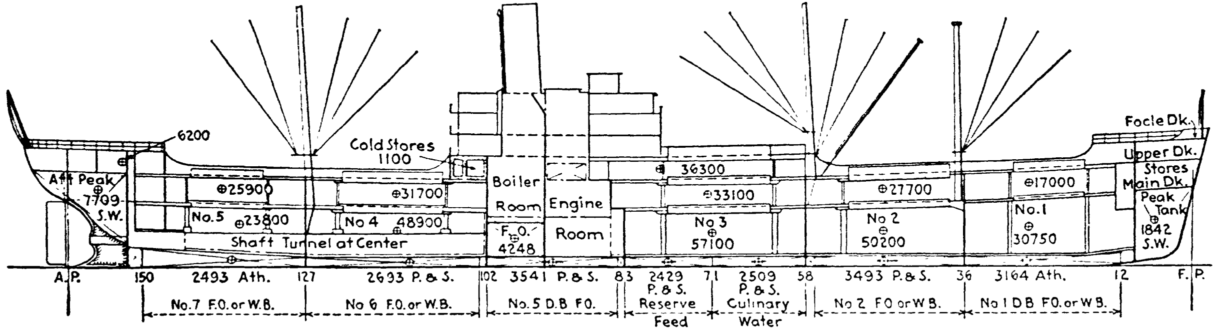


Fig. 523. Effect of Initial List

The best disposal of miscellaneous cargo is a problem which requires careful and serious consideration. In general, dense cargo such as steel rails, plates, billets and other metals should be stowed in the bottom of the holds with lighter cargo on top. The heavier cargo is more likely to injure the lighter cargo if placed on top of it and the heavy cargo low down tends to lower the center of gravity and increase the metacentric height. This can be carried too far and give a dangerously short period of roll. Where a considerable amount of dense cargo has to be carried, some of it should be stowed in the 'tween deck spaces to give a proper balance to the ship. Where heavy weights such as big bridge girders, locomotives, and the like have to be carried high because they cannot be put in the holds, or must be unloaded before lighter cargo, it may be necessary to fill some of the ballast tanks in the double bottom space. When ballasting for this purpose, the tanks should be filled right up into the sounding tube to insure that there is no free surface with its attendant loss of metacentric height. It is usually permissible to put off such ballasting until the ship is clear of the harbor and outside where good clean sea water free from muck and mud can be obtained.

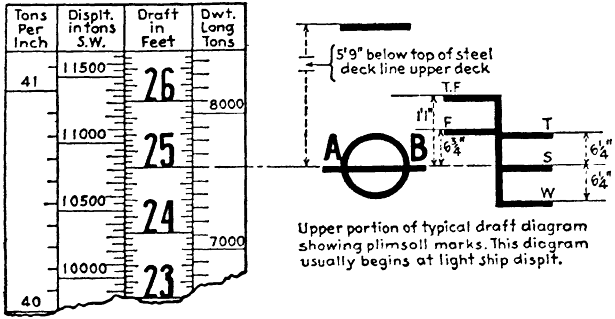
It happens frequently that a ship is to visit several ports in succession, according to a set schedule, discharging and taking on cargo at each and finally discharging completely at the last port, where the available depth of water is only a little greater than the load draft of the ship. The conflicting requirements to be met call for the exercise of clear thinking and ingenuity. The cargo to be discharged first should be on top. If only a small amount of cargo is to be received or delivered at any port, it should not be necessary to open up all cargo holds. Cargo taken on at any port must not be put on top of that which is to be discharged before the cargo so placed. Adequate stability on each leg of the voyage must be provided for by a balanced disposition of dense and light cargo. Deck cargoes should be avoided as far as possible. Further, the ship should have as nearly as possible the same draft forward and aft when entering the port in which it is to be discharged, if its mean draft is near the designed load draft. Otherwise the maximum draft may exceed the minimum depth of water in the channel. Trim may be corrected by taking ballast water into the fore or after peak tank, but such ballasting also increases the mean draft and, if the ship is near its maximum draft, may not be permissible.

If mixed cargo is carried, the simplest solution is to have the center of gravity of the cargo at the same height as it would have if the hold were completely filled with a homogeneous cargo of the same weight. Generally speaking, the stability of a ship is adequately provided for if this is done.



Note:
All capacities are in cubic feet
Center of gravity of cargo spaces and tanks
indicated thus: ⊕

Length B.P. .... 390′0″
Beam (Molded) .... 55′0″
Depth Molded to Upper Dk. (Side) .... 30′6″
Gross Tonnage 4772.70
Net Tonnage 2946.00



Upper portion of typical draft diagram showing plimsoll marks. This diagram usually begins at light ship displt.

Typical Summary Table

Fuel Oil and Salt Water Ballast Tanks

Frame	Tanks		Cu. Ft.	Gals.	Bbls.	S.W. Ton
F.P.-10	Fore Peak		1842			52.64
12-36	No. 1 Double Bottom	Ath.	3164	23660	563.3	90.37
36-57	No. 2 Double Bottom	Port	3493	26130	622.1	99.81
36-57	No. 2 Double Bottom	Stbd.	3493	26130	622.1	99.81
84-102	No. 5 Double Bottom	Port	3541	26480	630.5	
84-102	No. 5 Double Bottom	Stbd.	3541	26480	630.5	
94-102	Service	Port	2672	19990	476.0	
94-102	Service	Stbd.	2672	19990	476.0	
94-102	Deep Tank	Port	4248	31780	756.7	
94-102	Deep Tank	Stbd.	4248	31780	756.7	
103-127	No. 6 Double Bottom	Port	2693	20140	479.5	76.93
103-127	No. 6 Double Bottom	Stbd.	2693	20140	479.5	76.93
127-150	No. 7 Double Bottom	Ath.	2493	18650	444.0	71.24
152-168	After Peak		7709			220.24
	Totals		48502	291350	6936.9	778.97

FIG. 524. Capacity Plan

Fig. 524 is what is known as a Capacity Plan. It is of the greatest usefulness in solving all these problems regarding the proper disposal of cargo. It gives the capacity of each of the lower holds, 'tween deck spaces and tanks and the location of the center of gravity of each of these spaces. The capacity of cargo spaces other than tanks is generally given in cubic feet for bale cargo and bulk cargo. The latter is the larger figure because grain, ore, etc. will flow around the frames and other structure but cargo in bales and cases will not. The capacity of tanks may be given in cubic feet, gallons, barrels, tons, or a combination of these. Capacity in tons is generally given only for water or oil, the specific gravity of which is pretty well known.

Let us consider first the effect of loading on stability, i.e., the vertical location of the ship's center of gravity. If the center of gravity of a hold space is not marked on the capacity plan, it may be estimated after a little experience unless the space is near the ends and has much curvature. Most such spaces are rectangular. The center of gravity of a rectangle is at the intersection of the diagonals.

Examples: 1. A ship must load 200 tons of pig lead in the 'tween deck space above #3 hold. The center of gravity of this metal will be 34 feet above the keel, #3 hold is 40 feet deep, the tank top is 36 inches above the outer bottom, and the center of gravity of the complete hold is 23 feet above the keel. How much ballast must be taken into the double bottom to compensate for carrying this dense cargo so high?

The **center of gravity** of the **lead** is $34 - 23 = 11$ feet **above** the center of gravity of the hold. Similarly, the **center of gravity** of the **ballast water is** $20 + \frac{3}{2} = 21.5$ feet **below** that of the hold.

Let B = number of tons of ballast water required.

$$\text{Then } B = \frac{200 \times 11}{21.5} = 102 \text{ tons}$$

2. A ship has the holds filled with lumber and 500 tons are on deck. The draft is 29 feet forward and 28 feet aft. Load draft is 29 feet 6 inches. The center of gravity of the deck cargo is 5 feet above the upper deck which is 38 feet above the keel. The double bottom tanks are 3 feet deep. Is it possible to ballast to compensate for the deck cargo without exceeding the load draft?

Tons per inch = 52.5
Height of center of gravity of hold = 20.5 feet above keel

Mean draft = 28 feet 6 inches
Height of center of gravity of deck cargo = 5 + 38 = 43 feet
Distance from c.g. of hold to c.g. of deck cargo = 43 − 20.5 = 22.5 feet
Distance from c.g. of ballast tanks to c.g. of hold = 20.5 − 1.5 = 19 feet

$$B = \frac{500 \times 22.5}{19} = 592 \text{ tons}$$

$$\text{Increase in draft due to ballasting} = \frac{592}{52.5} = 11.27 \text{ inches}$$

Mean draft after ballasting = 29 feet 5¼ inches

It will be possible to ballast to compensate for the deck cargo, since the draft after ballasting will be ¾ inch less than the load draft.

3. The depth of a ship at a central hold space is 41 feet divided as follows: double bottom space 3 feet, lower hold 20 feet, lower 'tween decks 9 feet, upper 'tween decks 9 feet. In what proportion should a shipment of steel rails be divided between the lower hold and the upper 'tween decks so that the center of gravity of the shipment will be at the center of gravity of the hold?

Since we are not given the height of the center of gravity of the hold space but are told that it is central, it may be assumed that it is rectangular and the center of gravity will be half its depth above the tank top. The height above the keel then is (38 ÷ 2) + 3 = 22 feet. The rails resting on the tank top will be 22 − 3 = 19 feet below the center of gravity of the hold. The second deck is 41 − 9 = 32 feet above the keel. Rails resting directly on the second deck will therefore be 32 − 22 = 10 feet above the center of gravity of the hold. To keep the center of gravity of the shipment at the center of gravity of the hold, we must put 22 tons of rails in the upper 'tween deck space for every 10 tons in the lower hold. This assumes that the depth of the pile will in each case be small. It will probably be satisfactory to put two tons in the 'tween deck space for one in the lower hold.

Let us now consider the effect of loading and ballasting on trim.

4. A ship of 17,300 tons displacement is 420 feet long and has a longitudinal metacentric height of 442 feet. She is down 6 inches by the head. How much oil must be pumped from a forward oil tank to an after one (distance between tanks is 240 feet) in order to bring the ship to the same draft, forward and aft?

In the first place, let us compute the moment to change trim one inch.

$$MTI = \frac{\Delta \times GM_L}{12\,L} = \frac{17{,}300 \times 442}{12 \times 420} = 1517 \text{ foot-tons}$$

To produce a change of trim of 6 inches will require a trimming moment of six times the moment to change trim one inch.
Trimming moment required = 6 × 1517 = 9102 foot-tons

$$\text{The amount of oil to be shifted} = \frac{9102}{240} = 37.93 \text{ tons}$$

If there are 300 gallons to the ton, the amount of oil to be pumped is 11,380 gallons.

5. In light condition, displacement 4100 tons, a ship 460 feet long draws 6 feet forward and 13 feet aft. Moment to change trim is 950 foot-tons. Tons per inch = 45. The fore peak tank is capable of holding 140 tons of sea water. Its center of gravity is 220 feet forward of the midship section. What will be the drafts if the ship is ballasted by filling this tank?

$$\text{Trimming moment} = 140 \times 220 = 30{,}800$$

$$\text{Change of trim} = \frac{30{,}800}{950} = 32.4 \text{ inches}$$

This change of trim will cause an **increase** in **draft forward** of 16.2 inches and a **reduction** in **draft aft** of the same amount.

$$\text{Increase in mean draft} = \frac{140}{45} = 3.1 \text{ inches}$$

Initial draft forward	6 ft. 0.0 in.	aft 13 ft. 0.0 in.
Increase in mean draft caused by ballasting	3.1 in.	3.1 in.
Change in draft caused by ballasting	1 ft. 4.2 in.	(−)1 ft. 4.2 in.
Final draft	7 ft. 7.3 in.	11 ft. 10.9 in.

6. A ship is drawing 22 feet forward and 25 feet aft. At its destination the ship must cross a bar where the depth of water at high tide is 25 feet. The harbor pilot requires a maximum draft not greater than 24 feet. How much ballast water must be taken into the forepeak tank having its center of gravity 220 feet forward of the midship section to bring the ship to the same draft forward and aft and what will this draft be? Moment to change trim one inch = 1260 foot-tons; tons per inch = 50.5.

Mean draft = 23 feet 6 inches
Trimming moment required = 36 × 1260 = 45,360 foot-tons

$$\text{Weight of water to give this trimming moment} = \frac{45{,}360}{220} = 206 \text{ tons}$$

$$\text{Increase in mean draft} = \frac{206}{50.5} = 4.08 \text{ inches}$$

Level draft after ballasting = 23 feet 10 inches.

Let us now consider the matter of list.

7. A ship is to carry a 50-ton locomotive on the port side of the weather deck 30 feet off of the centerline. What list will the ship take when the locomotive is landed if the displacement is 12,500 tons and $GM = 1.50$ feet?

From equation (501) we have

$$\tan \theta = \frac{w \times d}{\Delta \times GM} = \frac{50 \times 30}{12{,}500 \times 1.5} = 0.08$$

$$\theta = 4^\circ\, 34'.$$

8. How many gallons of oil must be carried in a starboard tank provided the corresponding port tank is kept dry, in order to take the list out of the ship of example 7? The centers of gravity of the tanks are 17 feet off of the centerline of the ship.

The listing moment of the oil must be equal to the listing moment of the locomotive which is $50 \times 30 = 1500$ foot-tons.

$$\text{Weight of oil required} = \frac{1500}{17} = 88.2 \text{ tons.}$$

If there are 300 gallons to the ton, this will require $300 \times 88.2 = 26{,}460$ gallons.

QUESTIONS

531. What effects are caused by weight changes on a ship?

532. Why is it necessary to furnish some side support when a ship is docked on the center keel only?

533. What calculation may be made to determine if a ship grounded on the keel is in danger of capsizing?

534. What are the two effects on stability of the mobility of liquid?

535. Give the formula for rise of the ship's center of gravity due to free surface and explain the meaning of the terms.

536. Discuss various loading problems which the operating officer has to meet and the stability considerations which should be taken into account in their solution.

537. Is excessive metacentric height desirable? Give reason for your answer.

PROBLEMS

531. A square barge 80 × 30 × 10 feet, drawing 3 feet in salt water has a turbine rotor weighing 8 tons on the deck at the center. What will be the maximum draft when the rotor is rolled off of one end? $GM_L =$ 175 feet.

Ans. 3 feet 3.20 inches.

532. A yacht has a displacement of 1200 tons and a transverse metacentric height of 2.3 feet with all oil tanks completely filled. A small amount of oil is consumed from several tanks which extend 15 feet on each side of the center line and 40 feet fore and aft. What will the transverse metacentric height then be? $r = 0.92$.

Ans. 0.38 feet.

533. A yacht grounds on a gently sloping beach during ebb tide having a draft of 9 feet 8 inches. The corresponding displacement is 1277 tons; the tons per inch, 15.5; the transverse metacentric height, 2.5 feet; the height of the center of gravity above the keel line, 10 feet; and the tide has 20 inches to fall before low water is reached. Make the necessary calculations to determine whether the vessel will become unstable.

534. Given the following data for a yacht: Draft forward, 9 feet; draft aft, 9 feet 8 inches; length between perpendiculars 310 feet; displacement, 1215 tons; tons per inch, 15.5; longitudinal metacentric height, 550 feet; transverse metacentric height, 2.5 feet; condition, even keel. What will be the drafts and inclination if machinery weighing 26.3 tons is placed 32 feet abaft the dead flat with its center of gravity 4 feet to port of the centerline of the ship?

Ans. 8 feet 11.7 inches forward; 9 feet 11.6 inches aft; $\theta = 2°$.

535. A ship is 460 feet long, 60 feet 10 inches beam, draft forward 28 feet, draft aft, 24 feet, center of gravity above keel 25 feet. How much ballast water having its center of gravity 200 feet aft of the midship section will be required to bring the ship to the same draft forward and aft, and what will these drafts be? Moment to change trim one inch = 1260 foot-tons; tons per inch immersion = 50.5.

Ans. 26 feet 6 inches.

CHAPTER 6

BUOYANCY AND STABILITY IN DAMAGED CONDITION

Section 61. Hazards of ships in peace and war. *Arts.:* 611. Hazards of ships in peace. 612. Hazards of ships in war. 613. Historical casualties to ships.

611. Hazards of ships in peace. The principal hazards to which a ship is exposed in peace are (1) grounding, (2) collision, (3) wind and weather, and (4) fire. In the case of grounding, the damage is mainly to the bottom structure, which may be destroyed over a very considerable extent. A second skin offers the best protection to this form of damage. Since damage due to grounding is more probable forward than aft (ships seldom back on a reef), if the ship is too small to have a complete inner bottom, it should at least have one forward of the machinery space.

Collision damage is mainly to the side plating and here again experience indicates a higher probability forward than aft. The best protection against collision damage is to divide the ship into a number of watertight compartments by watertight transverse bulkheads. Subdivision by longitudinal bulkheads is dangerous because of the upsetting moment created when water is admitted to one side of the ship.

Adequate freeboard, particularly the freeboard forward, furnishes the best protection against the hazards of wind and weather. In addition, tight hatches, high hatch coamings and adequate freeing ports help to give protection against such hazards.

Protection against fire involves (1) a fire protection system consisting of adequate pumping capacity, fire mains and fire plugs with hose which will reach all parts of the ship; (2) a smothering system; (3) fire alarm system; (4) fire resisting bulkheads; (5) use of fire-resisting materials of construction; and (6) a crew thoroughly trained in fire fighting. For ships carrying oil and other hazardous cargoes, special types of fire extinguishing apparatus are also required.

612. Hazards of ships in war. In time of war, it is probable that merchant ships will be escorted in large groups by warships. When approaching a zone of probable enemy activity, ships will be darkened at night. Lighthouses, beacons, and other usual navigational aids, which might be of assistance to an enemy, will be put out of action. The probability of stranding and collision are therefore greater in war time than in peace. The probability of damage due to wind and weather or fire is no less and, in addition, there are the strictly wartime hazards of enemy attack. This may take one of three forms: (1) attack by gunfire, which is not usual or likely to cause the destruction of the ship; (2) underwater attack; and (3) aerial attack. The last two are more likely to occur and to result in the sinking of the ship. A merchant ship threatened by a surface warship may be expected to surrender without sustaining an attack by gunfire. Underwater attack is likely to be given without warning by a submarine or result from the ship's encounter with a mine. Air attack without warning to merchant ships is also highly probable. Near misses of aircraft bombs are a very effective form of attack. They have the same effect as a torpedo or mine explosion. Underwater explosions in contact with the hull of a merchant ship may damage the side plating for a distance of 30 to 40 feet fore and aft and open up an area of 200 to 400 square feet to flooding. No pumps can cope with flooding through such holes. The only protection against such extensive damage is watertight subdivision of the hull.

613. Historical casualties to ships. Before going into the safety regulations which have been developed from experience and technical considerations, it is well to note the more important facts in some of the severest marine casualties.

(*a*) *S.S. Titanic* collided with an iceberg in April, 1912, on her maiden voyage. Extensive damage forward resulted in flooding several forward compartments and submerged the deck at the bow. Progressive flooding of these compartments used up the ship's reserve of buoyancy and she sank with a loss of 1590 out of 2201 on board. The ship remained afloat for three hours after the collision. The principal reason for the large loss of life was the inadequacy of the lifeboat equipment. This spectacular casualty has led to several important safety regulations.

(*b*) *S.S. Empress of Ireland* was in collision with *S.S. Storstat,* May, 1915, in the St. Lawrence River. Extensive damage was done to the side plating forward. The ship had longitudinal subdivision which resulted in flooding on the damaged side only. The ship capsized and sank with large loss of life in a very short time.

(*c*) *S.S. President Hoover* ran aground south of Formosa about midnight, Dec. 10, 1937. Extensive damage was done to the bottom structure. Ship was a total loss but there was no loss of life.

(*d*) *S.S. Lusitania* was struck by two torpedoes off Ireland in May, 1915. The ship took an immediate list of 15 degrees and capsized in 20 minutes with large loss of life. This ship had some longitudinal subdivision.

(*e*) *U.S.S. Mt. Vernon* (ex *S.S. Kronprinzessin Cecile*) was torpedoed during World War I westward bound from France, flooding two boiler rooms. The longitudinal bulkheads had been rendered non-watertight, so that the ship took a list of only 4 degrees and was brought safely to port.

(*f*) *S.S. Malolo* was seriously damaged on the side forward due to collision while on trial trip, May 25, 1927. Special attention had been given to subdivision and notwithstanding very extensive damage, the ship returned to port.

(*g*) *S.S. Vestris* sank due to loss of stability, Nov. 12, 1928, with the loss of 110 lives. The ship left port with an initial list. The efforts of the ship's personnel to reduce the list by pumping were ineffective because the bilge suction was on the high side of the vertical keel. The water on the low side could not therefore be pumped overboard. Further, the removal of the water, which was low down in the ship, resulted in a rise of the ship's center of gravity and reduced the metacentric height which was already too small.

(*h*) *S.S. Morro Castle* burned off the coast of New Jersey, Sept. 8, 1934, with ultimate loss of ship and 134 persons.

QUESTIONS

611. What are the principal peacetime hazards to which merchant ships are exposed? What are the parts of the ship most subject to damage from these hazards and what parts of the ship or other measures furnish the most effective protection against such hazards?

612. What are the principal hazards to which a merchant ship may be exposed in time of war? What are the parts of the ship most subject to

damage from these hazards and what parts of the ship or other measures furnish the most effective protection against such hazards?

613. Give the most important facts in connection with the loss of the following ships and the lessons to be learned therefrom: (1) *S.S. Titanic,* (2) *S.S. Empress of Ireland,* (3) *S.S. President Hoover,* (4) *S.S. Lusitania.*

614. Give the most important facts in connection with the historic casualties of the following ships and the lessons to be learned therefrom: (1) *U.S.S. Mt. Vernon,* (2) *S.S. Malolo,* (3) *S.S. Vestris,* (4) *S.S. Morro Castle.*

Section 62. Floodable length calculations.

Arts.: 621. Definition of terms. 622. Principles of subdivision.

621. Definition of terms. While freeboard was used as early as 1774 as a measure of ships' safety, it was recognized as being insufficient as long ago as 1854. Recent safety regulations include stability, floodable length, and factor of subdivision. These are discussed in this section.

The **floodable length** at any point of a ship is the length of the space, having its center at that point, which can be flooded without causing the ship to sink. For example, if the floodable length of a 400-foot ship at a point 100 feet from the bow is 60 feet and the ship has bulkheads located 70 feet and 130 feet from the bow, the ship will not sink if the space between these bulkheads is flooded.

The **margin line** is a line parallel to the line of the bulkhead deck at side located 3 inches below that line; see Fig. 601.

The **bulkhead deck** is the deck over the tops of the main transverse watertight bulkheads.

A ship which can withstand the flooding of one but not two main compartments without foundering is known as a **one-compartment ship.** Similarly if the flooding of two compartments will sink the ship only to the margin line, the ship is a **two-compartment ship.** A **three-compartment ship** can suffer the flooding of three main compartments without being lost.

The reciprocal of the compartment standard of a ship is called the **factor of subdivision.** It is consequently a factor not greater than unity by which the floodable length is multiplied to get the compartment length. For example, if the factor of subdivision is 0.50, the length of each compartment is 50 percent of the floodable length in that location. The **degree of subdivision** is a relative term expressing the adequacy of the actual subdivision of the ship as compared with that required. For instance, if the regulations require a factor of subdivision of 0.50 and a ship actually is a three-compartment ship, i.e., has an actual factor of subdivision of 0.33, the degree of subdivision is good. If, on the other hand, such a ship falls short of the two-compartment standard, the degree of subdivision is poor.

The floodable length depends upon the freeboard. The load line, upon which the floodable length calculations are based, is generally speaking the legal load line, which is described and discussed in Section 42. In special cases the subdivision load line may be at a shallower draft than the load line; it can never be at a deeper draft, because such is illegal.

In floodable length calculations the volumes of spaces are taken to molded lines (see Art. 413), and when the space extends above the margin line only the volume below the margin line is used.

The volume of the **machinery space** is the volume, computed as indicated in the foregoing paragraph, above the top of the keel between the extreme main transverse watertight bulkheads which bound the spaces occupied by the propelling machinery including auxiliaries, boilers, and permanent coal bunkers.

Passenger spaces are those for the accommodation and use of passengers, except spaces for baggage, stores and provisions and the mail room. Crew spaces below the margin line are regarded as passenger spaces for permeability and criterion numeral calculations.

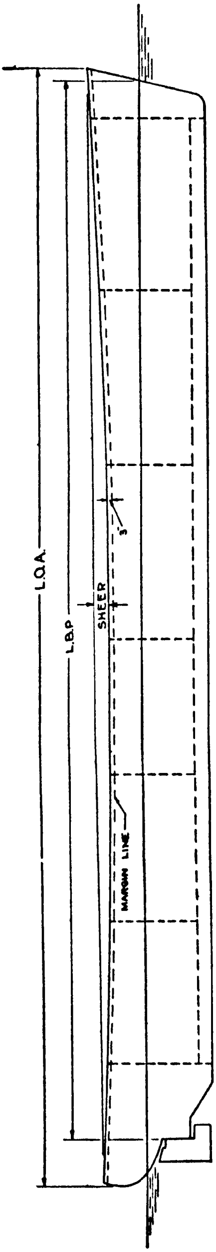


FIG. 601. Margin Line

The **permeability** of a space is the percentage of the volume which can be occupied by water if the compartment is flooded. Nearly every space on board ship has some material in it. The volume of water which can enter is the difference between the volume of the compartment and the volume of water-excluding materials in it. This difference expressed as a percentage of the volume of the compartment is the permeability.

Cargo-stowage factor is the number of cubic feet occupied by one ton of a given material when stowed in the usual manner.

The **criterion of service numeral,** frequently called simply the **criterion numeral,** is a number usually between 23 and 123 which expresses the type of service of a given ship. This is discussed at greater length in Art. 622.

The amount of water which can be admitted to the various compartments of a ship depends upon their permeability. The permeability of cargo spaces varies widely, depending upon the type of cargo. Table 61 gives the permeability and cargo stowage factor of various types of cargo. Dense cargo such as steel rails and bars may bring the ship to its load line without nearly filling the hold. The permeability in such cases may run as high as 80 percent. On the other hand, baled cotton, lumber and other light cargo can be packed into a hold until it is chock full without exceeding or often reaching the load draft. Such cargo may have permeabilities as low as 36 percent. If a ship is designed and built for one type of service, such as a collier or ore carrier, and the cargo density is definitely known, the permeability of the cargo spaces can be definitely computed. For vessels carrying mixed cargo of a varying nature, it is necessary to assume some average figure for the probable permeability and base the floodable length calculations on that.

The permeability of passenger spaces and machinery spaces is much more uniform, being about 95 percent for the former and 80 percent for the latter on steamships, and 85 percent on Diesel ships.

It is usual to compute the floodable length of a ship at a number of points along the ship's length and plot a curve of floodable length on a profile of the ship. See Fig. 602, which is the floodable length curve of a troop transport. The breaks in the curve occur at bulkheads where there is a change in permeability. The curve ends in a straight

TABLE 61. STOWAGE FACTORS AND PERMEABILITIES

Commodity	Type of packing	Stowage factor in cubic feet per ton	Permeability of cargo in full hold
Autos (knock down)	Case (4 ton)	110	80
Autos	Case (2 ton)	220	84
Tractors	Case	200	75
Auto parts	Case	90	70
Autos	Open	...	95
Apples	Barrels	104	61
Apples	Boxes	72	40
Acid	Drums	45	40
Acid	Barrels	50	35
Barbed wire	Rolls	55	85
Beans	Bags	60	50
Biscuits	Cases	142	79
Blankets	Bales	153	78
Butter	Boxes	56	20
Canned goods	Cans in cases	50	30
Cable	Reels	31	50
Cardboard	Bundles	210	88
Cartridges	Boxes	30	30
Castings	Boxes	22	50
Castings	Barrels	31	70
Cement	Bags	35	63
Cement	Barrels	36	72
Chain	Barrels	12	60
Cheese	Boxes	45	30
Coffee	Bags	58	42
Conduits	Boxes	31	78
Copper	Slabs	7	18
Copper	Bars	10	26
Cork	Bales	187	24
Corn	Barrels	65	54
Corn	Bags	55	42
Dates	Boxes	45	30
Dry fruit	Boxes	45	30
Dry goods	Boxes	100	60
Earth	Bags	56	30
Eggs	Cases	100	45
Electric motors	Boxes	50	40
Fish	Boxes	65	70
Fish	Barrels	53	42
Flour	Bags	48	29
Flour	Barrels	73	44

TABLE 61. STOWAGE FACTORS AND PERMEABILITIES — *Continued*

Commodity	Type of packing	Stowage factor in cubic feet per ton	Permeability of cargo in full hold
Furniture	Boxes	156	80
Gasoline	Drums	61	40
General cargo		70	60
Grapefruit	Boxes	70	46
Grape juice	Case (bottles)	70	46
Hardware	Boxes	50	50
Hay	Bales	120	60
Hides	Bales	102	30
Iron	Pigs	10	17
Lanterns	Cases	375	80
Lard	Boxes	45	20
Laths	Bundles	107	37
Leather	Bales	80	35
Lime	Bags	52	45
Linoleum	Rolls	70	30
Linseed	Bags	60	50
Machinery	Cases	50	85
Machinery	Boxes	46	55
Magazines	Bundles	75	70
Meat	Cold storage	90–100	66
Motors, gasoline	Cases	100	80
Newspapers	Bales	120	63
Nitrate	Bags	24	55
Nuts	Bags	70	55
Oats	Bags	77	48
Oil	Barrels	50	35
Oil	Cases	50	34
Oil	Drums	45	40
Onions	Barrels	104	60
Onions	Bags	78	48
Overcoats	Bales	160	40
Oranges	Boxes	78	46
Paper	Rolls	80	70
Paper	Bales	80	70
Paper	Boxes	60	52
Paint	Drums	24	40
Paint	Barrels	28	30
Paint	Cans	36	30
Peas	Bags	55	55
Poultry	Boxes	95	60
Potatoes	Bags	60	49

TABLE 61. STOWAGE FACTORS AND PERMEABILITIES — *Continued*

Commodity	Type of packing	Stowage factor in cubic feet per ton	Permeability of cargo in full hold
Potatoes	Barrels	75	61
Plumbing fixtures	Crates	100	60
Rags	Bales	149	76
Rails	None	15	50
Raisins	Boxes	54	50
Rice	Bags	58	55
Roof paper	Rolls	80	30
Rope	Coil	72	55
Rubber	Bundles	140	25
Rugs	Bales	146	70
Silk	Bolts	80	40
Soap	Boxes	45	20
Soap powder	Boxes	90	70
Sugar	Bags	47	48
Sugar	Barrels	58	60
Starch	Boxes	59	55
Steel rods	None	12	28
Tallow	Barrels	66	35
Tasajo (dried beef)	Bales	90	40
Tea	Boxes	91	80
Thread	Cases	60	45
Tile	Boxes	50	20
Tin	Sheets	7	15
Tires	Bundles	168	85
Tobacco	Boxes	134	60
Transformers	Cases	30	30
Typewriters	Cases	110	80
Waste (cotton)	Bales	175	81
Wax, vegetable	Bags	50	25
Wax	Barrels	70	35
Wheat	Bulk	47	45
Wool	Bales	160	30
Zinc	Slabs	7	15

line, which makes an angle to the horizontal of 63 degrees 26 minutes, if the same scale is used for floodable length as for length of ship.

There are two general methods of computing the values for plotting a curve of floodable length. The first is a " rule of thumb " type of method, the values being taken from curves or tables based on careful calculations of the floodable lengths of ships of " standard " form.

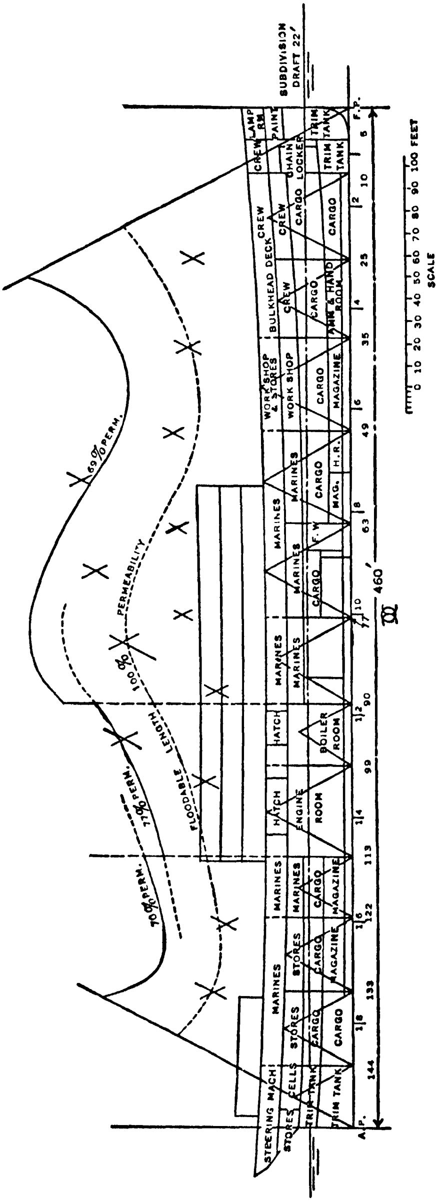


FIG. 602. Floodable Length Curve

This method has the advantages of speed and fair accuracy if the ship is like the " standard." The error may be large, however, in the case of ships which have some marked difference of form. The other method of calculation, known as the direct method, is based on the fundamental principles of buoyancy and stability following the " lost buoyancy " method. Floodable length computations are definitely a job for naval architects, not ships' officers.

622. Principles of subdivision. Floodable length curves, without information of where the main transverse bulkheads are, do not tell how many compartments may be flooded without sinking. This is shown by the diagonal lines which are drawn from the feet of the main transverse watertight bulkheads parallel to the end lines of the curve. If each pair of these lines meet below the floodable length curve, the ship everywhere meets the one-compartment standard. If the diagonal lines for each pair of compartments meet below the curve, the ship meets the two-compartment standard, etc.

The spacing of the main transverse watertight bulkheads depends on many things. The distance between the machinery space bulkheads depends upon what kind of machinery the ship has and its horsepower. The latter depends upon the ship's speed. The spacing of the other bulkheads depends upon such things as the ship's general strength, convenience in berthing, cargo stowage and the safety of the ship. Considerations of safety require an intermediate value of compartment length. Close spacing of bulkheads may give a high compartment standard. If, however, the bulkheads are too close together, an underwater explosion or collision may destroy one bulkhead and cause the flooding of two compartments. Short compartments make necessary large numbers of cargo hatches, much cargo handling gear and many doors and passages for access. Since underwater explosions may open up the side for a fore and aft distance of forty feet, there is no gain in safety by making the compartments shorter than this. We therefore have a definite minimum length for the main compartments of the ship; the maximum length is limited by the floodable length and the compartment standard desired.

Since there is a definite minimum to the length of any compartment, the compartment standard which it is possible to obtain depends upon the ship's length. There is no disagreement with the principle that passenger carrying ships should have somewhat greater safety against

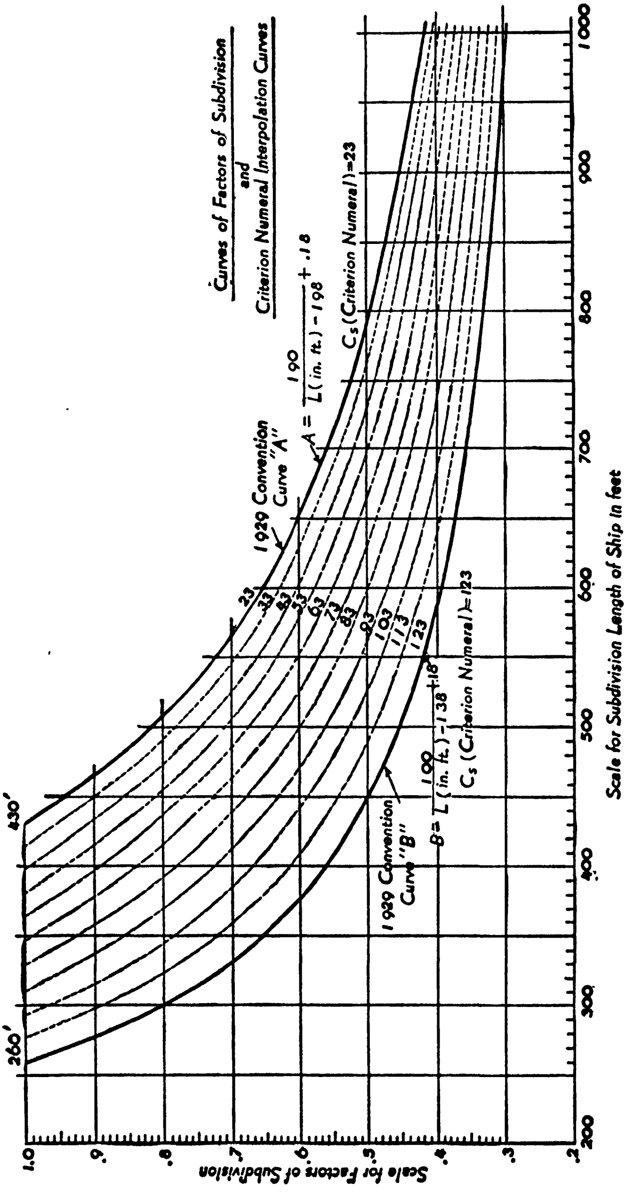


FIG. 603. Curves of Factor of Subdivision

marine accidents than cargo ships. In view of the difficulty of drawing any hard and fast line of distinction between passenger ships and cargo carriers, the criterion of service numeral was worked out in the 1914 Convention on Safety of Life at Sea and its use made compulsory by the 1929 Convention. Fig. 603 shows curves of factor of subdivision based on length and criterion numeral. The criterion numeral is computed by either of two formulas which have been chosen so as to yield a value of about 23 as the criterion numeral for slow-speed cargo vessels. The numbers used in the formulas are the volumes of passenger and machinery spaces. The criterion numeral of a high-speed passenger liner comes out about 123. There are therefore one hundred grades between the slow-speed pure freighter and the express liner. If a ship has a criterion numeral of about 70, it would be a passenger cargo ship of moderate speed.

The greatest length which a compartment may have is equal to the floodable length multiplied by the factor of subdivision. This is known as the **permissible length.** We may therefore compute the permissible length at a number of points and plot a curve of these values.

Any increase of safety from values of the factor of subdivision which give compartment standard values between 1 and 2, or 2 and 3, etc., may be questioned. It is apparent that even if the floodable length calculations were exact, which they are not, the 3 inches of freeboard remaining after damage is not sufficient to insure the safety of the ship. It is simply a margin to allow for the approximate nature of the calculations, but it is a very slender margin indeed. Consider now the case of a ship which has a factor of subdivision of 0.75, midway between 1.0 and 0.5. Such a ship will be a 1.33-compartment ship; i.e., the flooding of two compartments will result in foundering. In what respect is such a ship better than a one-compartment ship? It is better in the increased margin of safety if one compartment is flooded.

QUESTIONS

621. Define (1) floodable length, (2) factor of subdivision, (3) permissible length. What is the relation if any between these three?

622. Define criterion of service numeral, tell what it is based on, and state how it is used in connection with safety regulations of ships.

623. Define (1) margin line, (2) two-compartment ship, (3) permeability. What are good average values of the permeability of (1) passenger spaces, (2) machinery spaces, (3) cargo spaces?

624. What limits the minimum spacing of main transverse bulkheads and what is this minimum?

625. In what respects is a ship with a factor of subdivision of 0.40 better off than a similar ship with one of 0.50?

Section 63. Damaged stability calculations.

Arts.: 631. General discussion of bilging. 632. Effects of flooding compartments.

631. General discussion of bilging. The effect of flooding on the buoyancy and draft of a ship has been discussed in Section 62. The effect of such damage on the stability of the ship has also to be considered. The longitudinal stability of ships is so great that no case of sinkage due to longitudinal instability is known. It is true that, as in the case of the *S.S. Titanic,* ships have sunk having a large longitudinal inclination, but the sinking in these cases was due to loss of buoyancy, not to loss of stability. On the other hand, the *S.S. Lusitania* turned completely turtle and landed on the floor of the ocean, bottom side up. The sinking of that ship was caused by loss of transverse stability. A discussion of the effect of bilging on stability may, therefore, be limited to transverse stability.

The water which enters the ship as a result of damage may be regarded as an added weight. The method of solution based on this idea is called the **added weight method.** For severe cases of damage, i.e., those for which damaged stability calculations are most necessary, it has been found simpler to consider that the ship has lost part of the original buoyant volume. This is known as the **lost buoyancy method.** Solution of flooding problems is far from simple, regardless of what method is used. They are not the job of the operating officer and are therefore not given in this text.

632. Effects of flooding compartments. For a proper discussion of the effects on stability of the bilging of compartments on an actual ship, three cases must be considered: (1) when the bilged compartment is completely filled, (2) when the bilged compartment has a free surface but is not in free communication with the sea, and (3) when the bilged compartment has a free surface and is in free communication with the sea.

(a) Case 1. Compartment completely filled. Since the water comes from the sea, the compartment must be below the original waterline. Since in most merchant ships the center of gravity is near the waterline, the effect of a compartment completely filled is usually to increase the metacentric height. The freeboard, however, is reduced. The importance of the freeboard to the range of stability was brought out in Art. 523. The effects of flooding when the compartment is completely filled are seldom serious. The ship may suffer some loss of range of stability but unless the compartment is far from the centerline or at one end of the ship, so that a large list or change of trim is produced, there is no danger.

(b) Case 2. Compartment has free surface. The effect of mobility of a liquid is a reduction of the metacentric height and the righting arms at all angles of heel. When water enters a ship, partially filling a compartment, but communication with the sea is cut off, the effect on stability is twofold. Since the center of gravity of the added water is, in general, below that of the ship, the weight effect is to increase the metacentric height. The free surface effect is to reduce the metacentric height. The resultant metacentric height will therefore depend upon the relative weight and free surface effects. If the water is very low down in the ship and the surface is narrow, there will probably be no reduction in metacentric height; there may even be a slight increase. If the weight of water is small, its center of gravity near the waterline and the surface of the water wide, there is almost certain to be a reduction in metacentric height. Other combinations of circumstances may produce increase, decrease, or no change in metacentric height. No general rule can be given. If the compartment extends the entire width of the ship, and the weight of water is small, the reduction in metacentric height may be serious. If the surface is wide, and the compartment large, the loss of freeboard may be serious. Flooding which results in a free surface, even though communication with the sea is interrupted, cannot be lightly dismissed.

(c) Case 3. Compartment has free communication with the sea. This is the general case when a ship suffers severe underwater damage due to stranding, collision, or underwater attack. If the compartment has its center of gravity in the centerline plane of the ship, the effect on stability is no different from Case 2 for a compartment of the same size. The loss of freeboard cannot be less and, therefore, will on the average be greater than for Case 2. If the center of gravity of the flooded compartment lies off the centerline of the ship, the reduction of metacentric height due to free surface is greatly increased. The effect of flooding accompanied by free communication with the sea is therefore, almost without exception, a reduction both in metacentric height and freeboard, and consequently a reduction in the maximum righting arm, the range of stability and the dynamical stability. In the case of severe underwater damage, the last named may govern.

Calculations for stability after damage are complex problems in naval architecture. The operating officer should understand the principles involved so that he can do something to improve the situation if his ship is bilged. This includes breaking free communication with the sea and eliminating free surfaces. If the inflow of water has been stopped, it may be better to admit water through a controllable source than to attempt to pump it overboard. An error in judgment of this nature was contributory to the loss of the *S.S. Vestris*. In the case of this ship, the free surface could not be eliminated. The loss of metacentric height would have been less if more water had been taken in, thereby lowering the ship's center of gravity.

After the floodable length curve of a ship has been obtained, the stability of the ship in damaged condition should also be investigated. Of what value is it to know that the ship has sufficient reserve buoyancy to stand a certain amount of damage, but will turn turtle and sink? Oil burning ships usually carry the fuel low down in the ship between the inner and outer bottoms. As this fuel is consumed the metacentric height suffers a steady reduction during a voyage. This may be counteracted by admitting ballast water into empty fuel spaces. The ballast tanks should be filled right up into the sounding tubes so that they have no free surfaces. If this is done there is no reduction of freeboard if the weight of the water taken in is about the same as the weight of oil consumed. The ship may then make the voyage with practically no change in stability.

QUESTIONS

631. Are merchant ships more likely to lose their longitudinal stability or their transverse stability? Give reasons for your answer.

632. What are the added weight method and the lost buoyancy method of making calculations for loss of buoyancy and stability due to damage?

633. State the three cases of flooding with the effects on metacentric height and freeboard in each case.

Section 64. Emergency repairs. *Art.:* 641. Emergency repairs.

641. Emergency repairs. When a ship has been seriously damaged either by stranding, collision, or underwater explosion, the prompt application of remedial measures may prevent its loss. The first thing is to stop or slow down the inflow of water. If this cannot be done, then every effort should be made to restrict the flooding to the damaged compartments. Small holes in the side or bottom plating may sometimes be plugged by a bale of waste or rags using a stout timber as a lever to force it into the opening against the water pressure. If the opening is larger, a tarpaulin may be hauled over it on the outside. This will reduce but not stop the inflow of water. It may slow down the flooding enough to permit the fitting of a wooden mask over the hole on the inside. Other means may suggest themselves by the circumstances attending the accident. The principal thing is to do something helpful. Any measure which to any extent interferes with the free inflow of water delays the sinking of the ship and gives added time to get the passengers and crew into the lifeboats or move them to another place of safety.

Another important thing to remember is that the flooding should be confined to the damaged compartment. For example, if the ship grounds, breaking holes in the bottom plating, but the tank top remains intact, do not trust blindly to its remaining so. Watch the manholes giving access to the double bottom space for any leakage or bulging. If any leakage shows up, it may be reduced by calking with cotton, rags, or lead wire, depending on the size of the leak. If the manhole gives any evidence of bulging, it should be shored down to prevent possibility of its carrying away and flooding the hold space above the tank top.

Similarly, if a hold space is flooded, as by a collision, do everything possible to restrict the inflow of water, but also do not forget to shore the bulkheads at the ends of the flooded compartment. Otherwise these may carry away under the water pressure. The bulkheads should be searched for any evidence of leaks and any found should be calked. Any doors or manholes should be closed and shored to prevent their failure. It will also usually be necessary to calk these around their edges.

Pumps should be started promptly and efforts made to clear the ship of water. If the location of pump suctions is such that the water cannot all be removed and the ship has little stability, it may be desirable to hold the water at a certain level which gives added stability. If the ship gives unmistakable evidence of reduced stability, such as an appreciably lengthened period of roll, the stability may be improved by the lowering of high weights, such as boats, or the jettisoning of deck cargo.

QUESTIONS

641. What may be done to reduce the rate of flooding on a damaged ship?

642. What means should be taken to restrict the flooding to the damaged compartment?

CHAPTER 7

STEERING AND RUDDERS

71. Steering and rudders. *Arts.:* 711. Forces and moments due to rudder action. 712. Path of ship in turning. 713. Types and size of rudder.

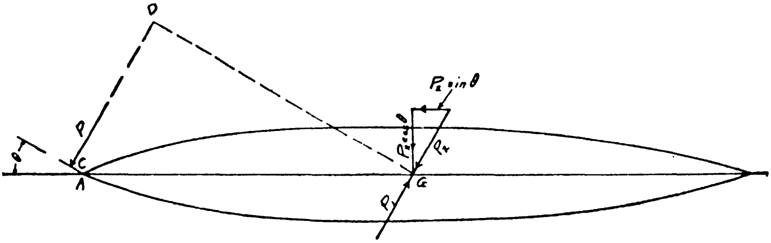


FIG. 701. Forces on Rudder

711. Forces and moments due to rudder action.

When the rudder is put over on a ship going ahead, the result is a pressure force on the rudder perpendicular to its surface, as represented by P in Fig. 701. The pressure normal to the rudder may be resolved into two forces, one parallel to the ship's direction of motion and the other perpendicular to it. The latter is called the lift and the former the drag. The drag, $P_2 \sin \theta$ of Fig. 701, as its name suggests, merely causes the ship to lose speed; the lift, $P_2 \cos \theta$, causes the ship to change heading.

The total normal force on the rudder depends upon the rudder angle, the area, and the square of the speed. For many years, formulas developed by Joessel as a result of experiments with rectangular plates in the River Loire at Indret in 1873 were used in rudder design. These are:

$$P = \frac{0.787\, A_R\, v^2 \sin \theta}{0.195 + 0.305 \sin \theta} \tag{701}$$

$$z = (0.195 + 0.305 \sin \theta)w \tag{702}$$

where P = force in pounds perpendicular to rudder
A_R = rudder area in square feet
v = speed in feet per second
θ = rudder angle to centerline of ship
w = length of rudder in feet
z = distance of center of pressure of rudder from leading edge in feet.

The center of pressure of the rudder is the point at which the total force perpendicular to the rudder is applied.

Equations (701) and (702) were good enough for ships and rudders up to a few years ago. These equations are, however, deficient in having no terms to take account of the effects of shape. It is not possible to cover all variables in a simple equation.

In discussing the effects of the normal rudder force, P, it is of assistance to assume two equal and opposite forces P_1 and P_2 each equal to P acting at G, the ship's center of gravity. Since these forces are equal in amount and of opposite signs, their sum is zero. Their use, therefore, has no effect on the system of forces employed. This device does, however, help in obtaining an understanding of the effects of rudder action. The forces, P and P_1 constitute a couple (see Art. 511) equal to P multiplied by GD, which makes the ship change heading. The force P_2 may be resolved into two forces, one parallel to the ship's direction of motion and opposite in direction, and the other perpendicular to the first. $P_2 \sin \theta$ is a force opposing the ship's motion; it is an increased resistance to movement ahead due to rudder action and, therefore, **as soon as the rudder is put over, the ship slows down.** The force $P_2 \cos \theta$ is a force urging the ship sideways away from the center of turning. Before the ship begins to change heading it will be noted that it moves bodily sideways away from the center of turning.

In addition to the **three effects of rudder action** which have been discussed, viz., **loss of speed, broadside movement** away from the center of turning, and **change of heading,** there is frequently a fourth effect, **heeling.** This effect is due to the force $P_2 \cos \theta$. Fig. 701 may be taken as a horizontal section through the ship at the height of the center of pressure of the rudder. This is assumed to be at the height of the center of gravity of the rudder area. Except by accident the center of pressure of the side of the ship will not be at the same height as the center of pressure of the rudder. The center of pressure of the side of the ship is the center of gravity of the part of the centerline plane below the waterline. It is known as the **center of lateral resistance** and designated by L in Fig. 703. The resistance of the ship to lateral motion may be considered to be concentrated here. If the force $P_2 \cos \theta$ acts at this point, the ship moves directly abeam, but if it acts above or below the center of lateral resistance, the ship is also heeled over. In Fig. 702, which is a transverse section through the center of lateral resistance, it is assumed that the center of pressure of the rudder is above the center of lateral resistance. At the center of lateral resistance, two opposing forces, P_3 and P_4, each equal to $P_2 \cos \theta$, are introduced for the purpose of clearing up the situation. As with P_1 and P_2, their use makes no change in the system of forces, since their combined effect is zero. The force P_4, being at the height of the center of lateral resistance, causes only outward drift of the ship. The equal forces $P_2 \cos \theta$ and P_3 form a couple which heels the ship outward, i.e., away from the center of turning. If the center of lateral resistance were above the rudder's center of pressure, the force P_4 would still cause outward drift, but the couple due to $P_2 \cos \theta$ and P_3 would then produce inward heel, i.e., heeling towards the center of turning. The relative vertical positions of the center of pressure of the rudder and the center of lateral resistance depend upon the vertical position of the rudder, its shape and the shape of the immersed centerline plane. This is discussed more fully in Art. 712.

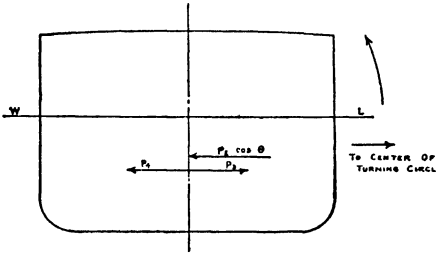


Fig. 702. Heeling due to Rudder Action

The four effects of rudder action previously discussed become noticeable very quickly after the rudder is put over. A **fifth effect,** which becomes apparent only after the ship is turning steadily, is **outward heel** due to centrifugal force. Nearly everyone has experienced the sensation of being thrown outward when riding in a vehicle which makes a sharp turn at high speed. The force acting away from the center of turning is known as centrifugal force. This force acts at the center of gravity and depends upon the square of the speed and the radius of the turning circle. A sharp turn at high speed, therefore, results in large centrifugal force. Fig. 703 shows a centrifugal force P_5 acting at the center of gravity of the ship and its direction is to be taken as away from the center of turning. The opposing forces P_6 and P_7, each equal to P_5, are introduced at the center of lateral resistance. The force P_7, like P_4 in the discussion in the preceding paragraph, simply produces outward drift of the ship, but the equal forces P_5 and P_6 form a couple which causes the ship to heel outward. Practically all ships have the center of gravity above the center of lateral resistance, and therefore the heeling due to centrifugal force is almost always outward.

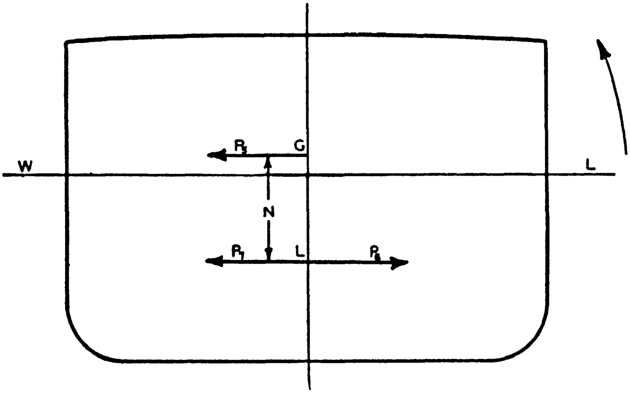


FIG. 703. Heeling due to Centrifugal Force

Many ships which have the center of pressure of the rudder below the center of lateral resistance, and therefore a tendency to heel inward at the beginning of the turn, do not actually take any noticeable inward heel because the centrifugal force comes into action and creates a greater moment producing outward heel. If such a ship takes an excessive outward heel during a turn, it is entirely wrong to endeavor to correct this condition by reversing the rudder. With the rudder reversed, the moment, which previously opposed the moment due to centrifugal force, then acts with the latter and the outward heel is increased. If the heel is already dangerous, an increase may cause the ship to capsize. This has actually happened. The proper action to take is to slow down without changing the rudder until the ship begins to straighten up. Since the centrifugal force varies with the square of the speed, slowing down is the most effective way to reduce its effect. This is very important for the operating officer to remember.

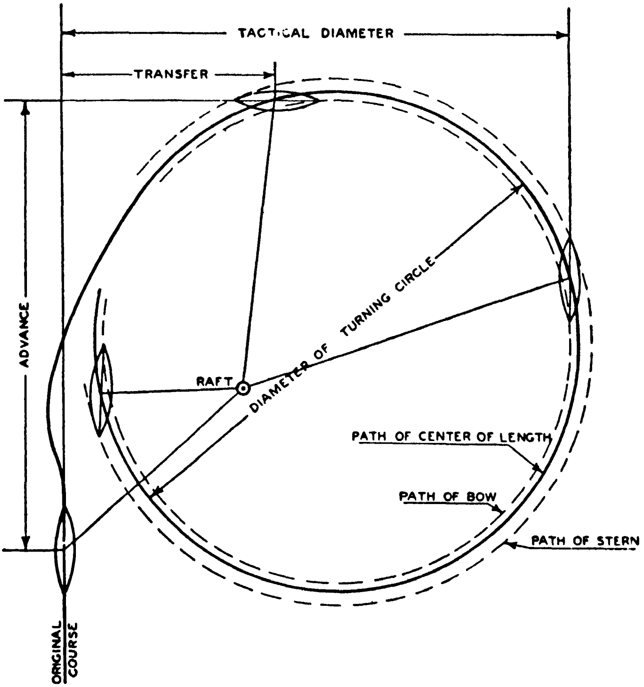


FIG. 704. Path of Ship in Turning

712. Path of ship in turning. Fig. 704 shows the path of a ship in turning through 360 degrees. When the rudder is first put over, the ship first continues on its original course but at reduced speed due to the effect of the force $P_2 \sin \theta$. The next stage of the turn is a movement away from the center of turning (caused by $P_2 \cos \theta$), but without any change in heading. The ship's head then moves toward the side to which the rudder has been moved and its center of gravity moves in a spiral path, which becomes circular when the heading has changed about 90 degrees. As shown in Fig. 704, the ship's bow is at all times inside the path of its center of gravity. The following definitions relating to the path of the turning ship are important.

Advance is the distance **parallel** to the original course traversed by the ship from the time the rudder is put over until the heading of the ship has been changed 90 degrees.

Transfer is the distance **perpendicular** to the original course traversed by the ship from the time the rudder is put over until the heading of the ship has been changed 90 degrees.

Tactical diameter is the distance **perpendicular** to the original course from the ship's position when the rudder is put over to that which it occupies when the heading has been changed 180 degrees.

Radius of turning circle is the radius of the circle described by the ship after its path becomes circular. The length of the straight line connecting the ship's positions at 180 and 360 degrees change of course is the **diameter of the turning circle.**

Since the ship's bow is inside the path of the ship's center of gravity, the tangent to this path makes with the ship's centerline, an angle known as the **drift angle.** When the ship's path becomes circular, the drift angle is steady.

A perpendicular to the ship's centerline from the center of the turning circle meets the centerline in a point known as the **pivoting point.** This point is always forward of the midship section, generally about one-quarter of the ship's length from the bow. The pivoting point is so named because a person standing there sees the ship pivoting about him.

The radius of the turning circle depends upon the time required to put the rudder over, the shape of the immersed centerline plane, the size of the ship, the rudder angle and the rudder area. The steering is also influenced by the direction of the sea, direction of rotation of the propeller for single screw ships, number of propellers and position of rudder with respect to the propeller race.

On all except the smallest ships, the rudder is operated by a steering engine. Power steering gives ships the ability to make sharper turns than they could with hand steering. Automatic steering devices detect the ship's departure from a set course more quickly than a helmsman. These devices, therefore, give more effective steering.

The more nearly rectangular in shape the immersed centerline plane is, the greater the radius of the turning circle. This can be reduced by cutting away the **deadwood,** as the vertical surfaces near the stern are called. This, however, does not always improve the steering qualities of the ship.

Theoretically, the rudder angle for minimum turning circle is 45 degrees. Actually, most ships have stops at between 35 and 40 degrees. The least radius of turning circle is obtained with hardover rudder. The area of the rudder on ocean-going merchant ships is usually about two percent of the area of the immersed centerline plane.

A following sea increases the difficulty of steering a steady course, because of the oblique impact of the waves which results in an unbalanced pressure on the rudder. Also, in restricted channels there is frequently a tendency to yawing. The presence of sharp shoulders in the channel aggravates this tendency.

Starting from rest, a single screw ship with a right-hand propeller turns its head to port, one with a left-hand propeller to starboard. The turning circle of twin screw ships can be materially reduced in size by stopping or backing the inside screw. The best position of the rudder for effective steering is directly aft of and close to the propeller or propellers. Most ships have only one rudder which, therefore, has the most favorable location for small turning circle only in single and triple screw ships. Twin screw ships consequently have greater turning circles than single or triple screw ships unless they have twin rudders or use the engines to assist in making the turn.

Rudders with airfoil sections, which have the maximum thickness at one-third the rudder length aft of the leading edge, have a greater turning moment than plane rudders. Consequently, they give a ship a smaller turning circle. Rudders which are deep compared to their length, such as the ordinary barn-door rudder on a single screw freighter, have a large turning moment at small rudder angles, but the angle of maximum turning effect is less than with rudders which are more nearly square. If the rudder is to be most effective at about 35 degrees, the ratio of rudder depth to length should not be too great. The effect of the rudder outline apart from the depth to length ratio is negligible.

The effectiveness of rudders is increased by the use of streamlined rudder posts and reduction of the gap between the rudder post and the rudder.

713. Types and size of rudder. The types of rudder shapes most in use are shown in Figs. 705 to 710. In section, these rudders may be of three types: simple plate rudders, partially streamlined, or airfoil sections. The last gives the least increase in propulsive resistance; the first the greatest. In the case of a barn-door, plate rudder with the plate on one side of the stock, the resistance of the rudder may be as much as 15 percent of that of the hull.

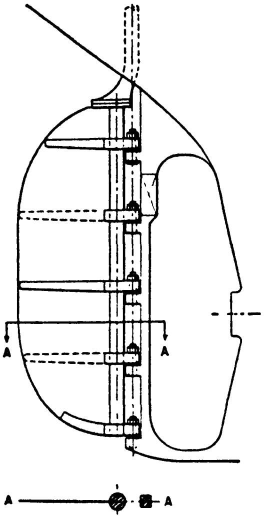


Fig. 705. Unbalanced Single Plate Rudder

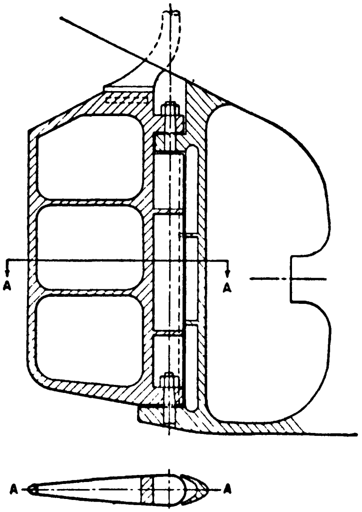


Fig. 706. Unbalanced Double Plate Rudder

The object in placing the axis of the rudder stock aft of the leading edge of the rudder is to reduce the effort required to put the rudder over. Equation (702) is Joessel's formula for the distance of the center of pressure of the rudder from the leading edge. If the axis of the rudder stock passed through the center of pressure, the least twist would turn it, because the pressure on the forward and after parts of the rudder would be exactly balanced. Unfortunately, the position of the center of pressure depends upon the rudder angle, being only 19½ percent of the rudder length from the leading edge when the rudder angle is 0 degrees and 34¾ percent for 30-degree rudder angle. Rudders are frequently designed to be balanced at 15 degrees. Such design requires comparatively little power for the usual rudder angles used in steering. If about 25 percent of the rudder area is forward of the axis, the rudder is balanced at about 15 degrees.

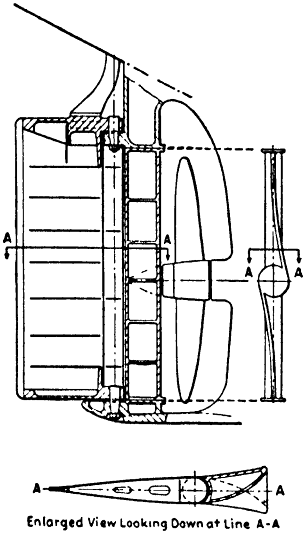


FIG. 707. Contra-guide Rudder

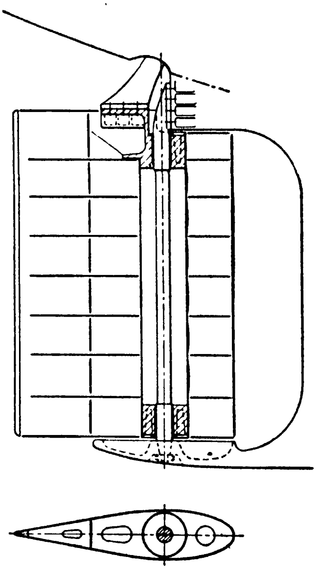


FIG. 708. Balanced Double Plate Rudder

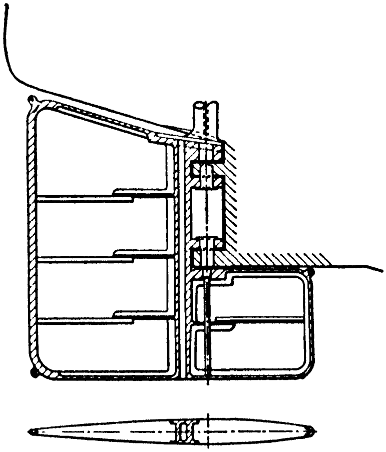


FIG. 709. Semi-balanced Double Plate Rudder

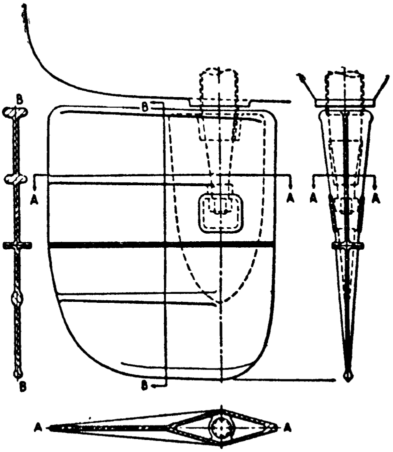


FIG. 710. Spade Rudder

When going astern, the following edge becomes the leading edge and the moment of the rudder force with respect to the rudder axis is much greater than when the ship is going ahead at the same speed. Since it may be necessary to use the rudder when backing, some designers overbalance the rudder for ahead motion, i.e., put more area forward of the axis than necessary for balancing.

The flat part of the rudder is called the **blade.** This may be either simply a flat plate or a double-plated structure of airfoil or partially streamlined section. In the latter case, it is usually filled with soft wood or other light material on account of the difficulty of making it absolutely watertight. The shaft which turns the blade is called the **stock.** The stock enters the ship through a watertight stuffing box. It has at its upper end a tiller, yoke, or quadrant, which is moved by the steering mechanism. The blade must be rigidly secured to the stock so that these move as a unit. The weight of the rudder is frequently carried at the top where the stock enters the hull. There are several projections on the sternpost. Pins, which are securely fastened to the rudder, fit in holes in these projections and form the pivoting axis of the ship. The pins are called **pintles** and the projections on the rudder post are called **gudgeons.** See Fig. 705. The size of rudder stocks for merchant ships is given by the classification society to whose rules the ship is constructed.

QUESTIONS

711. Explain by aid of suitable diagrams the four effects of rudder action which become apparent immediately after the rudder is put over.

712. In which direction does a ship heel during steady turning? Show by a suitable diagram why this is so and discuss the force which causes it. What is the proper action to take if a ship gets an excessive inclination during a turn?

713. Sketch the path of a ship making a 360-degree turn to starboard and mark the following: advance, transfer, tactical diameter, radius of turning circle, drift angle, pivoting point.

714. Define center of lateral resistance, deadwood.

715. What is the effect of each of the following on the ease of steering and tactical diameter: direction of the sea, direction of rotation of propellor, shape of rudder, position of rudder, rudder area?

716. Sketch three usual rudder shapes used and give their names. What is meant by balancing a rudder? Name the parts of a rudder and tell what they are.

CHAPTER 8

OCEAN WAVES AND ROLLING

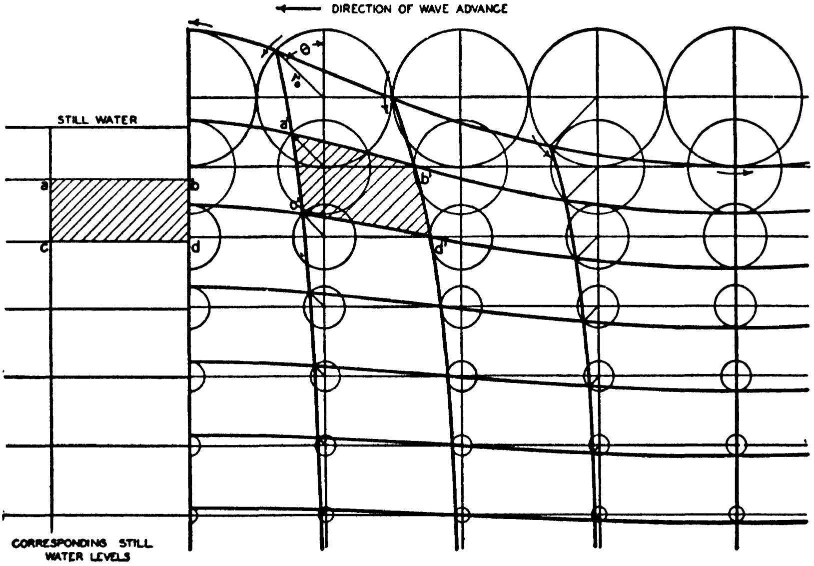
Section 81. Ocean waves. *Art.:* 811. Ocean waves.

811. Ocean waves. It is generally agreed by those who have studied the matter carefully that water waves in the ocean and other large bodies of water conform to the trochoidal theory first stated by Gerstner in 1802. In accordance with this theory, the water particles in wave motion revolve at uniform angular speed in vertical planes as indicated in Fig. 801. The mathematical findings based on this theory agree very well with the observed characteristics of water waves. Since the mathematics of trochoidal waves is simpler than that of any other theory which agrees at all well with the observations of actual waves, the trochoidal theory has been uniformly adopted.

The water in a wave does not move over the ground unless the whole body of water moves in a tidal or other current. It is the wave motion which moves. The principal characteristics of trochoidal waves are: (1) in deep water the wave speed depends upon the length only, and (2) all water particles in a vertical line have the same phase, but as shown in Fig. 801, the amount of vertical motion rapidly gets smaller as we go below the surface of the water. All of these conditions are met by actual waves.

Wind of a certain speed can generate waves of different lengths and velocities which travel in the same direction and may ride over each other. Sometimes the wave crests of the component waves will coincide and then a wave of unusual height results. When the crest of one wave coincides with the trough of another, practically still water results. Further, as the wind changes direction, diverging waves are generated. These also may ride over each other. These effects result in a confused sea, such as generally is found during and immediately after a storm. Outside the storm area and after the storm winds have ceased, a fairly regular long sea is found. Long waves continue to absorb energy from the wind long after shorter waves become so high that they break and fade out. A regular sea is consequently usually composed of long waves.

Accurate observations of waves at sea require great care in the taking and recording of data. Little difficulty is encountered in measuring the length. The dimension most commonly exaggerated is the wave height. Waves higher than 30 feet are seldom seen, although once every few years a sea-going person may even meet a



TROCHOIDAL WAVE MOTION

A VOLUME SUCH AS abcd IN STILL WATER IS DISTORTED AS a'b'c'd' IN WAVE WATER

Fig. 801. Trochoidal Waves

wave 40 or 50 feet high. Waves up to 90 feet in height have been reliably reported, but one may spend a lifetime at sea without encountering one. Nearly every landsman who has made one crossing of the Atlantic and encountered a hatfull of wind states that the waves were "the highest the captain ever saw in 20 years' experience." Inexperienced people often report waves 15 or 20 feet high as having been 80 or 90 feet. The facts of the matter from careful observations are that waves longer than 500 feet are rare. For waves this long or longer, the height is not greater than one-twentieth of the length.

For very long waves the height is more likely to be one-fortieth or one-fiftieth of the length. Very high waves occur only as a result of combination of two fairly high waves. Wave periods are comparatively short: a 400-foot wave has a period of 9 seconds, a 1200-foot wave (most unusual) has one of 15 seconds.

QUESTIONS

811. What is the usually accepted theory for water waves and what are the facts which justify its use?

812. What are the principal characteristics of trochoidal waves? Discuss the actual dimensions of ocean waves.

Note: It is convenient to remember that a wave of 10 seconds' period has a length of about 500 feet and a speed of about 30 knots. Such a wave would have a maximum height of about 25 feet.

Section 82. Rolling and other ship oscillations.

Arts.: 821. Rolling. 822. Anti-rolling devices. 823. Other ship oscillations.

821. Rolling. A ship, regarded as a rigid body, oscillates among waves in a manner which has taxed the best brains of the world to secure a mathematical solution. To simplify the problem, this motion is usually resolved into three straight-line oscillations parallel to the longitudinal, transverse and vertical axes through the ship's center of gravity, and three rotary oscillations about them. The linear oscillations are known respectively as 'scending, lateral drifting, and heaving; the rotary oscillations are rolling, pitching, and yawing. The most important of all of these is rolling; the others are dealt with in Art. 823.

Rolling is usually produced by waves. The manner in which this may be done is shown by Fig. 802. As indicated in *A*, a ship floating upright in still water is struck broadside by waves advancing from the left. If the wave is long compared with the ship's breadth, the intersection of the wave's profile with the midship section of the ship is very nearly a straight line. If the ship remained upright when the wave moved past it, we would have the condition indicated in *B* when the ship was midway between trough and crest. The volume of displacement has changed from *WOLKW to W'OL'KW'*. The center of buoyancy has moved from *B* to *B'*. Under these conditions the center of gravity, *G*, and the center of buoyancy, *B'*, are no longer in the same vertical line. The ship is not in equilibrium. Rotation of the ship occurs in the effort to establish equilibrium. As the wave changes slope, the perpendicular distance between the verticals through the various positions of the center of buoyancy and the fixed position of the center of gravity changes continuously. Consequently, the ship rotates back and forth about a longitudinal axis through *G*. **It rolls.**

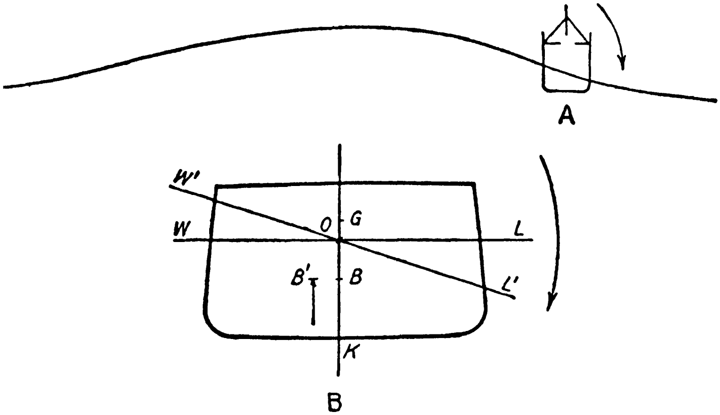


Fig. 802. Ship among Waves

If a ship is given one impulse, such as being heaved down on one side and let go, it oscillates in its own natural period like a pendulum pulled to one side and let go. With a ship among waves, however, conditions are different. Assuming a regular sea, the wave impulses come at equal intervals of time. Now a pendulum has a definite period of oscillation but, if we strike it periodically, it can be forced to vibrate in the period of the impulses applied. It is the same way with ships. If the waves are of different period from the ship and continue for an appreciable time, the ship is forced into rolling in the wave period instead of in its own period. This is known as **forced rolling,** while rolling in the ship's natural period is **free rolling.** A ship always tries to roll in its natural period. Waves of absolutely fixed period are seldom long sustained. Consequently, the period of rolling among waves is usually not very different from the ship's natural period.

Heaviest rolling occurs when the period of ship and waves is the same. This is known as **synchronous rolling.** Heavy rolling is due to the fact that the wave slope is always in the proper direction to increase the roll of the ship. Fig. 802 represents a ship in the trough of the sea, so that the **apparent wave period** is the true wave period. If a ship is proceeding at an angle to the waves, the apparent wave period or **period of encounter** depends upon the relative speeds of ship and waves and the angle between the ship's course and direction of the sea. Synchronous rolling can therefore be overcome by changing course or speed or both. Such changes are usually warranted when a condition of synchronous rolling is met.

A good equation for the period of roll of most ships is:

$$T = \frac{0.44\,B}{\sqrt{GM}} \tag{801}$$

where T = period of roll from port to starboard and back to port again in seconds.

B = ship's breadth in feet.

GM = transverse metacentric height in feet.

The metacentric height of a ship may be computed by equation (801) if the breadth is known and the period of roll is carefully timed.

Example: The time of ten complete consecutive rolls for a ship of 70 feet beam is 3 minutes 40 seconds. What is the approximate value of the metacentric height?

Three minutes 40 seconds equals 220 seconds. Since this is the time required for ten consecutive rolls, the average time for one roll is one-tenth of this or 22 seconds. From equation (801)

$$22 = \frac{0.44 \times 70}{\sqrt{GM}}$$

$$GM = \left(\frac{0.44 \times 70}{22}\right)^2 = (1.4)^2 = 2.96 \text{ feet.}$$

What period of roll should a merchant ship of 4-foot metacentric height and 80 feet beam have?

$$T = \frac{0.44 \times 80}{\sqrt{4}} = 17.6 \text{ seconds.}$$

Equation (801) may also be used to estimate the stability of a ship after damage.

In the sinking of the *Vestris,* some of the passengers commented on the " sluggishness " of the ship just before the disaster. By sluggishness, they meant of course the lengthening of the period of roll and even to them, this indicated a condition of near instability, even though they had no means of evaluating it. From equation (801) we can get an idea of the **proportionate loss of stability** from the proportionate increase in the rolling period, because clearly the beam of the ship has not changed and equation (801) involves only these three quantities.

Example: A ship in a certain condition of loading has a period of 20 seconds. A broken propeller shaft and stern tube produces extensive flooding aft and the period after damage is found to be 30 seconds. How much metacentric height has been lost?

From equation (801)

$$B = \frac{T\sqrt{GM}}{0.44}$$

$$\text{Before damage, } B = \frac{20\sqrt{(GM)_1}}{0.44} \qquad (802)$$

$$\text{After damage, } B = \frac{30\sqrt{(GM)_2}}{0.44} \qquad (803)$$

Where $(GM)_1$ = Metacentric height before damage

$(GM)_2$ = Metacentric height after damage

Since the beam of the ship has not changed, we have from equations (802) and (803)

$$\frac{20\sqrt{(GM)_1}}{0.44} = \frac{30\sqrt{(GM)_2}}{0.44}$$

From which, by squaring both sides and reducing,

$$(GM)_2 = \frac{\;}{9}(GM)_1$$

Or $\frac{5}{9}$ over one-half, of the original metacentric height has been lost.

It was brought out in Art. 523 that the stability characteristics of a ship are determined by the freeboard and the metacentric height. The former has the greatest effect on the angle of maximum righting arm and the range of stability; the latter has the greatest effect on the initial stability and dynamical stability. Damage inevitably reduces the freeboard and consequently the angle of maximum stability and range of stability. Equation (801) permits an estimate of what has happened to the metacentric height, the measure of the ship's resistance to small inclinations, and its ability to withstand the dynamic impulses of the waves. A marked increase in period is evidence of greatly reduced metacentric height. Fig. 803, curve *A*, is the same as curve *A* of Fig. 517. Curve *B* is the statical stability curve for the same ship having a metacentric height of 0.375 feet, one-fourth of that of curve *A*. The marked reduction in initial stability, range of stability and dynamic stability is apparent. The action to be taken in any specific case depends upon circumstances, but the ability of the master to take the proper action depends largely on a correct knowledge of the principles of stability.

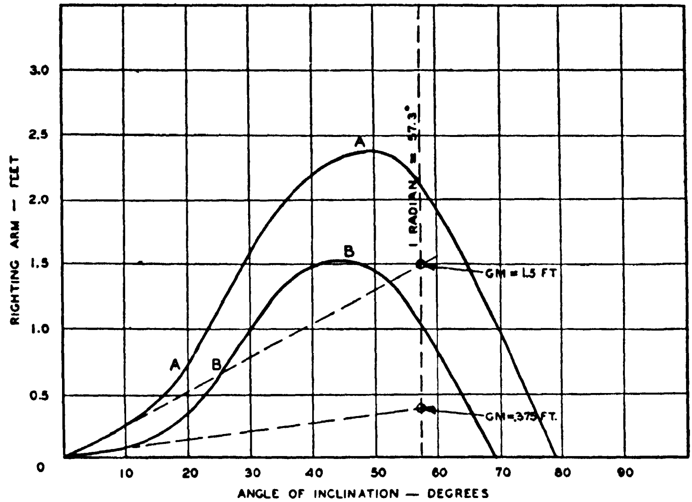


FIG. 803. Effect of *GM* on Statical Stability

Example: A ship of normal form, 75 feet beam, when loaded to its marks with homogeneous cargo in the holds, has a metacentric height of 3 feet and period of roll of 19 seconds. When loaded with lumber, including deck cargo, it is found to have a rolling period of 30 seconds. Compute the metacentric height in the second condition of loading. From equation (801)

$$30 = \frac{0.44 \times 75}{\sqrt{(GM)_2}}$$

$$(GM)_2 = \left(\frac{0.44 \times 75}{30}\right)^2 = 1.20 \text{ feet}$$

This calculation can be made more simply as follows:

Let T_1 = period of roll in first condition of loading and T_2 = period of roll in second condition of loading

$$T_1 = \frac{0.44\,B}{\sqrt{(GM)_1}}$$

$$T_2 = \frac{0.44\,B}{\sqrt{(GM)_2}}$$

$$\frac{T_1}{T_2} = \frac{\dfrac{0.44\,B}{\sqrt{(GM)_1}}}{\dfrac{0.44\,B}{\sqrt{(GM)_2}}} = \frac{\sqrt{(GM)_2}}{\sqrt{(GM)_1}}$$

Or $$\sqrt{(GM)_2} = \sqrt{(GM)_1} \times \frac{T_1}{T_2}$$

and $$(GM)_2 = (GM)_1 \times \left(\frac{T_1}{T_2}\right)^2$$

$$= 3 \times \left(\frac{19}{30}\right)^2 = \frac{361}{300} = 1.20 \text{ feet.}$$

Very slow rolling is evidence of small metacentric height; erratic rolling with no fixed period in still water indicates negative metacentric height. The former may be all right as long as the ship suffers no damage and has ample freeboard; the latter should be corrected without delay.

822. Anti-rolling devices. Seasickness is a very common ailment at sea. Due to the fact that this, as well as increased stresses in the ship, loss of speed, reduction of accuracy in gunfire and general interference with normal modes of living on board ship are in such large measure caused by rolling, a great deal of effort has been put into the design and development of anti-rolling apparatus. Practically all ocean-going ships are equipped with bilge keels. Anti-rolling devices all cost money to provide, weigh something, require power for their operation and in general occupy space which could be used to produce revenue. They are installed because the economics of a ship are materially affected by its rolling characteristics.

823. Other ship oscillations.

(a) 'Scending. The fore and aft surging of a ship among waves is called 'scending. It is of little importance because when a ship is in motion ahead, the forward speed due to propeller thrust is greater than the astern speed due to 'scending, and consequently this oscillation is swallowed up in the ahead motion.

(b) Lateral drifting. Careful observations of a rolling ship will show that it oscillates from side to side of its mean position also. This is lateral drifting. It is not of any importance and there is nothing that can be done about it.

(c) Heaving. When a ship rolls or pitches there is a vertical rise and fall of the ship as a whole. This is heaving. The amount of heaving may be 15 feet or even more. Heaving produces a small increase in the stresses in a ship.

(d) Pitching. Rotary oscillation of a ship about a transverse axis through the ship's center of gravity is called pitching. The period of pitching is shorter than the period of rolling, being generally between one-third and two-thirds of the latter. The maximum angle of pitch is usually less than that of rolling but the vertical movement at the ends of a pitching ship may be very great.

(e) Yawing. Rotary oscillation of a ship about a vertical axis through its center of gravity is called yawing. This motion is usually caused by waves. Yawing also causes heeling. Yawing increases the distance run; slows down the ship, due to use of rudder and is, in every respect, undesirable. The reduction of yaw lies in (1) providing large rudders, and (2) in the use of automatic steerers. The latter detect a departure from the set course more quickly than skilled helmsmen and apply the necessary rudder angle before the swing away from the course has become large.

QUESTIONS

821. Name the oscillations of a ship among waves. Define rolling.

822. Explain how waves set up rolling.

823. Define and distinguish between free rolling, forced rolling, and synchronous rolling. What action can be taken to put an end to synchronous rolling?

824. Give the formula for the metacentric height of a merchant ship in terms of the period of roll and beam. Of what value to the operating officer is this equation?

825. Define (1) 'scending, (2) lateral drifting, (3) heaving, (4) pitching, and (5) yawing.

826. Discuss the causes and prevention of yawing.

PROBLEMS

821. A ship of normal form and 60 feet 10 inches beam has an observed period of roll of 16 seconds; what is the metacentric height in feet and as a percentage of the beam?

Ans. $GM = 2.80$ feet $= 4.6$ percent of beam.

822. A ship in intact condition having a period of roll of 15 seconds is in collision with an iceberg, after which the period of roll is observed to be 25 seconds; what is the ratio of the metacentric height after damage to that of the intact ship?

Ans. 0.36.

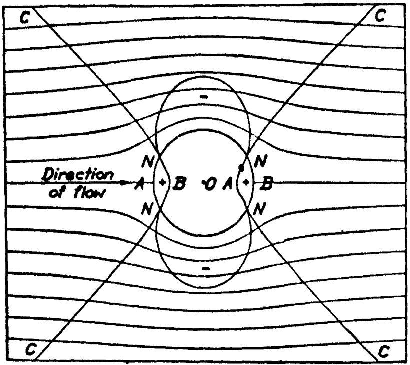
CHAPTER 9

PROPULSION

Section 91. Resistance of ships. *Arts.:* 911. Flow of water past a ship. 912. Eddy resistance. 913. Wave resistance. 914. Frictional resistance. 915. Air resistance; residuary resistance.

911. Flow of water past a ship. Anyone who has ever rowed a boat knows that the water offers resistance to the movement of any floating body and that energy must be expended to produce and maintain such motion. Surface ships are partly in the air and partly in the water. Due to its greater density (water is about eight hundred times as dense as air), the water gives by far the greater part of the resistance to the motion of a ship, although the resistance of the air is not always negligible. The resistance of the water is first considered. This is composed of: (1) eddy resistance, (2) wave resistance, and (3) frictional resistance.

The term **streamline** is one which has come into very common use in recent years without any definite idea on the part of most people of its meaning. A streamline is simply the path of a particle of fluid, liquid or gaseous, passing around a solid. It makes no difference whether the fluid or the solid is considered to be in motion. It is only the relative motion of the two which counts. Fig. 901 shows the lines of flow of a perfect fluid past a frictionless cylinder. Actual streamlines depart from those shown in Fig. 901 depending upon the properties of the fluid and the surface of the solid, but the principles involved in the study of fluid flow are best understood by reference to the ideal diagram. Pressures are plotted radially, positive pressures inside the circle and negative pressures or suctions outside. The lines of flow are spaced to represent an equal quantity of fluid flowing between each pair of lines. Crowding of the streamlines, therefore, indicates an increase in velocity, and separation a reduction in velocity. It is noted that an increase of velocity goes with a reduction of pressure, while an increase in pressure is associated with a reduction of



AB represents impact pressure. NN points of neutral pressure. NC lines of neutral pressure. All pressure differences are measured radially from surface of cylinder, in for excess, out for defect.

Fig. 901. Flow of Perfect Liquid by Frictionless Cylinder

velocity. The foregoing is a general principle of fluid flow past a solid and furnishes the explanation of the suction which draws two ships together when their courses cause them to pass close aboard in a narrow channel. The ships reduce the cross-sectional area of the channel through which the water can flow. This requires a marked increase in the velocity of the water flowing by the ships. This increase in velocity is accompanied by a reduction of pressure, i.e., a suction which brings the ships together. It may also be stated in passing that velocity of flow over a solid varies from point to point and only at the four points marked *N* is the actual rubbing speed of the fluid equal to the speed of the solid through the fluid. Over a large part of the surface the rubbing speed is appreciably greater than the speed of the ship over the ground.

912. Eddy resistance. Fig. 902 shows the lines of flow past a surface set at an angle to the direction of flow. Comparing this figure with Fig. 901, it will be seen that one of the streamlines in Fig. 902 is interrupted, whereas all the streamlines in Fig. 901 are continuous. The crowding of the streamlines at the edges of the surface is much greater than those abreast the middle of the cylinder. The fluid, which on the upstream side of the plane lies between *K* and *A* and between *K* and *B*, forms on the downstream side a confused eddying mass which lies inside the zone of fluid where the flow is continuous. This action is accompanied by a rise in pressure

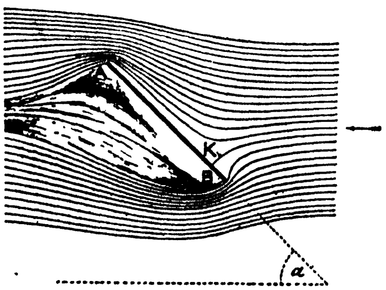


Fig. 902. Flow by Plane at an Angle to Flow

on the upstream side and a suction on the downstream side. We may get an effect similar to that shown in Fig. 902 from propeller brackets. The increase in pressure on the upstream side and reduction in pressure on the downstream side increase the resistance to the ship's forward motion. This kind of resistance is called **eddy resistance.** In well formed ships it is a minor part of the total.

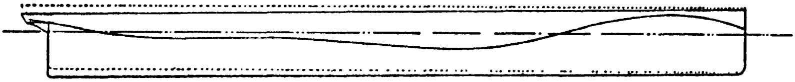


FIG. 903. Ship's Wave

913. Wave resistance. It is a matter of common observation that the movement of a ship through the water is accompanied by the generation of waves. The reason for this may be found in Fig. 901. In a liquid, increase in pressure manifests itself by a rise of the surface and a suction by a depression at the surface. In other words, the only interpretation of the pressure variations along the surface of the cylinder is a variation in the water level, i.e., the formation of waves. The transverse wave of a high-speed ship is shown in Fig. 903. The dotted lines in this figure show the position of the ship when it is not in motion.

The formation of waves by the ship requires the expenditure of energy by the ship. Work or energy is equal to force times distance. The energy expended by a ship in the formation of waves divided by the distance run is called the **wave resistance.** Wave resistance is second in importance only to frictional resistance. Its value is between 10 and 30 percent of the total for most ships, occasionally rising to 50 percent or more.

A ship generates four series of waves, two at the bow and two at the stern. Fig. 904 shows the bow waves. The stern waves are similar but, being formed in water which is already in motion due to the bow waves, are not so easily distinguished. The waves whose crests make an angle of approximately 19 degrees with the ship's direction are known as the series of **diverging waves.** Having once been generated, these waves travel clear of the ship and give no further trouble. The other series of waves, which have their crests perpendicular to the centerline plane of the ship are known as **transverse waves.** Transverse waves of the bow system combine with those of the stern system. If conditions are such that the stern would raise a crest where the bow wave has a hollow of the same amount, the water which would form the crest simply flows into the hollow and the wave is smoothed out. In other words, the energy required to generate and maintain the ship's wave systems depends to a certain extent on the phase relation of the bow and stern transverse wave systems. The humps and hollows or points of unfairness on curves of resistance, such as in Fig. 905, between four and five knots are due to this cause.

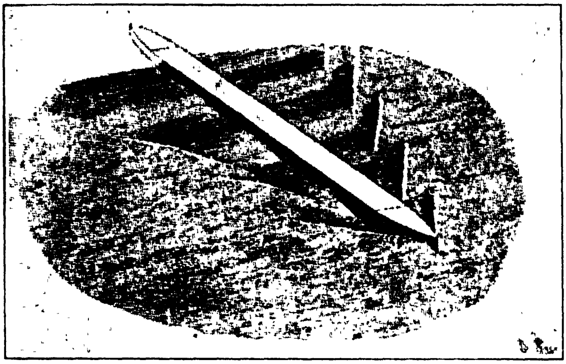


FIG. 904. Bow Waves

914. Frictional resistance. Just as there is friction between two solids when one is moved over the other, there is friction between a solid and a liquid moving past it. To overcome this friction, the application of force is required. The force necessary to overcome the frictional resistance at any speed is equal to the frictional resistance. The term frictional resistance, sometimes called **skin resistance,** may therefore be used to designate either this resistance itself or the force required to overcome it. Except for a very small percentage of ships, driven at extremely high speeds for their length, the frictional resistance is more than half of the total. For high-speed passenger ships, the frictional resistance is about 70 percent of the total, and for slow freighters it may be as high as 90 percent.

The friction between the ship's surface and the water in contact with it exerts a drag on this water tending to pull it along with the ship. As a result, the water in contact with the hull acquires a velocity in the direction in which the ship is moving. The acquired velocity depends upon the roughness of the surface and the speed of the ship. As the ship moves into undisturbed water, the water, which has been set in motion by friction with the ship's surface, follows after the ship and may be observed as a current flowing through the surrounding comparatively undisturbed water. This current is known as the **wake** or **wake current.** It has an important bearing on propulsion.

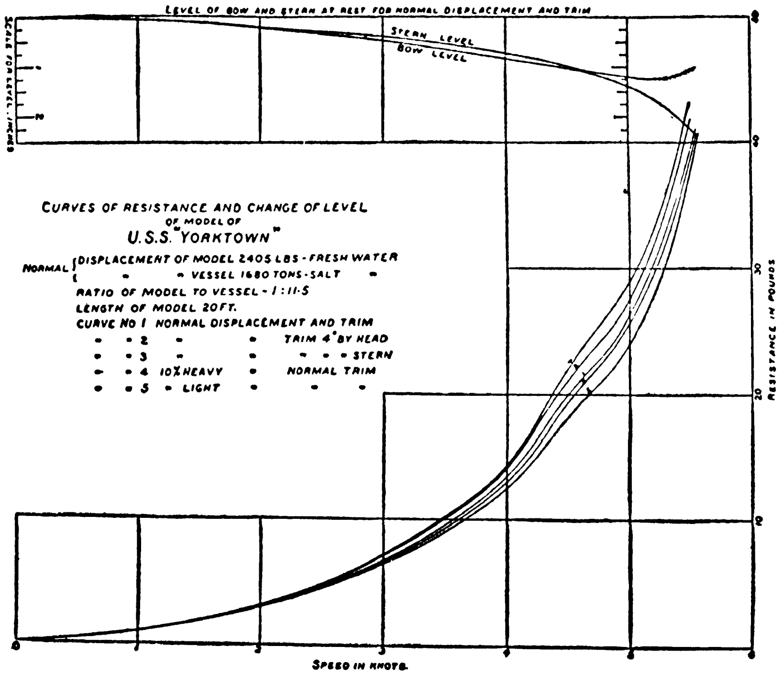


Fig. 905. Curves of Resistance

Frictional resistance is most readily computed by a formula of the following nature:

$$R_f = fSV^n \tag{901}$$

where R_f = frictional resistance

f = coefficient of friction

S = wetted surface

V = speed

n = power of speed with which R_f varies.

The coefficient of friction is affected principally by the type of surface, although there are certain other minor factors. One of the most important purposes in drydocking ships is to clean and paint the bottom. This is done not only to prevent corrosion but also to keep down the frictional resistance and consequently the fuel consumption. Under conditions favorable to fouling (as the growth of marine life on the underwater hull of a ship is called), the frictional resistance may show an increase of as much as 200 percent in five months and 300 percent in a year. An increase of 0.5 percent per day is moderate.

The exponent of the speed, designated by n, to be used in frictional resistance calculations has been thoroughly and carefully investigated. It also depends upon the smoothness of the surface. Theoretical considerations would indicate a value of 2 for n, but actual experiments show that this value is too high for smooth surfaces, such as that of a steel ship just out of drydock. While there is some diversity of findings, as it is to be expected in experimental work, use of the value of 1.83 is recommended by the author. It may seem at first as if it makes little difference whether a value of 2 or 1.83 is used. That such is not the case at high speeds may be seen by reference to the following tabulation.

Speed, V	1	5	10	20
$V^{1.83}$	1	19	67.6	240.4
V^2	1	25	100.0	400.0
$\dfrac{V^{1.83}}{V^2}$	1	0.76	0.676	0.601

Example: A ship 460 feet long has a wetted surface of 36,000 square feet. The coefficient of friction for a steel ship with clean bottom of this length is 0.00892. Assuming that the resistance at 5 knots is all frictional, what will be the pull on the towline if she is towed at this speed?

If the resistance is all frictional the pull on the towing hawser is equal to the frictional resistance as computed from equation (901). This value will be in pounds if the speed is taken in knots and the wetted surface in square feet. We have, therefore,

$$R_f = fSV^{1.83} = 0.00892 \times 36{,}000 \times 5^{1.83} = 6107 \text{ pounds}$$

Note: In order to raise any number to any power, we multiply the logarithm of the number by the power and then find the number corresponding to the logarithm thus obtained. For example, to raise 5 to the 1.83 power, as required in the foregoing example, we multiply the logarithm of 5 which is 0.6990, by 1.83.

$$1.83 \times 0.6990 = 1.2792$$

The number whose logarithm is 1.2792 is 19.02
Therefore $5^{1.83} = 19.02$

915. Air resistance; residuary resistance. The various resistances offered by the water to the motion of the underwater body have their counterparts in the resistance offered by the air to the motion of the above-water parts. The total air resistance of ships is small and is practically all eddy resistance.

The eddy resistance of the water and air resistance are both small, and together with the wave resistance, result from pressure variations set up by the motion of the hull. For ease of computation these are therefore lumped together and called the **residuary resistance.** The total resistance of the ship is, consequently, composed of the frictional resistance and the residuary resistance.

No satisfactory formula has been developed for computing the residuary resistance. This component of a ship's resistance is most accurately obtained by computation from the measured resistance of a model. This calculation is based on the Law of Comparison or Froude's Law, which may be expressed in words as follows:

The residuary resistances of similar ships at corresponding speeds vary directly as their displacements. Corresponding speeds are speeds which vary directly as the square root of linear dimensions.

Putting this in the form of an equation, we have:

$$\left.\begin{aligned} &\text{If,} \quad \frac{\text{Speed of model}}{\text{Speed of ship}} = \frac{\sqrt{\text{Length of model}}}{\sqrt{\text{Length of ship}}} \\ &\text{Then,} \quad \frac{\text{Residuary resistance of model}}{\text{Residuary resistance of ship}} = \frac{(\text{Length of model})^3}{(\text{Length of ship})^3} \end{aligned}\right\} (902)$$

When a model is towed for resistance, all that can be measured directly is its total resistance. The frictional resistance may then be computed by substituting the proper values for the symbols in equation (901). The total model resistance minus the computed frictional model resistance gives the residuary model resistance. The residuary ship resistance at the corresponding speed may be computed by equation (902). The ship frictional resistance at the corresponding speed is then calculated by equation (901). The sum of these gives the total ship resistance at a speed equal to the model speed multiplied by the square root of their length ratio. For example, if we had a 20-foot model of a ship which is 500 feet long, a speed of 20 knots for the ship would correspond to 4 knots for the model, since

$$\frac{4}{20} = \frac{\sqrt{20}}{\sqrt{500}}$$

Since the **ship** is **25 times as long** as the model, its **residuary resistance** at **20 knots** would be **$(25)^3$ = 15,625** times as great as the residuary resistance of the model at **4 knots.**

Example: The total resistance of the 20-foot model of a 500-foot ship at 5 knots is 6 pounds. The frictional resistance of the model is 4 pounds. What is the residuary resistance of the ship at corresponding speed and what is the corresponding speed?

Let V_m = speed of model in knots

And V_s = speed of ship in knots

Then $V_s = V_m \dfrac{\sqrt{500}}{\sqrt{20}} = 5\dfrac{10\sqrt{5}}{2\sqrt{5}} = 5 \times 5 = 25$ knots.

Therefore, the speed of the ship corresponding to 5 knots of the model is 25 knots.

Let R_r = residuary resistance of ship in pounds

$$\text{Then } R_r = (6 - 4) \times \left(\frac{500}{20}\right)^3 = 2 \times (25)^3$$

$$= 2 \times 15{,}625 = 31{,}250 \text{ pounds.}$$

Owing to the importance of the relation between the speed and the square root of the length of a ship, in connection with its residuary resistance, this ratio has been given the name **speed-length ratio.** The speed is given in knots and the length in feet, and it is expressed thus:

$$\frac{V}{\sqrt{L}}$$

The various methods of determining the horsepower of the propelling machinery required to drive the ship at designed speed are given in Section 94.

QUESTIONS

911. Name and define the components of resistance to the motion of a ship through the water.

912. Define streamline. Discuss the changes in velocity and pressure which occur in liquid moving past a solid in the stream.

913. Describe the wave systems generated by a ship moving through the water. What is the relative importance of the various components of resistance?

914. How is the frictional resistance of a ship computed? Define wake.

915. How is the residuary resistance of a ship determined? State Froude's Law. Define corresponding speeds.

PROBLEMS

911. A 25-foot model of a ship 625 feet long when towed at a speed of 285 feet per minute has a measured total resistance of 5 pounds. The frictional resistance of the model is computed to be 2 pounds. What is the residuary resistance of the ship at the corresponding speed and what is this corresponding speed in knots, if there are 6080 feet in a sea mile?

Ans. 46,875 pounds. 14.08 knots.

912. A ship 500 feet long is designed for 21 knots. The frictional resistance of the ship at this speed is computed to be 101,250 pounds. At what speed in feet per second should a 20-foot model of the ship be towed for a determination of the ship's residuary resistance? If the residuary resistance of the model at the above speed is 14 pounds, find the residuary and total resistances of the ship.

Ans. 7.09 feet per second; residuary resistance = 218,750 pounds; total resistance = 320,000 pounds.

Section 92. Ship propellers. *Arts.:* 921. Principles of self-propulsion. 922. Screw propellers.

921. Principles of self-propulsion. Just as a motor car is a very different vehicle from a horse car or a cable car, so a ship which has within it the means of generating and applying the power required for its motion through the water is a very different vessel from one propelled by wind, towing, or other agencies outside of the ship. The principle underlying the design of all types of ship propulsion apparatus is Newton's third law of motion: that every action has an equal and opposite reaction. The principle of ship propulsion is illustrated by the common type of rotating garden spray which is turned in one direction by the reaction of the water shooting out in the opposite direction. Ship propellers of all kinds, i.e., paddle wheels, jet propellers, and screw propellers, all impart a forward motion to the ship by driving water astern. It is a very common and equally erroneous idea that paddle wheels act like the wheels of a tractor, and a screw propeller like a screw thread advancing through a fixed nut. Such an idea gives an entirely wrong approach to the problems of self-propulsion and should, therefore, be discarded before entering upon this study.

The action of a screw propeller is very like that of a screw pump. Water flows to the pump (propeller) from ahead and is discharged astern. The stream flowing aft is called the **propeller race.** It may be clearly seen from the after part of a screw-propelled ship, flowing through the surrounding still water.

No propeller, regardless of its type, is capable of 100 percent efficiency. This has nothing to do with deficiencies in the propelling apparatus itself, but is caused by the fact that, in order for the ship to move forward, water must be driven astern. Water in motion has energy and this energy is lost to the ship. Since some of the work done by the propeller is lost, it cannot have 100 percent efficiency. The efficiency of a well designed propeller is between 50 and 70 percent.

The erroneous comparison of the operation of paddle wheels to tractor wheels and of the screw propeller to a screw conveyor leads to an erroneous conception of the purpose of slip in propulsion. **True** or **real slip** is the ratio of the difference between the speed of the propeller and the speed of advance to the speed of the propeller. In symbols

$$s = \frac{V_p - V_a}{V_p} \tag{903}$$

where s = slip or slip ratio. If multiplied by 100, it is the slip in percent.

V_a = speed of ship through the water in knots

V_p = speed of propeller in knots

In the case of paddle wheels

$$V_p = \frac{60\ \pi dN}{6080} = \frac{\pi dN}{101.33} \tag{904}$$

where d = diameter of paddle wheel in feet

N = revolutions per minute of paddle wheel.

In the case of screw propellers

$$V_p = \frac{60\ pN}{6080} = \frac{pN}{101.33} \tag{905}$$

where p = pitch of screw propeller in feet

N = revolutions per minute of screw propeller.

The **pitch** of a screw propeller is the distance, parallel to its axis, which the propeller would advance in one revolution if working, say, in a solid nut. This is discussed at somewhat greater length in Art. 922.

Examples:

1. A paddle wheel steamer has a speed of advance of 10.5 knots. The paddle wheels are 12 feet in diameter and make 35 revolutions per minute. Compute the true slip in percent.

$$V_p = \frac{\pi dN}{101.33} = \frac{3.14 \times 12 \times 35}{101.33} = 13.03 \text{ knots}$$

$$s = \frac{V_p - V_a}{V_p} = \frac{13.03 - 10.5}{13.03} = \frac{2.53}{13.03} = 0.194$$

Therefore, the true slip is 19.4 percent.

2. A screw propelled ship makes 90 r.p.m. (revolutions per minute) to make a speed of advance of 15 knots. The pitch of the propeller is 22.50 feet. What is the true slip?

$$V_p = \frac{pN}{101.33} = \frac{22.50 \times 90}{101.33} = 19.98 \text{ knots}$$

$$s = \frac{V_p - V_a}{V_p} = \frac{19.98 - 15}{19.98} = \frac{4.98}{19.98} = 0.25$$

Even though a ship may be in a body of still water, such as a large lake or the ocean, its speed over the ground is greater than its speed through the water, because the ship is surrounded by water which it has set in motion. This movement of the water immediately surrounding the ship, through the still water beyond it, is known as the **wake** or **wake current.** It can be plainly seen abaft a sailing ship. In fact, sailing masters estimate their leeway by looking at the angle between the wake and the ship's heading. Since a propeller is operating in the wake, its speed of advance with relation to the water surrounding it is less than the speed of the ship over the ground. For this reason the apparent slip is always less than the true slip.

The **apparent slip** is the ratio of the difference between the speed of the propeller and the speed of the ship over the ground in still water to the speed of the propeller.

$$s_a = \frac{V_p - V}{V_p} \tag{906}$$

where s_a = apparent slip as a fraction; to convert into percent, multiply by 100.

V = speed of the ship over the ground in knots

The wake current is the difference between the speed of the ship over the ground, V, and the speed of the advance, V_a. It is usually expressed as the product of a **wake fraction,** w, by the speed of the ship over the ground. Thus, we have the wake current wV is equal to $V - V_a$, i.e., $wV = V - V_a$, or

$$w = \frac{V - V_a}{V} \tag{907}$$

Examples:

3. The actual speed over the ground of the ship of example 1 was found to be 12.5 knots. What was the strength of the wake current, the value of the wake fraction, and the apparent slip in percent?

$$\text{The wake current } wV = V - V_a$$
$$= 12.5 - 10.5 = 2.0 \text{ knots}$$

$$\text{The wake fraction } w = \frac{V - V_a}{V} = \frac{2.0}{12.5} = 0.16$$

The apparent slip is given by equation (906)

$$s_a = \frac{V_p - V}{V_p} = \frac{13.03 - 12.50}{13.03} = \frac{0.53}{13.03} = 0.04$$

The apparent slip is 4 percent. Compare this with the true slip which is 19.5 percent.

4. The ship of example 2 makes 20.5 knots over the ground. Compute the strength of the wake current, the wake fraction, and apparent slip.

$$wV = V - V_a = 20.5 - 15 = 5.5 \text{ knots}$$

$$w = \frac{5.5}{20.5} = 0.27$$

$$s_a = \frac{19.98 - 20.50}{19.98} = \frac{-0.52}{19.98} = -0.03$$

The apparent slip is negative and has a value of 3 percent

These examples illustrate a very important principle in propulsion. If the strength of the wake current is greater than the difference between the speed of the propeller and its speed of advance, the apparent slip is negative. In order for the apparent slip to be negative, the wake current must be strong. The strength of the wake current depends on a number of things but principally on the frictional drag on the water and the form of the after body of the ship. Whether or not negative apparent slip indicates efficient propulsion depends on why the wake current has a large value. If it is due to excessive surface roughness of the ship, it indicates inefficient propulsion. A clean ship which has a strong wake current and negative apparent slip has efficient propulsion. It should be remembered that the **true slip is always positive** and must be positive in order that the ship may move ahead. The value of the apparent slip gives little indication of the propulsive efficiency unless we know the components of the wake current.

When any propelling apparatus pushes against the water in which the ship is floating, the water moves away from the propeller. The only way that the propeller can push on the water long enough to make it flow aft is for the propeller to follow up the departing water. In other words, the propelling apparatus must slip backwards with the water it is driving astern. It follows, therefore, that **slip is an essential characteristic of any propelling apparatus** and not an undesirable characteristic which should be eliminated.

922. Screw propellers. There are, practically speaking, only two types of propelling apparatus, screw propellers and paddle wheels.

Screw propellers are much more numerous than paddle wheels, which are used very little except on small vessels operating in inland waterways and harbors. No further discussion of paddle wheels will be given.

Fig. 906 shows two views of a three-bladed screw propeller, with important points, lines, dimensions and parts marked thereon. A **screw propeller** (called simply a propeller for brevity in the following discussion), consists of several propeller blades equally spaced around the axis of rotation, and a **hub,** by which the propeller is keyed to the propeller shaft. A **propeller blade** may be defined as a solid, the working surface of which is a helicoidal surface. A **helicoidal surface** is the surface generated by a line, set at an angle to an axis, which revolves about this axis at constant angular speed and at the same time advances along the axis at constant linear speed.

The blades and hub may be cast as a unit, in which case the propeller is said to be a **solid propeller,** or the blades may be made separate and each one secured to the hub, in which case we have a **built-up** or **detachable blade propeller.** In the latter case, the blades terminate in flanges which are bolted to the hub. When the blades are detachable, there is usually some arrangement for changing slightly the twist of the blades. This changes the pitch of the propeller. The working surface of a blade, i.e., the helicoidal surface, the surface which drives the water astern when the ship is going ahead, is called the **face.** The opposite surface is called the **back.** Considerable confusion sometimes arises from the use of these terms because the back is the forward surface of the blade, while the face is the after surface. To avoid such confusion the words forward and after should not be used with reference to the surfaces of propeller blades; instead, the terms face and back should be used in their correct meanings. The **tip** of a blade is the point farthest from the axis. The **leading edge** is the blade edge which cuts through the water when driving the ship ahead; the opposite edge is the **following edge.** The leading edge and following edge meet at the tip.

The **diameter** of a propeller or propeller blade is the diameter of the circle generated by the tip. This dimension is sometimes spoken of as the diameter of the tip circle. The area of the tip circle is called the **disc area** of the propeller. The area of the projection of a propeller blade on a plane perpendicular to the axis is the **projected area**

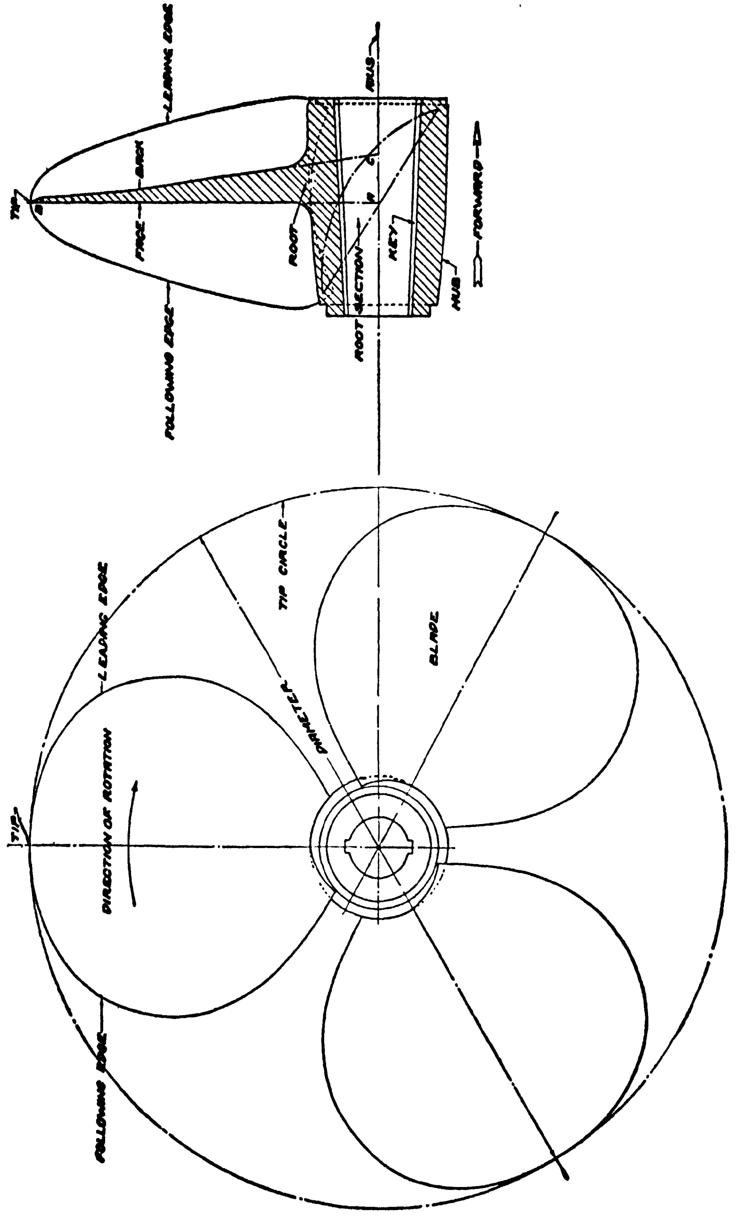


Fig. 906. Three Bladed Propeller

of the blade. The projected area of the propeller is equal to the projected area of one blade multiplied by the number of blades. A helicoidal surface cannot be developed into a plane, just as the surface of a sphere cannot. By the principles of descriptive geometry it is, however, possible to draw a plane figure which has very nearly the same outline and area as the helicoidal surface of a propeller blade. This area is called the **developed area** of the blade and the developed area of the propeller is that of one blade multiplied by the number of blades.

The **pitch** of a blade is the axial advance in one revolution, assuming that the blade is working in a fixed nut. If each point of the face has the same pitch, the blade has **uniform pitch.** There are several ways of varying the pitch which are used in actual propellers. If the pitch increases as we pass from the leading edge to the following edge, the blade has axially increasing pitch. If the pitch decreases from hub to tip, the blade has radially decreasing pitch. The pitch of a blade may vary both axially and radially at the same time. For blades of varying pitch, the average pitch, or **mean pitch,** is frequently used in calculations as if it were the uniform pitch of the blade. In an ideal blade of no thickness the pitch of face and back is the same. In actual blades, which have the metal necessary for strength added on the back, the pitch of the back varies widely from that on the face. For blades of the usual section, the pitch at the leading edge of the back is less, and that at the following edge of the back greater, than the pitch of the face. The term pitch when used unqualifiedly always refers to face pitch.

The angle between the helicoidal surface at any point and a plane at right angles to the axis is known as the **pitch angle** or **angle of the screw.** On a blade of uniform pitch, the pitch angle increases as we go in from the tip towards the hub.

If the line which generates the face of the blade is not perpendicular to the axis, the blade is said to have a **rake.** The rake may be either forward or aft, but is nearly always aft. The rake angle is the angle between the generating line and a line perpendicular to the axis, in Fig. 906 the angle at *A* between *AB* and a line perpendicular to the axis.

The direction of rotation of a propeller is designated as **right-handed** if it turns clockwise as viewed by an observer looking at the face when it drives the ship ahead. If under the foregoing conditions the propeller turns counterclockwise, it is a left-handed propeller. When a ship has two propellers it is usual to have them turn in opposite directions. If the starboard screw is right-handed and the port screw is left-handed, the ship is said to have **out-turning screws.** If the starboard screw is left-handed and the port screw right-handed, the ship has **in-turning screws.**

Propellers for ship propulsion practically all have three or four blades. A few propellers of two blades and some of more than four blades have been tried, but too few to warrant their discussion here. The considerations affecting the choice of three or four blades will be discussed later.

When the tip speed or the pressure on a blade, or both, become high, cavities are formed on the face and back. At excessive speeds the extent of these cavities is such as to cause a falling off of propeller efficiency and speed of ship. This phenomenon is known as **cavitation;** and the speed at which it occurs, as the cavitating speed of the propeller.

In Section 91, the resistance opposing the motion of a ship through the water was discussed. In the present section the principles of propeller action have been given. It now remains to connect the propeller thrust with the ship resistance. The action of a screw propeller is like that of a pump which takes suction from the water immediately forward of it and discharges this water astern. The propeller therefore creates a suction over the after part of the hull, which is immediately forward of the propeller. Suction over the after part of the ship makes necessary an increase in the force required to drive the ship ahead. Propeller suction is sometimes spoken of as **augmentation of resistance,** but more commonly as **thrust deduction.** It is expressed as a fraction of the propeller thrust, T, to which it is intimately related. For example, suppose we have a ship which requires a pull of 50,000 pounds to tow it at 15 knots through the water. If we put a propeller behind this ship, it will be found that when the ship is making 15 knots through the water, the propeller thrust is greater, say 60,000 pounds. This increase in resistance of 10,000 pounds is due to propeller suction acting over the after parts of the hull. Reducing the above to general terms, we may say that R_T' the resistance of the self-propelled ship is equal to T, the propeller thrust when the ship's speed is constant, and R_T' is greater than R_T, the resistance of the same ship at the same steady speed when towed. The augmentation of resistance or the thrust deduction is therefore $R_T' - R_T$. This quantity is also expressed as tT.

Then $tT = R_T' - R_T$

$= T - R_T$, since $T = R_T'$

and $R_T = T(1 - t)$ (908)

where $(1 - t)$ is the **thrust deduction factor.**

Examples:

1. The pull on the hawser of a ship towed at 5 knots is 7000 pounds. The propeller thrust at the same speed is 8500 pounds. What is the thrust deduction factor?

$$(1 - t)T = R_T$$

$$(1 - t) = \frac{R_T}{T} = \frac{7000}{8500} = 0.82$$

2. If a ship is known to have a thrust deduction coefficient of 0.20 and the tow rope resistance at 15 knots is 40,000 pounds, what propeller thrust will be required to make this speed?

$$T = \frac{R_T}{1 - t} = \frac{40{,}000}{1 - 0.20} = \frac{40{,}000}{0.80} = 50{,}000 \text{ pounds.}$$

In Art. 921, it was pointed out that when a ship advances through the water at a speed, V_a, the speed over the ground is a greater speed, V, because the water immediately surrounding the ship has a forward velocity equal to the wake current, wV, caused by friction and other things. In other words, if a propeller thrust, T, gives a speed through the water of V_a, the ship's speed over the ground is V, which is equal to $wV + V_a$. From equation (907) we have that

$$V_a = V - wV = V(1 - w) \qquad (909)$$

The reciprocal of the quantity $(1 - w)$, i.e., $\frac{1}{1 - w}$ is called the **wake factor** or the **wake gain factor.**

Example: A ship is to make 20 knots over the ground. The wake fraction is estimated at 0.22. What is the wake current and wake gain factor?

$$wV = 0.22 \times 20 = 4.4 \text{ knots}$$

$$\frac{1}{1 - w} = \frac{1}{1 - 0.22} = \frac{1}{0.78} = 1.28$$

The power absorbed in propelling a ship over the ground at a speed, V, is equal to the product of this speed by the tow-rope resistance at that speed, i.e., to VR_T. The power delivered by the propeller is equal to the product of the thrust, T, by the speed of advance of the propeller through the water, i.e., to V_aT. The ratio of the power absorbed by the ship to that delivered by the propeller is called the **hull efficiency,** which is designated by e_H.

From the foregoing, we have:

$$e_H = \frac{VR_T}{V_aT} \tag{910}$$

Substituting for R_T its value from equation (908), and for V_a its value from equation (909), we have:

$$e_H = \frac{VT(1 - t)}{V(1 - w)T} = \frac{1 - t}{1 - w} \tag{911}$$

Both t and w vary widely in different ships, depending on the form of the hull, the position, number and direction of rotation of the propellers and the interference of underwater appendages, such as shaft brackets, spectacle frames, etc. Generally speaking, conditions favorable for increasing w also increase t. The value of the fraction $\frac{1 - t}{1 - w}$ is not very far from unity, or 1, for most ships and consequently when no better value is known, the hull efficiency may be assumed to be 100 percent.

Example:

1. The thrust deduction coefficient is 0.20 and the wake fraction is 0.22. What is the hull efficiency?

$$e_H = \frac{1 - t}{1 - w} = \frac{1 - 0.20}{1 - 0.22} = \frac{0.80}{0.78} = 1.026$$

QUESTIONS

921. State the fundamental principle of the self-propulsion of ships.
922. Define and discuss slip and wake.
923. For what types of vessels are paddle wheels used?
924. Sketch and describe a screw propeller and mark the following: hub, blade, back, face, leading edge, following edge, tip, diameter.
925. Define and discuss the various areas of a propeller and propeller pitch.
926. Define: rake, right-hand propeller, out-turning screws, cavitation.
927. Define and discuss thrust deduction factor and hull efficiency.

Section 93. Characteristics of ships in motion.

Arts.: 931. Squat and change of trim. 932. Effects of shallow water.

931. Squat and change of trim. There are certain respects in which a ship in motion differs from the same ship at rest. The effect of the interaction of the ship and water on the efficiency of propulsion, i.e., wake gain and thrust deduction, has already been discussed. The vertical position of a ship in motion is not the same as when at rest. In general, both the mean and the maximum drafts of a moving ship are greater than when at rest and the draft aft is greater on a screw propelled ship than on one being towed. The change of mean draft due to forward movement is called **squat.** The causes of squat and change of trim are the changes of water level adjacent to the ship due to the streamline flow of the water. This is illustrated in Fig. 903.

Up to speeds corresponding to speed-length ratio of 1 (i.e., 20 knots for a 400-foot ship), the bow and stern both settle bodily about the same amount. For short full-formed vessels the bodily settlement is greater than for those which are long and fine-formed. Few merchant ships exceed this speed. If, however, the ship is driven to higher speed, the bow begins to rise and the stern continues to settle, so that a rapid change of trim by the stern occurs. For ships driven to excessive speeds, such as 40 knots for a 400-foot ship, the stern settlement ceases while the bow continues to rise. The bodily settlement of the ship as a whole has, therefore, been reached. On account of the depression in the surface of the water adjacent to the ship it may appear to have risen above its still level, but accurate measurements on models have shown that for ships of normal form the center of gravity of the ship in motion is always below that of the ship at rest.

Sea sleds and similar craft having excessive power for their size do, however, raise themselves above their still level.

932. Shallow water effects. Except for ships driven at excessive speeds, the effect of shallow water is to increase the resistance. This is largely due to the fact that the restriction on the flow of water around the ship results in the generation of higher pressures in the water and the formation of higher waves. A phenomenon which has not as yet been satisfactorily explained is that ships which are driven at speeds such that the speed-length ratio is about 2 or a little greater actually experience a reduction of resistance in shallow water. For ships of usual form, at speeds not exceeding that corresponding to a speed-length ratio of 0.9, it has been found that the minimum depth for no increase in resistance is equal to about ten times the draft multiplied by the speed-length ratio.

The increase in the velocity of the water flowing past the ship, which gives rise to greater wave resistance in shallow water, also results in an increase in the bodily settlement of the ship. When the speed is great enough to produce change of trim by the stern (speed-length ratio somewhat greater than 1), the change of trim experienced in shallow water is greater than that in deep water. Due to bodily settlement in shallow water, ships may strike bottom even though their still draft is less than the depth of water. Since bodily settlement increases with increase of speed, the dictates of prudence are to go slowly when the indicated clearance is small. Based on observations of the bodily settlement of a large number of ships leaving New York harbor, Babcock states that when the clearance is not greater than 10 percent of the draft there is a bodily settlement in feet equal to 20 percent of the speed in statute miles. For example, the *S.S. Queen Mary* drawing 40 feet might be expected to touch bottom at a speed of 17.6 knots (20 statute miles per hour) where the depth was 44 feet.

QUESTIONS

931. Discuss changes of level and trim of a ship in motion in deep water.

932. Discuss the effect of shallow water on resistance.

933. What is the minimum depth for no increase in resistance?

934. Give Babcock's rule for bodily settlement of ships in restricted channels.

PROBLEMS

931. What is the minimum depth of water in fathoms which would give no increase in resistance to the ship of problem 912, assuming a load draft of 30 feet?

Ans. 47 fathoms.

932. What is the maximum speed in knots that the ship of problem 912 should steam through a channel 33 feet deep?

Ans. 13.03 knots.

Section 94. Powering of ships.

Arts.: 941. Powering by calculation. 942. Powering by model experiments. 943. Speed and power trials.

941. Powering by calculation. The power required to drive a ship at a given speed has a profound effect on the economics of operation because of the rapid way in which the cost of operation increases with increase of power. This is due in part to the following factors: increased initial cost, increased wages, increased fuel cost and decreased paying deadweight. The determination of power is therefore a very important economic matter as well as a difficult technical problem. There are two general methods of determining the horsepower which the propelling machinery must generate in order to drive a ship at a desired speed: by straightforward calculation, and by calculations based on the measured resistance of a model having a definite size relation to the ship. The latter is regarded as the most accurate method and is always used for large ships and those of high speed and power. For ships of relatively low speed and small power, the expense of this method of power determination is frequently not warranted by the gain in accuracy obtained. Also, in the early stages of the design of large ships and those of high power, methods of estimating power which give approximate values quickly are of material assistance, even though the accuracy may be less than that of a power computation based on model experiments. It is not necessary that the operating officer should be familiar with all of the various powering methods, but a knowledge of one or two is desirable and materially increases his ability to deal intelligently with operating problems concerning variations of speed and power.

Before embarking on any discussion of powering, it is desirable to define the various horsepowers of a ship. One horsepower has been defined as the power of an engine which does 33,000 foot-pounds of work per minute. The **effective horsepower** of a ship, abbreviated **E.H.P.,** is the horsepower required to tow the ship.

$$\text{E.H.P.} = R_T \times \frac{6080\ V}{60} \div 33{,}000, \text{ where}$$

R_T = tow rope resistance in pounds and
V = speed in knots.

The speed in knots is multiplied by 6080 to convert it to feet per hour and divided by 60 to convert this to feet per minute. We have then

$$\text{E.H.P.} = \frac{6080\ R_T V}{60 \times 33{,}000} = 0.0030707\ R_T V \qquad (912)$$

$$= \frac{R_T V}{325.7} \qquad (913)$$

The **shaft horsepower,** abbreviated **S.H.P.,** is the power on the propeller shaft. The **indicated horsepower, I.H.P.,** is the power generated in the cylinders of a reciprocating steam engine or Diesel engine. The relation between the effective horsepower and the shaft horsepower is called the **propulsive efficiency** or the **propulsive coefficient** of the ship. It is equal to the product of the propeller efficiency and the hull efficiency.

Admiralty coefficients. The method of powering by use of Admiralty coefficients was developed and long used by the British Admiralty and British merchant ship designers. Probably a greater number of ships and a greater volume of tonnage have been powered by this method than all other methods. There are two Admiralty coefficients, C_1 and C_2, which are known as the displacement coefficient and the midship section coefficient, respectively. The equations for the indicated horsepower of the propelling machinery are:

$$\text{I.H.P.} = \frac{\Delta^{2/3} V^3}{C_1} \qquad (914)$$

$$\text{I.H.P.} = \frac{A_{\otimes} V^3}{C_2} \qquad (915)$$

where Δ = displacement of ship in tons
V = speed of ship in knots
$A_{\otimes}$ = area of midship section in square feet.

When equations (914) and (915) were developed, the reciprocating steam engine was the sole source of power for ship propulsion. Since then the marine turbine and Diesel engine have been applied to this purpose. The principal difficulty in the use of this method of powering lies in the choice of proper values of C_1 and C_2. These are not constant for the same ship at different speeds and show wide variation for ships of different types. The method is only accurate when it is known that the resistance is almost entirely frictional and where the ship to be powered is very much like the parent ship in form and not much different in size. This method is interesting primarily on account of its historical background.

Circle C Method. A method for computing the power of cargo ships, which has given excellent results, is known as the "Circle C" method, from the fact that the computation makes use of a coefficient, which is designated by the symbol ©. The formula is

$$\copyright = \frac{427.1 \text{ E.H.P.}}{\Delta^{2/3} V^3} \qquad (916)$$

Curves of values of © for ships of various characteristics, such as length and position of parallel middle body, coefficients of fineness, etc., have been given by several authorities and the method is very useful in powering ships whose characteristics are covered by these curves, principally comparatively slow-speed cargo carriers. This method gives only the effective horsepower. To determine the S.H.P. or I.H.P., we must estimate the propulsive efficiency of the ship. The Circle C Method, like the method using Admiralty coefficients, assumes that the resistance is practically all frictional and that the power varies as the cube of the speed.

Ayre's method. A formula of the same general nature as the Circle C formula has been developed and published by Ayre, which gives excellent results for slow and moderate speed ships of normal form.

$$\text{E.H.P.} = \frac{\Delta^{0.64} V^3}{C_A} \qquad (917)$$

where C_A = Ayre's coefficient.

Ayre has given curves from which C_A may be obtained from values of the speed-length coefficient and the characteristics of the ship. The principal difference between Ayre's method and the Circle C method lies in the difference in the exponent of the displacement (0.64 in the former and $\frac{2}{3}$ in the latter), and in the method of plotting C_A and ©. The principles underlying the two methods are identical.

Extended Law of Comparison. Froude's Law was given in Art. 915. If this principle were applicable to the total resistance of the ship instead of only to the residuary resistance, we should have:

If
$$\frac{V_1}{V_2} = \frac{\sqrt{L_1}}{\sqrt{L_2}} = \frac{\sqrt[6]{\Delta_1}}{\sqrt[6]{\Delta_2}}$$

$$\frac{R_1}{R_2} = \frac{\Delta_1}{\Delta_2}$$

and
$$\frac{\text{E.H.P.}_1}{\text{E.H.P.}_2} = \frac{\Delta_1^{7/6}}{\Delta_2^{7/6}} \tag{918}$$

where the subscripts 1 refer to the speed, length, etc., of a ship of known speed and power, which is geometrically similar to a projected ship whose characteristics and dimensions are designated by the subscript 2.

Equation (918) is the equation of the Extended Law of Comparison. If the propulsive efficiency of ship 1 and ship 2 are the same we have:

$$\frac{\text{I.H.P.}_1}{\text{I.H.P.}_2} = \frac{\text{E.H.P.}_1}{\text{E.H.P.}_2} = \frac{\Delta_1^{7/6}}{\Delta_2^{7/6}}$$

and
$$\frac{\text{S.H.P.}_1}{\text{S.H.P.}_2} = \frac{\text{E.H.P.}_1}{\text{E.H.P.}_2} = \frac{\Delta_1^{7/6}}{\Delta_2^{7/6}}$$

This method cannot be used in powering a ship from the measured resistance of a small scale model, because of the fact that the frictional resistance which, in the case of over 90 percent of the ships is at least 70 percent of the total resistance, does not follow the Law of Comparison. It may be used only when the differences of size and speed of the parent ship and projected ship are not great, and the forms of the two ships practically identical.

942. Powering by model experiment. The powering methods given in the preceding article are often sufficiently accurate for ships of conventional design and small power and they are very useful in the early stages of the design of large, high-speed ships, because the effect of varying different ship characteristics can be approximated in a comparatively short time. For large, high-speed passenger ships, the determination of the engine power is practically always based on the measured resistance of models run at corresponding speeds in a model basin such as the one near Washington.

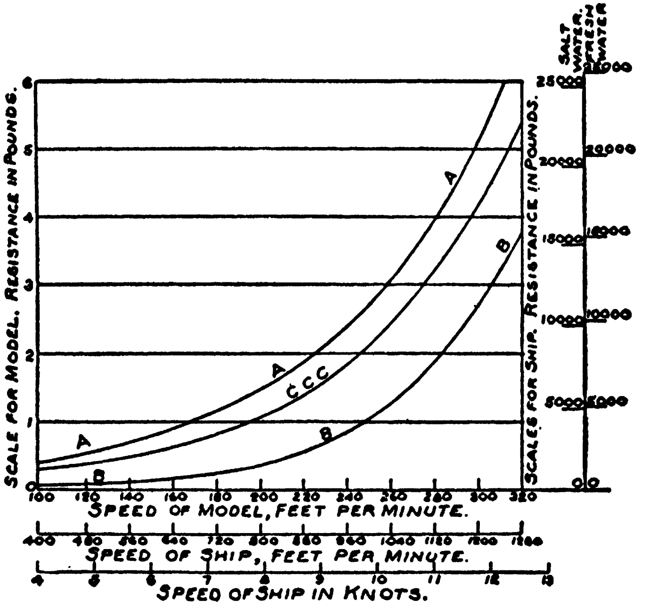


FIG. 907. Curves of Resistance

The frictional resistance is always computed. There is no known method of measuring the frictional resistance of a ship form. The purpose of the model experiment is to determine the residuary resistance of the model. This determination is based on the assumption that, by means of equation (901) or another formula, the frictional resistance can be accurately computed. Since there is no method of measuring the frictional resistance, the confidence which is reposed in powering by model experiments is based on the fact that the results have been satisfactory.

Fig. 907 illustrates the method of obtaining the resistance curve of a ship. A model is towed at various speeds and the towing force is noted when the speed is steady. This gives data for plotting curve

AAA of Fig. 907, the curve of total resistance of the model. The frictional resistance of the model at a number of speeds is computed and subtracted from the total measured resistance. This gives the necessary information for plotting curve *BBB*, the curve of residuary resistance of the model. Since there is a definite relation between the residuary resistances of ship and model, it is only necessary to change the speed and resistance scales to make curve *BBB* the curve of residuary resistance of the ship. For a given value of the speed-length coefficient, $\frac{V}{\sqrt{L}}$, the residuary resistances of ship and model are in the ratio of their displacements. This gives the information necessary to change the scales of resistance and speed, so as to make *BBB* the curve of residuary resistance of the ship. The frictional resistance of the ship may then be computed and added to the residuary resistance to give a curve of total ship resistance, *CCC*. It is to be noted that *CCC* falls below *AAA*. In other words, if the total resistance of the ship were computed on the assumption that this follows the Law of Comparison, the value of the total resistance of the ship so obtained would be materially in error on the high side. The total resistance of a ship is considerably less than the total resistance of the model, at corresponding speed, multiplied by the ratio of their displacements.

From the total resistance of the ship, the effective horsepower at any speed within the limits of the curve can be computed by equation (912), and a curve of E.H.P. constructed. In order to determine the shaft horsepower of the propelling machinery, the hull efficiency and propeller efficiency must be determined. The propeller design gives the latter quantity; the former is obtained by running the model self-propelled by model propellers, which are geometrically similar to the propellers which will drive the full-sized ship. The details of the method are very involved and are not information with which the operating officer is concerned.

943. Speed and power trials. The shipbuilder's contract for the construction of a ship usually contains certain requirements of speed and power and sometimes of fuel consumption. Whether or not these conditions are satisfied can generally best be determined by speed and power trials on an accurately surveyed course in deep water. Other conditions may warrant a speed and power trial and, in view of the fact that operating officers are frequently present as observers or assistants, it is desirable to give some of the important facts concerning such trials.

There are several accurately surveyed trial courses on the east and west coasts of the United States. The one most frequently used is near Rockland, Maine. This course meets more of the requirements of such a course than any other. As shown in Fig. 908, a trial course consists of an accurately measured sea mile, clearly marked with range beacons at each end, and with sufficient sea room for maneuvering at each end. The method of conducting the trial is to run the mile at constant engine speed, maintaining a steady course without the use of rudder. Upon crossing the line of the range beacons at the beginning of the mile run, a stop watch or other accurate time measuring device is started and the readings of the engine revolution counters noted. (Engine revolution counters are like the mileage indicators on automobile speedometers. They show the total number of revolutions the engine has made since it started or since the counter was last set). During the run, measurements of the power output of the propelling machinery are made by means of indicators for reciprocating engines, torsion meters for turbines, and electric meters for electric driven shafts. When the ship crosses the range beacons at the other end of the mile, the time measuring device is stopped and the engine revolution counters again read. From the time required to run the mile, the speed in knots is obtained. (Speed in knots is equal to 60 divided by the time in minutes required for the run.) By subtracting the engine revolution counter reading at the beginning of the run from that at the end of the run, the total number of revolutions for the mile run is obtained. Dividing this by the time in minutes, the number of revolutions per minute required to make the indicated speed is obtained. The power determinations made during the run are averaged to give the horsepower of the propelling machinery required to make the speed attained on the run.

By making several runs at not less than four different speeds, and repeating the process given above, information is obtained for plotting a curve of speed in knots against speed in revolutions per minute, and another of horsepower against either speed in knots or speed in revolutions per minute. The first curve, known as the standardization curve, makes it possible to determine from engine speed the speed in

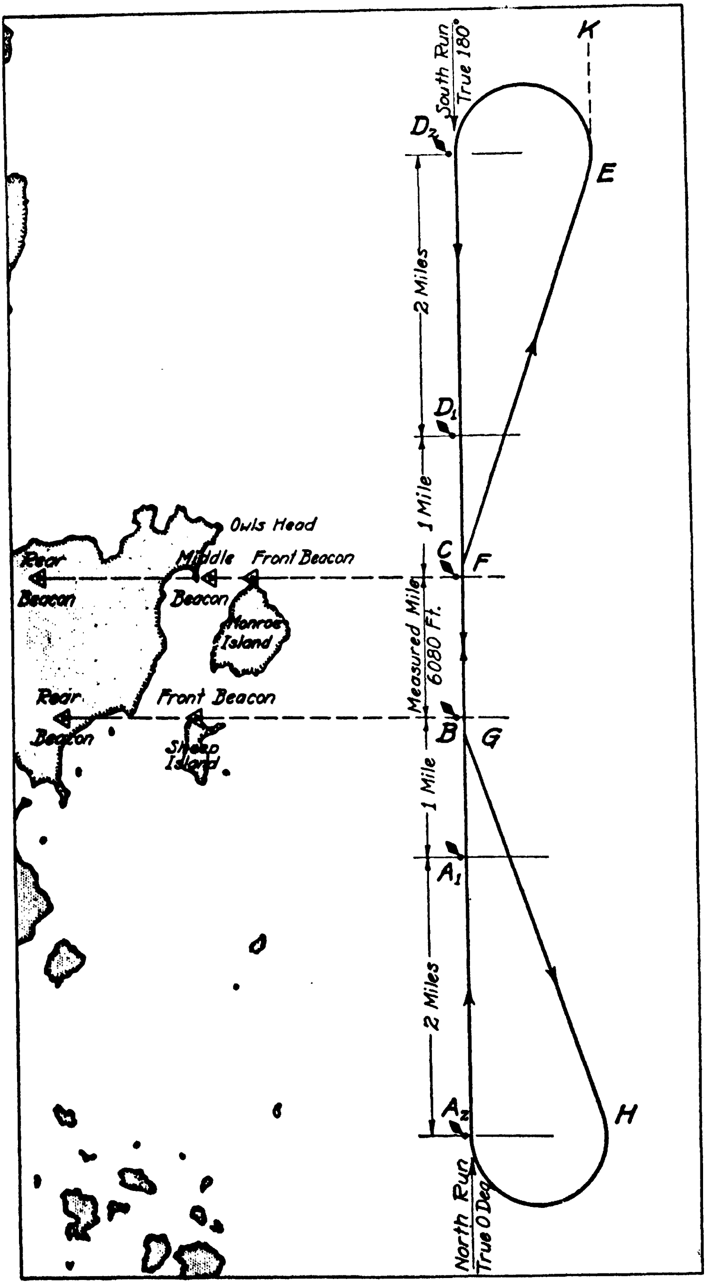


Fig. 908. Trial Course, Rockland, Me.

knots at sea. The second curve permits a comparison of the actual performance of the ship to that predicted in the ship's design and the compliance of the ship with the guarantees of the shipbuilder's contract.

QUESTIONS

941. What are Admiralty coefficients? Give equations showing how they may be used in powering ships. What are the principal sources of error in this use of them?

942. Describe the Circle C and Ayre's method of powering ships.

943. Give the equation of the Extended Law of Comparison. When may this be used for powering a ship?

944. Describe the steps involved to determine from model experiments the engine power required to drive a ship at a specified speed.

945. What information is recorded on speed and power trials and what use is made of it?

APPENDIX

Section 101. Classification of ships. *Arts.:* 1011. Origin and functions of classification societies. 1012. Types and symbols of classification. 1013. Rules of classification societies.

1011. Origin and functions of classification societies. Classification societies originated in connection with and as an adjunct to the business of marine insurance. As an aid in arriving at a reasonable premium to be assessed on a given ship, a survey of the ship from the standpoint of structural adequacy, seaworthiness, and stability was very helpful. Later on, the idea of inspecting a ship during the period of construction gained favor as a more accurate means of determining these characteristics. The final step in the evolution of the classification society was to divorce it from any financial connection with the business of marine insurance. Today, the various classification societies are technical organizations which perform certain services for the shipbuilder, owner, operator, and marine insurance companies, but they are entirely independent of any and all of these. The American Bureau of Shipping, the United States classification society, is a nonprofit organization.

The original classification society was Lloyd's Register of Shipping, which dates from 1760 as a marine insurance organization, although its activities as a classification society began somewhat later. Lloyd's classification and insurance functions are now handled by two entirely independent organizations. Other classification societies are British Corporation Registry, Germanischer Lloyd's, Registro Italiano, Bureau Veritas, Norske Veritas, and Imperial Japanese Marine Corporation. Except for Great Britain, every maritime nation has one such organization which performs similar functions for ships of that nationality. Many of these societies have reciprocal agreements with societies of other nationalities, thus making it possible to reduce the number of branch offices required for the performance of their functions in all of the ports of the world.

Briefly stated the functions of the various classification societies are, as follows:

(a) Publication of a register. Periodically the society publishes a list of vessels concerning which it has reliable information. This publication gives the name and former names of the vessel, the classification assigned, builder and date of construction, present owner, tonnages, type, principal dimensions and characteristics of ship and propelling and auxiliary machinery and other pertinent information upon which an estimate of risk, from an insurance point of view, can be based.

(b) Publication of rules for the construction of ships of various types. These rules will be dealt with more fully in Art. 1013. They give the structural and other requirements which must be met by the ship in order to secure the society's certificate of classification, without which it is practically impossible to secure insurance on ship or cargo. These rules are, therefore, of the utmost importance to the shipbuilder and operator.

(c) Inspection of ships under construction. In order to insure that the ship is built in accordance with the society's rules and that the standard of workmanship employed is of the high order specified in the rules, the society's representatives makes periodic inspections of the work on the ship during the construction period. In addition, important structural and arrangement plans must be referred to the society before proceeding with the work.

(d) Inspection of material and equipment. All structural material and important items of equipment, including the boilers, propelling machinery, and auxiliaries, are inspected at the place of manufacture and may not be put into the ship unless they have the society inspector's stamp of approval. The services listed herein and in subparagraph (c) must be paid for by the shipbuilder, who naturally includes them in the cost of the ship. It may appear strange that a ship owner is willing to pay an outside organization for conducting inspections to see that the ship is built in accordance with the rules of a specific organization. The answer lies in the value which attaches to a certificate of classification furnished by an entirely independent and technically adequate organization. This certificate of classification is accepted at face value as a true and complete statement of the ship's structural adequacy and seaworthiness. Without it, no insurance company will underwrite the risk.

(e) Survey of ships. It is not sufficient to know that a ship was properly designed and built; it is essential to insure that it is properly maintained and kept up in service. To make sure of this, annual surveys and special surveys at intervals of four years are required. The special surveys increase in severity as the ship gets older and are conducted in dry dock and with fires dead so that a complete and thorough survey of the hull and machinery can be made. Any deficiencies found as a result of such surveys must be made good in order for the ship to hold its classification. Occasionally, when the ship gets old the classification is reduced, or the freeboard is required to be increased; sometimes the allowable steam pressure is reduced. In addition to these periodical surveys the societies require a survey whenever the ship is damaged in collision, stranding, or any other accident. The society's surveyor has the power of approving the methods of repair and the sufficiency of the job on completion. The societies therefore contribute materially to the safety of lives and cargoes on board ships.

1012. Types and symbols of classification. The highest classification given a ship indicates that the ship and its equipment have been subject to inspection during construction, that the ship has been constructed in accordance with the society's rules for the highest classification, and that the society believes the ship to be structurally adequate for the loads to be carried and sufficiently seaworthy to operate anywhere in the world. Such a ship is indicated by the symbol ✠ A 1Ⓔ in the register of the American Bureau of Shipping and ✠ 100 A 1 in Lloyd's Register. If the ship was built to the society's rules for highest classification as shown by the working drawings and verified by a survey of the completed ship, but was not subject to inspection during construction, the symbol ✠ is omitted in the classification certificate and register. Similarly, if the equipment was not inspected prior to installation by the society's inspector or does not fully meet the society's requirements, the symbol Ⓔ is omitted in the register of the American Bureau and the symbol 1 in Lloyd's register, and instead, a dash (—) is used to indicate this deficiency. Vessels built of lighter scantlings than required by the rules may be given a classification symbol with the words "**with freeboard**" added. These words signify that the freeboard assigned by the American Bureau is greater than that required by law for vessels of the highest classification and the vessel is safe for trade in any part of the world, provided this freeboard is maintained. Similarly, vessels which are built for a particular trade, the conditions of which warrant a reduction in strength and seaworthiness may be assigned a lower classification which is indicated by a descriptive phrase, such as "River Service," "New York - Boston Service," after the classification symbol. Lloyd's gives 90 A and rarely 80 A classification, which indicate ships which fall below the society's standards for 100 A classification in essential particulars.

If the propelling machinery conforms to the American Bureau's requirements for the highest class and was subject to inspection during fabrication, this is indicated in the register by the symbol ✠ A.M.S. If it was not inspected during fabrication, the star ✠ is omitted. ✠ R.M.C. indicates that the refrigerating machinery was inspected during fabrication and meets the society's requirements for the highest class. Omission of the star indicates lack of the society's inspection during fabrication.

1013. Rules of classification societies. The rules of the American Bureau of Shipping include:

1. Rules for Classification and Construction of Steel Ships.
2. Rules for Construction of Machinery.
3. Rules for the Inspection and Testing of Material.
4. Rules for Surveys.
5. Tables of Scantlings.
6. Tables of Equipment.

The Rules for Classification and Construction of Steel Ships contain the general and detail requirements of the Bureau as regards workmanship, freeboard, subdivision, plans and inspection during construction, as well as the general structural requirements. The thickness of plating and size of other structural members are given in the Tables of Scantlings. The Rules for the Construction of Machinery give the general and detail requirements of the boilers and engines for main propulsion. The Rules for the Inspection and Testing of Material give the methods of testing all materials both for hull and machinery. The Tables of Equipment give the characteristics which must be met by equipment, such as boat and anchor handling gear, steering gear, and the like, in order to obtain the symbol Ⓔ in the classification.

These rules and tables are based on a great amount of experience with ships from many different builders, handling all kinds of cargoes in all of the ports of the world. It is sometimes stated that they are a little on the conservative side and require a ship that is heavier than needed. The societies have shown a willingness to modify their requirements where it can be clearly proved that they are unduly severe, but have been unwilling to let down the bars until it can be definitely established that this can be done without loss of safety. The technical personnel of the societies are of high order and the societies are progressive. The details of the rules are not matters which concern the operating officer and are therefore not discussed here. The sizes of the structural members are based on the principal dimensions of the ship.

QUESTIONS

1011. Tell how the classification societies originated. What functions do the classification societies now perform?

1012. Give the symbols of classification used by the American Bureau of Shipping and Lloyd's Register of Shipping and explain the meaning of each symbol.

1013. What rules are published by the American Bureau of Shipping and of what do these rules treat?

Section 102. Load line calculations.

Art.: 1021. Authority and basis for establishment of load lines. 1022. Computation of summer draft. 1023. Computation of seasonal and zonal drafts.

1021. Authority and basis for establishment of load lines. In view of the facts (1) that the freeboard is a good measure of the safety of a ship in operation, and (2) that it is comparatively easy to measure, it was the first ship characteristic subject to regulation. Early regulations varied widely in their requirements and methods, but in recent years greater uniformity has been secured through international conventions participated in by all the principal maritime nations. The load line regulations for ships of United States registry are promulgated by the Department of Commerce under authority of Acts of Congress. The American Bureau of Shipping has been designated as the agency to certify the correctness of the load line calculations. The regulations are contained in The Loadline Pamphlet obtainable from the U. S. Government Printing Office. In this section there is given a digest of these regulations and the method of computation illustrated by the example of a steel, steam cargo ship. For the purpose of load line calculations, ships of United States registry are classified as follows:

1. Merchant vessels engaged on a foreign or coastwise voyage.
   - *a.* Steamer
   - *b.* Sailing ship
   - *c.* Steamer carrying timber deck cargo
   - *d.* Tanker
   - *e.* Lumber schooner

2. Merchant vessels engaged in special services on coastwise or inter-island voyages.
   - *a.* Steam collier
   - *b.* Tug
   - *c.* Towed barge
   - *d.* Self-propelled barge

3. Merchant vessels engaged in a voyage on the Great Lakes.
   - *a.* Steamer
   - *b.* Tanker

The method of computation is similar for all types of vessels. First the summer draft is calculated, from which certain seasonal and zonal drafts are obtained by the use of minor corrections. The summer freeboard is based on the assumption that a flush deck ship of "standard" form should have a certain freeboard which varies only with the length of the ship, and that any departure of an actual ship from this standard flush deck ship warrants an increase or decrease in the freeboard depending upon whether the departure makes for reduced or greater safety. The standard ship has a block coefficient of 0.68 at draft equal to 85 percent of the depth, a ratio of length to depth of 15, a camber of one-fiftieth of the beam, and a sheer of freeboard deck at side as given in Table 1024.

1022. Computation of summer draft. The load line rules permit the computation of the maximum legal draft. The actual draft at which a ship should be operated depends on a large number of economic and technical considerations. The operating draft is frequently fixed by the depth of channels through which the ship must pass. Table 1021 taken from the load line regulations gives the freeboard in inches for steel, steam cargo ships of standard form. This is the point of departure, so to speak, in the calculation of the actual freeboard and draft of the ship. If the block coefficient at a draft equal to 85 percent of the depth is greater than 0.68, the tabular freeboard is multiplied by a factor equal to $\frac{0.68 + b}{1.36}$, where b is the actual block coefficient. (The student should follow the computation in Table 1025 in conjunction with this discussion.) The required freeboard is not reduced if b is less than 0.68.

If the depth of the ship is greater than one-fifteenth of the length, the freeboard is increased in accordance with the following formula:

$$\text{Correction to freeboard in inches} = \left(D - \frac{L}{15}\right) R, \qquad (1021)$$

where $R = 3$, if $L > 390$ feet

and $R = \frac{L}{130}$, if $L < 390$ feet

D = depth in feet

L = length in feet.

It will be noted that if D is less than $L/15$, the correction has a negative value, i.e., the required freeboard is reduced, but this is subject to certain other conditions given in the regulations.

If a ship has a complete deck above the upper deck to the hull, the freeboard of the upper deck may be reduced without any reduction of safety. Such a ship is known as a **shelter deck ship.** Table 1022, also taken from the regulations for steel, steam cargo ships, shows the reduction in freeboard for ships of various lengths which have a complete deck above the upper deck. If a ship does not have a complete deck but does have some watertight superstructures above the upper deck, the required freeboard is subject to some reduction. Table

1023, from the same source and for the same type of ship, gives the percentage of reduction from Table 1022 for superstructures having various percentages of the length. For example, for the ship of Table 1025, the reduction in freeboard for a complete superstructure is 42 inches. This ship has a superstructure for only 40 percent of its length and therefore from Table 1023 the reduction in freeboard is 27½ percent of 42 inches or 11.55 inches. While theoretically the values given in Table 1021 are the freeboards of a flush deck ship, the regulations require an increase of freeboard of 1½ inches per 100 feet of length if the ship is entirely without superstructures, and the fineness correction, given in the first paragraph of this article, is applied to the sum of the tabular freeboard plus the flush deck correction in the case of flush deck ships.

The regulations give in terms of the length of the ship the ordinates of the standard sheer curve of the upper deck at side in inches at intervals of one-sixth of the length. See Table 1024. By putting these ordinates through Simpson's First Rule, adding and dividing by 18, we obtain the mean ordinate of the sheer curve. The mean ordinate of the sheer curve of the actual ship in inches is computed similarly. The difference between the value of the mean ordinate of the standard sheer curve and that of the actual one is the basis for the computation of the sheer correction, which involves an increase of freeboard if the sheer of the actual ship is less than the standard, and a reduction of freeboard if the actual ship has greater sheer. The formula for computing the sheer correction, S_c, is:

$$S_c = d\left(0.75 - \frac{S}{2\,L}\right) \qquad (1022)$$

where d = difference between mean ordinate of standard sheer curve and that of actual sheer curve, computed as given above.

S = length of superstructures in feet

L = length of ship in feet

The standard camber is one-fiftieth of the breadth. The freeboard must be increased by one-fourth of the deficiency of camber multiplied by the ratio of the length of the part of the deck not covered by superstructures to the entire length. If the actual camber exceeds the standard, a similar reduction of freeboard may be made, provided the actual camber does not exceed twice the standard.

The basic tabular freeboard, corrected as indicated above, gives the summer freeboard of the ship, and the depth minus this freeboard gives the summer draft and location of the summer load line.

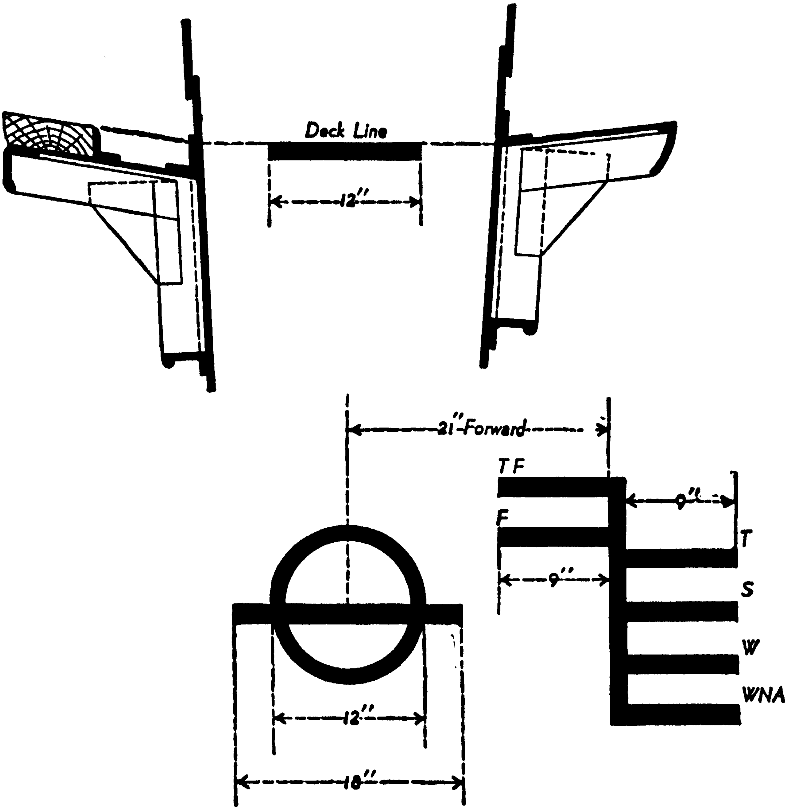


FIG. 1021. Load Line Marking

1023. Computation of seasonal and zonal drafts. Since the percentage of days of bad weather is usually greater in winter than in summer, the load line regulations require a greater freeboard in winter. The number of inches increase in freeboard is equal to one-fourth the summer draft in feet. If the ship is less than 330 feet long, the winter freeboard in the North Atlantic Ocean must be 2 inches greater than the winter freeboard.

Ships operating in the tropics, where good weather is the rule, are allowed a reduction of freeboard in inches equal to one-fourth the summer draft in feet.

The regulations allow a reduction of freeboard in fresh water equal to the displacement at the summer load line, divided by 40 times the tons per inch immersion at that load line; see Art. 419. If either of these quantities is not known, the reduction in freeboard for fresh water is the same as for tropical operation. For operation in fresh water in the tropics, a reduction of freeboard equal to the sum of the tropical and fresh water reductions is permitted.

Fig. 1021 from the Load Line Regulations shows the method of locating and marking the load lines on the sides of a ship. The load line disc is centered on the midship section of the ship. The lines are one inch wide and the top of the summer load line passes through the center of the disc. The freeboard is measured from the top of the deck line to the top of the governing load line. The markings of the various load lines are as follows:

TF = tropical fresh water
F = fresh water
T = tropical
S = summer
W = winter
WNA = winter North Atlantic

The initials of the agency certifying the correctness of the load line calculations are placed beside the disc. For ships of United States registry, this is the American Bureau of Shipping and the letters used are AB placed just above the summer load line passing through the disc, and the A on one side of the disc and the B on the other. See Fig. 1021. Other initials used by ships of foreign registry are LR for Lloyd's Register, BC for British Corporation, etc. The load line disc is sometimes called the Plimsoll mark.

TABLE 1021. BASIC FREEBOARD FOR STEEL CARGO STEAMERS

Length in feet	Freeboard in inches	Length in feet	Freeboard in inches	Length in feet	Freeboard in inches	Length in feet	Freeboard in inches
80	8.0	250	32.3	420	77.8	590	127.0
90	9.0	260	34.4	430	80.9	600	129.5
100	10.0	270	36.5	440	84.0	610	132.0
110	11.0	280	38.7	450	87.1	620	134.4
120	12.0	290	41.0	460	90.2	630	136.8
130	13.0	300	43.4	470	93.3	640	139.1
140	14.2	310	45.9	480	96.3	650	141.4
150	15.5	320	48.4	490	99.3	660	143.7
160	16.9	330	51.0	500	102.3	670	145.9
170	18.3	340	53.7	510	105.2	680	148.1
180	19.8	350	56.5	520	108.1	690	150.2
190	21.4	360	59.4	530	110.9	700	152.3
200	23.1	370	62.4	540	113.7	710	154.4
210	24.8	380	65.4	550	116.4	720	156.4
230	28.5	400	71.5	570	121.8	740	160.5
240	30.3	410	74.6	580	124.4	750	162.5

TABLE 1022. REDUCTION IN FREEBOARD FOR COMPLETE SUPERSTRUCTURE

Length in feet	Reduction in Freeboard in inches
80	14
280	34
400 and above	42

TABLE 1023. PERCENTAGE OF VALUE FROM TABLE 1022 FOR PARTIAL SUPERSTRUCTURES

Superstructures	0	0.1 *L*	0.2 *L*	0.3 *L*	0.4 *L*	0.5 *L*	0.6 *L*	07. *L*	0.8 *L*	0.9 *L*	1.0 *L*
	%	%	%	%	%	%	%	%	%	%	%
All types with forecastle and without detached bridge....	0	5	10	15	23.5	32	46	63	75.3	87.7	100
All types with forecastle and detached bridge............	0	6.3	12.7	19	27.5	36	46	63	75.3	87.7	100

TABLE 1024. ORDINATES OF STANDARD SHEER CURVE

Station	Ordinate	Multiplier
A.P.	$0.1\,L + 10$	1
⅙ *L* from A.P.	$0.0445\,L + 4.45$	4
⅓ *L* from A.P.	$0.011\,L + 1.1$	2
⨯	0	4
⅓ *L* from F.P.	$0.022\,L + 2.2$	2
⅙ *L* from F.P.	$0.089\,L + 8.9$	4
F.P.	$0.2\,L + 20$	1

TABLE 1025. LOAD LINE CALCULATION FOR SHIP

Data

Ship length = 460 feet
beam = 60 feet 10 inches
depth = 38.06 feet
camber = 15.25 inches
displacement at draft of 32.30 feet = 17,500 tons
length of superstructures forecastle = 35 feet
bridge = 100 feet
poop = 50 feet
sheer A.P. = 50 inches
⅙ *L* = 22.50 inches
⅓ *L* = 5 inches
⨯ = 0
⅓ *L* = 11 inches
⅙ *L* = 45 inches
F.P. = 100 inches

Solution

$$b = \frac{35 \times 17{,}500}{460 \times 60.83 \times 32.30} = 0.68$$

$$\text{Fineness correction} = \frac{0.68 + 0.68}{1.36} = 1$$

$$\text{Depth correction} = \left(D - \frac{L}{15}\right) R = \left(38.06 - \frac{460}{15}\right) 3$$

$$= (38.06 - 30.66)3 = 7.40 \times 3 = 22.20 \text{ inches}$$

Superstructure correction
Forecastle = 35
Bridge = 100
Poop = 50

Total = 185 = 40% of *L*

Reduction for total superstructure = 42 inches
Reduction for 40% (Table 1023) = 27.5%
Superstructure correction = 11.55 inches

Sheer correction (see Table 1024)

Station	Rule ordinate	Multiplier	$f(S)$	Actual ordinate	$f(S)$
A.P.	56.00	1	56.00	50.00	50.00
⅙ L	24.92	4	99.68	22.50	90.00
⅓ L	6.16	2	12.32	5.00	10.00
⊗	0.00	4	0.00	0.00	0.00
⅓ L	12.32	2	24.64	11.00	22.00
⅙ L	49.84	4	199.36	45.00	180.00
F.P.	112.00	1	112.00	100.00	100.00
Sums			504.00		452.00

$$d = \frac{504 - 452}{18} = 2.83$$

$$S_e = 2.83\left(0.75 - \frac{185}{2 \times 460}\right) = 2.83 \times 0.55 = 1.58 \text{ inches}$$

Camber correction

Standard camber = $\frac{1}{50}$ of 60.83 × 12 = 14.60 inches
Actual camber = 15.25 inches

$$\text{Camber correction} = \frac{1}{4} \times \frac{275}{460} \times (15.25 - 14.60) = 0.10 \text{ inches}$$

Basic freeboard from Table 1021		90.20 inches
Fineness correction		0.00 inches
Depth correction	+	22.20 inches
		112.40
Superstructure correction	−	11.55 inches
		100.85
Sheer correction	+	1.58 inches
		102.43
Camber correction	−	0.10 inches
Summer freeboard		102.33 inches
		8 feet 6⅜ inches

Summer draft = 38 feet 0¾ inches − 8 feet 6⅜ inches
= 29 feet 6⅜ inches

Seasonal and zonal corrections

Winter $\frac{29.53}{4} = 7.22 = 7\frac{1}{4}$ inches

Tropical $\frac{29.53}{4} = 7\frac{1}{4}$ inches

Fresh water $\frac{29.53}{4} = 7\frac{1}{4}$ inches

Tropical fresh water = 7¼ + 7¼ = 14½ inches
Winter North Atlantic = same as Winter since $L = 330$ feet

Résumé

	Freeboard	Draft
Summer	8 ft. 6⅜ in.	29 ft. 6⅜ in.
Winter	9 ft. 1⅝ in.	28 ft. 11⅛ in.
Tropical	7 ft. 11⅛ in.	30 ft. 1⅝ in.
Fresh water	7 ft. 11⅛ in.	30 ft. 1⅝ in.
Tropical fresh water	7 ft. 3⅞ in.	30 ft. 8⅞ in.

QUESTIONS

1021. What are the reasons which have led to regulation of freeboard?

1022. What agency is authorized to assign the load lines for ships of United States registry and whence does this agency get its authority?

1023. What is the underlying principle in the calculation of the summer draft of a ship?

1024. State briefly the steps in the computation of the summer load line for a steel cargo steamer.

1025. How are the zonal and seasonal load lines obtained from the summer draft?

PROBLEM

1021. Calculate the various freeboards and drafts of the following steel cargo steamer: length 400 feet, beam 54 feet, depth 33.05 feet, displacement at draft of 28.05 feet (85 percent of depth) 13,500 tons, camber 13½ inches; length of superstructures, forecastle 30 feet, bridge 90 feet, poop 40 feet; ordinates of sheer curve in inches A.P. 44, ⅙ *L* 19.50, ⅓ *L* 4.67, ⊗ 0, ⅓ *L* 9.75, ⅙ *L* 39, F.P. 88.

Ans. Summer freeboard 7 feet 2 inches.

Section 103. Tonnage calculations. *Arts.:* 1031. Method of calculating gross tonnage. 1032. Method of calculating net tonnage. 1033. Suez and Panama Canal tonnage.

1031. Method of calculating gross tonnage. In determining the gross tonnage, all space which is enclosed within the watertight structure of the ship is included, with the exception of certain exempted spaces. **Exempted spaces** are those which, in addition to being unavailable for carrying cargo, are desirable to increase the safety of the ship, such as ballast tanks in the double bottom space, and the forward and after peak tanks. These spaces are usually measured but are not included in the summation of spaces to determine the gross tonnage. All other spaces are designated as **included spaces.**

The gross tonnage is made up of (a) the under-deck tonnage, (b) the 'tween deck tonnage, (c) tonnage of inclosed spaces above upper deck, and (d) excess of hatchways.

(a) Under-deck tonnage. The capacity in measurement tons of all the included spaces below the tonnage deck is known as the **under-deck tonnage.** The **tonnage deck** is the uppermost structural deck of the hull except in the case of vessels having three or more such decks, in which case it is the second deck from below. The calculation is made in the same manner as the computation of the volume of displacement using the areas of the stations; see Art. 416. The number of transverse sections depends upon the **tonnage length** of the ship, which is the length under the tonnage deck and inside the ship. If the tonnage length is not over 50 feet, it is divided into six equal spaces, giving seven sectional areas; if the tonnage length is over 250 feet, it is divided into sixteen equal spaces; if the tonnage length is between 50 and 250 feet an intermediate number of sections is used. At each section the depth of the hold is measured. The measured depth is subject to correction to compensate for the camber or pitch of the deck and the pitch or dead rise of the bottom of the hold space. If the tonnage depth of the midship section does not exceed 16 feet, the area of the sections is computed by Simpson's First Rule using five ordinates (four equal spaces). If the tonnage depth exceeds 16 feet, the computation is similarly made using seven ordinates (six equal spaces). In measuring the breadths for computing the areas of the sections, the dimensions are taken from the surface of the ceiling or cargo battens (average thickness) usually fitted in cargo holds. The volume of the under-deck space is computed from the sectional areas by Simpson's First Rule and the tonnage obtained by dividing the volume (in cubic feet) by 100.

(b) 'Tween deck tonnage. The tonnage of the space between the tonnage deck and the uppermost structural deck of the ship is called the **'tween deck tonnage.** The 'tween deck space is divided into the same number of spaces as the tonnage length was for computation of the under-deck tonnage. The width of the space at the mid-height of the 'tween deck space is then measured and the area of the surface at the mid-height computed by Simpson's first rule. The volume of the space is then obtained by multiplying this area by the height of the 'tween deck space, and its tonnage by dividing the volume in cubic feet by 100.

(c) Inclosed spaces above upper deck. The volume of spaces on the upper deck is not included in computing the gross tonnage unless the space is "inclosed." None of the space above the first deck which is not a deck to the hull is included, if such space is used for passenger accommodation. Generally speaking, an inclosed space is one which has permanent means of closing, but the specific requirements of the tonnage regulations on this matter are too involved to permit summarizing and these details, while extremely important to the ship designer and builder, are only of limited interest to the operating officer. It should, however, be noted that for tonnage measurements the space between the upper deck and shelter deck of a shelter deck ship is not considered an inclosed space. The tonnage of the inclosed spaces above the upper deck is computed in a similar manner to that of the 'tween deck space. The area of the surface at the mid-height of such a space is obtained by dividing it into an even number of spaces, the common length of which is most nearly equal to that of the distance between the sections employed in computing the underdeck tonnage, then measuring the breadth at each point of division at the mid-height of the space and making the computation of area by Simpson's First Rule. The tonnage is equal to the area of this surface multiplied by the height of the space divided by 100.

There are numerous exemptions in the measurement of inclosed spaces above the upper deck. These include:

(1) Spaces appropriated to and fitted with machinery.
(2) Wheelhouse for sheltering men at the wheel.
(3) Spaces used for cooking and baking.
(4) Condenser space.
(5) Water-closets or privies for officers, crew, and passengers.
(6) Skylights and domes for ventilation, light, and air.
(7) Companions and booby hatches.

(d) Excess of hatchways. Realizing that high coamings around cargo hatches gave increased protection to the ship in bad weather, early tonnage regulations allowed the volume of such hatchways to be excluded in computing the gross tonnage. Violation of the spirit of this provision by the construction of excessively high hatchways led to a provision in the current regulations limiting the tonnage of hatchways to one-half of one percent of the gross tonnage. The total tonnage of hatchways less one-half of one percent of the gross tonnage is known as the **excess of hatchways** and included in the gross tonnage of the ship.

1032. Method of calculating net tonnage. The net tonnage of a ship is equal to the gross tonnage minus the tonnage of the deducted spaces. The deducted spaces are in general those which are essential for the operation of the ship and are not available for carrying freight. Such spaces include:

1. Machinery space including fuel bunkers
2. Crew space
3. Master's cabin
4. Steering engine room
5. Chain locker and anchor engine space
6. Boatswain's storeroom
7. Chart house
8. Donkey engine and boiler space
9. Radio house
10. Sail storage space (on sailing vessels only)

No space may be deducted unless it was included in the computation of the gross tonnage.

The largest single deduction is for the space occupied by the propelling machinery. This space includes the engine room, boiler room, fuel bunkers, shaft alleys and escape. In the case of screw propelled vessels, the permissible deduction for the machinery is 32 percent of the gross tonnage if the actual tonnage of this space is above 13 percent and under 20 percent of the gross tonnage. If the actual tonnage lies outside of these limits, the permissible deduction is 175 percent of the actual tonnage. In the case of paddle wheel steamers, the permissible deduction is 37 percent of the gross tonnage if the actual tonnage of the machinery space is between 20 and 30 percent of the gross tonnage, and 150 percent of the actual tonnage if it lies outside of these values. If the actual tonnage of the machinery space is less than the 13 or 20 percent minimum value required to obtain the 32 or 37 percent deduction, the tonnage of the machinery space may be brought up to this value by including that of part of the engineroom skylight, which is ordinarily exempted in the determination of the gross tonnage. This results in a slight increase in the gross tonnage, but the deduction thus obtained is usually worth it, since most charges are based on the net tonnage.

The deductions for the other spaces listed above is simply their own volume, except that the sail storage space is limited to 2.5 percent of the gross tonnage. The deduction for crew space is contingent on providing in the assigned spaces certain minimum deck areas and volumes per man, as well as conformity with certain other requirements such as hospital spaces, toilets, washrooms, etc.

1033. Suez and Panama Canal tonnage. The rules for computing the tonnage of ships for assessment of tolls for passage through the Suez and Panama Canals are slightly different from those given in the preceding articles. The differences are in matters of detail and concern exempted and deducted spaces principally. These details are covered in the publication " Measurement of Vessels " issued by the Bureau of Marine Inspection and Navigation, which publication gives the rules for tonnage calculations for United States vessels. Ships expecting to transit these canals must have tonnage certificates prepared in accordance with the instructions of the Universal Maritime Canal Company of Suez and the Governor of the Panama Canal, respectively. These certificates are prepared by customs officers of the United States for ships of United States registry on the application of the owners.

QUESTIONS

1031. What are the principles upon which the computation of gross and net tonnage is based?

1032. By whom are the tonnage regulations for ships of United States registry issued and from whom is the authority for their issuance derived?

1033. What is a measurement ton? Is the tonnage certificate of a United States ship accepted at face value in London? In Osaka? Discuss this.

1034. Define included space, exempted space, deducted space.

1035. What are the components of the gross tonnage?

1036. Tell how the under deck tonnage and the tonnage of the 'tween deck spaces are computed. Define excess of hatchways.

1037. Tell how the net tonnage is obtained from the gross tonnage. Give the rule for the permissible deduction for machinery space.

Section 104. Rules of Mensuration. *Arts.:* 1041. Trapezoidal rule. 1042. Simpson's First Rule, geometrical proof. 1043. Simpson's First Rule, analytical proof.

1041. Trapezoidal rule. If, in Fig. 1041, we had a series of straight lines BC, CD, DM, MO, OQ and QS instead of the smooth curve $BCDMOQS$, the area between these straight lines and AR could be computed by plane geometry. The figure bounded by the straight lines AB, BC, CF and AF is a trapezoid. The area of a trapezoid is equal to the altitude multiplied by one-half the sum of the bases. That is

$$\text{Area of trapezoid } ABCF = AF \times \tfrac{1}{2}(AB + FC) \qquad (1401)$$

Similarly, the figure bounded by the straight lines FC, CD, DE and EF is a trapezoid and its area is equal to $FE \times \frac{1}{2}(FC + ED)$. All of the figures below the straight lines DM, MO, OQ and QS and above the line AR are trapezoids and their areas are given by expressions similar to equation (1401).

Let A equal the total area under the straight lines connecting B, C, D, M, O, Q and S.

$$\begin{aligned} \text{Then } A = {} & \text{area of trapezoid } ABCF + \text{area of trapezoid } FCDE + \\ & \text{area of trapezoid } EDML + \text{area of trapezoid } LMON + \\ & \text{area of trapezoid } NOQP + \text{area of trapezoid } PQSR \end{aligned} \qquad (1402)$$

$$\begin{aligned} \text{Or } A = {} & AF \times \tfrac{1}{2}(AB + FC) + FE \times \tfrac{1}{2}(FC + ED) \\ & + EL \times \tfrac{1}{2}(ED + LM) + LN \times \tfrac{1}{2}(LM + NO) \\ & + NP \times \tfrac{1}{2}(NO + PQ) + PR \times \tfrac{1}{2}(PQ + RS) \end{aligned} \qquad (1403)$$

$$\text{Now, } AF = FE = EL = LN = NP = PR = s \qquad (1404)$$

$$\text{Let } \left.\begin{aligned} AB &= y_0 \\ FC &= y_1 \\ ED &= y_2 \\ LM &= y_3 \\ NO &= y_4 \\ PQ &= y_5 \\ RS &= y_6 \end{aligned}\right\} \qquad (1405)$$

Substituting the values from equations (1404) and (1405) in equation (1403), we have:

$$A = s(\tfrac{1}{2}y_0 + \tfrac{1}{2}y_1) + s(\tfrac{1}{2}y_1 + \tfrac{1}{2}y_2) + s(\tfrac{1}{2}y_2 + \tfrac{1}{2}y_3) + s(\tfrac{1}{2}y_3 + \tfrac{1}{2}y_4) + s(\tfrac{1}{2}y_4 + \tfrac{1}{2}y_5) + s(\tfrac{1}{2}y_5 + \tfrac{1}{2}y_6) \quad (1406)$$

From which we have, by taking out the common factor s and adding like terms,

$$A = s(\tfrac{1}{2}y_0 + y_1 + y_2 + y_3 + y_4 + y_5 + \tfrac{1}{2}y_6) \quad (1407)$$

or for n equal spaces

$$A = s(\tfrac{1}{2}y_0 + y_1 + y_2 + \cdots + y_{n-1} + \tfrac{1}{2}y_n) \quad (1408)$$

which is the trapezoidal rule.

If the sections of a curve are flat so that the area between the chord and the arc is very small, or if the curve is of such a nature that the areas under the curve which are not included in the trapezoids, such as the areas between the arcs BC and CD, and the chords BC and CD are about equal to the areas inside other trapezoids which are outside the curve, such as the areas between the chords OQ and QS and the arcs OQ and QS, the trapezoidal rule gives accurate results. If, however, the curvature is all of one nature, so that all of the errors are plus or minus, the areas given by the trapezoidal rule may be in error by several percent.

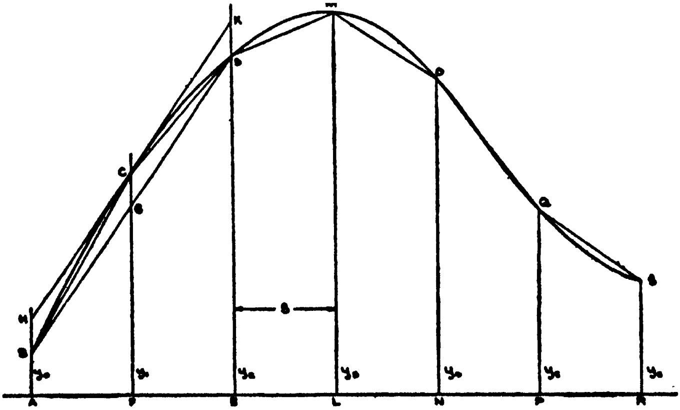


FIG. 1041. Curve for Calculations

1042. Simpson's First Rule, geometrical proof. The area between the curve BCD of Fig. 1041 and the straight line AFE is equal to the area of the trapezoid *ABGDE* plus the area between the curve *BCD* and the straight line *BGD*.

Let

A_1 = area between curve *BCD* and straight line *AFE*.

Then

$$A_1 = ABGDE + BCDG \tag{1409}$$

If the curve *BCD* is a parabola of the second degree

$$\text{Area } BCDG = \tfrac{2}{3} \text{ (area } BHCKDG) \tag{1410}$$

where

$$BH = GC = DK$$

and *HCK* and *BGD* are parallel straight lines.

Therefore *BHCKDG* is a parallelogram

and

$$\text{Area } BHCKDG = AE \times GC \tag{1411}$$

$$AF = FE = s$$

$$AE = 2s \tag{1412}$$

$$GC = FC - FG \tag{1413}$$

$$FC = y_1 \tag{1414}$$

$$FG = \tfrac{1}{2}(AB + DE) = \tfrac{1}{2}(y_0 + y_2) \tag{1415}$$

since the figure *ABGDE* is a trapezoid, and the median line of a trapezoid is equal to one-half the sum of the bases.

Substituting the values from equations (1414) and (1415) in (1413), we have:

$$GC = y_1 - \tfrac{1}{2}y_0 - \tfrac{1}{2}y_2 \tag{1416}$$

Substituting the values from equations (1412) and (1416) in (1411), we have

$$\text{Area } BHCKDG = 2s\,(y_1 - \tfrac{1}{2}y_0 - \tfrac{1}{2}y_2) \tag{1417}$$

Substituting the value given in equation (1417) in (1410) we have

$$\text{Area } BCDG = \frac{4s}{3}(y_1 - \tfrac{1}{2}y_0 - \tfrac{1}{2}y_2) \tag{1418}$$

$$\text{Area } ABGDE = AE \times \tfrac{1}{2}(AB + DE) \tag{1419}$$

Substituting the values of *AE*, *AB* and *DE* from equations (1412) and

(1415), we have

$$\text{Area } ABGDE = 2s \times \tfrac{1}{2}(y_0 + y_2) \tag{1420}$$

and, finally, substituting the values from equations (1420) and (1418) in (1409), we have

$$\begin{aligned} A_1 &= 2s \times \tfrac{1}{2}(y_0 + y_2) + \frac{4s}{3}(y_1 - \tfrac{1}{2}y_0 - \tfrac{1}{2}y_2) \\ &= s(y_0 + y_2 + \tfrac{4}{3}y_1 - \tfrac{2}{3}y_0 - \tfrac{2}{3}y_2) \\ &= s(\tfrac{1}{3}y_0 + \tfrac{1}{3}y_2 + \tfrac{4}{3}y_1) \\ &= \frac{s}{3}(y_0 + 4y_1 + y_2) \end{aligned} \tag{1421}$$

Equation (1421) is the basis for Simpson's First Rule.

Let A_2 = area between curve DMO and ELN.

By a similar process, it can be shown that

$$A_2 = \frac{s}{3}(y_2 + 4y_3 + y_4) \tag{1422}$$

Similarly, if A_3 is the area between the curve OQS and NPQ, we can show that

$$A_3 = \frac{s}{3}(y_4 + 4y_5 + y_6) \tag{1423}$$

Let A = the area between the curve $BCDMOQS$ and AR

Then $$A = A_1 + A_2 + A_3 \tag{1424}$$

Substituting the values from equations (1421), (1422) and (1423) in (1424) we have:

$$A = \frac{s}{3}(y_0 + 4y_1 + 2y_2 + 4y_3 + 2y_4 + 4y_5 + y_6) \tag{1425}$$

Or, for n equal spaces,

$$A = \frac{s}{3}(y_0 + 4\,y_1 + 2\,y_2 + 4\,y_3 + 2\,y_4 + \cdots 2\,y_{n-2} + 4\,y_{n-1} + y_n) \tag{1426}$$

which is the general statement of Simpson's First Rule.

1043. Simpson's First Rule, analytical proof.

(a) If the curve is a second degree parabola

$$y = a_0 + a_1x + a_2x^2 \tag{1427}$$

$$A = \int_0^{2s} y\,dx \tag{1428}$$

$$= \int_0^{2s} (a_0 + a_1x + a_2x^2)\,dx$$

$$= ax + \frac{a_1}{2}x^2 + \frac{a_2}{3}x^3\Big]_0^{2s}$$

$$= 2\,a_0s + 2\,a_1s^2 + \tfrac{8}{3}\,a_2s^3 \tag{1429}$$

$$\text{Let } A = Xy_0 + Yy_1 + Zy_2 \tag{1430}$$

$$\text{when } \begin{cases} y = y_0, & x = 0 \\ y = y_1, & x = s \\ y = y_2, & x = 2s \end{cases}$$

$$\begin{aligned} A &= Xa_0 + Y(a_0 + a_1s + a_2s^2) + \\ &\quad Z(a_0 + 2\,a_1s + 4\,a_2s^2) \\ &= a_0(X + Y + Z) + a_1\{s(Y + 2Z)\} \\ &\quad + a_2\{s^2(Y + 4\,Z)\} \end{aligned} \tag{1431}$$

Since equations (1429) and (1431) are identities, the coefficients of a_0, a_1 and a_2 must in each case be equal. We, therefore, have that

$$\left.\begin{aligned} X + Y + Z &= 2s \\ Y + 2Z &= 2s \\ Y + 4Z &= \frac{8s}{3} \end{aligned}\right\} \tag{1432}$$

Solving equation (1432) for X, Y, and Z, we have

$$\left.\begin{aligned} X &= \frac{s}{3} \\ Y &= \frac{4s}{3} \\ Z &= \frac{s}{3} \end{aligned}\right\} \tag{1433}$$

Substituting the values given by equation (1433) in (1430), we have:

$$A = \frac{s}{3}(y_0 + 4y_1 + y_2) \tag{1434}$$

which is the same as equation (1421) and may be expanded to the general expression for Simpson's First Rule in the same manner as was done in Art. 1042.

(b) If the curve is a third degree parabola

$$y = a_0 + a_1x + a_2x^2 + a_3x^3 \tag{1435}$$

$$A = \int_0^{2s} ydx = \int_0^{2s} (a_0 + a_1x + a_2x^2 + a_3x^3)\, dx \tag{1436}$$

$$= ax + \frac{a_1}{2}x^2 + \frac{a_2}{3}x^3 + \frac{a_3}{4}x^4 \Big]_0^{2s}$$

$$= 2\,a_0s + 2\,a_1s^2 + \frac{8}{3}a_2s^3 + 4\,a_3s^4 \tag{1437}$$

Let

$$A = Xy_0 + Yy_1 + Zy_2 \tag{1438}$$

$$\begin{aligned} &= Xa_0 + Y(a_0 + a_1s + a_2s^2 + a_3s^3) \\ &\quad + Z(a_0 + 2\,a_1s + 4\,a_2s^2 + 8\,a_3s^3) \\ &= a_0(X + Y + Z) + a_1\{s(Y + 2\,Z)\} \\ &\quad + a_2\{s^2(Y + 4\,Z)\} + a_3\{s^3(Y + 8\,Z)\} \end{aligned} \tag{1439}$$

Following the same reasoning as in (a), we have

$$\left.\begin{aligned} X + Y + Z &= 2s \\ Y + 2Z &= 2s \\ Y + 4Z &= \frac{8s}{3} \\ Y + 8Z &= 4s \end{aligned}\right\} \tag{1440}$$

From equation (1440)

$$\left.\begin{aligned} X &= \frac{s}{3} \\ Y &= \frac{4s}{3} \\ Z &= \frac{s}{3} \end{aligned}\right\} \tag{1441}$$

Substituting the values from equation (1441) in (1438), we have:

$$A = \frac{s}{3}(y_0 + 4y_1 + y_2) \tag{1442}$$

Simpson's First Rule will therefore give the exact area under a curve which is a parabola of the second or third degree.

Section 105. Nomenclature of ships.

Abaft — Toward the stern of a ship; back; behind; back of; further aft than.

Aboard — On or in a ship.

Abreast — Side by side.

Accommodation Ladder — Stairs slung at the gangway, leading down the vessel's side to a point near the water, for ship access from small boats.

Aft — Near the stern; toward the stern.

After Body — That portion of a ship's body aft of the midship section.

After Frames — Frames aft of amidships, or frames near the stern of the ship.

After Peak — The aftermost tank or compartment forward of the stern post.

After Perpendicular — A line perpendicular to the base line intersecting the after edge of the stern post at the designed water line. On submarines or ships having a similar stern, it is a vertical line passing through the point where the designed water line intersects the stern of the ship.

Air Port — An opening in the side or deck house of a vessel, usually round in shape and fitted with a hinged frame in which a thick glass is secured.

Aloft — In the upper rigging; above the decks.

Amidships — In the vicinity of the middle portion of a vessel as distinguished from her ends. The term is used to convey the idea of general locality but not that of definite extent.

Anchor — A heavy iron or steel implement attached to a vessel by means of a rope or chain cable for holding it at rest in the water. When an anchor is lowered to the bottom, the drag on the cable causes one or more of the prongs, called flukes, to sink into the ground which provides holding power.

Anchor, Bower — The large anchors carried in the bow of a vessel. Three are usually carried, two (the main bowers) in the hawse pipes, or on bill boards, and a third (spare) lashed on deck or elsewhere about the vessel for use in the event either of the main bowers is lost. The weight varies with the size and service of the ship.

Anchor, Kedge — A small anchor used for warping or kedging. It is usually planted from a small boat, the vessel being hauled up toward it. The weight varies, being usually from 900 to 1,200 pounds.

Anchor, Sea — This is not a true anchor as it does not sink to the bottom. It is a conical-shaped canvas bag required by the Bureau of Marine Inspection to be carried in each lifeboat. When placed overboard it serves a double purpose in keeping the boat head-on into the sea and in spreading a vegetable or animal oil from a container placed inside the bag. It is sometimes called an oil spreader.

Anchor, Stream — An anchor weighing from about one-fourth to one-third the weight of the main bowers and used when mooring in a narrow channel or harbor to prevent the vessel's stern from swinging with the current or the tide.

Angle — Same as angle bar.

Angle Bar — A bar of angle-shaped section used as a stiffener and for attachment of one plate or shape to another.

Angle Bulb — A structural shape having a bulb on one flange of the angle, used as a frame, beam, or stiffener.

Angle Collar — A collar or band made of one or more pieces of angle bar and fitted tightly around a pipe, trunk, frame, longitudinal, or stiffener intersecting or projecting through a bulkhead or deck for the purposes of making a watertight or oiltight joint. See Stapling.

Appendages — Relatively small portions of a vessel extending beyond its main outline as shown by transverse and water plane sections, including such items as shafting, struts, bossings, docking and bilge keels, propellers, rudder, and any other feature, extraneous to the hull and generally immersed.

Area of Sections — The area of any cross section of the immersed portion of a vessel, the cross section being taken at right angles to the fore and aft centerline of the vessel.

Astern — Signifying position, in the rear of or abaft the stern; as regards motion, the opposite of going ahead; backwards.

Athwart — Across, from side to side, transverse, across the line of a vessel's course.

Athwartship — Reaching across a vessel, from side to side.

Auxiliaries — Various winches, pumps, motors, engines, etc., required on a ship, as distinguished from main propulsive machinery (boilers and engines on a steam installation).

Awning — A rooflike canopy of canvas suspended above a vessel's decks, bridges, etc., for protection against sun and weather.

Back Stay — Stays which extend from all mast levels, except the lower, to the ship's side at some distance abaft the mast. They serve as additional supports to prevent the masts going forward and also contribute to the lateral support, thereby assisting the shrouds.

Balanced Rudder — A rudder with its axis between the forward and after edge.

Ballast — Any weight carried solely for the purpose of making the vessel more seaworthy. Ballast may be either portable or fixed, depending upon the condition of the ship. Fixed or permanent ballast in the form of sand, concrete, lead, scrap, or pig iron is usually fitted to overcome an inherent defect in stability or trim due to faulty design or changed character of service. Portable ballast, usually in the form of water pumped into or out of the bottom, peak, or wing ballast tanks, is utilized to overcome a temporary defect in stability or trim due to faulty loading, damage, etc., and to submerge submarines.

Ballast Tanks — Tanks provided in various parts of a ship for introduction of water ballast when necessary to add weight to produce a change in trim or in stability of the ship, and for submerging submarines.

Ballast Water — Sea water, confined to double bottom tanks, peak tanks, and other designated compartments, for use in obtaining satisfactory draft, trim, or stability.

Ballasted Condition — A condition of loading in which it becomes necessary to fill all or part of the ballast tanks in order to secure proper immersion, stability, and steering qualities brought about by consumption of fuel, stores, and water or lack of part or all of the designed cargo.

Barge — A craft of full body and heavy construction designed for the carriage of cargo but having no machinery for self-propulsion.

Batten — Long, thin, strips of wood, steel, or plastic, usually of uniform rectangular section used in the drafting room and mold loft to lay down the lines of a vessel, but sometimes thinned down in the middle or at the ends to take sharp curves. A strip of wood or steel used in securing tarpaulins in place. To secure by means of battens, as to "batten down a hatch."

Battens, Cargo — A term applied to the wood planks or steel shapes that are fitted to the inside of the frames in a hold to keep the cargo away from the shell plating; the strips of wood or steel used to prevent shifting of cargo.

Beam — The extreme width of a ship. Also an athwartship or longitudinal member of the ship's structure supporting the deck.

Beam Knee — A bracket between a frame or stiffener and the end of a beam; a beam arm.

Beam Line — A line showing the points of intersection between the top edge of the beam and the molded frame line, also called "molded deck line."

Beam, Transom — A strong deck beam situated in the after end of the vessel connected at each end to the transom frame. The cant beams which support the deck plating in the overhang of the stern are attached to and radiate from it.

Bearer — A term applied to foundations, particularly those having vertical web plates as principal members. The vertical web plates of foundations are also called bearers.

Bearing — A block on or in which a journal rotates; a bearing block.

Bell Mouthed — A term used to signify the open end of a pipe when it expands or spreads out with an increasing diameter.

Below — Underneath the surface of the water. Underneath a deck or decks.

Bending Rolls — A large machine used to give curvature to plates by passage in contact with three rolls.

Bending Slab — Heavy cast-iron blocks with square or round holes for "dogging down," arranged to form a large solid floor on which frames and structural members are bent and formed.

Berth — A term applied to a bed or a place to sleep. Berths, as a rule, are permanently built into the structure of the staterooms or compartments. They are constructed singly and one above the other. Also, a place for a ship.

Between Decks — The space between any two, not necessarily adjacent, decks. Frequently expressed as "'tween decks."

Bevel — A term for a plane having any other angle than 90 degrees to a given reference plane.

Bevel, Closed — A term applied where one flange of a bar is bent to form an acute angle with the other flange.

Bevel, Open — A term applied where one flange of a bar is bent to form an obtuse angle with the other flange. Frame bars in the bow and the stern of a vessel are given an open bevel to permit access for riveting to shell and to keep the standing flange parallel to the deck beams.

Bight — A loop or bend in a rope; strictly, any part between the two ends may be termed the bight.

Bilge — The rounded portion of a vessel's shell which connects the bottom with side. To open a vessel's lower body to the sea.

Bilge Plates — The curved shell plates that fit the bilge.

Bilges — The lowest portion of a ship inside the hull, considering the inner bottom where fitted as the bottom hull limit.

Bill Board — An inclined platform, fitted at the intersection of the forward weather deck and the shell, for stowing an anchor. It may be fitted with a tripping device for dropping the anchor overboard. Seldom fitted since the stockless anchor has come into general use.

Bitter End — The inboard end of a vessel's anchor chain which is made fast in the chain locker.

Bitts — A term applied to short metal or wood columns extending up from a base plate secured to a deck or bulwark rail or placed on a pier and to timbers extended up through and a short distance above a deck for the purpose of securing and belaying ropes, hawsers, cables, etc. Also called bollards.

Bitumastic — A black tarlike composition largely of bitumen or asphalt and containing such other ingredients as rosin, portland cement, slaked lime, petroleum, etc. It is used as a protective coating in ballast and trimming tanks, chain lockers, shaft alleys, etc.

Bleeder — A small cock, valve, or plug to drain off small quantities of fluids from a container or system.

Blind Pulley — A circular block of hard wood with rounded edges perforated by several holes having grooves running from them to one side of the block. One of these blocks is secured to an end of a part of the standing rigging, as a shroud, and another to the chain plate or to some part of the ship and the two are connected to one another by a lashing passing through the holes. Commonly called " dead eyes."

Block — The name given to a pulley or sheave, or a system of pulleys or sheaves, mounted in a frame or shell and used for moving objects by means of ropes run over the pulleys or sheaves. The prefixes single, double, triple, etc., indicate the number of pulleys or sheaves in the block. The five principal parts of a block are (*a*) the shell, or outside frame, (*b*) the sheave, on which the rope runs, (*c*) the pin, on which the sheave turns, (*d*) the strap, by which the hook is held in position and which provides bearing for the pin, and (*e*) the hook, which may be open, sister, or shackle and fixed or swivel. The opening between the top of the sheave and the shell is called the swallow, that between the bottom of the sheave and the shell is called the breech, and the device attached to the bottom of the block opposite the hook for securing the standing part of the fall to the block is called the becket.

Block, Cheek — A half shell block with a single sheave bolted to a mast or other object which serves as the other half shell or cheek. Usually used in connection with halyards.

Block, Fiddle — A block having two sheaves of different diameters placed in the same plane one above the other.

Block, Snatch — A single sheave block having one side of the frame hinged so that it can be opened to allow the bight of a rope to be placed on the sheave, thus avoiding the necessity of threading the end of the rope through the swallow of the block. Usually employed as a fair lead around obstructions.

Blower — A mechanical device used to supply air under low pressure for artificial ventilation and forced draft, usually of the centrifugal type.

Boarding — The act of going on board a ship.

Bobstays — The chains or ropes attached underneath the outer end of the bowsprit and led aft to the stem to prevent the bowsprit from jumping up. Where two are fitted they are called the *inner* and the *cap* bobstays; when three are fitted they are called the *inner,* the *middle,* and the *cap* bobstays.

Body Plan — A plan consisting of two half transverse elevations or end views of a ship, both having a common vertical center line, so that the right-hand side represents the ship as seen from ahead, and the left-hand side as seen from astern. On the body plan appear the forms of the various cross sections, the curvature of the deck lines at the side, and the projections, as straight lines of the water lines, the bow and buttock lines, and the diagonal lines.

Boiler — Any vessel, container, or receptacle that is capable of generating steam by the internal or external application of heat. The two general classes are fire tube and water tube.

Boiler Casing — Walls forming a trunk leading from the boiler room to the boiler hatch, which protect the different deck spaces from the heat of the boiler room, etc.

Boiler Room — A compartment in the hold, in the middle or after section of a vessel, where the boilers are placed.

Bollards — See " bitts."

Bolster Plate — A piece of plate adjoining the hawse hole, to prevent the chafing of the hawser against the cheek of a ship's bow. A plate for support like a pillow or cushion.

Bolt — A metal rod used as a fastening. With few exceptions, such as drift bolts, a head or shoulder is made on one end and a screw thread to carry a nut is cut on the other.

Bolting Up — Securing by means of bolts and nuts parts of a structure in proper position for permanent attachment by riveting or welding. A workman employed on this work is called a " bolter-up."

Bonjean Curves — Curves of areas of transverse sections of a ship. The curves of the moments of these areas above the base line are sometimes included.

Booby Hatch — An access hatch from a weather deck protected by a hood from sea and weather. The hood is often fitted with a sliding cover to facilitate access.

Boom — A term applied to a spar used in handling cargo, or to which the lower edge of a fore-and-aft sail is attached.

Boom Table — A structure built up around a mast from the deck to support the heel bearings of booms and to provide proper working clearances when a number of booms are installed on or around one mast.

Boot topping — An outside area on a vessel's hull from bow to stern between certain waterlines to which special air, water, and grease-resisting paint is applied; also the paint applied to such areas.

Bosom — The inside of an angle bar.

Bosom Bar — An angle fitted inside another.

Bosom Plate — A plate bar or angle fitted in the bosoms of two angle bars to connect the ends of the two angles as if by a butt strap.

Boss — The curved, swelling portion of the ship's underwater hull around the propeller shaft.

Boss Plate — The plate that covers the boss.

Bottom — That portion of a vessel's shell between the keel and the lower turn of the bilge.

Bottom, Outer — A term applied to the bottom shell plating in a double bottom ship.

Bottom Plating — That part of the shell plating which is below the water line. More specifically, the immersed shell plating from bilge to bilge.

Bow — The forward end of the ship. The sides of the vessel at and for some distance abaft the stem, designated as the right-hand or starboard bow, and the left-hand, or port-bow.

Bow Lines — Curves representing vertical sections parallel to the central longitudinal vertical plane of the bow end of a ship. Similiar curves in the aft part of a hull are called buttock lines. Also, a rope leading from the vessel's bow to another vessel or to a wharf for the purpose of hauling her ahead or for securing her.

Bowsprit — A spar projecting forward over the bow for the purpose of holding the lower ends of the head sails.

Brace — A rope attached to the yard arm, used to alter the position of the yard arm in a horizontal plane. The operation is known as trimming the sail.

Bracket — A steel plate, commonly of triangular shape with a reinforcing flange on its free edge, used to connect two parts such as deck beam to frame, frame to margin plate, etc.; also used to stiffen or tie beam angles to bulkheads, frames to longitudinals, etc.

Breadth, Extreme — The maximum breadth measured over plating or planking, including beading or fenders.

Breadth, Molded — The greatest breadth of the vessel measured from heel of frame on one side to heel of frame on other side.

Breadth, Registered — Measured amidships at its greatest breadth to outside of plating.

Break of Forecastle or Poop — The point at which the partial decks known as the forecastle and poop are discontinued.

Breakwater — A term applied to plates or timbers fitted on a forward weather deck to form a V-shaped shield against water that is shipped over the bow.

Breast Hook — A triangular-shaped plate fitted parallel to and between decks or side stringers in the bow for the purpose of rigidly fastening together the peak frames, stem, and outside plating; also used, in conjunction with the above duties, to fasten the ends of side stringers firmly together.

Bridge — A high transverse platform, often forming the top of a bridge house, extending from side to side of the ship, and from which a good view of the weather deck may be had. An enclosed space called the pilot house is erected on the bridge in which are installed the navigating instruments, such as the compass and binnacle, the control for the steering apparatus, and the signals to the engine room. While the pilot house is generally extended to include a chartroom and sometimes staterooms, a clear passageway should be left around it. As the operation of the ship is directed from the bridge or flying bridge above it, there should also be a clear, open passage from one side of the vessel to the other. The term is also applied to the narrow walkways, called connecting bridges, which connect the bridge deck with the poop and forecastle decks. This type of bridge is usually found on tankers and is desirable whenever bulkwarks are not fitted.

Bridge House — A term applied to an erection or superstructure fitted about amidships on the upper deck of a ship.

Bridge, Navigating, or Flying — The uppermost platform erected at the level of the top of the pilot house. It generally consists of a narrow walkway supported by stanchions, running from one side of the ship to the other and the space over the top of the pilot house. A duplicate set of navigating instruments and controls for the steering gear and engine room signals are installed on the flying bridge so that the ship may be navigated in good weather from this platform. Awnings erected on stanchions and weather cloths fitted to the railing give protection against sun and wind.

Broken Backed — Said of a vessel when, owing to insufficient longitudinal strength, grounding, or other accident, her sheer is reduced or lost, thereby producing a drooping effect at both ends.

Brow — A gangplank, usually fitted with rollers at the end resting on the wharf to allow for the movement of the vessel with the tide. See watershed.

Buckle — A distortion, such as a bulge; to become distorted; to bend out of its own plane.

Buckler — Generally, but not exclusively, applied to various devices used to prevent water from entering hawse and chain pipes, etc.

Buckling — The departure of a plate, shape, or stanchion from its designed plane or axis when subjected to load.

Building Slip — An inclined launching berth where the ship is built.

Bulkhead — A term applied to any one of the partition walls which subdivide the interior of a ship into compartments or rooms. The various types of bulkheads are distinguished by the addition of a word or words, explaining the location, use, kind of material or method of fabrication, such as fore peak, longitudinal, transverse, watertight, wire mesh, etc. Bulkheads which contribute to the strength and seaworthiness of a vessel are called strength bulkheads, those which are essential to the watertight subdivision are watertight or oiltight bulkheads.

Bulkhead, After Peak — A term applied to the first transverse bulkhead forward of the stern post. This bulkhead forms the forward boundary of the after-peak tank and should be made watertight.

Bulkhead, Collision — The foremost transverse watertight bulkhead in a ship which extends from the bottom of the hold to the freeboard deck. It is designed to keep water out of the forward hold in case of collision damage. Usually, this is the fore peak bulkhead at the after end of the fore peak tank.

Bulkhead, Joiner — Wood or light metal bulkheads serving to bound staterooms, offices, etc., and not contributing to the ship's strength.

Bulkhead Stiffener — Members attached to the plating of a bulkhead for the purpose of holding it in a plane when pressure is applied to one side. The stiffener is generally vertical, but horizontal stiffeners are used and both are found on same bulheads. The most efficient stiffener is a T section; flat bars, angles, channels, zees, H and I sections are commonly used.

Bulkhead, Swash — A strongly built, nontight bulkhead placed in oil or water tanks to slow down the motion of the fluid set up by the motion of the ship.

Bulkhead, Wire Mesh — A partition or enclosure bulkhead, used largely in store rooms, shops, etc., made of wire mesh panels.

Bulldozer — A machine, usually hydraulic or electric, for bending bars, shapes or plates while cold.

Bulwark — A term applied to the strake of shell plating or the side planking above a weather deck. It helps to keep the deck dry and also serves as a guard against losing deck cargo or men overboard. Where bulwarks are fitted, it is customary to provide openings in them which are called freeing ports, to allow the water that breaks over to clear itself.

Bulwark Stay — A brace extending from the deck to a point near the top of the bulwark, to keep it rigid.

Bumped — A term applied to a plate which has been pressed or otherwise formed to a concave or convex shape. Used for heads of tanks, boilers, etc.

Bunk — A built-in berth or bed.

Bunker — A compartment used for the stowage of coal or oil fuel.

Buoyancy — Ability to float; the supporting effort exerted by a liquid (usually water) upon the surface of body, wholly or partially immersed in it.

Buoyancy, Reserve — The floating or buoyant power of the unsubmerged portion of the hull of a vessel. Usually referred to a specific condition of loading.

Butt — That end or edge of a plate or timber where it comes squarely against another piece, or, the joint thus formed.

Buttock — The rounded-in overhanging part on each side of the stern in front of the rudder, merging underneath in the run.

Buttock Lines — The curves shown by taking vertical longitudinal sections of the after part of a ship's hull parallel to the ship's keel. Similar curves in forward part of hull are "bow lines."

Butt Strap — A term applied to a strip of plate serving as a connecting strap between the butted ends of the plating. The strap connections at the edges are called seam straps.

Cabin — The interior of a deck house, usually the space set aside for the use of officers and passengers.

Caisson — A watertight structure used for raising sunken vessels by means of compressed air. Also the floating gate to close the entrance to a dry dock.

Calking — The operation of jamming material into the contact area to make a joint watertight or oiltight.

Camber, Round of Beam — The weather decks of ships are rounded up or arched in an athwartship direction for the purpose of draining any water that may fall on them to the sides of the ship where it can be led overboard through scuppers. The arching or rounding up is called the camber or round of the beam and is expressed in inches in connection with the greatest molded breadth of the ship in feet, thus, "the main deck has a camber of 10 inches in 40 feet." In is measured at the center line of the ship at the greatest molded breadth and is the distance from the chord to the top of the arch.

Cant — A term signifying an inclination of an object from a perpendicular; to turn anything so that it does not stand perpendicularly or square to a given object.

Cant Frame — A frame the plane of which is not square to the keel.

Capstan, Steam — A vertical drum or barrel operated by a steam engine and used for handling heavy anchor chains, heavy hawsers, etc. The engine is usually nonreversing and transmits its power to the capstan shaft through a worm wheel. The drum is fitted with pawls to prevent overhauling under the strain of the hawser or chain when the power is shut off. The engine may be disconnected and the capstan operated by hand through the medium of capstan bars.

Cargo — Merchandise or goods accepted for transportation by ship.

Cargo Boom — A heavy boom used in loading cargo. See "boom."

Cargo Hatch — A large opening in the deck to permit loading of cargo.

Cargo Mat — A mat, usually square and made of manila rope, used to protect the deck covering while taking stores, etc., on board.

Cargo Net — A square net, made in various sizes of manila rope or chain, and used in connection with the ship's hoisting appliances to load cargo, etc., aboard the vessel.

Cargo Port — An opening, provided with a watertight cover or door, in the side of a vessel of two or more decks, through which cargo is received and discharged.

Carlings — Short beams forming a portion of the framing about deck openings. Also called headers when they support the ends of interrupted deck beams.

Casings, Engine and Boiler Rooms — The walls or partitions forming trunks above the engine and boiler spaces, providing air and ventilation and enclosing the uptakes. They extend somewhat above the weather deck, or superstructure deck if fitted, and are of sufficient size to permit installation and removal of engines and boilers. Doors are fitted at the several deck levels to permit access to the gratings and ladders.

Cavil — A heavy timber fastened to the forward or after bitts about midway between the base and top to form a cleat. The bitt so built.

Ceiling — A term applied to the planking with which the inside of a vessel is sheathed. Also applied to the sheet metal or wood sheathing in quarters and storerooms.

Ceiling, Floor — Planking fitted on top of the floors or double bottom in the cargo holds.

Ceiling, Hold — Thick strakes of planking fastened to the inside flanges or edges of the framing in the cargo holds.

Centerline — The middle line of the ship from stem to stern as shown in any waterline view.

Center of Buoyancy — The geometric center of gravity of the immersed volume of the displacement or of the displaced water, determined solely by the shape of the underwater body of the ship. It is calculated for both the longitudinal location, forward or aft of the middle perpendicular, and the vertical location above the base line or below the designed waterline.

Center of Flotation — The geometric center of gravity of the water plane at which the vessel floats, forward or aft of the middle perpendicular. It is that point about which a vessel rotates longitudinally when actuated by an external force without change in displacement.

Center of Gravity — The point at which the combined weight of all the individual items going to make up the total weight of the vessel may be considered as concentrated; generally located longitudinally forward or aft of the middle perpendicular and vertically above bottom of keel or below a stated waterline.

Center of Lateral Resistance — The point through which a single force could act and produce an effort equal to the lateral resistance of the vessel. It is ordinarily assumed to be coincident with the center of gravity of the immersed central longitudinal plane.

Center of Pressure — The point in a sail or an immersed plane surface at which the resultant of the combined pressure forces acts.

Central Lateral Plane — The immersed longitudinal vertical middle plane of a vessel.

Chafing Plate — A plate fitted to take the wear due to dragging moving gear or to protect ropes from wearing where they rub on sharp edges. Also fitted on decks under anchor chains.

Chain Locker — Compartment in forward lower portion of ship in which anchor chain is stowed.

Chain Locker Pipe: Chain Pipe — The iron-bound opening or section of pipe leading from the chain locker to the deck, through which the chain cable passes.

Chain Plate — A bar or plate secured to the shell of a vessel to which the standing rigging is attached.

Chains — Usually refers to heavy chains attached to the anchor. Also applied to the lower parts of standing rigging which are attached to the chain plates.

Chain Stopper — A device used to secure the chain cable when riding at anchor, thereby relieving the strain on the windlass, and also for securing the anchor in the housing position in the hawsepipe.

Chamfer — A bevel surface formed by cutting away the angle of two intersecting faces of a piece of material.

Chart House — A small room adjacent to the bridge for charts and navigating instruments.

Chine — The line formed by the intersection of side and bottom in ships having straight or slightly curved frames.

Chock — A term applied to oval-shaped castings, either open or closed on top, and fitted with or without rollers, through which hawsers and lines are passed. Also applied to blocks of wood used as connecting or reinforcing pieces, filling pieces, and supports for life boats. Also applied to the brackets fitted to boiler saddles to prevent fore and aft motion and to small brackets on the webs of frames, beams and stiffeners to prevent tipping of the member.

Clamp — A metal fitting used to grip and hold wire ropes. Two or more may be used to connect two ropes in lieu of a short splice or in turning in an eye. Also a device, generally operated by hand, for holding two or more pieces of material together, usually called a " C " clamp.

Cleats — Pieces of wood or metal, of various shapes according to their uses, usually having two projecting arms or horns upon which to belay ropes. The term Cavil is sometimes applied to a cleat of extra size and strength.

Clinometer — An instrument used for indicating the angle of roll or pitch of a vessel.

Clip — A four- to six-inch angle bar welded temporarily to floors, plates, webs, etc. It is used as a hold-fast which, with the aid of a bolt, pulls objects up close in fitting. Also, short lengths of bar, generally angle, used to attach and connect the various members of the ship structure.

Close Butt — A riveted joint in which the ends of the connected members are brought into metal-to-metal contact by grinding and pulling tight by clips or other means before the rivets are driven.

Club-Foot — A fore foot in which displacement or volume is placed near the keel and close to the forward perpendicular, resulting in full water lines below water and fine lines at and near the designed water line, the transverse sections being bulbshaped. Also called a bulb or bulbous bow.

Coaming, Bulkhead — A term applied to the top and bottom strakes of bulkheads, which are usually made thicker than the remainder of the plating and which act as girder web plates in helping to support the adjacent structure.

Coaming, Hatch — A frame bounding a hatch for the purpose of stiffening the edges of the opening and forming the support for the covers. In a steel ship it generally consists of a strake of strong vertical plating completely bounding the edges of a deck opening.

Cofferdams — Empty spaces separating two or more compartments for the purpose of insulation, or to prevent the liquid contents of one compartment from entering another in the event of the failure of the walls of one to retain their tightness.

Collar — A piece of plate or a shape fitted around an opening for the passage of a continuous member through a deck, bulkhead, or other structure to secure tightness against oil, water, air, dust, etc.

Collier — A vessel designed for the carrying of coal, which may or may not be fitted with special appliances for coal handling.

Companion — The cover over a companionway.

Companionway — A hatchway or opening in a deck provided with a set of steps or ladders leading from one deck level to another for the use of personnel.

Compartment — A subdivision of space or room in a ship.

Composite Vessel — A vessel with a metal frame and a wooden shell and decks.

Cordage — A comprehensive term for all ropes of whatever size or kind on board a ship.

Counter — That part of a ship's stern which overhangs the stern post, usually that part above the water line.

Countersink — A term applied to the operation of cutting the sides of a drilled or punched hole into the shape of the frustum of a cone. Also applied to the tool by which countersinking is done.

Countersunk Hole — A hole tapered or beveled around its edge to allow a rivet or bolt head or a rivet point to seat flush with or below the surface of the riveted or bolted object.

Countersunk Rivet — A rivet driven flush on one or both sides.

Coupling — A device for securing together the adjoining ends of piping, shafting, etc., in such a manner as will permit disassembly whenever necessary. Flanges connected by bolts and pipe unions are probably the most common forms of couplings.

Cradle — A support of wood or metal shaped to fit the object which is stowed upon it.

Cradle, Boat — The heavy wood or metal supports for a ship's boat, cut to fit the shape of the hull of the boat and usually faced with leather, in which the boat is stowed.

Cradle, Launching — The structure of wood, or wood and steel, which is built up from the sliding ways, closely fitting the shell plating, which supports the weight of the ship and distributes it to the sliding ways when a ship is being launched. The extent of the cradle and the number of sections into which it may be divided depends on the weight and length of the ship.

Cradle, Marine Railway — The carriage on which the ship rests when being docked on a marine railway.

Crane — A machine used for hoisting and moving pieces of material or portions of structures or machines that are either too heavy to be handled by hand or cannot be handled economically by hand. Bridge, gantry, jib, locomotive, and special purpose cranes are used in shipyards.

Cribbing — Foundations of heavy blocks and timbers for supporting a vessel during the period of construction.

Cross Trees — A term applied to athwartship pieces fitted over the trees on a mast. They serve as a foundation for a platform at the top of a mast or as a support for outriggers.

Crown — Term sometimes used denoting the round-up or camber of a deck. The crown of an anchor is located where the arms join the shank.

Crow's Nest — A lookout station attached to or near the head of a mast.

Crutch — A term applied to a support for a boom. Also applied to the jaw of a boom or gaff.

Cutwater — The forward edge of the stem at or near the water line is called the cutwater.

Davit — A device used to lower and raise ship's boats and sometimes for other purposes. The rotary, or most common type, consists of a vertical pillar, generally circular in section, with the upper portion bent in a fair curve and having sufficient outreach to clear the side of the ship plus a clearance. Each ship's boat has two davits, one near its bow and one near its stern;

they both rotate, lifting the boat, by means of blocks and falls suspended from the overhanging end, from its stowage position on deck and swinging it clear of the ship's side. This type of davit is usually stepped in a socket attached to the side of the vessel or on the deck next below the boat deck near the side and held in place at the boat deck by a keeper or bearing.

Dead Eye — See " Blind Pulley."

Dead Flat — The midship portion of a vessel throughout the length of which a constant shape of cross section is maintained.

Deadlight — A term applied to a port lid or cover; a metal shutter fitted to protect the glass in a fixed or port light. Often incorrectly applied to a fixed light in a deck, bulkhead or shell.

Dead Rise — The amount which the straight portion of the bottom of the floor of the midship section rises above the base line in the half-beam of the vessel. Usually expressed in inches.

Deadweight — The difference between the light displacement and the full load displacement of a vessel; the total weight of cargo, fuel, water, stores, passengers, and crew and their effects that a ship can carry when at her maximum allowable draft.

Deadweight, Cargo — The number of tons remaining after deducting from the deadweight the weight of fuel, water, stores, dunnage, and crew and their effects necessary for use on a voyage. Also called " useful " or " paying " deadweight.

Deadwood — The vertical surfaces at the extreme after body of a ship.

Deck — A deck in a ship corresponds to a floor in a building. It is the plating, planking, or covering of any tier of beams above the inner bottom forming a floor, either in the hull or superstructure of a ship. Decks are designated by their location as upper deck, main deck, etc., and forward lower deck, after superstructure deck, etc. The after portion of a weather deck was formerly known as the quarter deck and on warships is allotted to the use of the officers.

Deck Bolt — A special type of bolt used to secure the planks of a wood deck to the beams or deck plating.

Deck, Bulkhead — The uppermost continuous deck to which all main transverse bulkheads are carried. This deck should be watertight to prevent flooding adjacent compartments if a compartment is bilged.

Deck, Freeboard — The deck to which the classification societies require the vessel's freeboard to be measured. Usually the upper strength deck.

Deck Heights — The vertical distance between the molded lines of two adjacent decks.

Deck House — A term applied to a partial superstructure that does not extend from side to side of a vessel as do the bridge, poop, and forecastle.

Deck Machinery — A term applied to capstans, windlasses, winches, and miscellaneous machinery located on the decks of ship.

Deck Planks, or Planking — A term applied to the wood sheathing or covering on a deck. Oregon pine, yellow pine, and teak are most commonly used. The seams between the planks should be thoroughly calked.

Deck Plating — A term applied to the steel plating of a deck.

Deck Stringer — The strip of deck plating that runs along the outer edge of a deck.

Deep Floors — A term applied to the floors at the ends of a ship which are deeper than the standard depth of floor at amidships.

Deep Tanks — Tanks extending from the bottom or inner bottom of a vessel up to or higher than the lowest deck. They are fitted with hatches so that they also may be used for cargo.

Deep Waterline — The waterline at which the vessel floats when carrying the maximum allowable load.

Depth Molded — The vertical distance from the molded base line to the top of the uppermost strength deck beam at side, measured at midlength of the vessel.

Derrick — A device consisting of a kingpost, boom with topping lift, and necessary rigging for hoisting heavy weights, cargo, etc.

Diagonal Line — A line cutting the body plan diagonally from the centerline, representing a plane introduced for line fairing purposes.

Dished Plates — Plates, generally of circular shape, which have been furnaced or pressed into a concave form.

Displacement — The weight of fluid displaced by a freely floating and unrestrained vessel, the weight of which exactly equals the weight of the vessel and everything on board at the time the displacement is recorded. Displacement is expressed in tons.

Displacement Curves — Curves drawn to give the displacement of the vessel at varying drafts. Usually these curves are drawn to show the displacement in either salt or fresh water, or in both.

Displacement, Designed — The displacement of a vessel when floating at her designed draft.

Displacement, Full Load — The displacement of a vessel when floating at her greatest allowable draft as established by the classification societies.

Displacement, Light — The displacement of the vessel complete with all items of outfit, equipment, and machinery on board but excluding all cargo, fuel, water, stores, passengers, dunnage, and the crew and their effects.

Dock — A basin for the reception of vessels. Wet docks are utilized for the loading and unloading of ships. Dry docks are utilized for the construction or repair of ships.

Dockyard — A shipyard or plant where ships are constructed or repaired.

Dog — A short metal rod or bar fashioned to form a clamp or clip and used for holding watertight doors, manholes, or pieces of work in place.

Dog Shores — Diagonal braces placed to prevent the sliding ways from moving when the shores and keel blocks are removed before launching. Dog shores are the last timbers to be knocked away at a launching.

Dolly Bar — A heavy steel bar used to hold against the heads of rivets while the points are being clinched when the space is not sufficient to permit the use of a regular holding-on tool.

Dolphin — A term applied to several piles that are bound together, situated either at the corner of a pier or out in the stream and used for docking and warping vessels. Also applied to single piles and bollards on piers that are used in docking and warping.

Donkey Engine — A small gas, steam, or electric auxiliary engine set on deck and used for lifting, etc.

Door, Airtight — A door so constructed that when closed it will prevent the passage of air under a small pressure. Used on air locks to boiler rooms under forced draft and in similar locations.

Door Frame — The frame surrounding a door opening on which the door seats.

Door, Joiner — A light door fitted to staterooms and quarters where air and watertightness is not required. Made of wood, light metal, and metal-covered wood. Metal joiner doors with pressed panels are extensively used.

Door, Watertight — A door so constructed that, when closed, it will prevent water under pressure from passing through. A common type consists of a steel plate, around the edges of which a frame of angle bar is fitted, having a strip of rubber attached to the reverse side of the flange that is fastened to the door plate. The strip of rubber is compressed against the toe of the flange of an angle-iron door frame by dogs or clamps.

Door, Weathertight — A term applied to outside doors on the upper decks which are designed to keep out the rain and spray.

Double Bottom — A term applied to the space between the inner and outer skins of a vessel called respectively the " inner bottom " and " shell," usually extending from bilge to bilge and for nearly the whole length of the vessel fore and aft, and subdivided into water or oil tight compartments.

Doubling Plate — An extra plate secured to the original plating for additional strength or to compensate for an opening in the structure.

Dowel — A pin of wood or metal inserted in the edge or face of two boards or pieces to secure them together.

Draft, Draught — The depth of the vessel below the waterline measured vertically to the lowest part of the hull, propellers, or other reference point. When measured to the lowest projecting portion of the vessel, it is called the " draft, extreme "; when measured at the bow, it is called " draft, forward "; and when measured at the stern, the " draft, aft "; the average of the draft, forward, and the draft, aft, is the " draft, mean," and the mean draft when in full load condition is the " draft, load."

Draft Marks — The numbers which are placed on each side of a vessel near the bow and stern, and often also amidships, to indicate the distance from the number to the bottom of the keel or a fixed reference point. These numbers are six inches high, are spaced twelve inches bottom to bottom vertically, and are located as close to the bow and stern as possible.

Drag — The designed excess of draft, aft, over that forward, measured from the designer's waterline. The drag is constant and should not be confused with trim.

Drift — When erecting the structure of a ship and rivet holes in the pieces to be connected are not concentric, the distance that they are out of line is called the drift. This should be corrected by reaming the holes, but common practice, which is prohibited, is to drive tapered pins, called " drift pins," into the unfair holes to force them into line.

Drift Pin — A conical-shaped pin gradually tapered from a blunt point to a diameter a little larger than the rivet holes in which it is to be used. The point is inserted in rivet holes that are not fair, and the other end is hammered until the holes are forced into line.

Dry Dock, Floating — A hollow floating structure of L- or U-shaped cross section, so designed that it may be submerged to permit floating a vessel into it, and that it may then raise the vessel and itself so that the deck of the dock and consequently the bottom of the vessel is above the level of the water. The bottom of a floating dry dock consists of one or more pontoons or rectangular-shaped vessels with high wing structure erected on one or both sides according to whether the section is to be L- or U-shaped. The deck of the pontoon is fitted with stationary keel blocks and movable bilge blocks which can be pulled under a vessel from the top of the wing structure. Pumps are fitted in the wings by which the dock can be quickly submerged or raised. Floating dry docks are used for repairing and painting the under-water portions of vessels and for docking a damaged vessel.

Dry Dock, Graving — A basin excavated at a waterway and connected thereto by gates or a caisson which may be opened to let a vessel in or out and then closed and the water pumped out. The dock is fitted with stationary keel blocks and movable bilge blocks, which usually are fitted on rack tracks, allowing them to be pulled under a vessel before the water is pumped out. Graving docks are common in navy yards, and although more expensive to construct than floating dry docks, they are practically permanent and supply a more rigid foundation for supporting a ship. The gate of a graving dry dock is usually a caisson which is a complete vessel in itself, having a strong rectangular-shaped keel and end posts which bear against the bottom sill and side ledges at the entrance of the dry dock. The caisson is designed so that its draft may be adjusted by water ballast until it bears against the sill and ledges and is equipped with flood valves and power pumps to make this adjustment. When a ship is to be docked, sluice valves in the caisson or in the dock structure are opened until the water in the dock reaches the same level as the water outside. The caisson is then floated to one side, allowing a vessel to enter the dock. The caisson is then floated back to close the entrance, completely separating the basin from the waterway, and after the vessel is lined up over the keel blocks the water is pumped out of the dry dock.

Dry Dock, Railway — A railway dock consists of tracks built on an incline on a strong foundation and extending from a distance in-shore sufficient to allow docking a vessel of the maximum size for which the dock is built, to a distance under water sufficient to allow the same vessel to enter the cradle. The cradle running on the tracks may be of wood or steel fitted with keel and bilge blocks and sufficiently weighted to keep it on the track when in the water. A hoisting engine with a winding drum or wildcat is fitted at the in-shore end of the railway which operates the cradle by a cable or chain. This type of dry dock is used for docking small ships. It is commonly called a " marine railway."

Dunnage — Any material, such as blocks, boards, paper, burlap, etc., necessary for the safe stowage of stores and cargo.

Dutchman — A piece of wood or steel fitted into an opening to cover up poor joints or crevices caused by poor workmanship.

Edge, Sight — That edge of a strake of plating which laps outside another strake and is, therefore, in plain sight.

Elbow-Ell — A pipe fitting that makes an angle between adjacent pipes, always 90 degrees unless another angle is stated.

Electrode — Either a positive or negative pole or terminal in an electric circuit; rod used to make an electric weld.

Engine Room — Space where the main engines of a ship are located.

Entrance — The forward underwater portion of a vessel at or near the bow. The angle formed between the center line of the ship and the tangent to the designed waterline is called the angle of entrance.

Equilibrium, Neutral — The state of equilibrium in which a vessel inclined from its original position of rest by an external force tends to maintain the inclined position assumed after that force has ceased to act.

Equilibrium, Stable — The state of equilibrium in which a vessel inclined from its original position of rest by an external force tends to return to its original position after that force has ceased to act.

Equilibrium, Unstable — The state of equilibrium in which a vessel inclined from its original position of rest by an external force tends to depart farther from the inclined position assumed after that force has ceased to act.

Erection — The process of hoisting into place and joining the various parts of a ship's hull, machinery, etc.

Evaporator — An auxiliary for supplying fresh water, consisting of a salt water chamber heated by coils or nests of tubing through which live steam is circulated, converting the water into steam which is passed to a condenser or distiller to make up loss of boiler feed water or for other purposes requiring fresh water.

Even Keel — When a boat rides on an even keel, its plane of flotation is either coincident with or parallel to the designed waterline.

Expansion Joint — A term applied to a joint which permits linear movement to take up the expansion and contraction due to changing temperature or ship movement.

Expansion Tanks — Overflow tanks used to provide for expansion, overflow, and replenishment of oil in stowage or cargo tanks.

Expansion Trunk — A trunk extending above a hold which is intended for stowage of liquid cargo. The surface of the cargo liquid is kept sufficiently high in the trunk to permit of expansion of the liquid without danger of excessive strain on the hull or of overflowing, and of contraction of the liquid without increase of the free surface and its accompanying effect upon the stability of the vessel.

Extra Strong — The correct term or name applied to a certain class of pipe which is heavier than standard pipe and not as heavy as double extra strong pipe. Often, but less correctly, called extra heavy pipe.

Eye — A hole through the head of a pin, bolt, etc., or a loop forming a hole or opening through which something is intended to pass, such as a hook, pin, shaft, or rope.

Eye Bolt — A bolt having either a head looped to form a worked eye or a solid head with a hole drilled through it forming a shackle eye.

Eyes — The forward end of the space below the upper deck of a ship which lies next abaft the stem where the sides of the ship approach very near to each other. The hawse pipes are usually run down through the eyes of a ship.

Fabricate — To shape, assemble, and secure in place the component parts in order to form a complete whole. To manufacture.

Face Plate — A flat plate fitted perpendicular to the web and welded to the web plate, or welded or riveted to the flange or flanges of a frame, beam stiffener, or girder to balance the continuous plating attached to the opposite flange of the member.

Fair Curves — Curves which do not in any portions of their entire lengths show such changes of direction as to mark those portions as out of harmony in any respect with the curves as a whole or with the other portions of the curves.

Fair or Fair Up — To so draw the lines of a vessel that the defined surfaces will show no irregularities throughout their entire extent. To line up the frames of a vessel under construction to their proper position. Rivet holes are said to be fair when corresponding holes in the members joined are concentric.

Fairleader — A fitting or device used to preserve or to change the direction of a rope, chain, or wire so that it will be delivered fairly or on a straight lead to a sheave or drum without the introduction of extensive friction. Fairleaders, or fairleads, are fixtures as distinguished from temporary block rigs.

Fairwater — A term applied to plating fitted to form a shape similar to a frustum of a cone around the ends of shaft tubes and strut barrels to prevent an abrupt change in the streamlines. Also applied to any casting or plating fitted to the hull of a vessel for the purpose of preserving a smooth flow of water.

Fall — The entire length of rope used in a tackle. The end secured to the block is called the standing part, the opposite end, the hauling part.

Fantail — The overhanging stern section of vessels which have round or elliptical after endings to uppermost decks and which extend well abaft the after perpendicular.

Fast — A rope or chain used to moor a vessel to a wharf, designated in accordance with the end of the boat with which it is used as bow-fast or stern-fast. See Painter.

Fathom — A nautical unit of length used in measuring cordage, chains, depths, etc. The length varies in different countries, being six feet in the United States and in Great Britain.

Fender — The term applied to various devices fastened to or hung over the sides of a vessel to prevent rubbing or chafing against other vessels or piers. On small craft, as tug boats fenders of timber faced with hardwood or flat steel plate, or of steel structure run fore and aft on the outside of the vessel above the waterline and are firmly secured to the hull. Wood spars, bundles of rope, woven cane, or rope-covered cork are hung over the sides by lines when permanent fenders are not fitted.

Fid — A wood or metal bar used to support the weight of a topmast or a top-gallant mast when in position, being passed through a hole or mortise at its heel and resting on the trestle trees or other support. Also a hardwood tapering pin or tool, used by sailmakers and riggers to open the strands of a rope, eye, grommet, etc. A " hand fid " is rounded at the ends, a " standing or cringle fid " is larger than a hand fid and has a flat base.

Fidley — Framework built around a weather-deck hatch through which the smoke pipe passes.

Fidley Deck — A partially raised deck over the engine and boiler rooms, usually around the smokestack.

Fidley Hatch — Hatch around smokestack and uptake.

Fife Rail; Pin Rail — A term applied to a rail worked around a mast and fitted with holes to take belaying pins for securing the running gears.

Fillet — A term applied to the metal filling in the bosom or concave corners where abrupt changes in direction occur in the surface of a casting, forging, or weldment.

Fin — A projecting keel. A thin plane of metal projecting from hull, etc.

Fixed Light — A thick glass, usually circular in shape, fitted in a frame fixed in an opening in a ship's side, deck house, or bulkhead to provide access for light. The fixed light is not hinged. Often incorrectly called a dead light.

Flagstaff — Flag pole, usually at the stern of a ship; carries the ensign.

Flange — The turned edge of a plate or girder which acts to resist bending. The turned edge of a plate or shape for tying in intersecting structural members. A casting or forging attached to or worked integral with a pipe to form a disk, normal to the axis of an exterior to the pipe, for connecting lengths of pipe.

Flare — The spreading out from the central vertical plane of the body of a ship with increasing rapidity as the section rises from the water line to the rail. Also a night distress signal.

Flat — A small partial deck, built without camber.

Floating Power — The sum of the utilized and the reserve buoyancy of a vessel, or the displacement of the completely watertight portion of the vessel when fully submerged. The utilized buoyancy is that buoyancy required to support the weight of the vessel.

Floodable Length — The length of vessel which may be flooded without sinking her below her safety or margin line. The value of the floodable length of a given vessel varies from point to point throughout her length due to change in form. Similarly at a given point it varies from time to time, depending upon the condition of loading and the permeability of the cargo.

Floor — A plate used vertically in the bottom of a ship running athwartship from bilge to bilge usually on every frame to deepen it. In wood ships the lowest frame timber or the one crossing the keel is called the floor.

Flukes — The palms or broad holding portions at the arm extremities of an anchor, which penetrate the ground.

Fore — A term used in indicating portions or that part of a ship at or adjacent to the bow. Also applied to that portion and parts of the ship lying between the midship section and stem; as, fore body, fore hold, and foremast.

Fore and Aft — Lengthwise of a ship.

Forecastle — A short structure at the forward end of a vessel formed by carrying up the ship's shell plating a deck height above the level of her uppermost complete deck and fitting a deck over the length of this structure. The name applied to the crew's quarters on a merchant ship when they are in the fore part of the vessel.

Forefoot — The lower end of a vessel's stem which is stepped on the keel. That point in the forward end of the keel about which the boat pivots in an endwise launching.

Fore Peak — The extreme forward end of the vessel below decks. The forward trimming tank.

Forward — In the direction of the stem.

Forward Perpendicular — A line perpendicular to the base line and intersecting the forward side of the stem at the designed waterline.

Foul — A term applied to the underwater portion of the outside of a vessel's shell when it is more or less covered with sea growth or foreign matter. It has been found that even an oily film over the vessel's bottom will retard the speed, while sea growth will reduce a vessel's propulsive efficiency to a large extent. Also, obstructed or impeded by an interference, etc.

Found — To fit and bed firmly. Also, equipped.

Founder — To sink as the result of entrance of water.

Frame — A term generally used to designate one of the transverse ribs that make up the skeleton of a ship. The frames act as stiffeners, holding the outside plating in shape and maintaining the transverse form of the ship.

Frame, Boss — A frame that is bent to fit around the boss in the way of a stern tube or shaft.

Frame Lines — Molded lines of a vessel as laid out on the mold loft floor for each frame, showing the form and position of the frames.

Frame Spacing — The fore-and-aft distances between frames, heel to heel.

Freeboard — The vertical distance from the waterline to the top of the weather deck at side.

Freeing Ports — Holes in the lower portion of a bulwark, which allow deck wash to drain off into the sea. Some freeing ports have swinging gates which allow water to drain off but which are automatically closed by sea-water pressure.

Furnaced Plate — A plate that requires heating in order to shape it as required.

Furrings — Strips of timber, metal, or boards fastened to frames, joists, etc., in order to bring their faces to the required shape or level, for attachment of sheathing, ceiling, flooring, etc.

Futtocks — The pieces of timber of which a frame in a wood ship is composed. Starting at the keel they are called the first futtock, second futtock, third futtock, and so on.

Gaff — A spar to which the top of a fore-and-aft sail is attached. It is usually fitted with a jaw at the mast end to clasp the mast.

Gage, Draft — An installation comprising a graduated glass tube, connected at the bottom end with the sea and with the top end open to the air, on which the draft of the vessel is shown by the level of the water in the tube.

Galley — The space on a vessel in which the food is prepared and cooked.

Gangboard, Gangplank — A term applied to boards or a movable platform used in transferring passengers or cargo from a vessel to or from a dock.

Gangway — The term applied to a place of exit from a vessel. Gangways are fitted in the sides of a vessel in the shape of ports requiring means of closure or may be movable portions of bulwarks or railing on the weather decks.

Gantline or Girtline — A rope reeving through a single block aloft and used for hoisting or lowering rigging, drying clothing and hammocks, etc.

Garboard — The strakes of outside plating next to the keel. These strakes act in conjunction with the keel and are usually thicker than the other bottom strakes.

Gear — A comprehensive term in general use on shipboard signifying the total of all implements, apparatus, mechanism, machinery, etc., appertaining to and employed in the performance of any given operation, as " cleaning gear," " steering gear," " anchor gear," etc.

Gib — A metal fitting to hold a member in place or press two members together, to afford a wearing or bearing surface, or to provide a means of taking up wear.

Gimbals — A device by which a ship's compass, chronometer, etc., is suspended so as to remain in a constant horizontal position irrespective of the rolling or pitching of the vessel. It consists of two concentric brass hoops or rings whose diameters are pivoted at right angles to each other on knife-edge bearings.

Girders — On ships this term is used to define a structural member which provides support for more closely spaced members, such as beams, frames, stiffeners, etc., which are at right angles to it and which either rest upon it or are attached to its web. It may be longitudinal or transverse, continuous or intercoastal, and is usually supported by bulkheads and stanchions. The term is also used to designate the longitudinal members in the double bottom.

Girth — The distance measured on any frame line, from the intersection of the upper deck with the side, around the body of the vessel to the corresponding point on the opposite side.

Gooseneck — A swivelling fitting on the heel or mast end of a boom for connecting the boom to the mast.

Grab, Hand — A metal bar fastened to a bulkhead, house side, or elsewhere, to provide means of steadying a person when the ship rolls or pitches.

Grapnel — An implement having from four to six hooks or prongs, usually four, arranged in a circular manner around one end of a shank having a ring at its other end. Used as an anchor for small boats, for recovering small articles dropped overboard, to hook on to lines, and for similar purposes. Also known as a Grappling Hook.

Gratings — A structure of wood or metal bars so arranged as to give a support or footing over an opening, while still providing spaces between the members for the passage of light and the circulation of air.

Gripe — The sharp forward end of the dished keel on which the stem is fixed. A curved piece of timber joining the forward end of the keel and the lower end of the cutwater. A lashing, chain, or the like, used to secure small boats in the chocks and in sea positions in the davits.

Grommet — A wreath or ring of rope. Fibre, usually soaked in red lead or some such substance, and used under the heads and nuts of bolts to secure tightness. A worked eye in canvas.

Ground Tackle — A general term for all anchors, cables, ropes, etc., used in the operation of mooring and unmooring a ship.

Groundways — Timbers fixed to the ground and extending fore and aft under the hull on each side of the keel, to form a broad surface track on which the ship is end-launched. "Groundways" for a side launching embody similar basic features.

Gudgeons — Lugs cast or forged on the stern post for the purpose of hanging and hinging the rudder. Each is bored to form a bearing for a rudder pintle and is usually bushed with lignum vitae or white bearing metal.

Gunwale — A term applied to the line where a weather deck stringer intersects the shell. The upper edge of the side of an open boat.

Gunwale Bar — A term applied to the bar connecting a stringer plate on a weather deck to the sheer strake.

Gusset Plate — A bracket plate lying in a horizontal, or nearly horizontal, plane. The term is often applied to bracket plates.

Gutter Ledge — A bar laid across a hatchway to support the hatch cover.

Guys — Wire or hemp ropes or chains to support booms, davits, etc., laterally, employed in pairs. Guys to booms that carry sails are also known as backropes.

Gypsy — A small auxiliary drum usually fitted on one or both ends of a winch or windless. The usual method of hauling in or slacking off on ropes with the aid of a gypsy is to take one or more turns with the bight of a rope around the drum and to take in or pay out the slack of the free end.

Half-Breadth Plan — A plan or top view of one-half of a ship divided by the middle vertical plane. It shows the waterlines, cross section lines, bow and buttock lines, and diagonal lines of the ship's form projected on the horizontal base plane of the ship.

Half Model — A model of one-half of a ship divided along the middle vertical plane.

Halyards — Light lines used in hoisting signals, flags, etc. Also applied to the ropes used in hoisting gaffs, sails, or yards.

Hamper, Top Hamper — Articles of outfit, especially spars, rigging, etc., above the deck, which, while ordinarily indispensable, may become in certain emergencies both a source of danger and an inconvenience.

Hard Patch — A plate riveted over another plate to cover a hole or break.

Harpings; Harpins — The fore parts of the wales of a vessel which encompass her bows and are fastened to the stem, thickened to withstand plunging. The ribbands bent around a vessel under construction to which the cant frames are temporarily secured to hold them in their proper position.

Hatch, Hatchway — An opening in a deck through which cargo may be handled, machinery or boilers installed or removed, and access obtained to the decks and holds below. Hatch is properly a cover to a hatchway but is often used as a synonym for hatchway.

Hatch Bar — A term applied to flat bars used for securing and locking hatch covers. A bar over the hatch for rigging a tackle.

Hatch Battens — A term applied to flat bars used to fasten and make tight the edges of the tarpaulins that are placed over hatches. The batten and the edge of the tarpaulin are wedged tightly in closely-spaced cleats.

Hatch Beams — A term applied to the portable beams fitted to the coamings for the purpose of supporting the hatch covers.

Hatch, Booby — An access hatchway leading from the weather deck to the quarters. A small companion which is readily removable in one piece. A wooden, hoodlike covering for a hatchway, fitted with a sliding top.

Hatch Carrier — The supports which are attached to the inside of the coaming to take the ends of the hatch beams.

Hatch Cleats — A term applied to the clips attached to the outside of the hatch coaming for the purpose of holding the hatch battens and wedges which fasten the edges of the tarpaulin covers.

Hatch Covers or Hatches — Covers for closing the hatchway, in cargo ships usually made of wood planks in sections that can be handled by the crew. In naval ships, steel hatch covers. The wood cover is made tight against rain and the sea by stretching one or more tarpaulins over them, secured at the edges by the hatch battens.

Hatch Rests — A term applied to the shelf fitted inside and just below the top of the coaming for the purpose of supporting the hatch covers.

Hatchway Trunk — A term applied to the space between a lower deck hatchway and the hatchway or hatchways immediately above it when enclosed by a casing. A trunk may be either watertight or nonwatertight.

Hawse — The hawse hole; also the part of a ship's bow in which the hawse holes for the anchor chains are located.

Hawse Bag — A conical-shaped canvas bag, stuffed with sawdust, oakum, or similar material, and fitted with a lanyard at apex and base, used for closing the hawse pipes around the chain to prevent shipping water through the pipes; also called a "jackass," "hawse plug," or "hawse block."

Hawse Bolster — A timber or metal bossing at the ends of a hawse pipe to ease the cable over the edges and to take the wear.

Hawse Hole — A hole in the bow through which a cable or chain passes.

Hawse Pipes — Tubes leading the anchor chain from the deck on which the windlass is located down and forward through the vessel's bow plating.

Hawser — A large rope or a cable used in warping, towing, and mooring.

Head of a Ship — The fore end of a ship which was formerly fitted up for the accommodation of the crew. A term applied to a toilet on board of a ship. A ship is trimmed by the head when drawing more water forward and less aft than contemplated in her design.

Heel — The convex intersecting point or corner of the web and flange of a bar. The inclination of a ship to one side, caused by wind or wave action or by shifting weights on board.

Heel Piece, Heel Bar — A bar that serves as a connecting piece between two bars which butt end-to-end. The flange of the heel bar is reversed from those of the bars it connects.

Helm — The term applied to the tiller, wheel, or steering gear, and also the rudder.

Hog Frame — A fore-and-aft frame, forming a truss for the main frames of a vessel to prevent bending.

Hogging — A term applied to the distortion of a vessel's hull when her ends drop below their normal position relative to her midship portion.

Hoist — To raise or elevate by manpower or by the employment of mechanical appliances; any device employed for lifting weights.

Hold — The space or compartment between the lowermost deck and the bottom of the ship, or top of the inner bottom if one is fitted. The space below decks allotted for the stowage of cargo.

Hold Beams — Beams in a hold similar to deck beams but having no decking or planking on them.

Home — Close up; snugly in place; as, to drive home a bolt.

Hood — A shelter over a companionway, scuttle, etc. It is generally built of canvas spread over an iron frame. It may also be constructed of light metal plating.

Horsing — Calking planking with oakum with a large maul or beetle and a wedge-shaped iron.

Housing — A term applied to an inclosure partially or wholly worked around fittings or equipment. That portion of the mast below the surface of the weather deck. Applied to topmasts, that portion overlapping the mast below.

Hull — The framework of a vessel, together with all decks, deck houses, and the inside and outside plating or planking, but exclusive of masts, yards, rigging, and all outfit or equipment.

Inboard — Toward the center.

Inboard Profile — A plan representing a longitudinal section through the center of the ship, showing deck heights, transverse bulkheads, assignment of space, machinery, etc., located on the center plane or between the center and the shell on the far side.

Initial Stability — The stability of a vessel in the upright position or at small angles of inclination. It is measured by the metacentric height.

Inner Bottom — A term applied to the inner skin or tank top plating. The plating over the double bottom.

Intercostal — Occurring between ribs, frames, etc. The term is broadly applied, where two members of a ship intersect, to the one that is cut.

Isherwood System — A system of building ships which employs close spaced, relatively light, longitudinal main framing supported on widespread transverse members of comparatively great strength instead of transverse main framing.

Jack Ladder — A ladder with wooden steps and side ropes.

Jack Rod — A term applied to a pipe or rod to which the edges of awnings or weather cloths are secured.

Jackstaff — Flagpole at the bow of a ship.

Jacob's Ladder — A ladder having either fibre or wire rope or chain sides with wood or metal rungs attached at regular intervals. One end is usually fitted with sister hooks or shackles for hooking on.

Joggled — A term applied where a plate or bar is offset in the way of a lapped joint. The object of the joggle is to permit a close fit of the attached member without the use of liners under alternate strakes of plating.

Joint, Butt — A term applied where a connection between two pieces of material is made by bringing their ends or edges together (no overlap) and by welding alone, or by welding, riveting, or bolting each to a strip or strap that overlaps both pieces.

Joint, Lapped — A term applied where a connection between two pieces of material is made by overlapping the end or edge of one over the end or edge of the other and by fastening the same by bolts, rivets, or welding.

Journal — That portion of a shaft or other revolving member which transmits weight directly to and is in immediate contact with the bearing in which it turns.

Jury — A term applied to temporary structures, such as masts, rudders, etc., used in an emergency.

Keel — A center-line strength member running fore and aft along the bottom of a ship and often referred to as the backbone. It is composed either of long bars or timbers scarfed at their ends or by flat plates connected together by riveting or welding.

Keel, Bilge — A fin fitted on the bottom of a ship at the turn of the bilge to reduce rolling. It commonly consists of a plate running fore and aft and attached to the shell plating by angle bars. It materially helps in steadying a ship and does not add much to the resistance to propulsion when properly located.

Keel, Blocks — Heavy timber blocks piled one above the other on which the keel of a vessel is supported when being built, or when she is in a dry dock. They are placed under the keel from bow to stern and a sufficient distance apart to allow working between them.

Keel, Docking — In dry docking, the weight of a ship is usually carried almost entirely on the keel blocks. The keel and keelson provide the means of distributing the pressure on the center line, and docking keels composed of doubling strips of plate or a heavier plate or built-up girders are sometimes fitted on the bottom at a distance from the center line corresponding to the best position for the side keel blocks. The docking keels are fitted in the fore and aft direction, generally parallel or nearly so to the keel.

Keelson, Vertical Center — The lower centerline girder which, in conjunction with a flat plate keel on the bottom and a rider plate on top, forms the principal fore-and-aft strength member in the bottom of a ship. In addition to its importance as a " backbone " or longitudinal strength member, it serves to distribute and equalize the pressure on the transverse frames and bottom of the ship when grounding or docking occurs. In steel ships this keelson usually consists of a vertical plate with two angles running along the top and two along the bottom. The girder, however, may be made up of various combinations of plates and shapes. This member should continue as far forward and aft as possible. Usually called the Vertical Keel.

King Post — A strong vertical post used to support a derrick boom. See Samson Post.

Knee — A block of wood having a natural angular shape or one cut to a bracket shape and used to fasten and strengthen the corners of deck openings and the intersections of timbers, and to connect deck beams to the frames of wood vessels. The term is also applied to the ends of steel deck beams that are split, having one leg turned down and a piece of plate fitted between the split portion, thus forming a bracket or knee.

Knot — A unit of speed, equalling one nautical mile (6,080.20 feet) an hour, as when a ship goes ten nautical miles per hour, her speed is ten knots.

Knuckle — An abrupt change in direction of the plating, frames, keel, deck, or other structure of a vessel.

Ladder — A framework consisting of two parallel sides connected by bars or steps which are spaced at intervals suitable for ascending or descending. On shipboard the term ladder is also applied to staircases and to other contrivances used in ascending or descending to or from a higher or lower level.

Ladder, Accommodation — A staircase suspended over the side of a vessel from a gangway to a point near the water to provide easy access to the deck from a small boat alongside.

Ladder, Companion — A staircase fitted as a means of access from a deck to the quarters.

Ladder, Sea — Rungs secured to the side of a vessel to form a ladder from the weather deck to the water.

Lagging — A term applied to the insulating material that it fitted on the outside of boilers, piping, etc.

Landing, Landing Edge — That portion of the edge or end of a plate over which another plate laps. The covered-up edge.

Lanyard — The present use of this term is generally limited to a piece of rope or line having one end free and the other attached to any object for the purpose of either near or remote control.

Lap — A term applied to the distance that one piece of material is laid over another; the amount of overlap, as in a lapped joint.

Launching — A term applied to the operation of transferring a vessel from the building ways into the water. End launching and side launching methods are employed; the former method is used when the vessel is built at an angle, usually at right angles, to the waterfront and the vessel is launched stern first, while in side launching the vessel is built parallel to the waterfront and launched sidewise. In preparing for an end launching, usually groundways made of heavy timbers are laid with an inclination of about ½″ to ⅝″ to the foot parallel to the center line of the ship one on either side of the keel, and spaced about one-third of the beam of the vessel apart. These groundways run the length of the vessel and for some distance out under the water. On top of the groundways are placed the sliding ways, also heavy timbers, and between these two ways is placed a coating of launching grease. The sliding ways are prevented from sliding on the greased groundways by a trigger or similar device and dog or dagger shores. Cradles are built up to fit the form of the vessel, and between the sliding ways and the cradle, wedges are driven and the weight of the ship thus transferred from the building blocks to the sliding ways. After the building blocks and shores are removed, the trigger is released and gravity causes the vessel to slide down the inclined ways. In some cases hydraulic jacks are set at the upper end of the groundways to exert pressure on the sliding ways to assist in overcoming initial friction along the ways. A similar procedure is followed in the case of side launchings, except that more than two groundways are usually used, depending on the length of the ship, and the inclination of the ways is steeper.

Laying Off — A term applied to the work done by a loftsman in laying off the ship's lines to full size in the mold loft and making templates therefrom. Also known as laying down.

Laying Out — Placing the necessary instructions on plates and shapes for shearing, planing, punching, bending, flanging, beveling, rolling, etc., from templates made in the mold loft or taken from the ship.

Leading Edge — That edge of a propeller blade which cuts the water when the screw is revolving in the ahead direction. That edge of a rudder, diving plane, or strut arm which faces toward the bow of the ship.

Length between Perpendiculars — The length of a ship measured from the forward side of the stem to the aft side of the stern post at the height of the designed water line. In naval practice, the total length on the designed water line.

Length Over All — The length of a ship measured from the foremost point of the stem to the aftermost part of the stern.

Lift a Template — To construct a template to the same size and shape as the part of the ship involved, from either the mold loft lines or from the ship itself, from which laying out of material for fabrication may be performed.

Lifting — Transferring marks and measurements from a drawing, model, etc., to a plate or other object, by templates or other means.

Light, Port — An opening in a ship's side, provided with a glazed lid or cover.

Lightening Hole — A hole cut out of any structural member, as in the web, where very little loss of strength will occur. These holes reduce the weight and in many cases serve as access holes. This condition is particularly true in floor plates and longitudinals in double bottom.

Lighter — A full-bodied, heavily-built craft, usually not self-propelled, used in bringing merchandise or cargo alongside or in transferring same from a vessel.

Limber Chains — Chains passing through the limber holes of a vessel, by which they may be cleaned of dirt.

Limber Hole — A hole or slot in a frame or plate for the purpose of preventing water from collecting. Most frequently found in floor plates just above the frames and near the center line of the ship.

Line — A general term for a rope of any size used for various purposes: small cords such as log line, lead line, or small stuff as marlin, ratline, houseline, etc.

Liner — A piece of metal used for the purpose of filling up a space between a bar and a plate or between two plates; a filler.

Lines — The plans of a ship that show its form. From the lines drawn full size on the mold loft floor are made templates for the various parts of the hull.

List — The deviation of a vessel from the upright position, due to bilging, shifting of cargo, or other cause.

Load Line — The line 18 inches long and 1 inch wide on each side of the ship at the midship section, which indicates the maximum draft to which the ship may be loaded.

Locker — A storage compartment on a ship.

Loftsman — A man who lays off the ship's lines to full size in the mold loft and makes templates therefrom.

Longitudinals — A term applied to the fore-and-aft frames in the bottom of a ship. These frames are usually made up from plates and shapes and are sometimes intercostal and sometimes continuous.

Louver — A small opening to permit the passage of air for the purpose of ventilation, which may be partially or completely closed by the operation of overlapping shutters.

Magazine — Spaces or compartments devoted to the stowage of ammunition. Often specifically applied to compartments for the stowage of powder as a distinction from shell stowage spaces.

Main Body — The hull proper, without the deck houses, etc.

Main Deck — The principal deck of the hull, usually the highest extending from stem to stern and providing strength to the main hull.

Manger — A term applied to the manger-like space immediately forward of the manger plate which is fitted just abaft the hawse pipes to prevent water entering through the pipes from running aft over the deck.

Manhole — A round or oval hole cut in decks, tanks, boilers, etc., for the purpose of providing access.

Manifold — A casting or chest containing several valves. Suction or discharge pipes from or to the various compartments, tanks, and pumps are led to it, making it possible for a pump to draw from or deliver to any one of several compartments.

Margin Plank — A plank forming the boundary or margin of the deck planking.

Margin Plate — The outer boundary of the inner bottom, connecting it to the shell plating at the bilge.

Marine Railway — See dry dock, railway.

Marline Spike — A pointed iron or steel tool used to separate the strands in splicing rope, and as a lever in marling or putting on seizings. The wire rope spike has a flat, rounded end and the manila rope spike has a sharp point.

Marlin — A double-threaded, left-handed tarred cord, about $\frac{1}{8}''$ diameter, made of a good grade of American hemp.

Mast — A long pole of steel or wood, usually circular in section, one or more of which are usually located, in an upright position, on the center line of a ship. Originally intended for carrying sails, they are now used more as supports for the rigging, cargo and boat-handling gear and wireless equipment.

Mast Collar — A piece of wood or a steel shape formed into a ring and fitted around the mast hole in a deck.

Mast Hounds — The upper portion of the mast at which the outrigger or trestle trees are fitted. Also applied to that portion at which the hound band for attaching the shrouds is fitted on masts without outrigger or trestle trees.

Mast Partners — A term applied to wood planking or steel plating worked around a mast hole to give side support to the mast.

Mast Step — A term applied to the foundation on which a mast is erected.

Mast Table — See Boom Table.

Messroom — A space or compartment where members of the crew eat their meals; a dining room.

Midship Beam — A deck beam located at the midpoint between the forward and after perpendiculars. Also applicable to the transverse dimension of the hull at the same point.

Midship Frame — The frame located at the midpoint between the perpendiculars.

Midship Section — The vertical transverse section located at the midpoint between the forward and after perpendiculars. Usually this is the largest section of the ship in area. Also, applied to a drawing showing the contour of the midship frame upon which is depicted all the structural members at that point with information as to their size and longitudinal extent.

Midships — Same as Amidships.

Mitred — Cut to an angle of 45 degrees or two pieces joined to make a right angle.

Mock Up — To build up of wood or light material to scale or full size a portion of the ship before actual fabrication of the steel work. Used to study arrangement, methods of fabrication, workability, etc.

Mold — A pattern or template. Also a shape of metal or wood over or in which an object may be hammered or pressed to fit.

Molded Line — A datum line from which is determined the exact location of the various parts of a ship. It may be horizontal and straight as the molded base line, or curved as a molded deck line or a molded frame line. These lines are determined in the design of a vessel and adhered to throughout the construction. Molded lines are those laid down in the mold loft.

Molded Edge — The edge of a ship's frame which comes in contact with the skin, and is represented in the drawings.

Mold Loft — A space used for laying down the lines of a vessel to actual size and making templates therefrom for laying out the structural work entering into the hull.

Mooring — A term applied to the operation of anchoring a vessel in a harbor, securing her to a mooring buoy, or to a wharf or dock by means of chains or ropes.

Mooring Lines — The chains or ropes used to tie up a ship.

Mooring Pipe — An opening through which mooring lines pass.

Mortise — A hole cut in any material to receive the end or tenon of another piece.

Motorship — A ship driven by some form of internal combustion engine. Not generally applied to small boats driven by gasoline engines which are usually called motorboats.

Mushroom Ventilator — A ventilator whose top is shaped like a mushroom and fitted with baffle plates so as to permit the passage of air and prevent the entrance of rain or spray. Located on or above a weather deck to furnish ventilation to compartments below deck.

Nautical Mile — See knot.

Nibbing Plank — A margin plank that is notched to take the ends of regular deck planks and insure good calking of the joint.

Niggerhead — A small auxiliary drum on a winch. See Gypsy.

Norman Pin — A metal pin fitted in a towing post or bitt for belaying the line.

Nosing — The part of a stair tread which projects beyond the face of the riser.

Oakum — A substance made from soft vegetable fibre such as hemp and jute impregnated with pine tar. It is principally used for calking the planking on wood decks of steel vessels and for calking all the planking on wood ships where watertightness is desired. It is also used for calking around pipes.

Offsets — A term used by draftsmen and loftsmen for the coordinates in ship curves. Also applied to joggles in plates and shapes of structural shapes.

Oiltight — Having the property of resisting the passage of oil.

Old Man — A heavy bar of iron or steel bent in the form of a **Z** used to hold a portable drill. One leg is bolted or clamped to the work to be drilled and the drill head is placed under the other leg which holds down the drill to its work.

On Board — On or in a ship; aboard.

On Deck — On the weather deck, in the open air.

Orlop Deck — The term formerly applied to the lowest deck in a ship; now practically obsolete.

Outboard — Away from the center toward the outside; outside the hull.

Outboard Profile — A plan showing the longitudinal exterior of the starboard side of a vessel, together with all deck erections, stacks, masts, yards, rigging, rails, etc.

Overboard — Outside, over the side of a ship into the water.

Overhang — That portion of a vessel's bow or stern which projects beyond a perpendicular at the waterline.

Overhaul — To repair or put in proper condition for operation; to overtake or close up the distance between one ship and another ship moving in the same direction.

Packing — A general term applied to a yielding material employed to effect a tight joint, also called gasket material.

Pad Eye — A fitting having one or more eyes integral with a plate or base to provide ample means of securing and to distribute the strain over a wide area. The eyes may be either "worked" or "shackle." Also known as lug pads, hoisting pads, etc.

Painter — A length of rope secured at the bow of a small boat for use in towing or for making it fast. Called also a bow-fast.

Palm — The fluke, or more exactly, the flat inner surface of the fluke of an anchor; a sailmaker's protector for the hand, used when sewing canvas; a flat surface at the end of a strut or stanchion for attachment to plating, beams, or other structural member.

Panting — The pulsation in and out of the bow and stern plating as the ship alternately rises and plunges deep into the water.

Panting Beams — The transverse beams that tie the panting frames together.

Panting Frames — The frames in the fore peak, usually extra heavy to withstand the panting action of the shell plating.

Paravane — The paravane is a special type of water kite which, when towed with wire rope from a fitting on the forefoot of a vessel, operates to ride out from the ship's side and deflect mines which are moored in the path of the vessel, and to cut them adrift so that they will rise to the surface where they may be seen and destroyed.

Parcelling — Narrow strips of canvas which are tarred and wound around ropes, following the lay and overlapping in order to shed water. The parcelling is applied after worming, preparatory to serving.

Partners — Similar pieces of steel plate, angles, or wood timbers used to strengthen and support the mast where it passes through a deck, or placed between deck beams under machinery bed plates for added support.

Pawl — A term applied to a short piece of metal so hinged as to engage in teeth or depressions of a revolving mechanism for the purpose of preventing recoil. Fitted to capstans, windlasses, etc. Also called Pall.

Paying — The operation of filling the seams of a wood deck, after the calking had been inserted, with pitch, marine glue, etc. Also applied to the operation of slackening away on a rope or chain.

Peak, Fore and After — The space at the extreme bow or stern of a vessel below the decks.

Peak Tank — Compartments at the extreme fore and aft ends of the ship for any use either as void spaces or as trimming tanks. When used for the latter purpose, water is introduced to change the trim of the vessel.

Peen — To round off or shape an object, smoothing out burrs and rough edges.

Pelican Hook — A type of quick releasing hook used at the lower end of shrouds, on boat grips, and in similar work where fast work may be necessary.

Period of Roll — The time occupied in performing one double oscillation or roll of a vessel as from port to starboard and back to port.

Periscope — An instrument used for observing objects from a point below the object lens. It consists of a tube fitted with an object lens at the top, an eye piece at the bottom and a pair of prisms or mirrors which change the direction of the line of sight. Mounted in such a manner that it may be rotated to cover all or a part of the horizon or sky and fitted with a scale graduated to permit of taking bearings, it is used by submarines to take observations when submerged.

Pillar — A vertical member or column giving support to a deck. Also called a stanchion.

Pilot House — A house designed for navigational purposes. It is usually located forward of the midship section and so constructed as to command an unobstructed view in all directions except directly aft along the center line of the vessel where the smokestack usually interferes.

Pin, Belaying — A small iron or tough wood pin, made with a head, shoulder, and shank. It is fitted in holes in a rail and is used in belaying or making fast the hauling parts of light running gear, signal halyards, etc.

Pintles — A term applied to the pins or bolts which hinge the rudder to the gudgeons on the stern post.

Pitch — A term applied to the distance a propeller will advance during one revolution, the distance between the centers of the teeth of a gear wheel, the axial advance of one convolution of the thread on a screw, the spacing of rivets, etc. Also applied to pine tar, asphalt and coal pitch used in paying seams of a deck.

Pitching — The alternate rising and falling motion of a vessel's bow in a nearly vertical plane as she meets the crests and troughs of the waves.

Pitting — The localized corrosion of iron and steel in spots, usually caused by irregularities in surface finish, and resulting in small indentations or pits.

Pivoting Point — That point during the progress of a launching at which the moment of buoyancy about the fore poppet equals the moment of the vessel's weight. At this point the stern begins to lift and the vessel pivots about the fore poppet. Also the point about which the ship appears to rotate when making a turn.

Plan — A drawing prepared for use in building a ship.

Planking — Wood covering for decks, etc. The shell of wood boats.

Platform — A partial deck.

Plating, Shell — The plating forming the outer skin of a vessel. In addition to constituting a watertight envelope to the hull, it contributes largely to the strength of the vessel.

Plimsoll Mark — A mark painted on the sides of a vessel designating the depth to which the vessel may, under the maritime laws, be loaded in different bodies of water during various seasons of the year.

Pontoon — A scow-shaped boat used in connection with engineering and military operations such as transporting men and equipment, bridge construction, supports for temporary bridges, salvage work, etc. Also applied to cylindrical air and watertight tanks or floats used in salvage operations.

Poop — The structure or raised deck at the after end of a vessel.

Poppets — Those pieces of timber which are fixed perpendicularly between the ship's bottom and the bilgeways at the foremost and aftermost parts of the ship, to support it when being launched. They are parts of the cradle.

Port — The left-hand side of a ship when looking from aft forward. Also an opening.

Port, Air — See air port.

Port Gangway — An opening in the side plating, planking, or bulwark for the purpose of providing access through which people may board or leave the ship, or through which cargo may be handled.

Porthole — See air port.

Proof Strain — The test load applied to anchors, chains, or other parts, fittings, or structure to demonstrate proper design and construction and satisfactory material.

Proof Strength — The proof strength of a material, part, or structure is the strength which it has been proved by test to possess.

Propeller — A propulsive device consisting of a boss or hub carrying radial blades, from two to four in number. The rear or driving faces of the blades form portions of an approximately helical surface, the axis of which is the center line of the propeller shaft.

Propeller Aperture — The opening in the stern frame of single-screw ships for the propeller.

Propeller Arch — The arched section of the stern frame above the propeller.

Propeller Guard — A framework fitted somewhat below the deck line on narrow, high-speed vessels with large screws, so designed as to overhang and thus protect, the tips of the propeller blades.

Propeller Thrust — The effort delivered by a propeller in pushing a vessel ahead.

Prow — An archaic term for the bow of a ship.

Puddening, Pudding — Pads constructed of old rope, canvas, oakum, etc., sometimes leather covered, in any desired shape and size and used to prevent chafing of boats, rigging, etc., and on the stem of a boat to lessen the force of a shock.

Punch — A machine for punching holes in plates and shapes.

Punch, Prick — A small punch used to transfer the holes from the template to the plate. Also called a " center punch."

Purchase — Any mechanical advantage which increases the power applied.

Quarter — The upper part of a vessel's sides near the stern; also portions of the vessel's sides about midway between the stem and midlength and between midlength and the stern. The part of a yard just outside the slings.

Quarters — Living spaces for passengers or personnel. It includes staterooms, dining salons, mess rooms, lounging places, passages connected with the foregoing, etc.; individual stations for personnel for fire or boat drill, etc.

Quay — An artificial wall or bank, usually of stone, made toward the sea or at the side of a harbor or river for convenience in loading and unloading vessels.

Rabbet — A groove, depression, or offset in a member into which the end or edge of another member is fitted, generally so that the two surfaces are flush. A rabbet in the stem or keel would take the ends or edges of the planking or shell plating.

Racking — Deformation of the section of a ship, generally applied to a transverse section, so that one set of diagonals in the plane of action is shortened while those at right angles thereto are lengthened.

Radio Room — A room, usually sound-proofed, used for sending and receiving radio messages.

Raft, Life — A frame work fitted with air chambers to support a number of people in case of accidents. Carried on deck and light enough to be handled without mechanical means.

Rail — The upper edge of the bulwarks. Also applied to the tiers of guard rods running between the top rail and the deck where bulwarks are not fitted.

Rake — A term applied to the fore and aft inclination from the vertical of a mast, smokestack, stempost, etc.

Range, Galley — The stove, situated in the galley, which is used to cook the food. The heat may be generated by coal, fuel oil, or electricity.

Rat Guard — A dished, circular piece of metal made in two parts and fitted closely on hawsers and lines to prevent rats boarding or leaving a ship while at a dock or wharf. The concave side is placed toward the shore to prevent boarding and the guard is reversed to prevent rats leaving the ship.

Ratlines — Short lengths of ratline stuff secured to the shrouds parallel to the waterline and serving as ladder rungs for the crew to ascend or descend.

Reaming — Enlarging a hole by the means of revolving in it a cylindrical slightly tapered tool with cutting edges running along its sides.

Reduction Gear — An arrangement of shafts and gears such that the number of revolutions of the output shaft is less than of the input shaft — generally used between a motor or a steam turbine shaft and the propeller shaft.

Reeving — The act of passing the end of a rope or chain through an opening, as passing a rope through a block.

Reverse Frame — An angle bar or other shape riveted to the inner edge of a transverse frame to reinforce it.

Ribband — A fore-and-aft wooden strip or heavy batten used to support the transverse frames temporarily after erection.

Ribs — A term applied to the transverse frames of a boat.

Ride — To float in a buoyant manner while being towed or lying at anchor.

Rider Plate — A continuous flat plate attached to the top of a center line vertical keel in a horizontal position. Its under side is attached to the floors, and when an inner bottom is fitted, it forms the center strake.

Rigging — A term used collectively for all the ropes and chains employed to support the masts, yards, and booms of a vessel, and to operate the movable parts of same.

Rise of Bottom — See deadrise.

Riser — The upright board of a stair. A pipe extending vertically and having side branches.

Rivet — A metal pin used for connecting two or more pieces of material by inserting it into holes punched or drilled in the pieces and upsetting one or both ends. The end that bears a finished shape is called the head and the end upon which some operation is performed after its insertion is called the point. Small rivets are " driven cold," i.e., without heating, and large ones are heated so that points may be formed by hammering.

Riveting — The art of fastening two pieces of material together by means of rivets.

Riveting, Chain — A term applied to an arrangement of the rivets in adjoining rows where the center of the rivets are opposite each other and on a line perpendicular to the joint.

Riveting, Staggered or Zig-Zag — A term applied to an arrangement of the rivets in adjoining rows where the rivets in alternate rows are one-half the pitch or spacing ahead of those in the other rows.

Rivets, Line of — A term applied to a continuous line of rivets whose centers fall on a line perpendicular to the joint.

Rivets, Row of — A term applied to a continuous row of rivets whose centers fall on a line parallel to the joint. Joints made by one row of rivets are known as single-riveted joints; by two rows, as double-riveted joints; by three rows, as treble-riveted joints; by four rows, as quadruple-riveted joints; etc.

Roll — Motion of the ship from side to side, alternately raising and lowering each side of the deck.

Rolling Chocks — Same as keel, bilge.

Rope — The product resulting from twisting a fibrous material, such as manila, hemp, flax, cotton, coir, etc., into yarns or threads which in turn are twisted into strands and several of these are laid up together. Fiber rope is designated as to size by its circumference. Wire rope is made of iron, steel, or bronze wires, with or without a fibre core or heart, twisted like yarns to form strands which are laid up to form the rope. Wire rope is designated as to size both by its diameter and by its circumference.

Rope Lay — The direction in which a rope is twisted up.

Rope, Ridge — A rope running through the eyes at the heads of the awning stanchions to which the edge of an awning is hauled out and stopped. The term center ridge rope is applied to the rope supporting the center of an awning.

Rope Worming — Filling in the contlines of a rope with marline. The marline should run with the lay of the rope.

Rubbing Strip — A plate riveted to the bottom of the keel to afford protection in docking and grounding. A strip fastened to the face of a fender or to the shell plating where contact is likely to occur.

Rudder — A device used in steering or maneuvering a vessel. The most common type consists of a flat slab of metal or wood, hinged at the forward end to the stern or rudder post. When made of metal, it may be built up from plates, shapes, and castings, with or without wood filling, or it may be a casting. The rudder is attached to a vertical shaft called the rudder stock, by which it is turned from side to side.

Rudder, Balanced — A rudder having the leading edge of a whole or a part of its area forward of the center line of the rudder stock thus reducing the torque required to turn the rudder.

Rudder Bands — The bands that are placed on each side of a rudder to help brace it and tie it into the pintles.

Rudder Chains — The chains whereby a rudder is sometimes fastened to the stern. They are shackled to the rudder by bolts just above the water line, and hang slack enough to permit free motion of the rudder. They are used as a precaution against losing a rudder at sea. These chains are also called " rudder pendants."

Rudder Frame — A term applied to a vertical main piece and the arms that project from it which form the frame of the rudder. It may be a casting, a forging, or a weldment.

Rudder Pintles — See pintles.

Rudder Post — See Stern post.

Rudder Stock — A vertical shaft having a rudder attached to its lower end and having a yoke, quadrant, or tiller fitted to its upper portion by which it may be turned.

Rudder Stops — Fittings attached to the ship structure or to shoulders on the rudder post to limit the swing of the rudder.

Rudder Trunk — A watertight casing fitted around a rudder stock between the counter shell plating and a platform or deck, usually fitted with a stuffing box at the upper end.

Rudder, Underhung — A rudder that is not hinged to or stepped on the stern post but is supported entirely by the rudder stock and the rudder stock bearings.

Run — The underwater portion of a vessel aft of the midship section or flat of the bottom. That portion of the after hull that tapers to the stern post.

Running Rigging — Ropes which are hauled upon at times in order to handle and adjust sails, yards, cargo, etc., as distinguished from standing rigging which is fixed in place.

Sagging — The deformation or yielding caused when the middle portion of a structure or ship settles or sinks below its designed or accustomed position. The reverse of hogging.

Sail Tracks — A device fitted on the after side of a mast in which slides, secured to the forward edge of a fore-and-aft sail, travel up and down the mast as the sail is hoisted or lowered; used in lieu of mast hoops.

Samson Post — A strong vertical post that supports cargo booms. See king post.

Scantlings — A term applied to the dimensions of the frames, girders, plating, etc., that enter into a ship's structure.

Scarf — An end connection made between two pieces of material by tapering them so that they will fit together in a joint of the same breadth and depth as the pieces.

Screen Bulkhead — A light bulkhead used as a shelter from an excess of heat, cold, or light, or to conceal something from sight.

Scrieve Board — A large board made of soft, clear, planed lumber, sometimes a section of the mold loft floor, on which a full-sized body plan of a ship is drawn. The lines were formerly cut in by the use of a scriving knife, which made a small U-shaped groove, to prevent them from being obliterated. Pencil lines have taken the place of cutting to a large extent. It is used in making templates of frames, beams, floors, etc., and in taking off dimensions. It is sanded smooth after it has served its purpose.

Scupper Pipe — A pipe conducting the water from a deck scupper to a position where it is discharged overboard.

Scuppers — Drains from decks to carry off accumulations of rain water or sea water. The scuppers are placed in the gutters or waterways on open decks and in corners of enclosed decks, and connect to pipes leading overboard.

Scuttle — A small opening, usually circular in shape and generally fitted in decks to provide access. Often termed escape scuttles, and when fitted with means whereby the covers can be removed quickly to permit exit are called quick acting scuttles.

Scuttle Butt — The designation for a container of the supply of drinking water for the use of the crew.

Sea Chest — An arrangement for supplying sea water to condensers and pumps, and for discharging waste water from the ship to the sea. It is a cast fitting or a built-up structure located below the waterline of the vessel and having means for attachment of the piping. Suction sea chests are fitted with strainers or gratings.

Sea Cock, Sea Connection — A sea valve secured to the plating of the vessel below the waterline for use in flooding tanks, magazines, etc., to supply water to pumps, and for similar purposes.

Seam — A term applied to an edge joint.

Seamstrap — A term applied to a strip of plate serving as a connecting strap between the butted edges of plating. Strap connections at the ends are called buttstraps.

Set Iron — A bar of soft iron used on the bending slab as a form to which to bend frames into the desired shapes.

Serve — To wrap any small stuff tightly around a rope which has been previously wormed and parcelled. Very small ropes are not wormed.

Set Up — To tighten the nut on a bolt or stud; to bring the shrouds of a mast to a uniform and proper tension by adjusting the rigging screws or the lanyards through the dead eyes.

Shackle Bolt — A pin or bolt that passes through both eyes of a shackle and completes the link. The bolt may be secured by a pin through each end, or a pin through one end and through the eye, or by having one end and one eye threaded, or one end headed and a pin through the other.

Shaft, Shafting — The cylindrical forging, solid or tubular, used for transmission of rotary motion from the source of power, the engine, to the propellers.

Shaft Angle — The angle between the center line of the shaft and the center line of the ship is the horizontal angle and the angle between the center line of the shaft and either the base line or the designed waterline is the vertical angle.

Shaft Alley — A watertight passage, housing the propeller shafting from the engine room to the bulkhead at which the stern tube commences. It provides access to the shafting and its bearings and also prevents any damage to the same from the cargo in the spaces through which it passes.

Shaft Coupling.— The means of joining together two sections of a shaft, usually by means of bolts through flanges on the ends of the sections of the shafts.

Shaft Pipe — See Stern Tube.

Shaft Strut — A term applied to a bracket supporting the outboard after end of the propeller shaft and the propeller in twin or multiple-screwed vessels having propeller shafts fitted off the center line. It usually consists of a hub or boss, fitted with a bushing, to form a bearing for the shaft, and two streamlined arms connecting it to the side of the ship. The inboard ends of the arms are fitted with palms for attachment to the shell or to interior framing.

Shape — A bar of constant cross section such as a channel, T-bar, angle bar, etc., either rolled or extruded.

Shaping — Cutting, bending, and forming a structural member.

Shears — Large machines for cutting plates or shapes.

Shear Legs — A rig for handling heavy weights, consisting of an A-frame of timber or steel with the top overhanging the base, having the lower ends fixed or pivoted and the top ends held either by fixed stays or by topping lifts which permit change of slope of the legs. Tackles are secured at the top of the frame through which the hoisting rope or cable is run. Sometimes called sheers.

Sheathing — A term applied to the wood planking fitted over a steel deck, to the planking fitted over the underwater portion of a steel hull, and to the copper or alloy sheets with which the bottom of a wood ship, or a steel ship sheathed with wood, is covered.

Sheave — A wood or metal disk, having a groove around its cylindrical surface to permit a rope or chain to run over it without slipping off and a bushing for bearing on the pin or bolt on which it revolves.

Sheave Holes — A term applied to apertures in masts, booms, and spars in which sheaves are installed.

Sheer — The longitudinal curve of a vessel's rails, decks, etc., the usual reference being to the ship's side; however, in the case of a deck having a camber, its center line may also have a sheer. The amount by which the height of the weather deck at the after or forward perpendicular exceeds that at its lowest point.

Sheer Plan — A side elevation of the ship's form.

Sheer Strake — The topmost continuous strake of the shell plating, usually made thicker than the side plating below it.

Shelf — A wood ship term applied to the fore and aft timber that is fastened to the frames to form a support for the ends of the beams. See clamp.

Shell Expansion — A plan showing the shapes, sizes, and weights of all plates comprising the shell plating, and details of their connections.

Shell Landings — Points marked on the frames to show where the edges of the shell plates are to be located.

Shelter Deck — A term applied to a deck fitted from stem to stern on a relatively light superstructure.

Shift of Butts — An arrangement of butts in longitudinal or transverse structural members whereby the butts of adjacent members are located a specified distance from one another, measured in the line of the members.

Shim — A piece of wood or iron let into a slack place in a frame, plank, or plate to fill out a fair surface or line. Also applied to thin layers of metal or other material used to true up a bed plate or machine or inserted in bearings to permit adjustment after wear of the bearing.

Shipshape — A nautical term used to signify that the whole vessel, or the portion under discussion, is neat in appearance and in good order.

Shores — Pieces of timber placed in a vertical or inclined position to support some part of a ship, or the ship itself, during construction or while in dry dock.

Shore, Spur or Side — A piece of timber placed in a nearby horizontal position with one end against the side of the ship and the other against the side of a dry dock or dock to keep the vessel at a desired distance from the face of the dock.

Shroud — A principal member of the standing rigging, consisting of hemp or wire ropes which extend from or near a masthead to the vessel's side, or to the rim of a top, to afford lateral support for the mast.

Sick Bay — A name applied to the space on board a ship where members of the crew and passengers are given medical service and includes the dispensary, operating room, wards, etc.

Side Plating — A term applied to the plating above the bilge in the main body of a vessel. Also to the sides of deck houses, or to the vertical sides of enclosed plated structures.

Siding of a Frame — The fore and aft dimension of a frame.

Sister Hook — A hook made in halves and set on eyes facing each other in such a manner that it may be made to function as a link.

Skeg — The extreme after part of the keel of a vessel, the portion that supports the rudder post and stern post.

Skin — The term usually applied to the outside planking or plating forming the watertight envelope over the framework. It is also applied to the inner bottom plating when it is called an inner skin.

Skylight — An erection built on a deck, having glass lights in its top and fitted over an opening in the deck for the purpose of admitting light and air to a compartment below.

Slack — The opposite of taut; not fully extended as applied to a rope; to "slack away" means to pay out a rope or cable by carefully releasing the tension while still retaining control; to "slack off" means to ease up, or lessen the degree of tautness.

Sleepers — Timbers placed upon the ground or on top of piling to support the cribbing, keel, and bilge blocks.

Sleeve — A casing, usually of brass, fitted over line or other shafting for protection against wear or corrosion, or as a bearing surface.

Sliding Ways — See launching.

Sling — A length of chain or rope employed in handling weights with a crane or davit. The rods, chains, or ropes attached near the bow and stern of a small boat into which the davit or crane tackle is hooked. The chain or rope supporting the yard at the masthead.

Slip — The difference between the pitch of a propeller, or the mean circumference of a paddle wheel, and the advance of the ship through the water corresponding to one revolution. An inclined launching berth. A space between two piers for berthing a vessel.

Slipway — The space in a shipyard where a foundation for launching ways and keel blocks exists and which is occupied by a ship while under construction.

Sluice — An opening in the lower part of a bulkhead fitted with a sliding watertight gate, or small door, having an operating rod extending to the upper deck or decks. It is used to permit liquid in one compartment to flow into the adjoining compartment.

Smokestack — A metal chimney or passage through which the smoke and gases are led from the uptakes to the open air.

Snubbing — Drawing in the waterlines and diagonals of a vessel abruptly at their ends. The checking of a vessel's headway by means of an anchor and a short cable. The checking of a line or cable from running out by taking a turn about a cleat, bitts, or similar fitting.

Soft Patch — A temporary plate put on over a break or hole and secured with tap bolts. It is made watertight with a gasket such as canvas saturated in red lead.

Sole Piece — The piece of steel or wood by which the sliding ways are bolted to the ground ways at the upper end. See Launching.

Sole Plate — A plate fitted to the top of a foundation to which the base of a machine is bolted. Also a small plate fitted at the end of a stanchion.

Sounding Pipe — A vertical pipe in an oil or water tank, used to guide a sounding device when measuring the depth of liquid in the tank. Also called a Sounding Tube.

Span — The distance between any two similar members, as the span of the frames. The length of a member between its supports, as the span of a girder. A rope whose ends are both made fast some distance apart, the bight having attached to it a topping lift, tackle, etc. A line connecting two davit heads so that when one davit is turned the other follows.

Spanner — A form of open-head wrench for use with special fittings whose character is such as to preclude the use of the ordinary type of wrench.

Spar — A term applied to a pole serving as a mast, boom, gaff, yard, bowsprit, etc. Spars are made of both steel and wood.

Spectacle Frame — A single casting containing the bearings for and furnishing support for the ends of the propeller shafts in a twin screw vessel. The shell plating is worked outboard so as to enclose the shafts and is attached at the after end to the spectacle frame. Used in place of shaft struts.

Spike — A stout metal pin headed on one end and pointed at the other, made of either square or round bar, and used for securing heavy planks and timbers together.

Splice — A method of uniting the ends of two ropes by first unlaying the strands, then interweaving them so as to form a continuous rope.

Spot Face — To finish off the surface around a bolt hole in a plane normal to the axis of the hole to provide a neat seat for the nut or washer.

Spring — The deviation from a straight line or the amount of curvature of a sheer line, deck line, beam camber, etc., an elastic body or device which recovers its original shape when released after being distorted.

Squatting — The increase in draft assumed by a vessel when running over that existing when she is at rest.

Stability — The tendency which a vessel has to return to the upright position after the removal of an external force which inclined her away from that position. To have stability, a vessel must be in a state of stable equilibrium.

Stability, Range of — The number of degrees through which a vessel rolls or lists before losing stability.

Stage — A floor or platform of planks supporting workmen during the construction or the cleaning and painting of a vessel, located either inside or outside the vessel.

Staging — Upright supports fastened together with horizontal and diagonal braces forming supports for planks which form a working platform or stage.

Stagger — To zigzag rivet holes in adjacent rows.

Stanchions — Short columns or supports for decks, hand rails, etc. Stanchions are made of pipe, steel shapes, or rods, according to the location and purpose they serve.

Standing Rigging — Rigging that is permanently secured and that is not hauled upon, as shrouds, stays, etc.

Stapling — Plates or angles fitted closely around or against continuous members passing through a watertight or oiltight member and calked or welded to maintain the water or oil tightness of the structure.

Starboard — The right-hand side of the ship when looking from aft forward. Opposite to port.

Stateroom — A private room or cabin for the accommodation of passengers or officers.

Stays — The ropes, whether hemp or wire, that support the lower masts, topmasts, top-gallant masts, etc., in a fore and aft direction.

Stealer — A strake of shell plating that does not extend completely to the bow or stern.

Steering Gear — A term applied to the steering wheels, leads, steering engine, and fittings by which the rudder is turned.

Stem — The bow frame forming the apex of the intersection of the forward sides of a ship. It is rigidly connected at its lower end to the keel.

Stern — The after end of a vessel; the farthest distant part from the bow.

Stern Chock — A round or oval casting, or frame, inserted in the bulwark plating at the stern of the vessel through which the mooring hawser or warping lines are passed. Also called Stern Pipe.

Stern Frame — A large casting or forging attached to the after end of the keel to form the ship's stern. Includes rudder post, propeller post, and aperture for the propeller in single-screw vessels.

Stern Post — The main vertical post in the stern frame upon which the rudder is hung. Also called the Rudder Post.

Stern Tube — The bearing supporting the propeller shaft where it emerges from the ship. It consists of a hollow cast-iron or steel cylinder fitted with brass bushings, which in turn are lined with lignum vitae, white metal, etc., bearing surfaces upon which the propeller shaft, enclosed in a sleeve, rotates.

Stiff, Stiffness — The tendency of a vessel to remain in the upright position, or a measure of the rapidity with which she returns to that position after having been inclined from it by an external force.

Stiffener — An angle bar, T-bar, channel, etc., used to stiffen plating of a bulkhead, etc.

Stocks — A general term applied to the keel blocks, bilge blocks, and timbers upon which a vessel is constructed.

Stop Water — A term applied to canvas and red lead, or other suitable material, placed between the faying surfaces of plates and shapes to stop the passage of oil or water. Also applied to a wooden plug driven through a scarph joint between timbers to insure water tightness.

Strain — The measure of the alteration of form which a solid body undergoes when under the influence of a given stress.

Strand — An element of a rope, consisting, in a fiber rope, of a number of rope yarns twisted together and, in a wire rope, of a primary assemblage of wires.

Strake — A term applied to a continuous row of plates. The strakes of shell plating are usually lettered, starting with A at the bottom row or garboard strake.

Strake, Bilge — A term applied to a strake of outside plating running in the way of the bilge.

Strake, Bottom — Any strake of plating on the bottom of a ship that lies between the keel and the bilge strakes.

Strength Member — Any plate or shape which contributes to the strength of the vessel. Some members may be strength members when considering longitudinal strength but not when considering transverse strength and vice versa.

Stress — The intensity of the force which tends to alter the form of a solid body; also the equal and opposite resistance offered by the body to a change of form.

Stringer — A term applied to a fore-and-aft girder running along the side of a ship and also to the outboard strake of plating on any deck. The side pieces of a ladder or staircase into which the treads and risers are fastened.

Stringer Plates — A term applied to the outboard plates on any deck, or to the plates attached to the top flanges of a tier of beams at the side of a vessel.

Strut — A heavy arm or brace.

Studding — The vertical timbers or framing of a wooden deck house, fitted between the sill and the plate.

Stuffing Box — A fitting designed to permit the free passage or revolution of a rod or a pipe while controlling or preventing the passage by it of water, steam, etc.

Superstructure — A structure built above the uppermost complete deck; a pilot house, bridge, galley house, etc.

Swallow — A term applied to the oval or round opening in a chock or mooring ring. See Block.

Swash Bulkheads — Longitudinal or transverse nontight bulkheads fitted in a tank to decrease the swashing action of the liquid contents. Their function is greatest when the tanks are partially filled. Without them the unrestricted action of the liquid against the sides of the tank would be severe. A plate serving this purpose is called a swash plate.

Swivel — A special link constructed in two parts which revolve in each other, used to prevent fouling due to turns or twists in chain, etc.

Tackle — Any combination of ropes and blocks that multiplies power. Also applied to a single whip which does not multiply power but simply changes direction.

Taff Rail — The rail around the top of the bulwark or rail stanchions on the after end of the weather deck, be it upper, main, raised, quarter, or poop.

Tail Shaft — The aft section of the shaft which receives the propeller.

Tanks — Compartments for liquids or gases. They may be formed by the ship's structure as double bottom tanks, peak tanks, deep tanks, etc., or may be independent of the ship's structure and installed on special supports.

Tank Top — The plating laid on the bottom floors of a ship, which forms the top side of the tank sections or double bottom; the inner bottom.

Tarpaulin — A canvas covering.

Taut — The condition of a rope, wire, or chain when under sufficient tension to cause it to assume a straight line, or to prevent sagging to any appreciable amount.

Tee Bar — A rolled or extruded structural shape having a cross section shaped like the letter T.

Telegraph — An apparatus, either electrical or mechanical, for transmitting orders, as from a ship's bridge to the engine room, steering gear room, or elsewhere about the ship.

Telemotor — A device for operating the valves of the steering engine from the pilot house by means of either fluid pressure or electricity.

Template — A mold or pattern made to the exact size of a piece of work that is to be laid out or formed, and on which such information as the position of rivet holes, size of laps, etc., is indicated.

Test Head — The head or height of a column of water which will give a prescribed pressure on the vertical or horizontal sides of a compartment or tank in order to test its tightness or strength or both.

Tie-Plate — A single fore-and-aft or diagonal course of plating attached to deck beams under a wood deck to give extra strength.

Tiller — An arm attached to the rudder head for operating the rudder.

Toe — The edge of a flange on a bar.

Toggle Pin — A pin having a shoulder and an eye worked on one end, called the head, and whose other end, called the point, has its extremity hinged in an unbalanced manner so that after being placed through a hole it forms a T-shaped locking device to keep the pin from working out or being withdrawn without first bringing the hinged portion into line with the shaft of the pin.

Tonnage, Gross — The entire internal cubic capacity of a vessel expressed in " tons " taken at 100 cubic feet each. The peculiarities of design and construction of the various types of vessels and their parts necessitate certain explanatory rulings in connection with this term.

Tonnage, Net — The internal cubic capacity of a vessel which remains after the capacities of certain specified non-revenue spaces have been deducted from the gross tonnage. Tonnage should not be confused with displacement.

Topping Lift — A rope or chain extending from the head of a boom or gaff to a mast, or to the vessel's structure, for the purpose of supporting the weight of the boom or gaff and its loads, and permitting the gaff or boom to be raised or lowered.

Topside — That portion of the side of the hull which is above the designed waterline. On or above the weather deck.

Transom — A seat or couch built at the side of a stateroom or cabin, having lockers (transom lockers) or drawers underneath.

Transom, Transom Board — The board forming the stern of a square-ended row boat or small yacht.

Transom Frame — The last transverse frame of a ship's structure. The cant frames, usually normal to the round of the stern, connect to it.

Transverse — At right angles to the ship's fore-and-after center line.

Transverse Frames — Vertical athwartship members forming the ribs.

Treads — The steps or horizontal portions of a ladder or staircase upon which the foot is placed.

Treenails — Wooden pins employed instead of nails or spikes to secure the planking of a wooden vessel to the frames.

Trim — The difference between the drafts forward and aft. The angle of trim is the angle between the plane of flotation and the mean water-line plane. A vessel " trims by the head " or " trims by the stern " when the vessel inclines forward or aft so that her plane of flotation is not coincident with her mean water-line plane. See Drag.

Tripping Brackets — Flat bars or plates placed at various points on deck girders, stiffeners, or beams as a reinforcement to prevent their free flanges from turning.

Trunk — A vertical or inclined shaft formed by bulkheads or casings, extending one or more deck heights, around openings in the decks, through which access can be obtained, cargo, stores, etc., handled, or ventilation provided without disturbing or interfering with the contents or arrangements of the adjoining spaces.

Tumble Home — The decreasing of a vessel's beam above the water-line as it approaches the rail. Opposite of flare.

Turnbuckles — Used to pull objects together. A link into whose opposite ends two threaded bars, one left-handed, the other right-handed, are inserted.

Umbrella — A metal shield in the form of a frustum of a cone, secured to the outer casing of the smokestack over the air casing to keep out the weather.

Upper Deck — Generally applied to the uppermost continuous weather deck.

Upper Works — Superstructures or deck erections located on or above the weather deck. Sometimes applied to the entire structure above the waterline.

Unship — To remove anything from its accustomed or stowage place; to take apart.

Uptake — A metal conduit connecting the boiler combustion space with the base of the smokestack. It conveys the smoke and hot gases from the boiler to the stack and is usually made with double walls, with an air space between to prevent radiation of heat into adjacent spaces.

Vang — Ropes secured to the outer end of a cargo boom, the lower ends being fastened to tackles secured to the deck, used for guiding and swinging and for holding the boom in a desired position. Also applied to ropes secured to the after end of a gaff and led to each side of the vessel to steady the gaff when the sail is not set.

Ventilation — The process of providing fresh air to the various spaces and removing foul or heated air, gases, etc., from them. This may be accomplished by natural draft or by mechanical means.

Ventilators, Bell-Mouthed or Cowl — Terminals on open decks in the form of a 90-degree elbow with enlarged or bell-shaped openings, so formed as to obtain an increase of air supply when facing the wind and to increase the velocity of air down the ventilation pipe.

Visor — A small inclined awning running around the pilot house over the windows or air ports to exclude the glare of the sun or to prevent rain or spray from coming in the openings when the glazed frames are dropped or opened. They may be of canvas or metal.

Warp — A light hawser or tow rope; to move a vessel by means of lines or warps secured to some fixed object.

Wash Plates — Plates fitted fore and aft between floors to check the rush of bilge water from side to side when the ship is rolling.

Waterline — A term used to describe a line drawn parallel to the molded base line and at a certain height above it, as the 10-foot waterline. It represents a plane parallel to the surface of the water when the vessel is floating on an even keel, i.e., without trim. In the body plan and the sheer plan it is a straight line, but in the plan view of the lines it shows the contour of the hull line at the given distance above the base line. Used also to describe the line of intersection of the surface of the water with the hull of the ship at any draft and any condition of trim.

Watershed — A fitting on the outside of the shell of a ship over an air port, a door, or a window to prevent water which runs down the ship's side from entering the opening. One over an air port is also called a Brow or Port Flange.

Watertight Compartment — A space or compartment within a ship having its top, bottom, and sides constructed in such a manner as to prevent the leakage of water into or from the space unless the compartment is ruptured.

Waterway — A narrow channel along the edge of the deck for the collection and disposal of water occurring on the deck.

Waterway Bar — An angle or flat bar attached to a deck stringer plate forming the inboard boundary of a waterway and serving as an abutment for the wood deck planking.

Ways — See launching.

Weather Deck — A term applied to the upper, awning, shade, or shelter deck, or to the uppermost continuous deck, exclusive of forecastle, bridge, or poop, that is exposed to the weather.

Web — The vertical portion of a beam; the athwartship portion of a frame; the portion of a girder between the flanges.

Web Frame — A built-up frame to provide extra strength consisting of a web plate with flanges on its edges, placed several frame spaces apart, with the smaller, regular frames in between.

Wedges — Wood or metal pieces shaped in the form a sharp V, used for driving up or for separating work. They are used in launching to raise the vessel from the keel blocks and thus transfer the load to the cradle and the sliding ways.

Whip — A term loosely applied to any tackle used for hoisting light weights and serves to designate the use to which a tackle is put rather than to the method of reeving the tackle.

Wildcat — A special type of drum whose faces are so formed as to fit the links of a chain of given size.

Winch — A hoisting or pulling machine fitted with a horizontal single or double drum. A small drum is generally fitted on one or both ends of the shaft supporting the hoisting drum. These small drums are called gypsies, niggerheads, or winch heads.

The hoisting drums either are fitted with a friction brake or are directly keyed to the shaft. The driving power is usually steam or electricity, but hand power is also used. A winch is used principally for the purpose of handling, hoisting, and lowering cargo from a dock or lighter to the hold of a ship and vice versa.

Windlass — An apparatus in which horizontal or vertical drums or gypsies and wildcats are operated by means of a steam engine or motor for the purpose of handling heavy anchor chains, hawsers, etc.

Wind Scoop — A scoop-shaped fitting of sheet metal which is placed in an open air port with the open side forward for the purpose of catching air and forcing it into a cabin, stateroom, or compartment.

Wing, Winging — A term used to designate structural members, compartments, sails, and objects on a ship that are located a considerable distance off the fore-and-aft center line.

Worming — Filling the contlines of a rope with tarred small stuff preparatory to serving, to give the rope a smoother surface and to aid in excluding moisture from the interior of the rope.

Wrinkling — Slight corrugations or ridges and furrows in a flat plate due to the action of compressive or shear forces.

Yard — A term applied to a spar attached at its middle portion to a mast and running athwartship across a vessel as a support for a square sail, signal halyards, lights, etc.

Yardarm — A term applied to the outer end of a yard.

Yoke — A frame or bar having its center portion bored and keyed or otherwise constructed for attachment to the rudder stock Steering leads to the steering gear are connected to each end of the yoke for the purpose of turning the rudder. Yoke lanyards are lines extending from the ends of the yoke to the stern sheets of a small boat for use in steering.

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