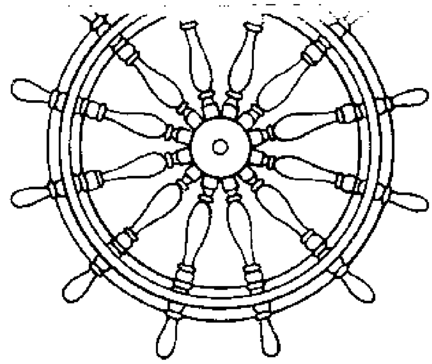

NAUTICAL EDUCATION FOR OFFSHORE EXTRACTIVE INDUSTRIES

TRANSPORTATION

G.H. HOFFMANN WITH FRED TOWNSEND AND WARREN NORVILLE

SEA GRANT PUBLICATION NO. LSU-B-77-00

CENTER FOR WETLAND RESOURCES • LOUISIANA STATE UNIVERSITY • BATON ROUGE, LOUISIANA 7080

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Sea Grant Publication No.
LSU-B-77-001

September 1977

This work is a result of research sponsored jointly by the Terrebonne Parish School Board and the Louisiana Sea Grant Program, a part of the National Sea Grant Program maintained by the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce.

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ACKNOWLEDGMENTS

The nature of this study required assistance and information from a large number of individuals and businesses, for which we are extremely grateful. Among those who contributed written material to the text were:

William Hamilton of Friede and Goldman, Naval Architects (naval architecture section).

V. J. Gianelloni, attorney and past director of the Lafourche Parish Nautical Science Program (rules and regulations section).

Capt. Cliff Barnett of Smit Lloyd Co. (towing section).

Gerald J. Bergeron, CPO, U.S. Navy (Ret.) (seamanship section).

Other consultants we want to acknowledge are:

Capt. Rudy Vorenkamp, executive vice-president, Acadian Marine Service (classification societies section).

Bob King, drilling superintendent, Exxon USA (drilling and production operations sections).

Jack Brandau, marine engineer (ship construction section).

We are particularly indebted to the staff and management of the following companies: Exxon USA, Houston, Tex; Tidewater Marine Inc., New Orleans, La.; Arthur Levy Boat Co., Morgan City, La.; International Logistics Inc., Houma, La.; Quality Equipment Inc., Houma, La.; the Offshore Co., Inc., Houston, Tex.; and Shell Oil Co., New Orleans, La.

Special thanks are due Jean Gazaway, LSU Center for Wetland Resources, Baton Rouge, La., who brought the manuscript together.

Photographs are printed courtesy of:

Jesse T. Grice, The Photo Mart (figures 2.1; 3.3; 4.1; 4.4; 4.5; 4.6; 4.7; 4.11; 4.15; 4.16; 4.17; 4.18; 4.19; 4.20; 4.21; 4.22 a, b, c, d; 5.1; 5.6; 16.5), who holds the copyright.

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Bell Aerospace (figure 4.24).

Offshore Co. (figure 4.9).

Global Marine (figure 4.12).

Dixie Carriers Inc. (Figures 4.2, 4.3).

Other photographs by Fred Townsend.

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1. BEGINNINGS OF THE OIL INDUSTRY

America's oil and marine industries have been closely linked, almost since the first discovery well was drilled. Highlights in development of today's modern petromarine industry include the following:

- Discovery of oil at Titusville, Pa., in 1859. Edwin Drake's successful well set off an exploration boom in western Pennsylvania that soon spread nationwide.

- Barge shipment of oil in wooden barrels. River ships and barges offered popular, convenient means of shipping commodities to market; early photographs show they were readily adapted to the new oil and refined products.

- Ocean shipment of oil in wooden barrels. Oil-thirsty European markets provided welcome export outlets for American crude oil and refined products.

- Metal tanks. Fitted in conventional ships as early as 1862, metal tanks marked a departure from the leaky, fire-prone wooden barrels originally used. Nevertheless, even to this day the barrel remains the standard unit of measure for oil in commerce.

- Oil tankers. Gluckhauf, the first truly successful oil tanker, was launched in 1887 after several earlier designs had failed. Oil tankers, already commonplace visitors in world parts by 1900, grew in numbers and size. Today's tankers are the world's leading category of ships.

Development of coastwise barges paralleled that of ocean-going tankers. Whenever a river, lake, or coastal sea could float a barge, such raft provided the best and cheapest means of transporting crude oil from field to refinery, and from refinery to market.

The relationship between the marine and petroleum industries strengthened further as the search for oil and gas extended from the land to offshore regions. Exploration of the continental shelves beneath the world's oceans marked man's first earnest ventures to recover mineral resources beneath the sea. Use of the marine hull was indispensable to offshore search for oil.

2. THE OFFSHORE REVOLUTION

Drilling in the ocean dates from the turn of the century when wells were drilled in California's coastal area. The drilling was done by rigs located on land or on piers along the beach.

Use of the marine hull was pioneered in south Louisiana. The Louisiana swampland was a difficult place to find solid land to support a land-drilling rig. This led to the use of marine hulls in oil exploration. In 1930, a rig was mounted on a barge, and the barge was sunk to the swamp bottom to drill a well. The "inland" drilling barge was successful, and these facilities became common along the coast of Louisiana.

Some south Louisiana oil fields were discovered in coastal swamp that was actually the edge of the Gulf of Mexico. The underground deposits of oil were formed millions of years ago, long before any land existed above the water level of the area. As far out as the oilmen dared to take an inland drilling barge, they found oil and gas. Logically, the oil field did not stop existing just because it became covered by deeper water.

The idea of developing oil fields in water deeper than the 10 to 15 feet working depth of the inland drilling barge became a challenge to the oil industry.

Oil men turned to the platform drilling concept for drilling in water too deep for an inland barge to work. Platform drilling had proved successful in Lake Maracaibo, Venezuela. As early as the 1920s, timber platforms had been constructed in Lake Maracaibo. Years later, concrete platforms were used there for drilling in water 120 feet deep. Similar platform operations were used in Cross Lake near Shreveport, La.

Just before World War II, the first wooden drilling platforms, in water too deep for an inland drilling barge, were erected in south Louisiana. The wildcat wells were drilled one-half mile from the coastline in the Gulf of Mexico. The field was named "Creole Field."

After World War II, oil men thought about drilling far enough offshore to be out of sight of land. There were some problems that had to be considered. For example, there was virtually no data in existence on the size of hurricane waves in ocean waters. Little research had been done to permit calculation of the force of hurricane waves upon an offshore structure. The first industry study of wave force led to a platform design for the offshore area. In 1947, the first steel drilling platform for offshore use was erected. The platform was atop 100 steel piles that were driven almost 200 feet into the ocean floor.

Fig. 2.1

The first platform supported only the drilling derrick. A large ocean barge was converted to carry supplies, to provide crew quarters, and to provide drilling mud treatment and pumping machinery. This barge was the first drilling tender.

By a stroke of luck, the first well drilled from the first platform found a new oil field. The offshore oil exploration facility became a production facility, and it has continuously operated since 1957. The offshore oil industry was successfully launched!

Between 1947 and 1954, many oil companies entered the search for oil and gas fields in Louisiana and Texas coastal waters. Discoveries were found in waters 20 to 60 feet deep. Many platforms were built large enough to be self-contained with crew quarters and equipment and supply storage space. But fixed platforms were too expensive for exploratory drilling. The demand arose for mobile drilling rigs. These mobile drilling rigs were similar in purpose to the inland drilling barges, but they were able to work in the open sea conditions of the Gulf of Mexico.

The first true offshore mobile drilling barges entered service in 1954. They were followed quickly by many further units of different designs, capable of working in ever increasing depths of water.

In succession, over a ten-year period from 1954, came the submersible drilling barge, the jackup drilling barge, the drill ship with anchors for holding station, the semi-submersible drilling unit, and, most recently, the dynamically positioned drill ship.

Since the inland drilling barges, used from 1930 onward, had to be supplied with personnel, supplies, and services, the offshore mineral and oil transportation support industry was born.

Small fast boats were used as floating buses to carry personnel. These boats were called crewboats. As rigs moved into rough ocean waters, the demand arose for larger and more seaworthy crewboats, which we see today.

Supplies for inland drilling barges were moved by inland-type barges. The barges carried supplies such as fuel, pipe, drilling mud, cement and tools. Supply barges were generally about 100 feet long, and they were towed by small tugs and even wooden luggers, which, in many cases, had been fishing and oystering craft.

As drilling moved offshore, the barges had to become more seaworthy, and the tugs also became larger, more powerful, and better designed for rough water. As barges proved too difficult to bring alongside offshore drilling rigs--especially when wind and waves came up--self-propelled supply barges were converted from surplus World War II tank landing vessels.

Inland drilling in the marshes and shallow coastal regions gave rise to the need for derrick barges for construction work. Offshore operations required still larger derrick barges, the early ones having cranes lifting 100 to 200 tons. Today, the largest cranes in service can pick up 2,000 tons at one time. Similarly, pipelines to carry oil and gas were first laid in inland areas by small barges. Offshore demands have seen pipelaying barges become giant vessels full of pipe-laying, welding, and mooring equipment.

Before a well is drilled offshore, the underwater area must be surveyed by seismic methods. Special vessels for this purpose were first employed right after the end of the second World War. Today many seismic vessels are full oceangoing vessels of 100 to 200 feet in length. Some survey boats are even larger.

So, as we can see from the foregoing, marine vessels of many types are vital in the entire operation of finding oil and gas and bringing it ashore for use by man.

The inter-relationship of the shipping and petroleum industries has existed since the oil search began over 100 years ago.

3. DRILLING A WILDCAT WELL

Before a well is drilled offshore, the underwater area must be surveyed. Vessels equipped with seismic instruments are sent into the area to be surveyed.

Fig. 3.1

In principle, the seismic vessel sets off a series of explosive charges in the water. The sound waves travel to the ocean floor and into the earth below the ocean floor.

The earth is made up of different materials at various levels. These levels are known as strata. From each strata, the sound waves reflect back to the seismic devices aboard the boat. The many reflections of sound waves are picked up by special listening devices called geophones. Other instruments record sound waves. When records are processed, a geologist can identify areas of possible oil and gas deposits. This is the place where drilling takes place.

Fig. 3.2

The term "wildcat well" is used in the oil industry to describe the exploration for oil. The drilling of a wildcat well begins with a bit twisting into the earth's surface at the ocean bottom. The drilling bit, shown in Figure 3.2 is equipped with teeth mounted on roller cones. From 20,000 to 75,000 pounds of weight is placed on the bit. By turning the drill-pipe at the surface, the rotation of the drill bit at speeds of 50 to 200 revolutions per minute is accomplished.

As the bit becomes hot during the drilling of the hole, it is necessary to cool it. The cooling of the bit, along with carrying cuttings out of the hole, stabilizing the walls of the hole, and containing high formation pressures, is done by using special drilling fluids. The drilling fluids often have densities twice that of water. These fluids are circulated at high rates of speed by several surface pumps which run up to 1,500 horsepower each.

When a bit is worn, as happens many times in the drilling of a deep well, it must be replaced. Each replacement may require 10 to 20 hours. The drill pipe must be pulled to the surface, disconnected into 90 foot lengths, and stacked in the derrick before the bit can be replaced. The drill pipe is made up again as the bit is returned to the bottom of the hole.

A predominant piece of equipment used in drilling a well is the blow-out preventer. The blow-out preventer is a safety device. It closes off the well in case of an emergency. An example of an emergency that would cause the blow-out preventer to be used is a situation where high pressure in the subsurface area threatens to blow the drilling fluid out of the hole.

Blow-out preventers are aimed at stopping catastrophies. However, oil well fires, which nearly everyone has seen pictures of, still occur. Blow-out preventers are hydraulically operated. A normal one weighs about 300 tons and stands 14 feet high.

Other important well equipment includes strings of casing, or large diameter pipe. Strings of casing are run into the well during the course of drilling the hole. The casing is cemented in place to prevent weaker strata from crumbling. Casing also protects against high pressure formation and makes it possible to re-enter the well in order to carry out any number of operations. In the typical 12,000-foot deep well, over 300 tons of casing and over 300,000 pounds of cement are used.

Fig. 3.3

The surface equipment of the derrick includes the travel block. The traveling block is the movable unit, containing six to eight sheaves and a large hook, which suspends the drill pipe. It may weigh over eight tons. The traveling block is raised and lowered by cable attached to the draw works, a large power-driven hoisting drum. The draw works may weigh up to 40 tons and can lift 250,000 pounds of drill pipe 90 feet in less than 30 seconds.

Operation of the drilling rig is a continuous job for a crew that averages five men per shift. Because of the great amount of material supply and services required in the drilling process, as many as 150 men become involved at one time or another on drilling location.

4. THE PETROMARINE FLEET

t We call the vessels that are involved in the offshore oil exploration and support industries the "petromarine fleet."

The following is a description of the vessels that make up the petromarine fleet.

4.1 Tankers

A tanker is a ship that carries crude oil or liquid petroleum products in bulk form. The cargo, as the petroleum

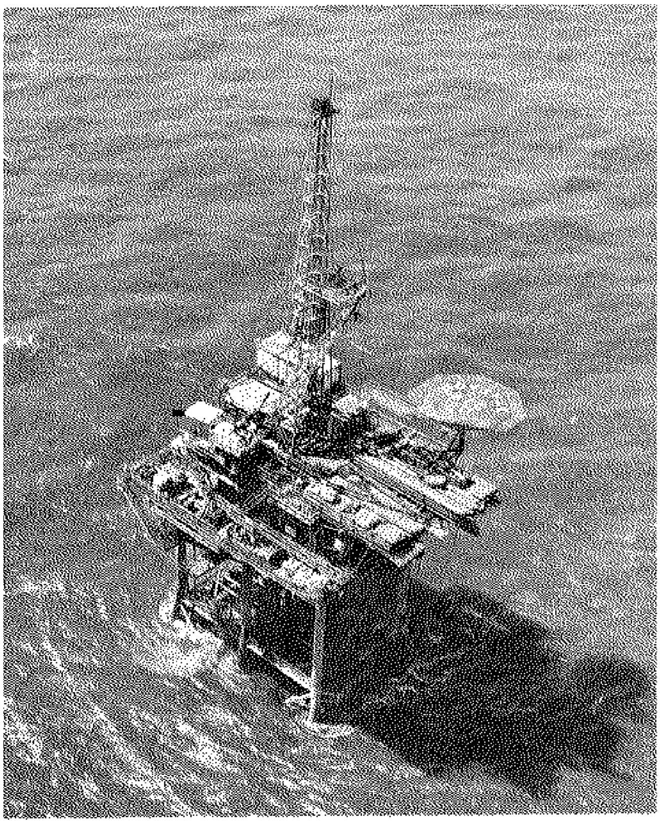


Fig. 2.1 Platform rig.

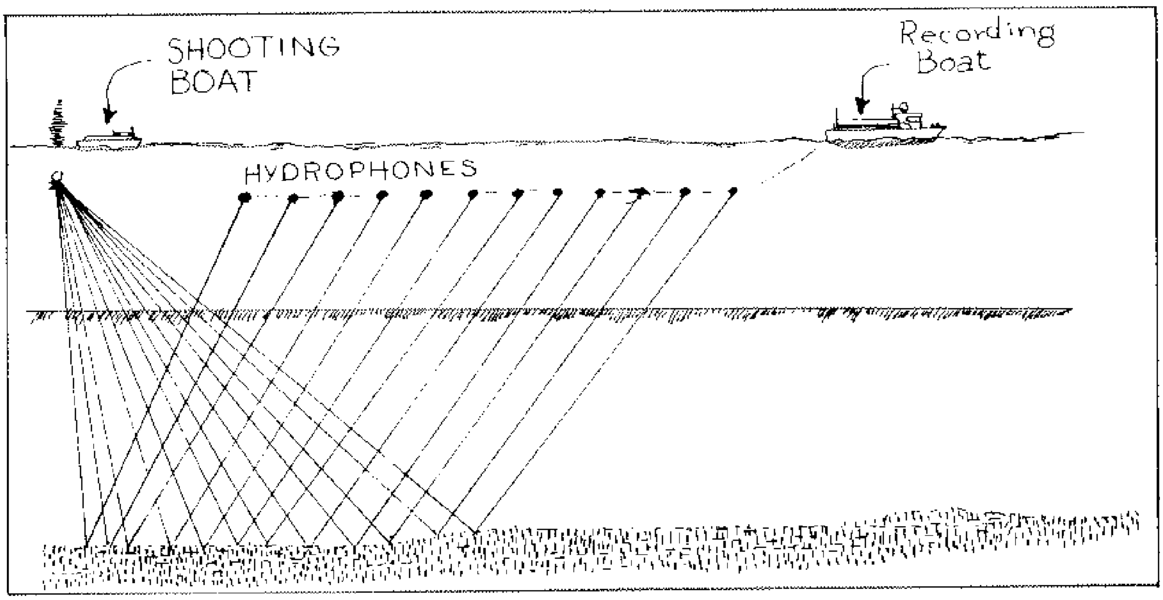


Fig. 3.1 Operation of a seismic boat.

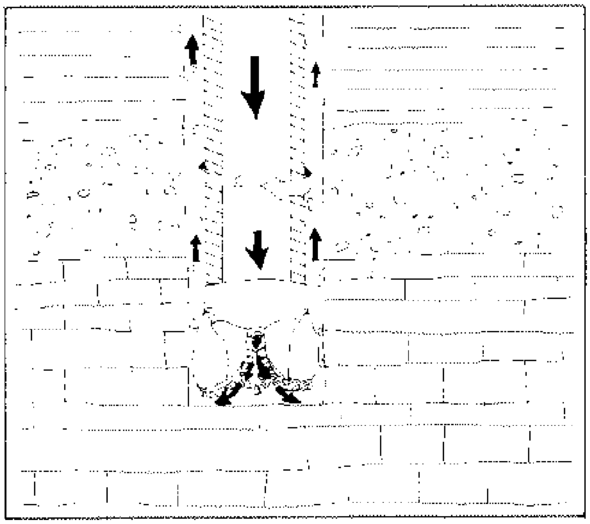


Fig. 3.2 Drilling bit.

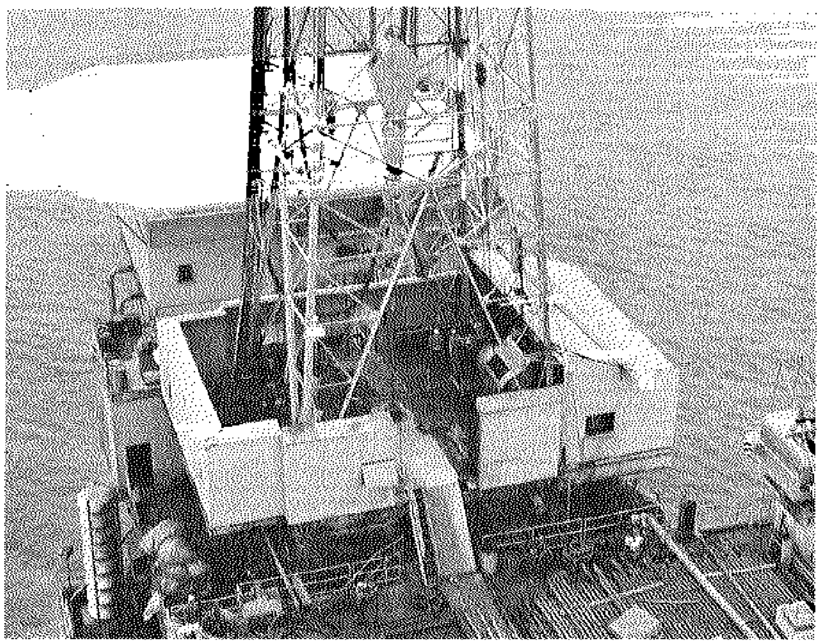


Fig. 3.3 Surface well equipment.

products are called, is carried in a number of large tanks, from which comes the name "tanker."

With few exceptions the modern tanker has its machinery, crew accommodations, and navigating facilities as far aft as possible. The entire hull, forward of the machinery space, is taken up by the cargo tanks, except for the most forward part of the ship, which is used for anchoring and mooring equipment and for a water ballast tank.

Tankers are built for carrying different commodities, and their size, number of tanks, piping and pumping systems, and other features vary in accordance to the type of commodities carried.

The size of the vessel may be determined by the tonnage that the owner wants to carry each trip. When a large supply of oil is available, the size of the ship may be limited only by man-made or natural restrictions. For example, the ship size might be limited by water depths in and near ports. That is the reason that oil companies have begun an effort to develop "superports" on the Gulf Coasts of Texas and Louisiana.

Tankers are usually divided into two types, though the distinctions are not always clearcut. One type is called the "dirty" tanker, the other type the "clean" tanker, or product carrier.

Crude oil tankers and those that carry other thick, black refined products such as bunker oil and asphalt are dirty tankers. Asphalt, crude oil, and the like, leave a residue of heavy oil and sludge in the tanks. If a clean product, such as gasoline, kerosene, and another light-colored product were carried in a tank that had previously carried dirty products, the clean product might become contaminated.

Some product carriers can simultaneously carry both clean and dirty products. A clean tank can usually be switched to carry a dirty product, but the tank must be meticulously cleaned before it is once again used for a clean product.

In almost all cases, the tankers carry cargo in only one direction. They sail back empty except for necessary water ballast. Crude oil carriers travel from the area where oil is produced to the refineries, then go back for another load.

Product carriers pick up their refined products at the refineries and carry them to terminals located in the consumer's port area. Then they return empty for another payload. In most cases there is no cargo available for a tanker to carry back to its oil loading port. To reduce the proportion of the distance sailed in ballast, some tankers have been constructed that can carry solid bulk cargoes on their return. These vessels are termed ore-oil carriers (OO) and oil-bulk-ore carriers (OBO).

To show how such a vessel is operated, an OBO may start in the Persian Gulf with a load of crude oil destined for Philadelphia. After discharge in Philadelphia, the vessel sails to New Orleans in ballast, and the crew cleans out the tanks to be used for dry cargo. In New Orleans, the ship loads grain for Japan. From Japan, the ship returns in ballast back to the Persian Gulf for another oil cargo.

By following the aforementioned pattern, the OBO may carry a paying cargo over 65 to 75 percent of the miles it sails, against the tanker's 50 percent figure. In turn, the OBO costs more to construct and operate, so that under some market conditions, it may be less profitable than a tanker.

Crude oil and most of the products derived from it require great care against fire and explosion. No smoking is permitted on the deck of a tanker, and precautions are taken against causing any sparks.

Petroleum product cargoes give off fumes that are highly explosive when mixed with oxygen. Any spark or open flame will set off the explosion. The subject of safety onboard tankers is a major item in itself, and it is only barely mentioned in this chapter. However, it will be covered in some depth later in the book.

On the deck of a tanker, one sees a great number of pipes and valves. These are used in loading the cargo into the tanks and for discharging the cargo at delivery. Smaller pipes carry water for washing down the decks, for fighting fires, for carrying steam to deck machinery, for heating heavy crude oil and thick bunker oil, and for taking aboard fuel oil and drinking (potable) water.

Cargo tanks must be cleaned at sea while sailing back in ballast to a loading port. Cleaning is necessary to be sure the tank is fit to accept the next load of cargo. The tanks must be cleaned and made gas free before any repair work can be done in the tank or on deck. Cleaning is carried out by powerful water-washing machines, often called Butterworth machines.

Butterworth machines hurl high pressure streams of water in all directions within the tank. In cases where the tanks carried heavy sticky oils, the water is first heated, and, in some cases, detergents are added. The bottom of the tank becomes full of a mixture of water and oil (and also chemicals, if they are used). This mixture at the bottom of the tank is termed "slop." Until recent years, the slop was pumped overboard at sea. An oily trail would extend for hundreds of miles behind the tanker. Such pollution is no longer acceptable, and all new ships must carry slop tanks to separate out the oil before pumping the slop water overboard.

Many newer tankers are equipped with inert gas generators which supply low-oxygen fuel gas to fans which force it, under pressure, into all the cargo tanks. The inert gas fills any space left in a filled tank. Also, the inert gas is forced into the free space when a tank is being pumped out. In addition, the inert gas is constantly forced into the empty tank, even during tank-washing operations. Proper use of inert gas results in safety against petroleum gas explosions.

When the cargo is loaded into the tanker from storage tanks on shore, the loading pumps near the land tanks force the oil through pipelines to the loading wharf.

Large flexible hoses connect the shore lines to the ship's loading pipes, through which the cargo is sent to the desired ship tank. Care must be taken not to let the tank overflow. An oil spill in port is dangerous and oil pollution causes huge fines to be levied against the ship.

For discharging cargo, the ship is typically equipped with three or four large, powerful pumps. The pumps take suction from any tank to which it is piped and sends it overboard through the land pipeline, under great pressure, to the land storage tank.

4.2 Seagoing Tank Barges and Tugs

Seagoing tank barges are fairly common in American coastwise service and have been for fifty years or so. Oddly enough, barges as a means of oil transport are rare in the rest of the world.

In some cases the barges are used for crude oil movement. Primarily, however, their present trades are in refined products.

The decision to build or charter tank barges rather than tankers is usually strictly one of economics. Both types of vessels can perform the same service.

The seagoing tank barge is much like a tanker except that it has no propulsion machinery, no navigating facilities, and quarters for only a small crew, if any.

The deadweight capacities of tank barges range from craft as small as several thousand tons to as large as 40,000 tons. The upper limit on size of the barges is decided by economics and by safe towing limitations.

Most tank barges are pulled by very long wire ropes while at sea. As the tow comes into restricted waters (harbors, channels, etc. requiring tight control of the tow), the towline is shortened up and towing speed is reduced. When sheltered water has been reached the tug usually comes alongside the barge, or pushes from the stern of the barge, to give best handling and safety.

Many seagoing tank barges have a V-shaped slot built into the stern area. The tug places its bow into the slot and pushes the barge from this position. With a deep slot taking about one-third of the tug's length, and with ample rubber fenders and securing wires, the tug can push the barge in open ocean until the waves become quite high.

Some operators claim safe push towing by this means can be accomplished in waves up to 10 feet high. When higher waves occur, the tug is released from the slot and takes up the conventional ahead-pulling position.

Why bother to push instead of pull the barge at sea? The answer is a higher speed with the same power and better steering control of the tug-barge combination.

Loading and discharging cargo is carried out much the same way as for a tanker. Cargo discharging pumps are usually driven by diesel engines. Tank-cleaning and gas-freeing must be done in port as there are neither manpower nor facilities fitted to the tank barges for these purposes.

A recent innovation is the tank barge and tug combination that secure together to form a rigidly connected vessel. The securing arrangements must be extremely strong because in high waves the tug can be flung half out of the water and a few seconds later be pushed deep into the ocean.

When joined together, the tug and barge actually become a self-propelled tanker. The tug may be readily detached from one barge and switched to another that is specially built for this usage.

For some trades, the rigidly connected tug-barge system has economic advantages, but only time will tell if there will be wide-spread usage of this concept.

Seagoing tugs for pulling or pushing ocean tank barges are not different from most other ocean tugs. Depending on the size of the barge being towed, the power of the tug may range from 1,600 to 3,200 horsepower for single-screw tugs, and from 4,000 to 10,000 horsepower for twin-screw tugs.

Even more powerful tugs are used in some cases. The modern trend is to have a raised forecastle for about one-half of the tug length forward, to keep the foredeck drier during heavy weather.

Fig. 4.1

A large towing winch, just aft of the middle of the vessel, is virtually a necessity for heavy towing. The winch is necessary because the towline may be of heavy wire up to two inches in diameter and some one-half mile of wire may separate the tug and the barge. Obviously such a towing line cannot be successfully handled without a large winch.

The winch is usually the automatic-tension type. This means that the winch will pay out wire in case of a heavy, sudden pull on the towing wire. As soon as the additional pull is no longer sensed, the winch automatically reels in the extra length of wire paid out during the surge load.

4.3 Inland Tank Barges and Towboats

The American inland waterways system utilizes thousands of tank barges for carrying crude oil, refined petroleum products, petro-chemicals, and even refrigerated liquified gases such as propane and butane.

The typical tank barge ranges between 200 and 300 feet in length, 50 feet in breadth, and has a loaded draft of 8 3/4 feet in fresh water.

Fig. 4.2

Most tank barges are moved in tows containing anywhere from two to forty barges. To make towing easier, most barges have one end raked (shaped to move through the water easily) and the other end squared off. When two barges have their square ends butted together, the two move through the water as one long shape.

Some barges are squared at both ends. These are called box barges. Box barges are placed in the middle of the tow to make the assembled tow longer with still only one shaped-end forward, and another shaped-end aft. Such groups of barges are called integrated tows.

The entire purpose of the integrated tow is to move the cargo as fast as safely possible, with the least expenditure of propulsion power.

Most oil barges are single skin vessels. This means the cargo tank extends to the shell and deck plating at the bottom, sides and on top. There is always at least one centerline bulkhead running the length of the cargo tank spaces, and a number of transverse bulkheads divide the cargo space further.

At the end of most barges is an empty space called a rake tank. The rake tanks have two main purposes. Most of the damage to barges occurs at the ends of the barge (note the term "most" does not mean "all"). The rake tank acts as a buffer zone, so that if holes are punctured in the end of the barge oil will not leak out. Also, the rake tanks provide flotation when all the cargo tanks are full of cargo.

Tank barges are equipped with piping and pumps to fill and discharge the cargo. The barges have towing fittings (bitts, cavels, buttons, winches, etc.) for connecting the barges into a tow, and for securing the tow to the towing (pushing) vessel.

Double-skin barges are used for some oil products that require high cleanliness. Also, double-skin barges are used for products such as hot asphalt. This is done to keep heat in the product. To make it pumpable the double walls and bottom keep a layer of air between the asphalt and the river water, and this serves as an insulator.

Double-skin barges are also used for products that require a higher degree of assurance against their being spilled into the water following collision or grounding damage to the barge.

Of course, the double-skin barge is more expensive to build than the single-skin barge but the difference is not too great. In recent years some owners have ordered double-skin barges for carrying ordinary oil products. Thus the chance of pollution is reduced in times of accidents. A major collision will easily penetrate both skins and still cause an oil spill, but most hull incidents will not be severe enough to go through more than one of the two skins.

Some petro-chemicals must be handled very carefully since they may be highly corrosive (acids) or make people sick or even be deadly (toxic).

In such cases the barge may have a set of long, cylindrical tanks that are not part of the barge structure, in which the cargo is carried. Such barges are called independent tank barges. The tanks may be made of stainless steel or may be rubber-lined to withstand corrosion by the cargo. Some independent tanks may carry the cargo under pressure, to keep it from evaporating into the atmosphere. Some independent tanks are heavily insulated to carry very hot or very cold liquids.

River tows are pushed, not pulled. Pushing permits more speed for the same horsepower. A pusher towboat makes possible excellent steering, stopping, and even going astern on the tow. Pulling a large tow of barges upstream would be very difficult, but pulling a tow coming downstream would be impossible.

Modern river towboats for long runs, with heavy tows, are usually twin, triple, or quadruple screw-craft with 3,000 up to 11,000 horsepower. Diesel engines are the only engines now used for river towboats. (Fig. 4.3)

Many towboats have cylindrical tubes around each propeller, called Kort nozzles. Behind each propeller is a large steering rudder, and in front of each propeller are one or two small rudders called flanking rudders.

The steering rudders are usually ample to steer a big tow around the twisting banks of a big river. When steering power is needed with the propellers going astern, the flanking rudders do the job. Sometimes both sets of rudders must be used under very tight maneuvering situations. A pilot needs a great deal of experience and skill to use all the rudders, as well as engines, to keep his tow from danger.

Of course, as a pusher, the towboat has big pushing knees at the bow which extend from the normal water level to some 10 to 15 feet above the water. In this way, the knees will come into contact with a high, empty barge, as well as a low, deeply loaded one.

Smaller towboats are used for small tows, and for tows in narrow channels, such as the Gulf Intracoastal Waterway. These boats may range from 1,000 to 2,000 horsepower, and they are small versions of the open river pushers.

4.4 Inland Drilling Barges

Fig. 4.4

Gulf Coast drilling people sometimes refer to inland drilling barges as swamp barges or mat barges. The first inland drilling barges entered service in the 1930-35 period. By 1950, more than 100 inland drilling barges were in service.

The total number of inland drilling barges has remained fairly constant since 1950. Prior to the first swamp barge, the drillers had to build up an area in the swamp to support a land drilling rig. This was costly and took up time.

The swamp barge carries the entire drilling rig, supplies, crew quarters, and everything else needed for drilling. A "slot" or vertical groove 8 to 12 feet wide runs down the middle of the hull for about half the hull length.

Drilling takes place through the slot. Upon completion of a well, and placement of the christmas tree (control manifold), the open slot enables the rig to move clear of the well and proceed to the next well site. Swamp barges can be used in swamp areas, inland lakes, and coastal areas not subject to severe ocean wave action. They are towed from one place to another. The hull has a number of ballast tanks, and these are filled to sink the barge at the desired place. Upon completing a well, the ballast tanks are pumped out and the rig resumes a floating position so that it can be towed away.

While afloat, some care is necessary to avoid capsizing the rig. Partly filled tanks (free surface) must be kept to a minimum. Drill pipe and casing should be secured against shifting when the barge rolls. Skilled drill barge superintendents are aware of steps necessary to assure against capsizing.

4.5 Offshore Drilling Tenders

Offshore drilling tenders were popular in the early years of offshore drilling. In recent years not many new ones have been built.

Fig. 4.5 The drilling tender is a self-propelled or non-propelled vessel that carries drilling supplies, crew accommodations, and most of the drilling mud system. It is moored within 20 feet or so of a small fixed drilling platform containing the derrick draw works and a minimum of other items.

Earlier drilling tenders were converted from surplus World War II vessels of 250 to 350 feet in length. The vessel has a large mooring system, consisting usually of eight big anchors and heavy chain, or wire-anchor lines. Anchors are laid radially outward from the tender to keep it close to the fixed platform.

During extremely large waves, the tender movements may become great enough to strike the platform. Before this can happen, the tender is moved further away from the platform by adjusting some of the anchor lines.

4.6 Submersible Drilling Vessels

The first offshore submersible drilling vessels were built in the 1950-55 period.

Fig. 4.6 The submersibles basically extended the inland barge principle to deeper water than the 10 foot working depths of the swamp barges. Additionally, the submersibles were built to withstand the force of hurricane waves.

Small submersible craft worked in the 15 to 40-foot water depth range. Larger units could go to 60 feet. After a while, even larger craft were built to sit on the bottom of the ocean floor in as much as 150 feet of water.

To keep rigs from capsizing while raising from or lowering to the bottom, a number of different concepts were used.

Some units were tipped, end first, to rest on the bottom, then the other end was lowered, all by ballasting. Some units used "legs" or "pods" which were hydraulically lowered to bottom, then the rig was ballasted and lowered.

The final, simplest, and most successful type of submersibles used the floating drydock principle. Vertical cylindrical caissons (very large tubes) extended from the lower hull to above the deepest water level to be worked in. These gave full, positive stability and great safety during submerging and raising.

The submersible drill barge has a lower hull of large size, and high above this is an elevated main deck supported by columns.

The main deck is intended to always be clear of wave action. On it are located the drilling machinery, crew quarters, power plant, and the drilling supplies.

The lower hull usually has a number of fuel oil and drill water tanks. The bulk of the hull volume is given over to ballast tanks.

Though popular for shallow waters, few submersibles have been built since 1960. Other types with greater water depth capability have taken over the field.

4.7 Jack-up Drilling Barges

Fig. 4.7 Jack-up drilling barges are the most common type of mobile drilling units. They make up about half of all mobile units in the world.

The typical jack-up consists of a large flotation hull with three or four long legs. Different sized units are built to work in water up to 300 feet deep.

Fig. 4.8 The jack-up floats to a new location with its tall legs towering over the hull. Powerful electric or hydraulic jacks push the legs down to the ocean floor, and they keep pushing it until the hull rises out of the water. The desired elevation of the jack-up is one that lifts the hull out of the water clear of expected storm wave action.

The hull contains all machinery, drill rig, supplies, fuel, water, quarters, helipad, etc.

In very soft ocean bottoms, the jack-up legs would keep sinking into the mud and never gain enough support to push the hull out of the water, so some jack-ups have their legs connected to a second hull, or mat. This mat rests on the soft ocean floor when the legs are jacked down.

Some ocean bottoms are so soft that this "mat" method is also ineffective, therefore the jack-up cannot work in such places.

The jack-up can be jacked up or down in calm water and in small waves. Many ocean areas are relatively calm except for occasional storms.

Jack-ups are excellent craft for areas of calm. Once jacked up the rig can survive great storms. But in regions where rough seas can be expected for much of the year, the jack-up can lose a great deal of time waiting for a rather quiet spell of weather. Like any good tool, the jack-up barge has many excellent capabilities. At the same time, there are some clear limitations. This can be said not only for the jack-ups, but just as well for the other types of drilling vessels described in this unit.

4.8 Semi-Submersible Drilling Vessels

Fig. 4.9 The semi-submersible is a direct development from the submersible. Like the submersible, the semi-submersible uses the dry dock principle for its stability.

While it is submerging to the ocean floor, if one stopped adding ballast water to a submersible the vessel would just stay partly submerged for as long as it was left that way.

When water depths became too great for submersibles and jack-ups, imaginative men decided they could drill from a moored submersible in the semi-submerged position.

When the drilling from a semi-submerged position was tried, it worked well. Further, a great benefit was the small motions caused to the rig by any wave other than the large ones.

Today the semi-submersible is the number one drilling craft for deep and rough waters. It is used in the North Sea, for example.

The semi-submersible depends on a huge anchoring system. Eight to twelve anchor lines radiate out in every direction. The anchor pattern looks like a giant spider web with a giant spider sitting in the center.

Fig. 4.10 Each anchor weighs 20,000 to 40,000 pounds, and the wire lines or chains are powerful in proportion.

Fig. 4.11 Semi-submersibles are steady and stable work platforms. However, amounts of supplies, fuel, water, pipe, etc. must be carefully checked daily. This is necessary to maintain stability and proper working draft.

Many variations in design and appearance may be seen among semi-submersibles. Some designs use two lower hulls. Others have three, four, and even more hulls. Without question, the semi-submersible features more fantastic design variations than are found in any other class of offshore rig.

4.9 Drill Ships

Fig. 4.12 Drilling ships are really similar to the drilling tenders discussed earlier in this section. The main exception is a hole (moon pool to a driller), which is cut through the middle of the ship. The drilling derrick is erected over the moon pool.

Fig. 4.13 Most drill ships have gigantic mooring systems similar to the semi-submersibles. Some ships are dynamically positioned, which means the vessel has a large number of propellers that can push or twist the vessel in any direction. Fig. 4.14

A computer tells each propeller how long and hard to work to keep the vessel closely positioned over the well that is being drilled.

The computer knows where the well is by means of sound waves from devices placed on the ocean floor. Sonar devices on the ship pick up the sound waves and inform the computer where the ship has moved relative to the well location.

Drill ships are usually 400 to 500 feet long. Some are built from scratch. Others are converted cargo ships.

When compared to the small and slow motions caused by waves to a semi-submersible, a drill ship jumps around quite a bit. Special equipment has been developed to compensate for vertical motion, called "heave." Mechanical handling devices are available to handle drill pipe and casing, while the ship is moving about. These improvements decrease the lost time due to bad weather.

A fully equipped drill ship can be a good performer in waves up to 10 feet high, perhaps higher for less delicate well operations.

A great advantage of the drill ship is its speed underway. Most drill ships make 10 to 12 knots and some new designs even run at 15 to 16 knots.

The drill ship is narrow enough to go through the Panama Canal, if it must be moved from the Atlantic to the Pacific, or vice versa. Jack-ups and semi-submersibles, with few exceptions, are too wide to move through the canal.

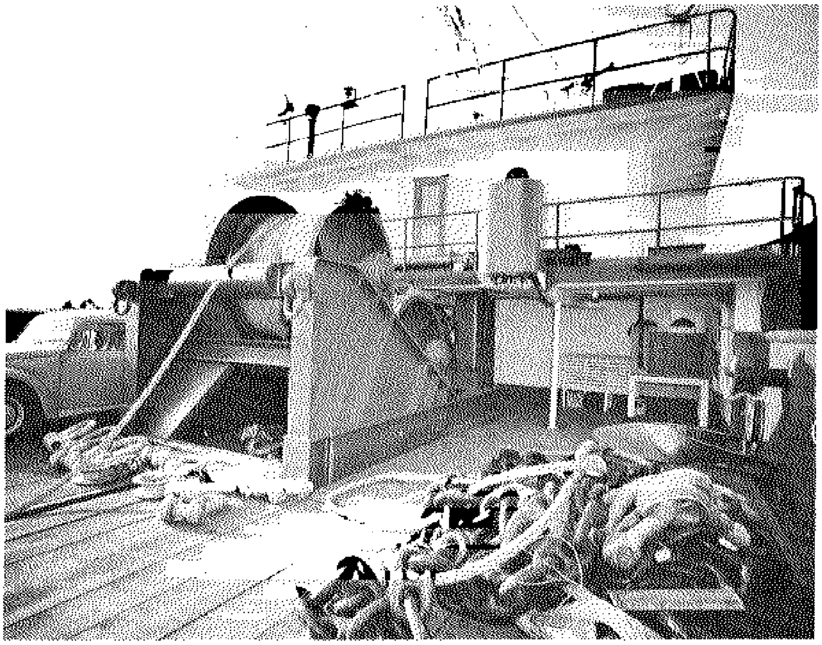


Fig. 4.1 Towing winch.

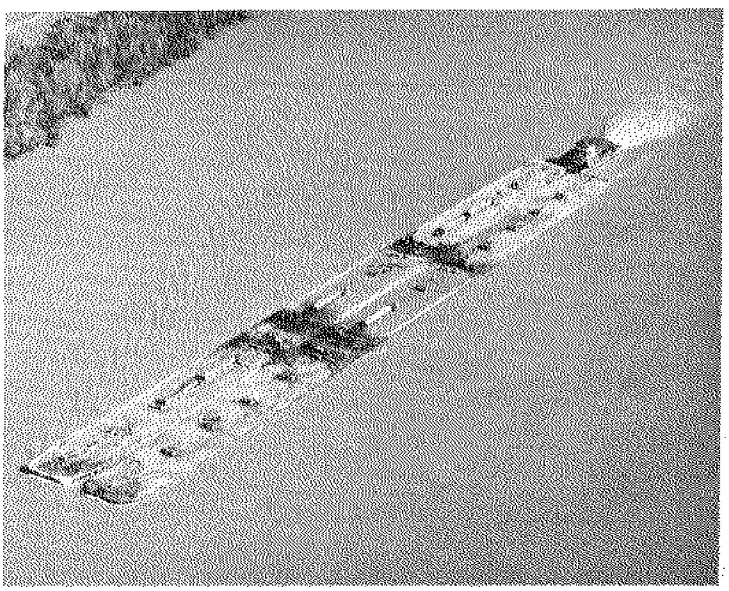


Fig. 4.2 Large river tow.

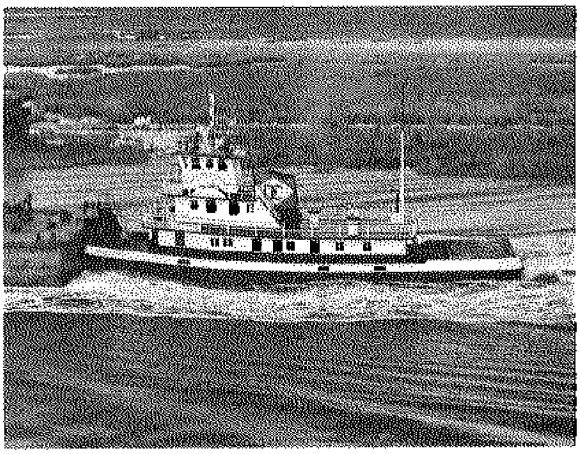


Fig. 4.3 Push boat with barges.

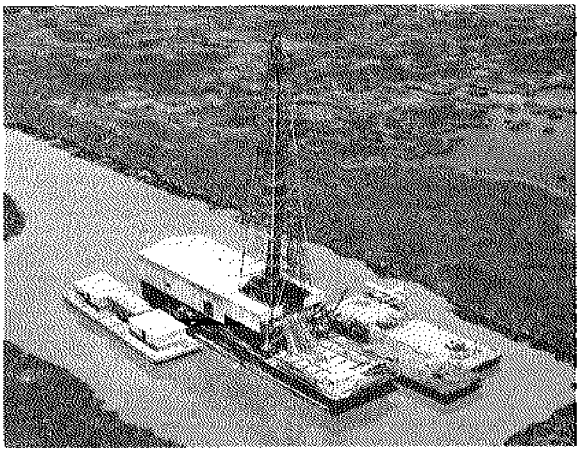


Fig. 4.4 Inland drilling barges.

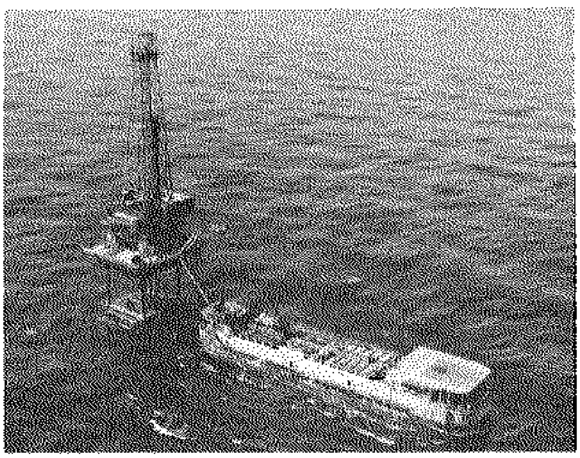


Fig. 4.5 Drilling tender.

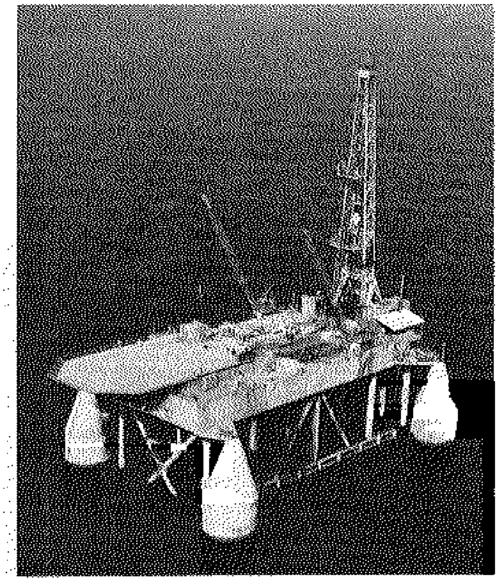


Fig. 4.6 Submersible drilling vessel.

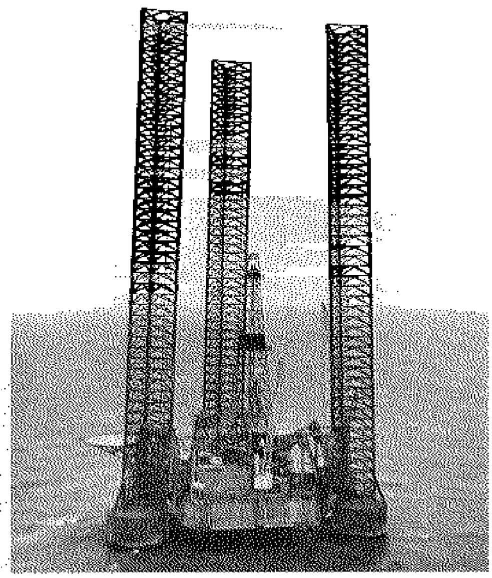


Fig. 4.7 Jack-up drilling rig.

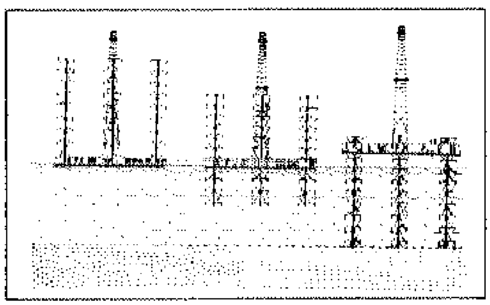


Fig. 4.8 How a jack-up moves into location.

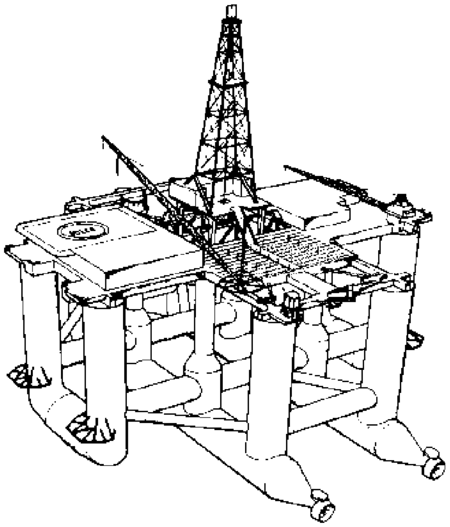


Fig. 4.9 Schematic of semisubmersible drilling rig.

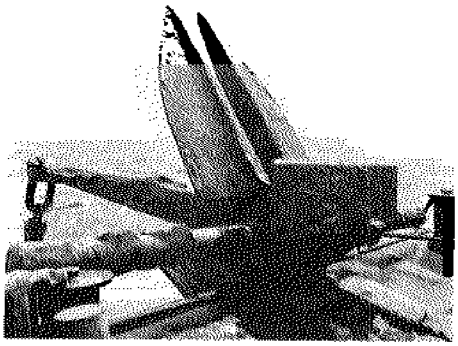


Fig. 4.10 Semisubmersible anchor.

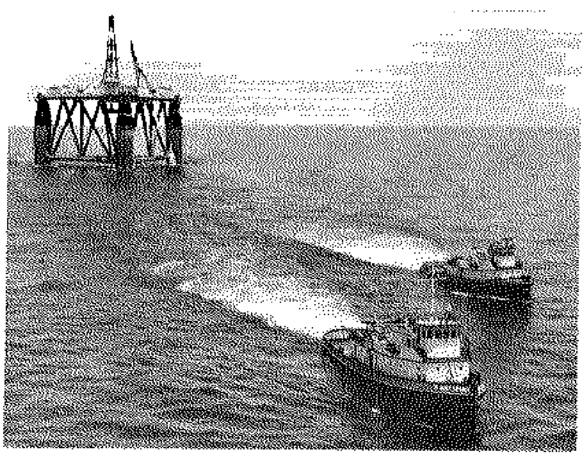


Fig. 4.11 Moving a semisubmersible.

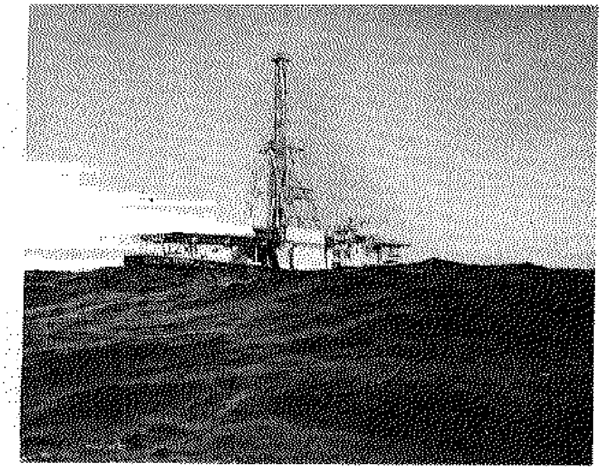


Fig. 4.12 The drillship Glomar II.

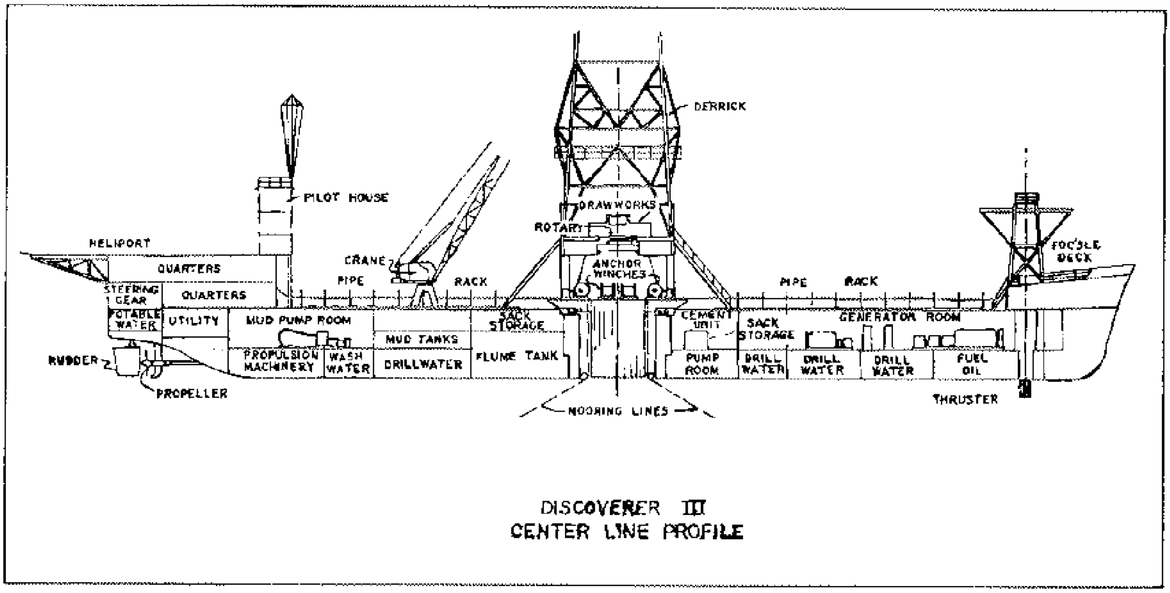


Fig. 4.13 Dynamically positioned vessel.

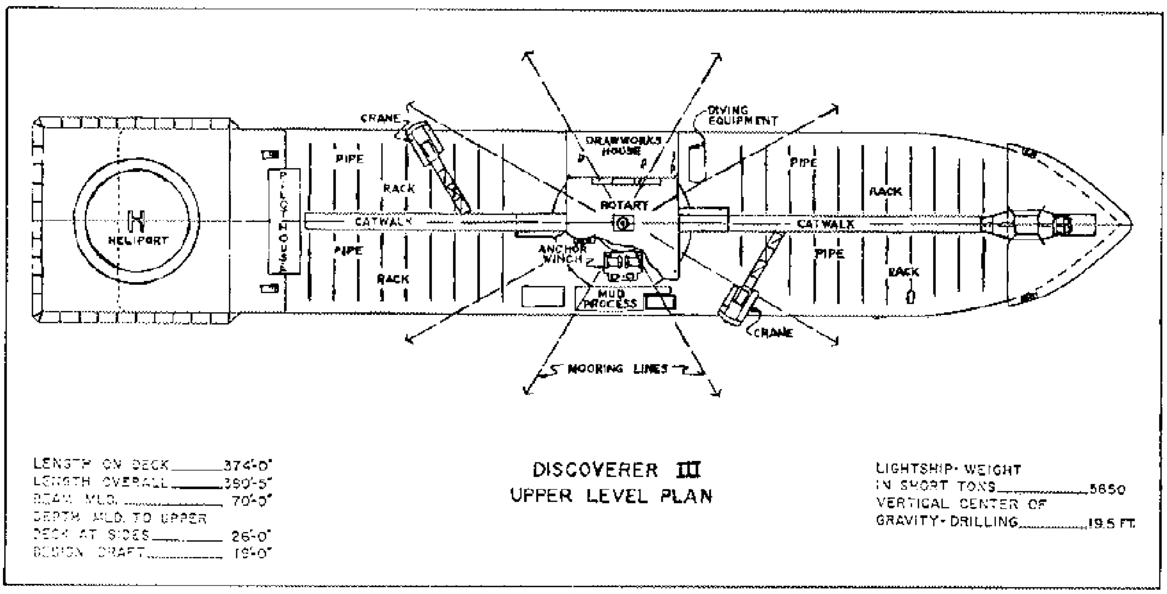


Fig. 4.14 Layout of Discoverer III.

Table 4.1 Drilling Vessels: Advantages and Disadvantages of Each Type.

	JACK-UP	SEMI-SUBMERSIBLE	SHIP SHAPE: MOORED	SHIP SHAPE: DYNAMIC POSITIONED
ADVANTAGES	Provides fixed drilling platform Less expensive than submersible for water depth over 40 feet Minimum area exposed to waves Can work soft bottom areas if equipped with mat Can easily be designed to withstand hurricanes and winter storms	Provides fairly stable drilling platform Water depths up to 1,500 feet Good survival capacity Good variable capacity while drilling	Extremely mobile Water depths up to 2,000 feet Large variable capacity underway and drilling Less expensive than semi-submersible	Extremely mobile Unlimited water depth Large variable capacity underway and drilling No anchor handling problems
DISADVANTAGES	Difficult to tow Moving parts Sensitive to waves when first going on or off location Must remove legs for long tows Poor underway safety record Limited variables when moving Limited to about 300 feet water depths	Difficult to anchor Somewhat difficult to tow Expensive Must use underwater BOP's and marine riser Limited variables underway	Excessive motions; must use pipe handling system Some anchoring problems Must use underwater BOP's and marine riser	Excessive motions; must use pipe handling system Must use underwater BOP's and marine riser Very expensive

Note: Primary factors to consider when selecting a new unit:
- Investment costs - short-term versus long-term outlook
- Mobility - likelihood of multiple short versus long moves
- Versatility - in coping with worldwide differences in drilling requirements
- Variable capacity - while drilling and moving

Table 4.1 Continued.

SPECIAL FEATURES OF EACH RIG TYPE

Feature	Self-Elevating	Column Stabilized	SURFACE UNITS Moored	SURFACE UNITS Dynamic Positioning
Stability				
On Station	Excellent	Good	Good	Good
Underway	Poor	Good	Good	Good
Payload				
On Station	Adequate	Good	Excellent	Excellent
Underway	Low	Reduced	Excellent	Excellent
Station Keeping	Absolute	Large expensive mooring system required	Moderate mooring system adequate	Requires active system which relies entirely upon power and automatic control
Mobility	Poor, must be towed; difficult to position	Good, but requires anchor handling	Excellent, but requires anchor handling	Excellent; no anchor handling required
Maximum Water Depth	350 feet	1,500 feet	3,000 feet	Unlimited
Platform Motions	None when elevated;	Very good, but still requires heave compensation	Excessive; often requires heave compensation and a pipe handling system	Excessive; often requires heave compensation and a pipe handling system
Investment Cost (Relative)	Low	High	Moderate	High
Best Application	Any waters to 350 feet	Rough waters to 1,500 feet	Calm to moderate waters to 3,000 feet	Calm to moderate waters over 5,000 feet

4.10 Crewboats

Crewboats are the water buses used for transport of men and light supplies. Crewboats offer higher speeds than any other boat can make.

Of course, helicopters also carry men and light cargo loads, and in most offshore oil operations, both crewboats and helicopters are used.

Crewboats are generally built of steel or aluminum. They are quite powerful, and fast for their size. In quiet waters and small waves, crewboats are fairly comfortable, but in rough waters, the crewboat must be run slowly. Their motions can sorely test the stomach of even the best of sailors.

The operation of crewboats requires reasonable skill and seamanship. Particular skill is needed to "come alongside" a drilling rig when a stiff wind is causing rough water.

Fig. 4.15 Crewboats running offshore have radar to help navigate during low visibility periods. Radio telephones keep them in contact with shore bases and rigs.

When the first offshore oil well was drilled in the Gulf of Mexico at the end of World War II, supplies and personnel were transported by a few tired, war-surplus craft or converted pleasure craft ill suited to the work.

The first crewboats were wooden craft with gasoline engines. Such boats fell short of meeting the demands of the offshore industry. Modified pleasure boats had high mortality rates because of light construction. Also, the hazards associated with gasoline engines caused problems.

Offshore passenger transportation was upgraded with the introduction of craft with a planing surface, a hull designed to receive dynamic lift from water surface upon which it moves, and constructed of steel and powered by diesel engines. A second step in the development of the modern crewboat was the introduction of light-weight, welded aluminum hull construction.

Fig. 4.16 Today, most crewboats are of aluminum or steel construction, diesel powered, with twin- or triple-screw engines. In addition, the modern crewboats are air-conditioned and equipped with modern electronic radar and full communications gear.

Despite the similarities, there are some differences in the types of operations undertaken by different kinds of crewboats.

Fig. 4.17 Inshore crewboats are usually those around 50 feet in length. These small crewboats have 200 to 500 horsepower engines. They are capable of speeds of 20 to 30 knots with passenger capacities of 12 to 20 men.

Fig. 4.18 Offshore crewboats vary in size. The boats in the 80 foot class can carry 50 to 75 passengers and may have from 1,000 to 1,500 horsepower. Average speeds of these boats is from 24 to 28 knots. Operational range for the boats is 75 to 100 miles offshore.

Larger crewboats ranging from 95 to 125 feet are used to carry men and supplies offshore. Boats of this size range may have from 1,500 to 2,500 horsepower, with a speed range of nearly 30 knots. Passenger capacity for the 95 to 125 footers is about 50 to 125 men. These boats are often used from 100 to 200 miles offshore.

Hull-form improvements in the crewboat will likely increase deck area, deckload capacity, and passenger space below deck. Future crewboats, with new hull designs, will also have a capability of higher speeds than today's crewboats.

4.11 Supply Vessels

The modern supply vessels are the heavy duty trucks of the offshore industry.

Fig. 4.19 Supply boats range from several hundred tons deadweight to as much as 2,000 tons deadweight. The supply boats are generally from 100 to 200 feet in length.

Every year supply boats carry thousands of tons of supplies and equipment to the rigs. The simplest supply vessels are strictly cargo carriers; some newer models have expanded duties including towing and anchor-handling.

Fig. 4.20 Most supply boats are designed with their superstructure forward with an open main deck. The long, open deck is perfect for loading pipe, machinery, and supplies.

Below deck, the supply vessels use several tanks to bring diesel oil and fresh water out to the rigs. The rest of the hull space is devoted to the engine room, fuel tanks, ballast tanks, and void spaces. Void spaces are hull compartments that are left unused.

Many supply boats have cylindrical dry-bulk tanks fitted below deck. Drilling operations utilize tons of dry materials, such as cement and drilling mud. Most offshore rigs are equipped with dry-bulk tanks, too. The handling of dry-bulk materials from the supply vessel to the rig is done by means of hoses and compressed air. The operation is fast and eliminates much physical handling.

Even with bulk tanks, however, a substantial number of sacks of specialized materials, including cement and mud, are regularly carried to the rigs.

Many supply vessels are equipped with powerful winches. Winches are placed just aft of the superstructure and usually a large roller is set at deck level, running transversely at the stern.

Vessels equipped with winches and rollers are called tug/supply vessels. The winches and rollers are necessary in anchor-handling duties, where the supply boats help the mobile drilling vessels place and recover their giant anchor systems. The winch is also a necessary piece of equipment when the supply vessel is performing towing duties in the open ocean.

Anchor handling and towing require much larger propulsion power than a supply vessel would need for its own running purposes. An ordinary supply vessel may have twin screws totaling 2,000 to 3,000 horsepower. For towing and anchor handling, power is increased to 6,000 to 10,000 horsepower.

Some supply vessels have controllable pitch propellers to give quick control of the amount of thrust both ahead and astern. A number of these vessels have nozzels around the propellers to increase the towing pull. Many supply vessels have bow thrusters forward. The bow thrusters push the bow one way or the other during low speed maneuvering. Handling quality at low speed is important in rough waters. The vessel must be positioned within close range of the drilling rig, and yet not drift into a collision.

A supply vessel with controllable pitch propellers and a bow thruster can be wonderfully well handled in rough water by a skilled seaman.

4.12 Tugs

Fig. 4.21 A great number of tugs are used in many areas and types of operations in the petroleum industry.

Some tugs are primarily harbor tugs to help dock the oceangoing tankers.

Other types of tugs tow the non-propelled barges and vessels in protected water. Still others tow non-propelled vessels in the open ocean.

The smallest tug may be only about 40 feet long, with a 200 horsepower diesel engine. The largest may approach 300 feet long with over 20,000 horsepower on two propellers.

Besides towing and docking, tugs are sometimes equipped with fire-fighting equipment. Large tugs often have huge towing winches. Some are equipped for anchor handling assistance to the mobile drilling rigs, offshore derrick barges, ocean pipelayers, etc.

Harbor tugs almost always have quite low freeboard amidship and aft. Low freeboard keeps the towline as low as possible. Freeboard is the vertical distance from the deck to the waterline.

When pulling a towline that is in any direction other than straight aft, the pull has a tripping or overturning effect upon the tug. The higher the towline is attached to the tug, the stronger the tripping effect is. Ship designers keep towing bitts as low as possible to minimize the tripping effect.

A tug operator takes care to prevent the towing line from coming too close abeam. With great tension in the towing line, the tug can be capsized and sunk.

The harbor tug is designed with emphasis on developing the highest thrust possible from its propeller, and it has a large rudder for greater steering capability.

The larger harbor tugs are often capable ocean tugs as well. Ocean tugs for long distance and heavy towing, need bigger hulls than the usual harbor tugs. Great quantities of fuel must be carried for non-stop transocean tows.

Many ocean tugs have a forecastle running about half their length. The forecastle keeps much of the green seas (rough water or large waves) from coming aboard. It also gives more reserve buoyance to the hull.

Some ocean tugs are equipped especially for salvage work. The salvage tugs carry large portable pumps, a heavy-lift cargo-boom, extra anchors and cables, and other equipment.

4.13 Derrick Barges

Construction of drilling and production platforms in the open ocean has required the development of giant derrick barges.

A typical derrick barge for open ocean work is 400 feet long by 100 feet wide. Near the stern is mounted a huge revolving crane that can lift from 800 to 1,200 tons. Even larger cranes are in service which are capable of 2,000 ton lifts.

Fig. 4.22, a-d

Derrick barges set the jackets, the tubular islands extending from the ocean floor to a short distance above the ocean surface. Long piles are driven through the tubular legs into the ocean floor. The crane then places the upper part of the island on top of the jacket. Heavy packages of machinery, quarters block, and other items are then placed.

To keep it from moving around at sea, the derrick barge is equipped with a mooring system like the one used in semi-submersible drilling units. During storm waves or high swells, however, the hull rolls and pitches too much for the crane to safely handle a load. Lifting work must therefore wait for calm weather. When the weather is suitable, work is carried out around the clock. The derrick barge provides the living quarters for the 100 to 200 workmen on the site.

Most derrick barges are non-propelled. A few exist that are self-propelled and capable of making a trip without tugs.

4.14 Pipelaying Barges

Pipelaying barges were first developed for laying pipelines in the coastal zone of Louisiana and Texas.

Oil found in the swampy regions could be collected in tanks, loaded in barges, and towed out. Or if the quantity were sufficient, a pipeline could be laid to the refinery.

With gas there was no choice. Gas could only be piped out. Early pipelaying "spreads" for marsh areas consisted of inland deck barges outfitted with crawler cranes to handle pipe, welding equipment, X-ray gear to check the quality of the welds, and space to wrap the pipe and coat it with the cement that weights it down underwater. All these operations were spread over a number of barges tied end to end.

The modern offshore pipelayer must put all these functions into one large hull as rough seas do not permit a number of smaller hulls to be tied together. In many cases, but not all, the pipelayer has a huge revolving crane to serve as a derrick barge. Thus, the description given for the derrick barge also applies to the pipelayer.

The pipelaying function requires some special equipment to do the job. Once the pipe is brought from shore and loaded on the pipelayer, the pipe must be welded together, starting usually with 40 foot lengths of pipe. The joints are first prepared on shore by coating with a cement-like mixture to protect and weigh down the pipe on or below the ocean floor. This mixture is not applied near the ends of the joint, where welding is done.

The joints are welded together, X-rayed, wrapped, and the weight-coating applied. The pipe is then lowered gradually to the sea bottom.

Fig. 4.23

The pipe is fed through tensioners that keep the pipeline under control while being paid out. The pipe goes down an inclined ramp to the stern of the layer, and from here it rests on a long framework, called a stinger, hinged to the stern of the layer.

As each joint of pipe is welded on and paid out, the barge moves ahead by taking in the bowlines and paying out the stern lines. Large pipe, 24 to 48 inches in diameter, can be laid at a rate of a mile or so a day. Smaller pipe is laid at a faster rate. There must be a lot of pipe supplied continuously to the layer, frequent movement of the anchors, resetting of the anchors, and pipelayer movement ahead, joint by joint.

Pipelaying requires good weather. Barge motions become too great for pipelaying when waves are 6 feet high or greater. In higher waves, it becomes too rough to transfer pipe from the supply vessel to the layer. Thus, in the North Sea, a pipelayer of the conventional barge-hull type gets very little done during rough winter months.

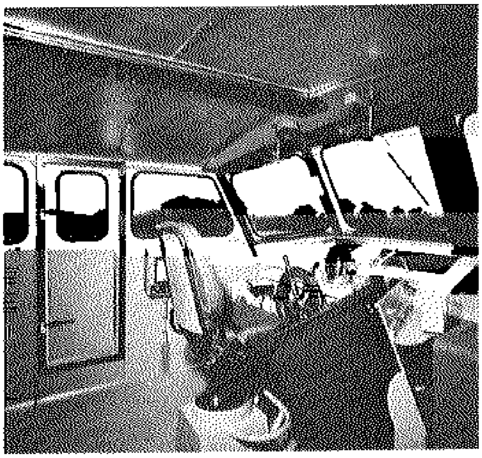


Fig. 4.15 Crewboat wheelhouse.

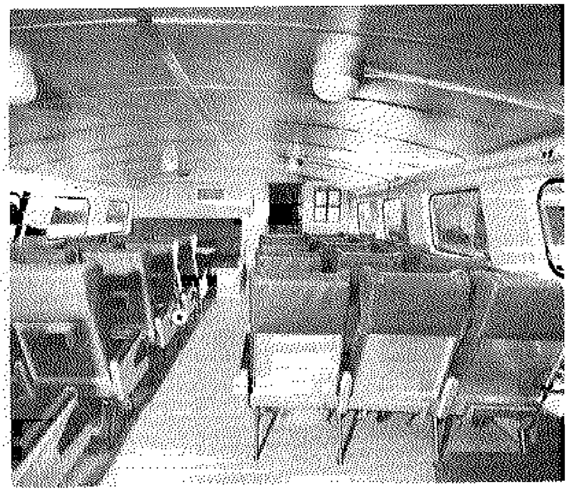


Fig. 4.17 Crewboat interior.

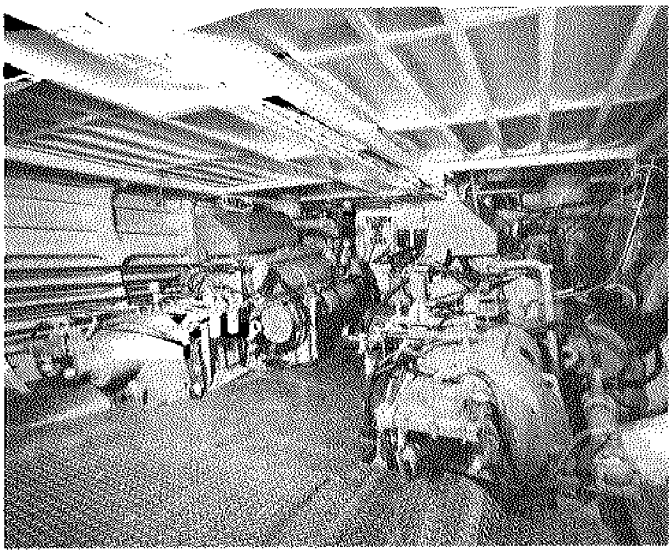


Fig. 4.16 Crewboat engine room

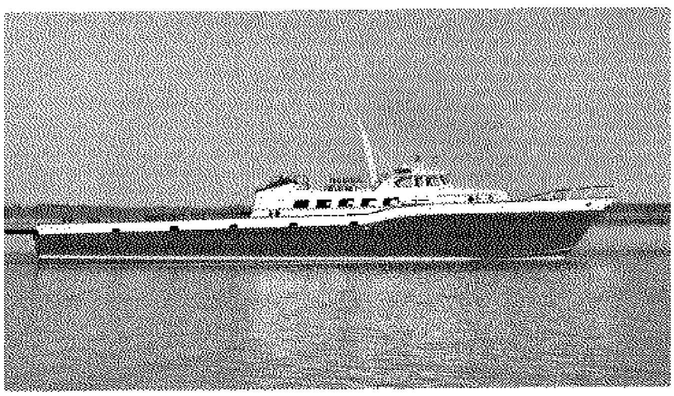


Fig. 4.18 Offshore crewboat.

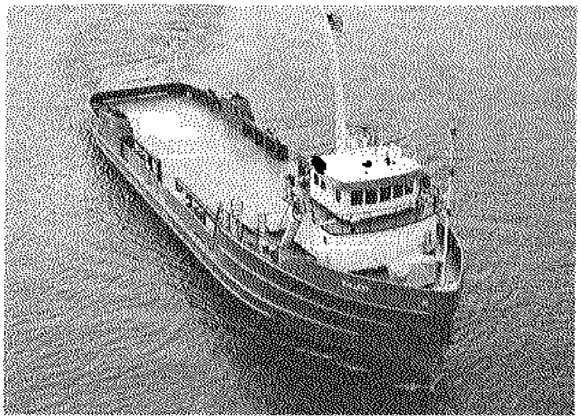


Fig. 4.19 Supply boat

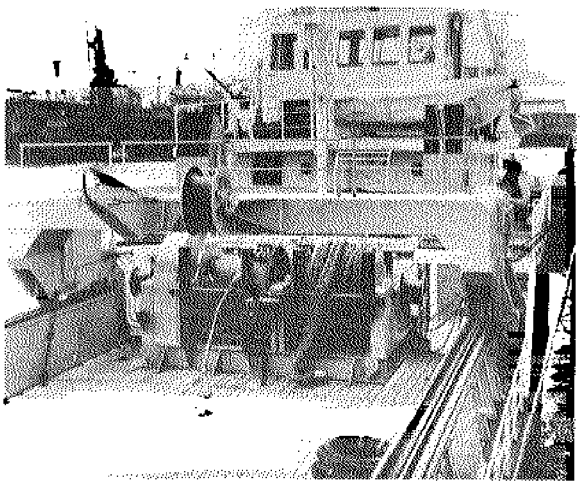


Fig. 4.20 Deck of tug/supply vessel.

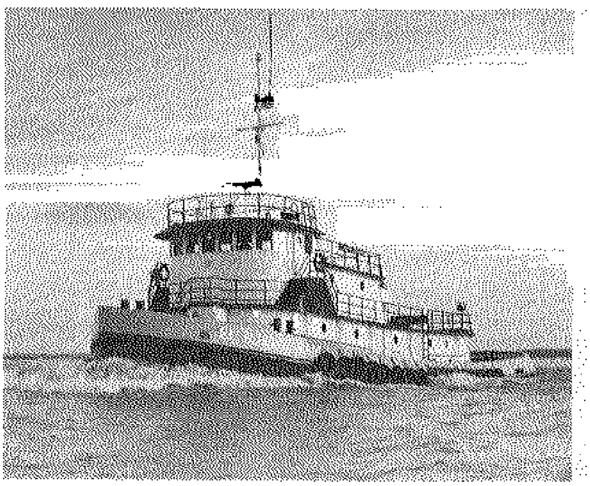


Fig. 4.21 Tugboat.

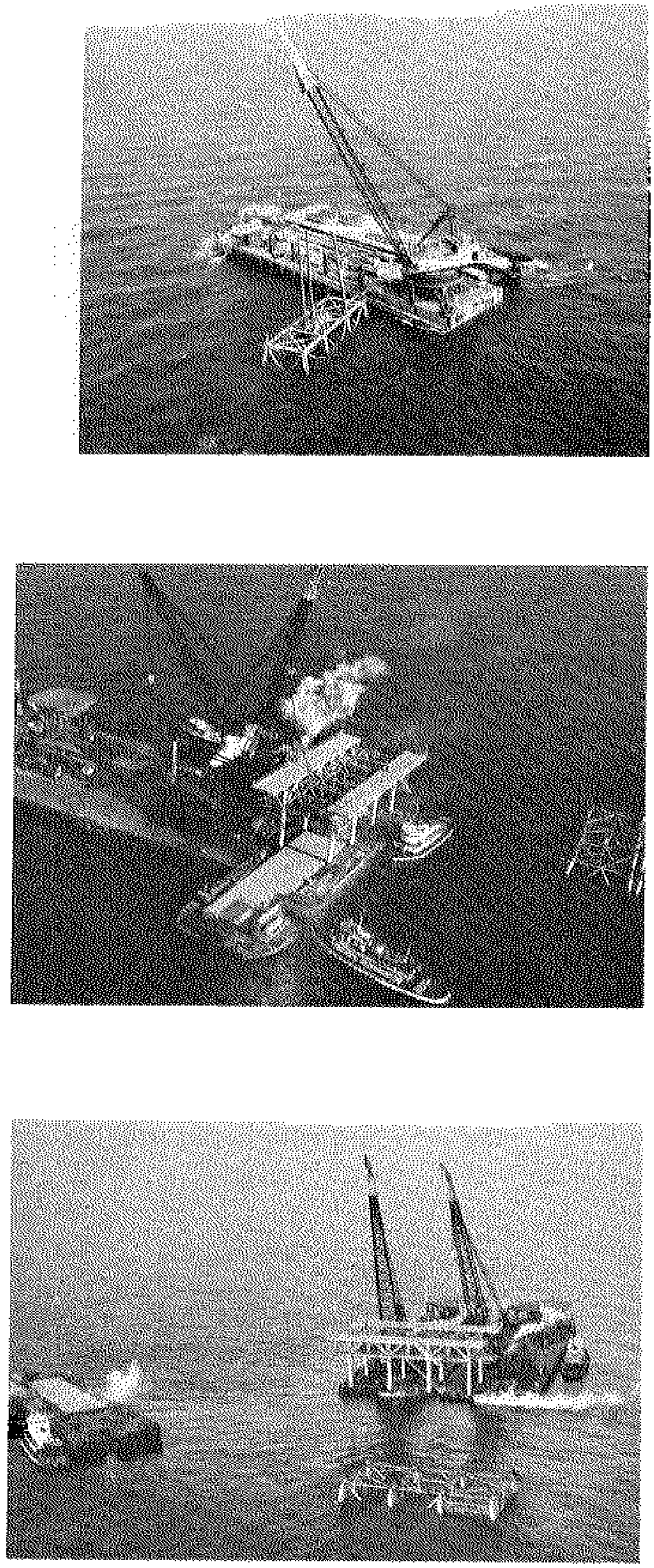


Fig. 4.22 a-c Installation of an offshore platform.

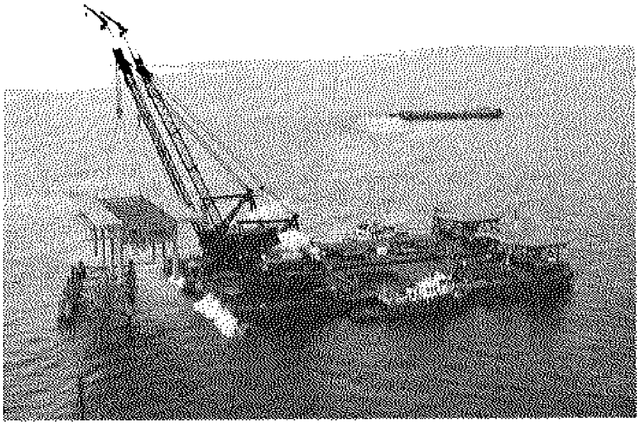


Fig. 4.22 d Installation of an offshore platform.

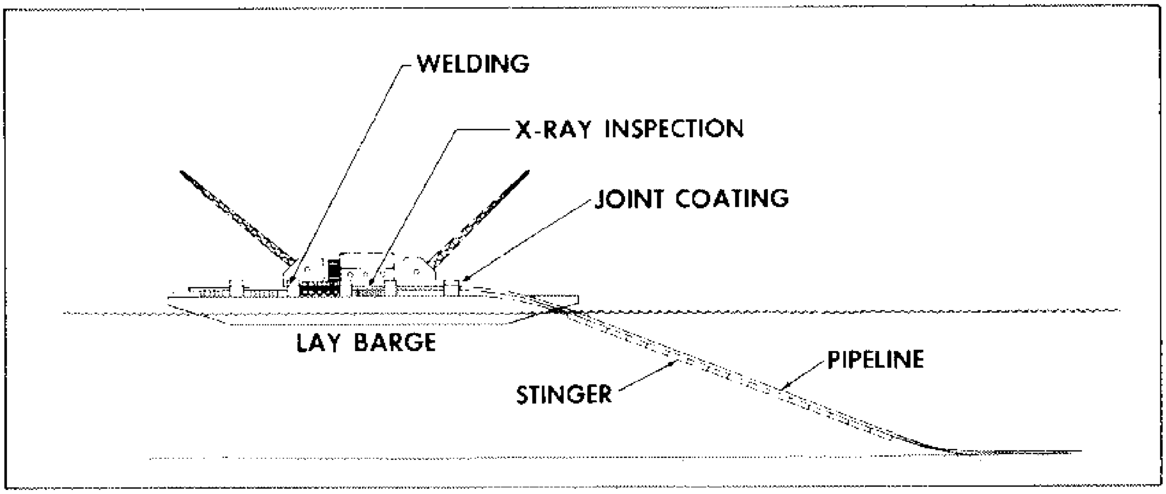


Fig. 4.23 Operation of lay barge.

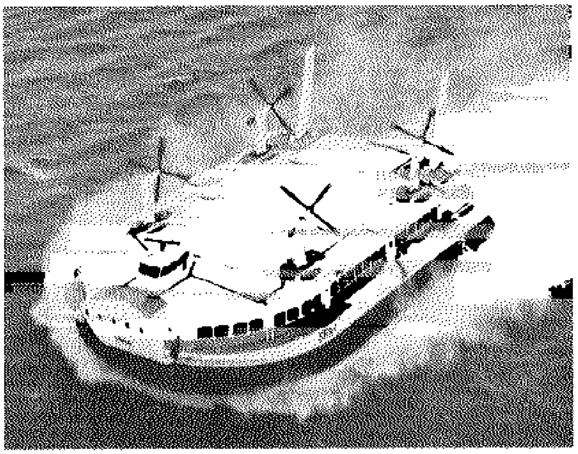


Fig. 4.24 Air cushion vehicles.

To overcome problems, the low-motion, semi-submersible principle is being applied to a new generation of pipelaying barges. While very high in initial cost, the new pipelayers are able to lay pipe in rough areas except when really bad storms occur.

4.15 Air Cushion Vehicles (ACV)

It is possible that in the future a new use may be found in the offshore mineral and oil transportation industry for the air cushion vehicle.

The ACV is a new mode of transportation with a lot of potential for crew and supply movement. It is a vehicle capable of being operated so that its weight, including its payload, is wholly or significantly supported on a continuously generated cushion or "bubble" of air. The air bubble or cushion is put under pressure by fans and generally contained beneath the vehicle's structure by flexible skirts or sidewalls.

Fig. 4.24

ACVs are also known as "hovercraft" or "surface effect" vehicles. The ACV has some advantages which include the fact that it is twice as fast as most modern crewboats. This speed becomes more important as oil leases move further offshore.

Load-bearing ability of hovercraft is similar to boats of the same size, which means that the ACVs should not force boat operators to trade cargo or payload for speed.

Additionally, the ACVs, which are currently in operation today, seem to be seaworthy, and they give a much more comfortable ride in moderate to light seas than the crewboat does.

Of course, there are a great number of unknowns when it comes to dealing with the ACVs. Would the crews currently operating the crewboats be able to handle ACVs? Would the maintenance costs be prohibitive? Would ACVs stand up to the actual offshore work load? These questions must be answered before the ACV becomes accepted as a member of the petromarine fleet.

5. PRODUCING OIL AND GAS

We have now discussed the methods used to find offshore oil deposits, means of drilling wells, and the marine vessels used in the process. Now we can turn to the area which follows exploration--the oil and gas production.

Once an oil field is discovered, and its dimensions outlined, the field must be developed. This development is accomplished by drilling a number of additional wells to drain oil and gas effectively, a process that might take from five to seven years.

The mobile drilling rig, which makes the initial
Fig. discovery, is moved to another location and replaced with a
5.1 "production" platform. It is from the production platform that additional wells are drilled. When a number of wells are drilled from a single platform, directional drilling techniques are used. Such directional drilling allows the
Fig. platform to reach oil more than one mile away, in horizontal
5.2 distance, from the platform. After twenty to sixty wells are drilled, the production platform then becomes the support facility for equipment through which the wells produce.

As drilling is completed on each well, production casing is placed in the hole and cemented into place. Additional, smaller pipe, called "tubing"--through which the petroleum is to flow--is usually suspended inside the innermost string of casing from an assemblage of valves and other equipment at the wellhead. The wellhead assembly is a series of valves, controls, and connections designed to regulate the flow of fluids from the well.

Devices called downhole safety valves are installed in the tubing string below the ocean floor. These valves are designed to automatically shut in the well when flow pressures vary from the normal predicted pressures. Some valves are designed to be operated from the surface.

Master switches, located at various places on the rig, are designed to shut down all operations should an emergency occur that might endanger life or property or cause an oil spill. Other safety devices include automatic and manually operated valves, alarms, and monitoring and recording equipment.

Dry holes are permanently plugged by pumping a cementing material into the well. This seals the layers that have penetrated and prevents leakage between the earth formations or into surface waters. All casing on a dry hole is cut off 15 feet below the ocean floor, and the ocean floor is then dragged for any remaining objects.

Wells are protected by a small four-pile installation known as a well jacket. Well jackets are connected to a production platform by the two- to four-inch diameter flowline. Usually, oil and gas are separated on the platform. It then flows ashore through pipelines.

Most production platforms are built of steel, but a few of the facilities in shallow water have concrete piling and deck sections.

A typical shallow-water production complex contains on its platform oil and gas separation equipment, pumping equipment, living quarters, and offices (Fig. 5.3).

Figure 5.3 shows a deepwater production platform in-
Fig. 5.3 stallation. The template, or jacket, is transported to location by barge. A derrick barge lifts the jacket, setting it in an upright position.

In an extremely soft-bottom sediment, mud skirts provide additional stability. Also, the derrick barge drives main piles that measure 30 to 48 inches in diameter. These piles penetrate the ocean bottom by 200 to 400 feet.

Deck sections are set on piles and welded in place. As much equipment as possible is pre-assembled on the deck sections. The pre-assembly reduces the number of derrick-barge lifts.

Early platforms were built using small sections. That was a time-consuming procedure and was replaced by the practice of fabricating larger sections. A drawback to the larger sections, however, was the strain placed on the lifting capacity of the derrick barges. As mentioned in the derrick barge section of this unit (section 4.13) the lifting capacity was continuously increased.

However, despite a growth in the lifting capacity of the modern derrick barges, some jackets weigh more than 2,000 tons. Derrick barges are unable to handle large platform jackets which are designed to be used in water depths of 200 feet or more.

Two techniques have been developed to install larger jackets. One is the method of launching the jacket from a barge. The second is to use a caisson-type floating jacket.

The jacket is launched from the barge into the water by ballasting the barge in a manner so that the jacket slides off into the water.

After launching, the jacket is rotated to a vertical position by a derrick barge. Then, the derrick barge drives the piles, sets the deck, and installs the equipment.

The floating jacket approach is used in remote locations where large derrick barges are unavailable, or in cases where the jacket is too heavy to be lifted with conventional equipment.
The caisson-type jacke
The caisson-type jacket is floated into position. The legs are normally 15 to 20 feet in diameter. The legs provide buoyancy and stability during the controlled sinking operation.

A number of major oil companies have taken leases in waters ranging to 900 feet. As the trend toward operation in deeper water continues, several companies have developed technology and equipment for completion and maintenance of underwater wells.

One application for this type of equipment arises when wells cannot reach all parts of a reservoir with directional wells drilled from a single platform. In such a case, satellite underwater completions can be used for surrounding wells. Another application springs from wells that produce directly to shore, without using production platforms. There are several such installations off the coasts of California and Peru.

The ultimate advantage of subsea systems is, of course, the deep water application. It is hoped that eventually
Fig. 5.4 subsea completions will provide production facilities in water depths where fixed platforms are likely to be unfeasible. Total subsea operations might also be necessary in hostile environments where ice presents a problem.

At present almost all subsea completed wells have their flowlines run to a platform, to shore, or to a buoy to accomodate and control the production.

New types of structures are being called upon to aid in the change from fixed bottom supported platforms to a total seafloor production. Most experts feel that some sort of platform will be required with subsea systems for quite some time to come. These platforms must provide crew quarters, oil storage facilities, separation equipment, auxilary
Fig. 5 5 equipment, and transportation facilities. One such structure is the Elf-Ocean articulated column, which was designed to support drilling and production operations. Floating production units, such as the tension leg platform and the SPAR floating storage platform, have a greater water depth capability than bottom supported storage structures and can

be moved from location to location. Many companies are currently using ELSMB (exposed location single mooring buoys) in conjunction with fixed platforms and subsea completions. These buoys receive crude production and deliver it directly to shuttle tankers that deliver the petroleum to refineries.

Huge new storage tanks and platforms (called gravity structures) have been built of concrete. Gravity structures are desirable in waters such as the North Sea where water is too deep or too rough to drive pilings. Unlike other fixed bottom supported platforms, gravity structures do not require piles to hold them in place. Ballast such as seawater keeps the structure anchored to the ocean floor.

Fig. 5.6

The heart of all subsea systems is the underwater christmas tree, which is installed on the subsea landing base by a mobile rig after the drilling and completion operations are complete.

Subsea christmas trees can be divided into two basic types, the "wet" and the "dry." The wet type has all components exposed to the sea and must be serviced by specially designed manipulators, conventional divers, or by recovering the tree or components to the surface. The dry type has all tree components housed in a chamber. This system can be serviced by men working in a normal pressure air environment on the seafloor.

Typically, the wet tree is completely assembled and tested before it is installed from the drilling rig. The tree is lowered and latched to the seafloor landing base with a hydraulic connector controlled from the rig floor. With the dry chamber system, the chamber is lowered and latched to the landing base in a manner similar to the wet tree. However, all of the tree parts are disassembled and stowed inside. After the rig moves off the location, a service boat is moored near the well and a capsule called a DUC (downhole utility capsule) transports men to and from the chamber where they assemble and service the tree.

With both systems divers are often required to perform various operations. Closed-circuit television is used to check on the position of the underwater drilling and production equipment. An experimental robot was recently built to perform a limited number of operations on a specially designed christmas tree.

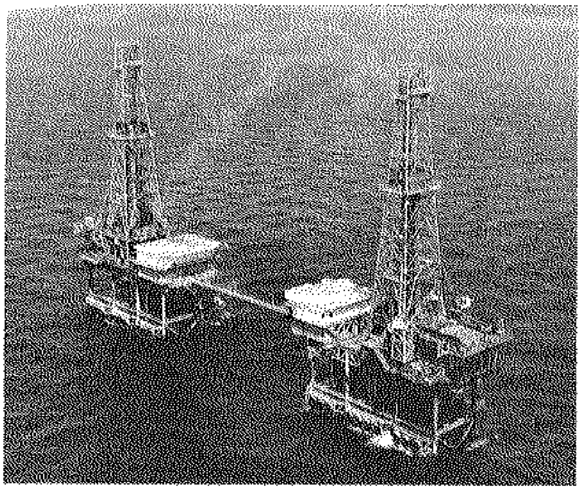


Fig. 5.1 Production platform.

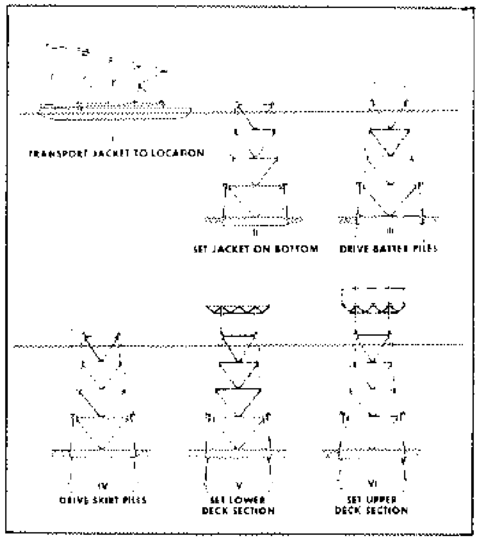


Fig. 5.3 Platform installation procedure.

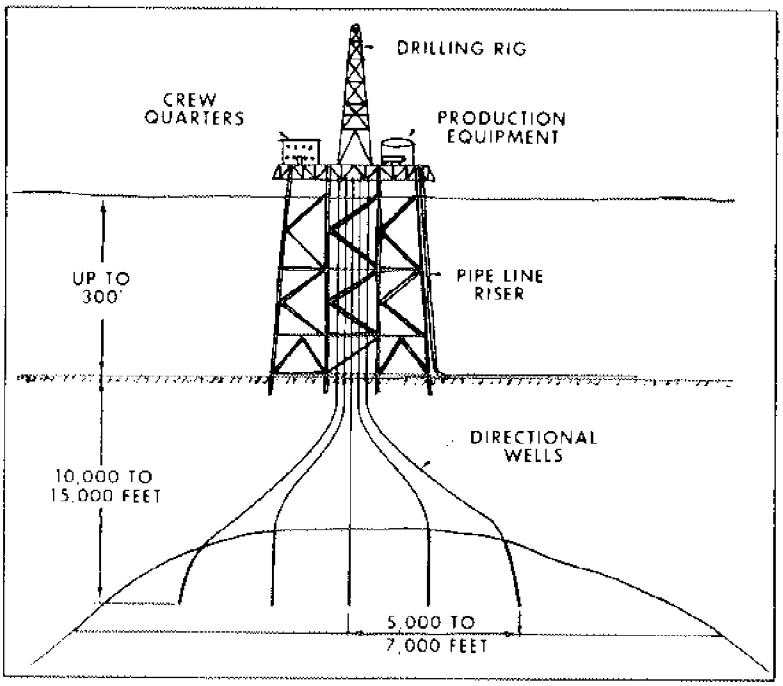


Fig. 5.2 Directional drilling techniques.

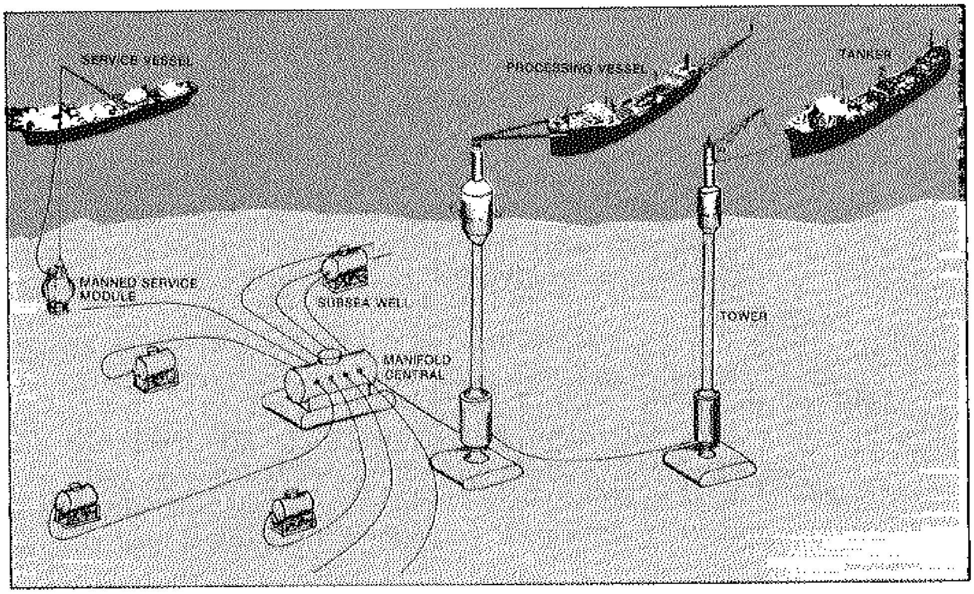


Fig. 5.4 Subsea production system.

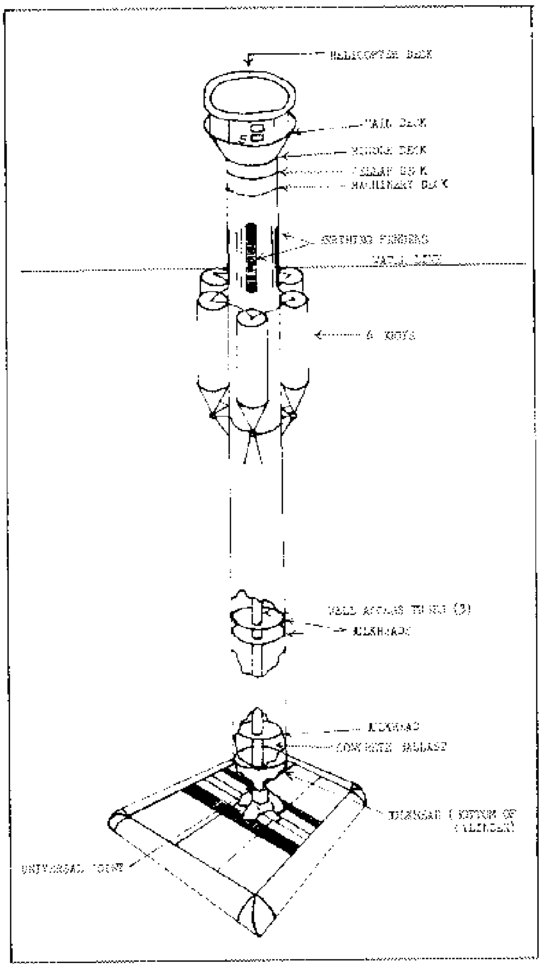


Fig. 5.5 Elf-Ocean articulated column.

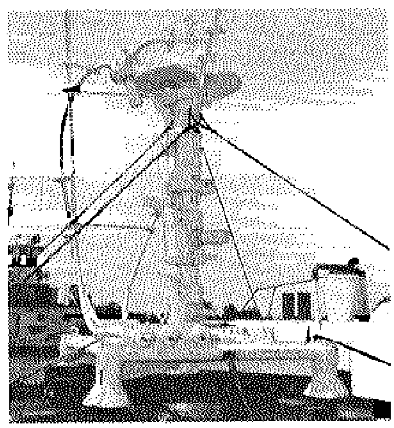


Fig. 5.6 Underwater christmas tree.

6. DESIGN PROCEDURES

In this part we shall consider the process by which a vessel is designed and built. The process is interesting and involves many people from the time the owner of a company desires to have a vessel built to the time the vessel is delivered to the owner by the shipyard.

You will have a first-hand look at design drawings, model testing, and construction procedure.

Vessels are not designed and built in a haphazard manner. Hopefully, the knowledge you gain in this part will cause you to appreciate and respect the wonderful vessel on which you may be employed one day.

6.1 Owner Requirements

The design process for any vessel or piece of equipment starts with the requirements of the owner who will pay for and use the vessel or equipment.

The owner first establishes his needs--that is, is he trying to drill for oil, move cargo from one place to another, supply already working oil rigs, or perform another service? The owner must also determine what type and size of vessel will suit his particular operation. Once he has estimated the type and size of the vessel, he must do an economic analysis.

The economic analysis cannot begin until the owner talks with a designer. The designer may be a consulting naval architect, a representative of a shipyard engineering department, or the owner's company engineer or design consultant. At any rate, the owner explains what he wishes to accomplish with the vessel he wants built.

The designer makes preliminary plans, and from the plans estimates the cost of construction. The owner's economic analysis begins by calculating the construction costs. Other factors to be considered are the crew costs, fuel, food, and repairs and maintenance. Also, interest on borrowed money (if any), taxes, port dues, overhead, and other expenses are figured.

From that point, the owner looks at estimated revenue. He must determine if the revenue will pay off the vessel in a reasonable period of time, usually seven to ten years, and provide a rate of return on the investment that is higher than he could make by investing his money in another way.

Once the owner has decided on a particular vessel for his company, he gives the designer all the data he can. The data will enable the designer to know exactly what the owner wants.

Data made available to the designer may vary from "Hey, John, design me a towboat to push a 6,000 ton oil tow up the Mississippi!" to a full set of performance specifications and preliminary plans.

The owner gives the naval architect all the information necessary to enable the designer to build the vessel suited to the owner's needs. The owner should specify how much and what type of cargo is to be carried and the speed requirements. The area of operation (North Sea, Gulf of Mexico, etc.), the number of crew and other persons to be carried are important. Special equipment, such as a crane or winch, or special cargo arrangements are important to the designer.

In areas where the owner is not specific, the designer must use his knowledge of the vessel type and operation to develop the best unit for the owner.

6.2 Design Drawings and Specifications

The process for designing a specific vessel is one of development. An estimate is first made of the physical dimensions of the hull and the power required for the design speed. Then the plans are developed to suit these estimated conditions. After the plans are sufficiently developed, those values that can be calculated are found, and if the first estimate was not quite correct, then the characteristics and dimensions are adjusted so that the vessel will be built within the budget. The designer gives detailed construction drawings to the shipyard as instruction. These drawings are also sent to the regulatory bodies for review at the completion of the design.

The specifications are an accumulation of facts and descriptions concerning the vessel to be built and a list of the requirements to be met by the builder concerning the performance and quality of the ship. The dimensions of the vessel along with the displacement, expected speed and deadweight, are all spelled out in the specifications. In addition, the number of cargo holds, type of machinery, number of staterooms, and a listing of the furniture and type of construction for the quarters is included. A complete listing of all the machinery and the machinery sizes and details, methods of operations of each piping system, and any other systems are also defined.

General arrangement drawings fully describe the arrangement of the vessel showing layouts of each deck, an inboard profile, and any other details necessary to show how the vessel will look after construction.

Fig. 6.1 The line drawing is a very special drawing which describes the exact shape of the hull of the vessel.

Some of the early shipbuilders made their craft from a small model and enlarged the proportions of this to the full-size ship. Others, at a later date, built from a scale drawing that depicted the contours of the hull by the use of various shaped planes.

The method employed today to depict a vessel's form is by a drawing called the lines, or more correctly, the lines of form. This drawing is a composite one, in which the shape of the hull is shown by various planes cut through the hull at stated intervals. Some planes are horizontal to show the shape of the ship at the stated points horizontally. Also some planes are vertical to show the shape of the ship vertically. In addition to these, there are also transverse planes cut across the ship vertically at given intervals, to show the shape of the ship at the stated points. (Fig. 6.2)

The horizontal planes are called the water lines, or water planes. They are drawn at, and parallel to, the surface of the water at which the ship is designed to float. If a model of a ship were whittled out of a block made up of horizontal layers and then taken apart, the shape of each layer would be the shape of a water plane at the joints between the layers.

The vertical planes are called the buttock lines and are planes parallel to the ship's center line and at right angles to the water line. They would be the shape of the layers, if the model referred to previously had been built with the layers in a vertical, fore and aft, direction.

The sections, stations, or frame lines are planes taken at right angles to the ship's center line and at right angles to the water lines. They depict the shape of planes cut through the hull in a transverse direction much in the same manner as a saw cut through a model would appear when looking directly at its face.

The lines drawing is composed of three views showing the successive horizontal planes in one view called the plan, in another showing the vertical planes called the profile, and in another showing the transverse sections called the body plan.

The plan shows the contours of all water lines, the shape of the deck, the location of the buttock lines, and the location of the sections or stations.

The deck line on the plan shows the half widths of the deck at all the stations as well as its contour around the stern of the vessel and at the bow. As both sides of the ship are alike, only half a plan is usually drawn.

The profile shows the contour of all of the buttock lines, the sheer or curvature of the deck, the shape of the bow and of the stern. On it is given the location of all the water lines and stations. This drawing is most generally drawn as a projection of the plan view, with the station lines continued across its surface from the plan below.

The body plan shows the shape of all transverse sections and is drawn with the sections aft of the midship section of the ship on one side of the center line, and the sections forward of midship on the other side of the center line. The body plan shows the water lines and buttocks as straight lines, sheer of the deck is shown in the body plan as a curved line if the deck has sheer, as a horizontal line if sheer is not present.

Structural drawings or scantling drawings show all of the structure and the sizes of the structural members used to build the vessel.

A midship section drawing shows a typical section of the vessel cut transversely to show the shell plating, side frames, longitudinal bulkheads, decks, and the frames that support these items. Profiles and deck plans complete the pictorial description of all of the structure that goes into the construction of the vessel.

Fig. 6.3

The machinery arrangements drawings depict the locations, types and sizes of all the major machinery and most of the auxiliary machinery. The main engines, reduction gears, shafting, bearings, and propellers are always well defined and arranged on the drawings. Generally, the innerbottom, each level in the machinery space, and all auxiliary space levels are shown. Elevations and sections of these areas are also included.

Fig. 6.4 Piping diagrams are generally included in the design plans to describe each piping system such as bilge, salt water, compressed air, fuel, and other lines to define the method and equipment to be built into the vessel.

Electrical diagram, generally referred to as the one line diagram, is another drawing made for the builder's use in estimating and building the vessel. This drawing describes, by one line on paper for each electrical connection, the power generation and distribution system for the ship.

The above drawings are the ones generally provided to describe the way the ship is to be built. The structure, shape, machinery, outfitting, and quarters are well defined by these drawings. The specifications require the builder to meet certain regulations, performance requirements, and they define other details and generalities that cannot be described by the drawings.

The following drawings are furnished to give the shipyard and the regulatory bodies data to confirm the design for stability and operational ability. These calculations and drawings are made by the designer based on the best estimates he can make, at this point, of the shape, weight estimate, and locations of equipment. All of these calculations and drawings are made again by the shipyard based on the final and exact data developed by them for the actual ship built. At this point in the development, however, it is essential that everyone--designer, owner, regulatory bodies, and shipyard--be sure that the vessel as designed will indeed do the job required and do it safely.

The hydrostatic curves or curves of form are most important at this point. This drawing, which is a set of curves that depict the characteristics of the vessel, is made with draft as the vertical scale and the following items plotted horizontally:

a) Displacement, both molded and total, in fresh and salt water.

b) Vertical center of bouyancy.

c) Longitudinal center of bouyancy.

d) The height of the transverse metacenter.

e) The height of the longitudinal metacenter.

f) The moment to trim the vessel one (1) inch.

g) The longitudinal center of flotation or center of area of the water planes.

h) The tons per inch immersion.

These values are calculated as explained later in this chapter.

The trim and stability calculations are made to show that the vessel has the ability to trim properly and retain adequate stability in any of the anticipated operating conditions. These are usually in the form of calculations, so made in a standard format that anyone familiar with these calculations can follow them no matter what vessel is being considered. The data for these is also defined in more detail later.

For larger vessels longitudinal strength calculations are also made. These figures show that the vessel has ample strength in the length of the ship for any loading condition that might be encountered, in calm water, or in any waves that are likely to be met by the ship.

6.3 Regulatory Agencies

All of the afore-mentioned drawings and calculations are sent to the regulatory bodies that exercise control over the design and operation of each vessel. These groups include the following.

6.3.1 The United States Coast Guard. This governmental agency is charged by law to preserve the safety of all vessels and their personnel. They, therefore, are very interested in the design of the ship for safety, navigational equipment (lights), lifesaving appliances, fire fighting equipment, and other equipment onboard the vessel that could cause an unsafe condition. The Coast Guard publishes regulations for all types of vessels. Those of interest to the oil industry would be passenger vessels, tankers, mobile offshore drill units, cargo and miscellaneous vessels, which would include supply vessels, and uninspected vessels, which include vessels not inspected for stability, strength, or equipment such as tug boats and river towboats.

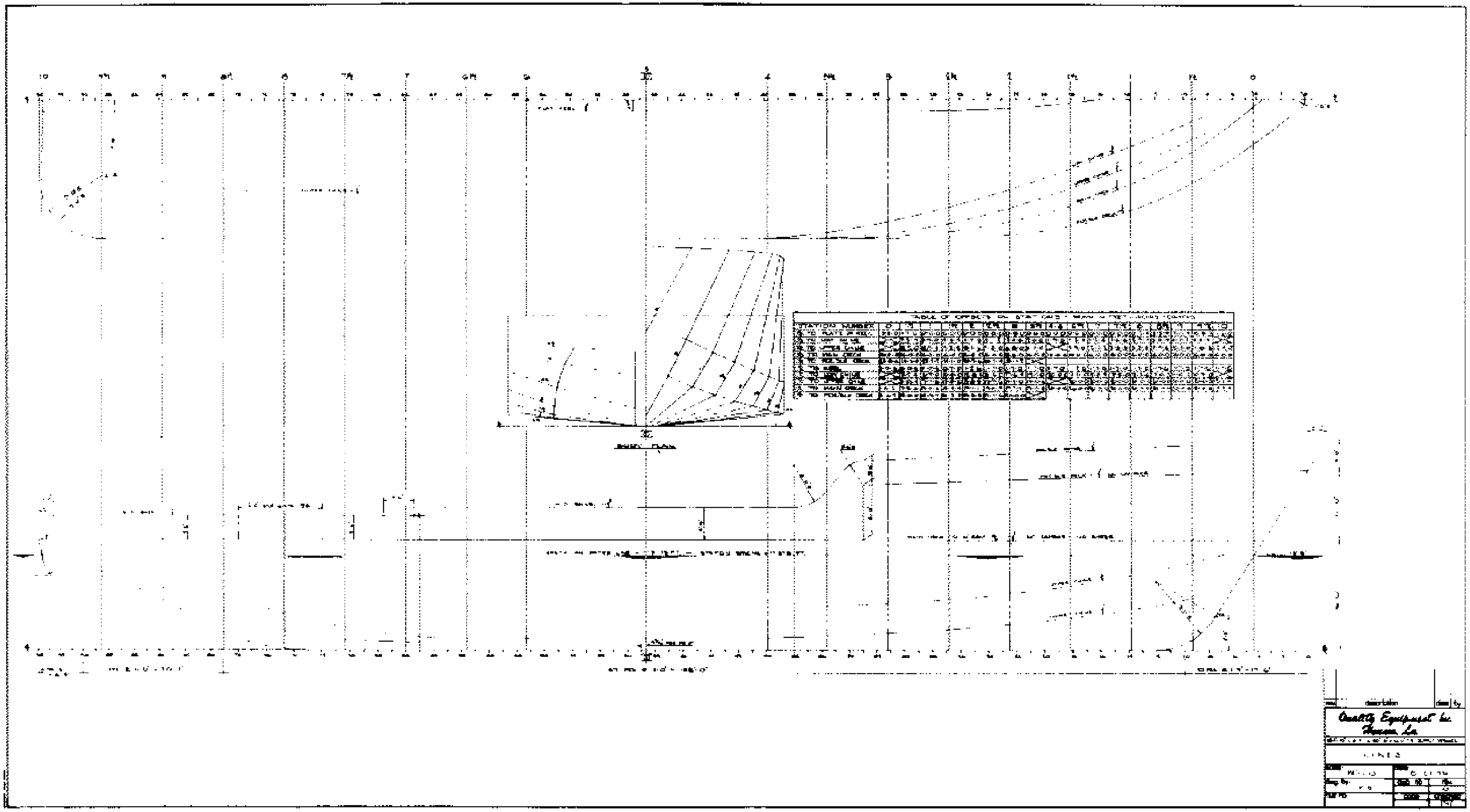


Fig. 6.1 Lines drawing.

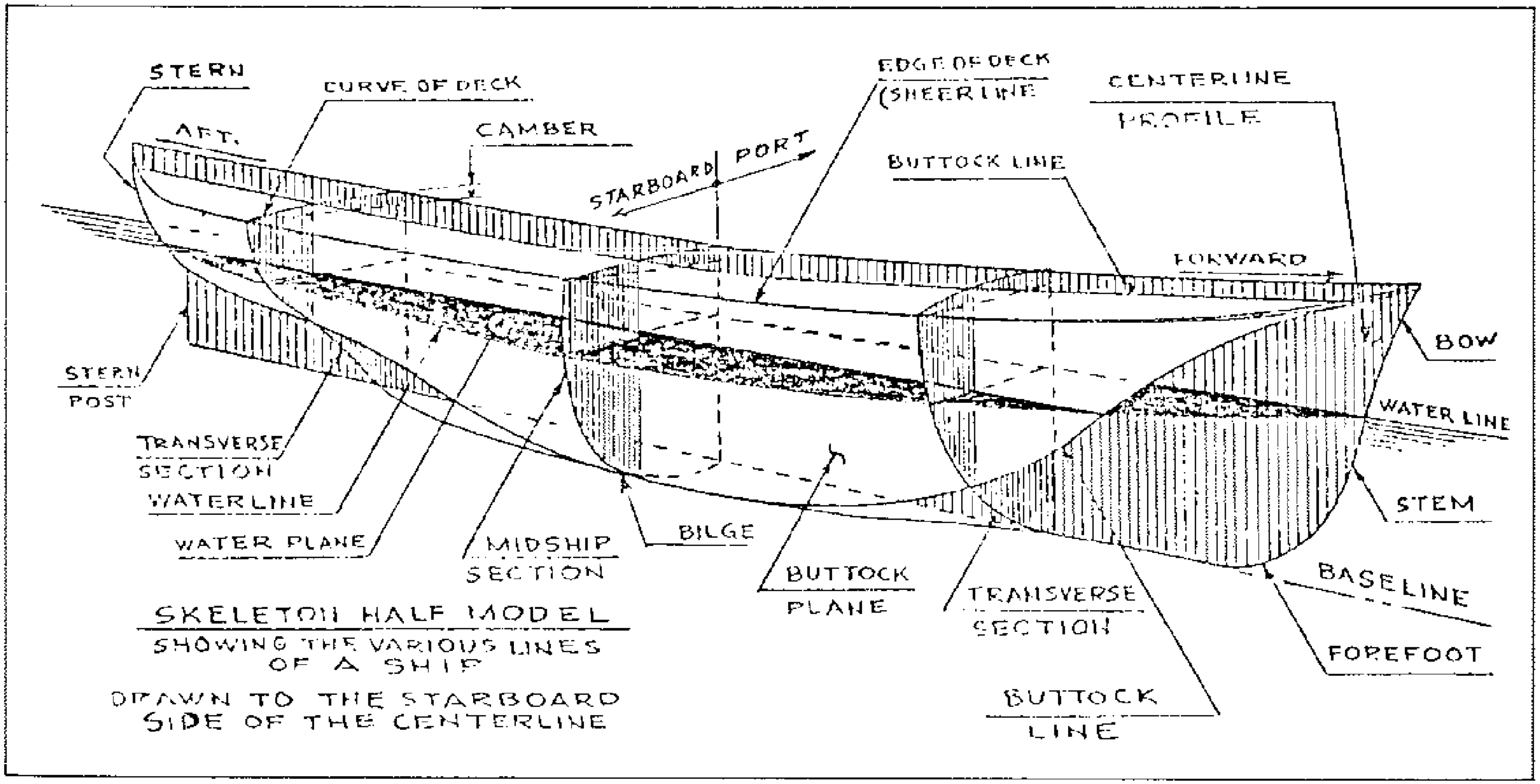


Fig. 6.2 Skeleton-half model and terminology.

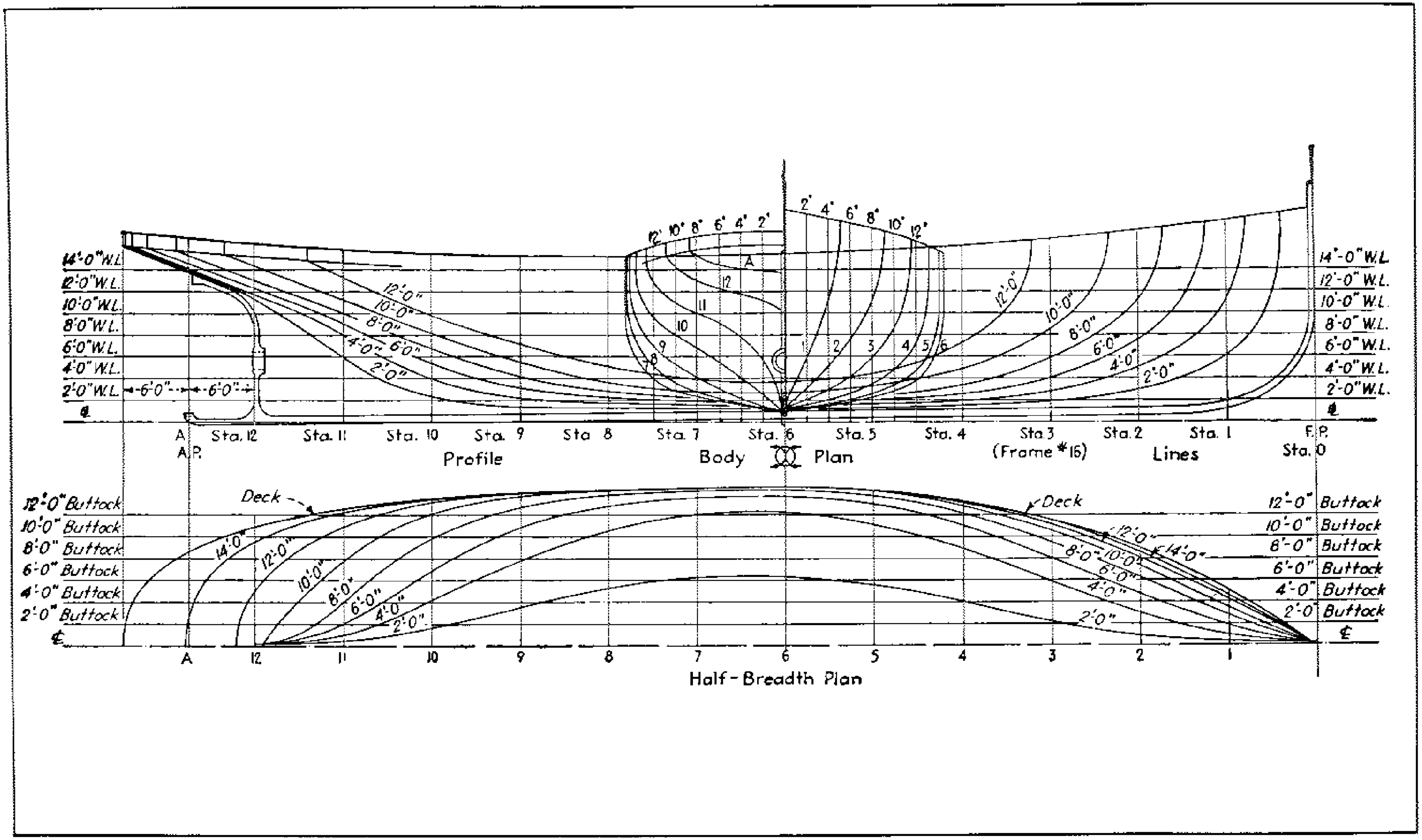


Fig. 6.3 Midships section drawing.

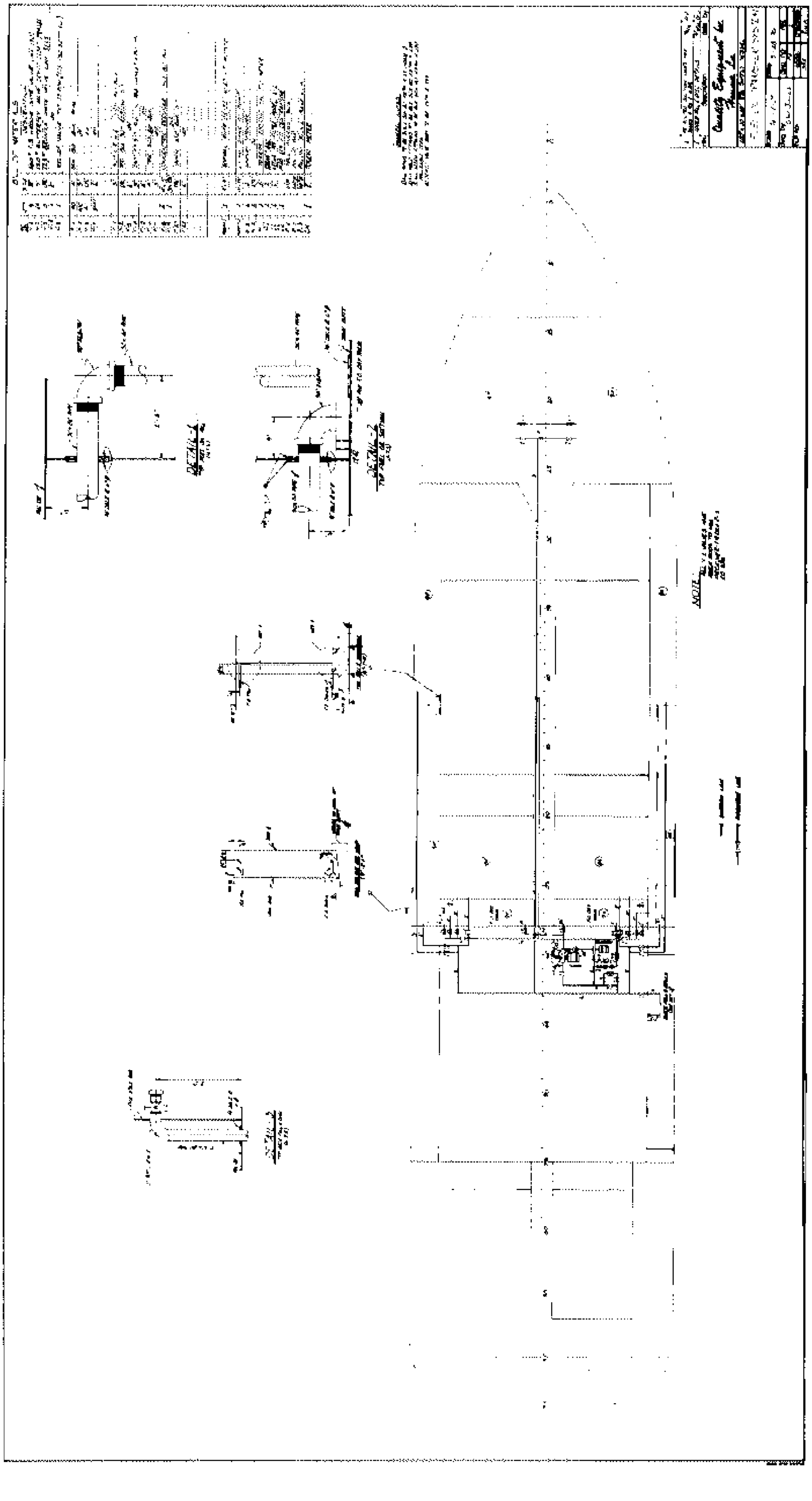


Fig. 6.4 Piping diagram.

The only interest here by the Coast Guard is in navigation lights and lifesaving and fire fighting equipment.

6.3.2 The American Bureau of Shipping. A non-profit society, the American Bureau of Shipping was formed by all the vessel owners to set standards of construction for all kinds of vessels so that the insurance companies and other interested parties will have a standard by which a vessel can be measured for safety. Lloyds Register in England, Bureau Veritas in France, Germanische Lloyd's in Germany, and Norske Veritas in Norway are other societies accomplishing the same purpose in their countries. Each of them can also class vessels in countries other than their own.

An owner will generally select the classification society, as these groups are known, which he wishes to have cognizance over his vessel. The specifications will also specify the class to which the vessel is to be built. That is, the society will list it for service--tanker, tug, supply vessel, etc.--and also for area of service such as full ocean going, rivers, or restricted ocean services. A supply vessel, for instance, which will operate in only the sheltered waters near shore would be classed as "Supply Vessel ✠ A1Ⓔ Restricted Coastwise." The maltese cross (✠) means that the vessel has been inspected during construction. The Ⓔ means that the equipment, such as anchor chain and hawsers, has been inspected and tested at the manufacturer's plant. The A1 indicates that the design has been reviewed and approved for strength.

These agencies generally require that the design drawings be sent for their review as early as possible. In addition they require the shipyard to send all of their detail drawings for approval before construction is started on any item on that drawing. The shipyards must also send drawings to the U.S. Public Health Service for review from a "sanitary construction" aspect. If the Maritime Administration is also involved in the financing or subsidizing of the construction of the vessel, they will require a set of construction drawings be sent to them for review.

6.4 Design Calculations

One of the most important aspects of a naval architect's work is the making of the calculations that determine the behavior of the vessel. It is essential to know, before the vessel is built, exactly how it will operate under the conditions anticipated for it. The operators of the vessel must be assured of the characteristics of their ship so that they know they are making a wise investment. The items of interest to the owner are how much cargo will it carry, how fast will it go, what happens if they move weights forward or aft or one side to the other, and, most importantly, will it remain stable, that is, stay upright through all its working life. All of these questions can be answered by the naval architect based on the following calculations:

6.4.1 Buoyancy and displacement. The fact that a steel vessel will float is often a puzzling problem to the layman. If a piece of steel is placed in water it would immediately sink even though a steel vessel in the same water will remain afloat. All such phenomena as this obey natural laws. The law of buoyancy was discovered by Archimedes. Stating it briefly, the principle underlying the Archimedian Law of Buoyancy is this: Any body immersed in a liquid will be supported in that liquid by a force equal to the weight of the liquid that it displaces.

The piece of steel that was thrown overboard, being heavier than the water which it displaced, sank. The volume of a ship is mostly hollow, and, since it weighs less than the volume of liquid it displaces, it floats. If we were to have thrown the steel bar into a pool of mercury instead of the water, we would have seen the uncommon sight of steel afloat. This would have been due to the fact that the steel, being lighter than the mercury of the same volume, would have been supported by a force equal to its weight.

If we were to fill a bowl with water to the point where it would not hold a drop more, and place a steel ball or other non-buoyant object in the water, we would find that a certain amount of water would overflow. If we were to measure the amount that overflowed, we would find that it exactly equalled the volume of the ball or other object placed in the liquid.

Carrying this experiment further, if we were to place a wooden ball in the water and again measure the overflow, we would find that the weight of the liquid overflowing would exactly equal the weight of the wooden ball.

From the foregoing it becomes evident that to know whether a body or ship will float or sink in water, two things must be known: first, the weight of the ship or body, and secondly, the volume. The weight of the ship can be calculated by taking each of the component parts and calculating its weight. The summation of all the separate weights will produce the weight of the ship as a whole. The volume of the immersed hull can readily be calculated by Simpson's Rules or other methods. If we know the weight and immersed volume, we can determine whether or not the ship will float.

So far we have dealt with water, disregarding its density. Fresh water will be less dense than sea water, and hence a ship will have to displace more fresh water than salt water to support a given weight. Ships leaving the Mississippi River at New Orleans, with a draft of about 28 feet, will draw about five inches less when they enter the Gulf of Mexico than they drew in the freshwater river.

A ship's displacement is generally calculated in units of tons of 2,240 pounds each (long tons). Thirty-five cubic feet of sea water or thirty-six cubic feet of fresh water will weigh one ton. Thus by dividing the immersed volume of the ship in cubic feet by thirty-five or thirty-six, we can get its weight in sea or fresh water.

The calculation of buoyancy is a rather simple one even though laborious. The areas of the water lines are first calculated and then put through Simpson's Rules for Volume. The volume in cubic feet is then divided by thirty-five to get the tons of water displaced by the vessel. In regular practice this process is repeated for each water line. The "curve of areas of the water planes" is first plotted, and from this, the areas are picked off at intervals and put through Simpson's Rules to get the volumes. From the volumes the displacement is calculated and plotted at the various water lines, giving us the ship's displacement curve.

The displacement curve gives the ship's displacement at any given draft and is much used by the ship operator to get the displacement after his ship is afloat. At each end of the vessel and amidships, before it is launched, marks indicating the draft are painted on the hull. Figures for these marks, as a general rule, are six inches high and spaced each foot. The bottom of the figure is the line of draft that the particular figure denotes. Thus if the vessel is floating half way up on the twelve foot mark, she is floating at a draft of twelve feet-three inches at that particular point. In the calculation of displacement, the mean of the two end marks is taken to read off the curve. Thus if she is floating at ten feet aft and eight feet forward, the mean of these two (nine feet) is taken as being the draft that is read off the displacement scale. Drafts are taken above the lowest point of the ship's keel.

Another useful curve relating to displacement is the curve of tons per inch of immersion, usually referred to as the tons per inch curve. This curve gives the amount of displacement that will be caused by the vessel sinking in the water, or increasing her mean draft, one inch. It is obtained at any given water line by dividing the area of that water line in square feet by twelve to convert a layer one inch thick into cubic feet, and then again by thirty-five to get the tons displacement in sea water.

6.4.2 Center of buoyancy. The center of buoyancy is a theoretical center point of the volume of the displaced water. Another way to look at it is that it is the point through which all the buoyancy force can be exerted on the hull and cause the same behavior of the hull as the total buoyancy force does acting all along the total hull. This center must be calculated from three different base lines. The naval architect is interested in how high the center of buoyancy is above the keel, how far it is from the midpoint of the vessel (the point called midships), and how far it may be off the center line one side or the other. Most vessels are symmetrical about the center line and therefore the center of buoyancy will always remain on that center line, but it is best to always remember that it must be defined in three dimensions. This center is essential in determining how the vessel will trim and in determining the vessel's stability.

Fig. 6.5

6.4.3 Center of gravity. The center of gravity is the center of the total weight of the parts of the ship including whatever it is carrying. It is the center of the total mass of the vessel and its contents. Its usefulness in calculations is in the characteristic that this is the point in the vessel through which all the weight of the vessel acts. The ship behaves as though all the weight is acting downward through the center of gravity. This corresponds to the center of buoyancy—the point through which all of the buoyant force of the ship acts. The center of gravity is calculated by summing up all of the weights and their moments about the same three base lines we used for the buoyant forces. The vertical moments taken about the keel, the longitudinal moments, either forward or aft, are taken about the midship point, and the transverse moments, to one side or the other, are taken about the center line. Please note that even though a hull may be symmetrical about its center line, it is not necessarily so that the weights of all of the structure or the cargo being carried is symmetrical about the center line. Therefore, it is important that the transverse center of gravity be calculated for any vessel to insure that there is no unbalance to one side or another to cause a permanent list in the vessel.

6.4.4 Stability. From the data developed from the lines plan the naval architect must calculate the stability of each vessel. The resultant answers are plotted at stability curves. These curves express the ability of the vessel, at various displacements, to right itself, that is, to return to its original upright position.

Another set of calculations must be done by the naval architect to determine the damage stability. The problem here is similar to the calculations done previously for stability except that certain compartments are considered damaged and, therefore, flooded from the sea. The vessel must be able to stay upright with any one major compartment flooded to be considered a one compartment ship and stay upright with any two compartments flooded to be a two compartment ship. Generally only passenger vessels are required to be two compartment ships while all other vessels should each be at least a one compartment ship.

6.4.5 Curves of form, deadweight scale, and capacity plan. When all of the ship's calculations are completed, they are gathered together on a large graph plan called the curves of form. This graph is compiled so that values of buoyancy, areas of water planes, moments to alter trim one inch, tons per inch of immersion, and the metacenter curves, both transverse and longitudinal, may be read off for the various drafts at which the ship may float.

Fig. 6.6

Some of this same information may be placed on the capacity plan. This is a plan showing the general arrangement of the ship which gives such information as may be needed to work the ship on the voyages. The plan will show the capacities of all the ship's tanks, the bale and grain capacities of the cargo holds as well as information pertaining to her cargo handling booms and arrangements. On this plan is also included a deadweight scale. This scale shows the displacement for all of the ship's drafts. The deadweight, tons per inch, and moment to trim are also given for these drafts.

Let us see just how useful this plan is to the ship's skipper. He is in port and has a certain amount of cargo to load. At the harbor entrance there is a bar that he must pass over to get to sea. He notes that the draft of his ship as it lies at the dock is so many feet. From the curves of form or the deadweight scale, he determines the displacement of his vessel. To this, he adds the weight of the cargo he is to take aboard. From the resultant displacement he reads off the new draft, and from the depth of water over the bar he knows whether it is safe to take on the proposed amount of cargo.

Fig. 6.7 On the deadweight scale is also included the moment necessary to alter trim one inch. This gives the skipper an idea of how to stow his cargo to get a certain trim on his vessel.

Let us also find how the tons per inch scale works. The ship is pretty close to the Plimsoll or freeboard mark, and this is as deep as she may be legally loaded. There is still about two hundred tons of cargo on the dock to be loaded. The tons per inch at the draft that the ship is floating is 54. It is loading in fresh water and still can go about five inches deeper, so a very simple problem in division will show that they still can load this amount. The deadweight scale will also show how much cargo may be loaded at a given draft, as this scale is, in reality, the true measure of how much cargo the ship will carry.

The Plimsoll or freeboard mark is another interesting part of the capacity plan. This mark has a bit of history attached to it. Years ago, in England, the ship owners were loading their vessels to such a point where they became unseaworthy. Many lives were lost through this practice and a bill was introduced in the Parliament by a man named Plimsoll to forbid this. The bill sought to assign enough freeboard to every vessel so that under all conditions she would be seaworthy. The underwriters were given the task of assigning this amount of freeboard. Now it is assigned by the classification society, under government supervision.

Freeboard. Freeboard is the distance from the water line to the top of the freeboard deck measured amidships, at any time.

Freeboard deck. The freeboard deck is the uppermost continuous deck to which all the main transverse watertight bulkheads are carried. The freeboard deck is also called the main deck.

Once the classification society assigns the minimum amount of freeboard for any particular vessel, the loadline mark is placed on the side of the vessel amidships. The mark is passed through a circle called the loadline disc. Previously we found that the draft of the ship will vary with the density of the water. Freeboard is assigned for ordinary salt water under normal conditions at sea. If the ship is loaded in fresh water it is evident that she can be loaded deeper than in salt, and divisions are marked alongside the disc to take care of this. For instance the ship can load the deepest in tropical fresh water and the least in the North Atlantic in the winter time.

Fig. 6.8 The American Bureau of Shipping's Rules for Building and Classing Steel Vessels definitely specify the arrangement and measurements of the loadline marks. The deck line is permanently marked or affixed amidships and the top of the line passes through the top of the deck plating on the freeboard deck. A symbol represents the classification society, AB, American Bureau of Shipping; L-R, Lloyds-Register.

A line through the center of the loadline disc marks the summer freeboard and the upper edge of the line passes through the center of the disc.

The loadline discs, lines, and letters are to be painted in white or yellow on a dark background or in black on a light background. They are also to be marked permanently by center punch, chisel cut, or bead weld.

Because the loadline marks indicate the minimum freeboard of a vessel, they also indicate her maximum draft.

The final loadline assignment, capacity plan, and curves of form are made by the shipyard after completion of the vessel. The naval architect, however, must make all of these calculations to develop the operating characteristics for the owner to insure the vessel will serve the owner's needs as a completed vessel.

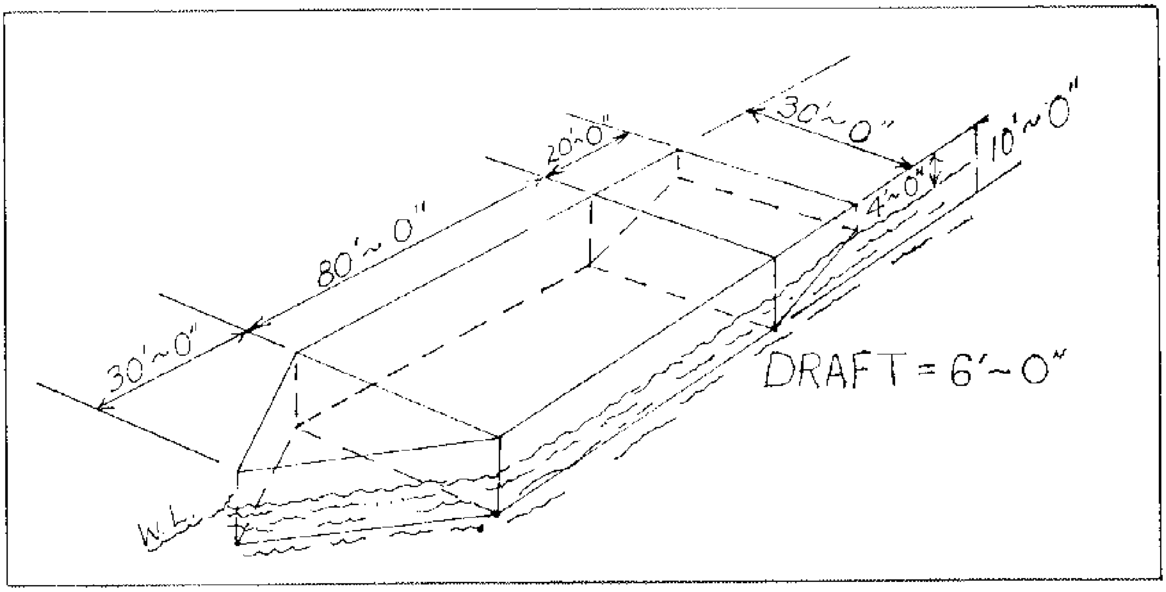
6.5 The Measurements of a Ship

Prior to a discussion of a ship's measurements the following terms should be understood:

Waterline. The waterline is the line of the water's edge where it meets the side of the vessel when she is afloat.

The load waterline. The load waterline is the line of the water's edge where it meets the side of the vessel when the vessel is loaded to her maximum draft.

The light waterline. The light waterline is the line of the water's edge where it meets the side of the vessel when she is not loaded with any cargo, stores, crew, passengers, fuel or water; in other words, when she is empty.



Column (1) Item	Column (2) Dimensions (ft)	Column (3) Volume (cu ft)	Column (4) Vertical Center Buoyancy (ft) Taken About BL	Column (5) (3)x(4) Vertical Moment	Column (6) Long'l Center Buoyancy (ft) Taken About Stem	Column (7) (3)x(6) Long'l Moment
Bow	30x30x6 x 1/2	2,700	3.0	8,100	20.0	54,000
Midbody	80x30x6	14,400	3.0	43,200	70.0	1,008,000
Stern	20x30x6 x 1/2	1,800	4.0	7,200	116.67	210,006
Total		18,900		58,500		1,272,006

Salt water displacement: $\Delta_{SW} = \frac{18{,}900 \text{ cu ft}}{35 \text{ cu ft/ton}} = 540.0$ long tons $\left(\frac{\text{Total (3)}}{35}\right)$

Vertical center of buoyancy: $KB = \frac{58{,}500}{18{,}900} = 3.1$ ft above baseline (keel) $\left(\frac{\text{Total (5)}}{\text{Total (3)}}\right)$

Long'l center of buoyancy: $LCB = \frac{1{,}272{,}006}{18{,}900} = 67.30$ ft from stem $\left(\frac{\text{Total (7)}}{\text{Total (3)}}\right)$

Fig. 6.5 Calculation of center of buoyancy.

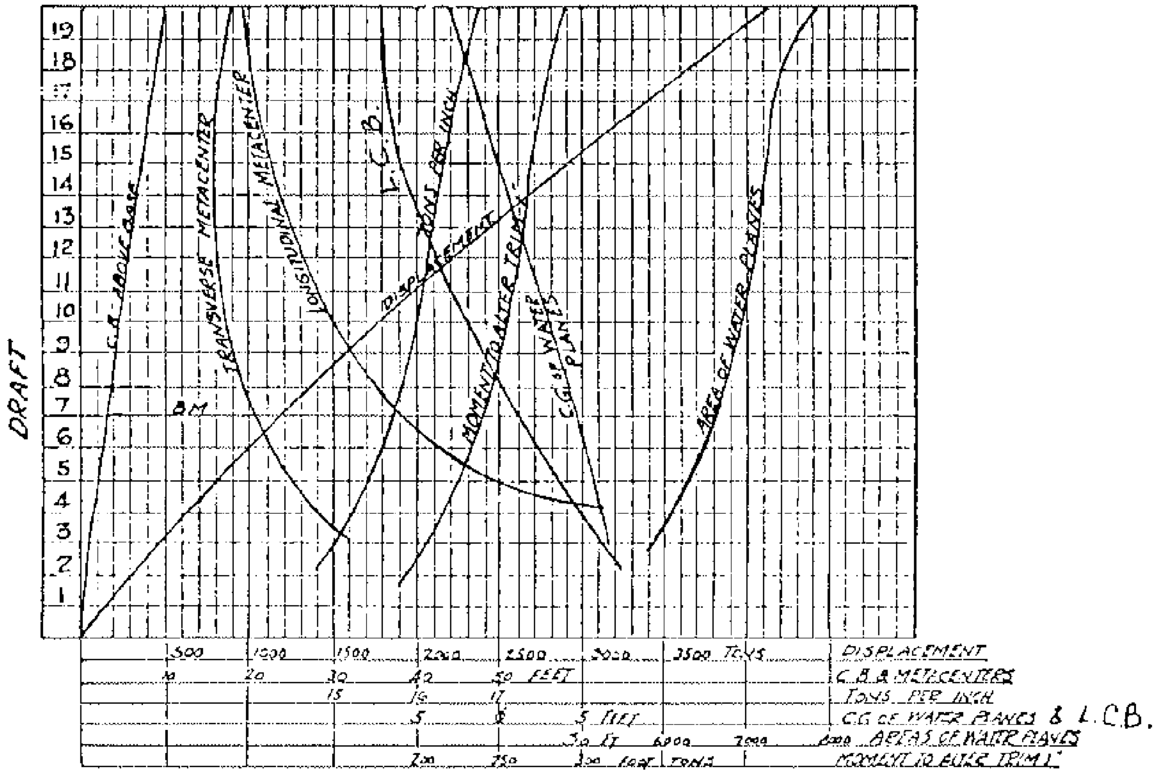


Fig. 6.6 Typical curves of form.

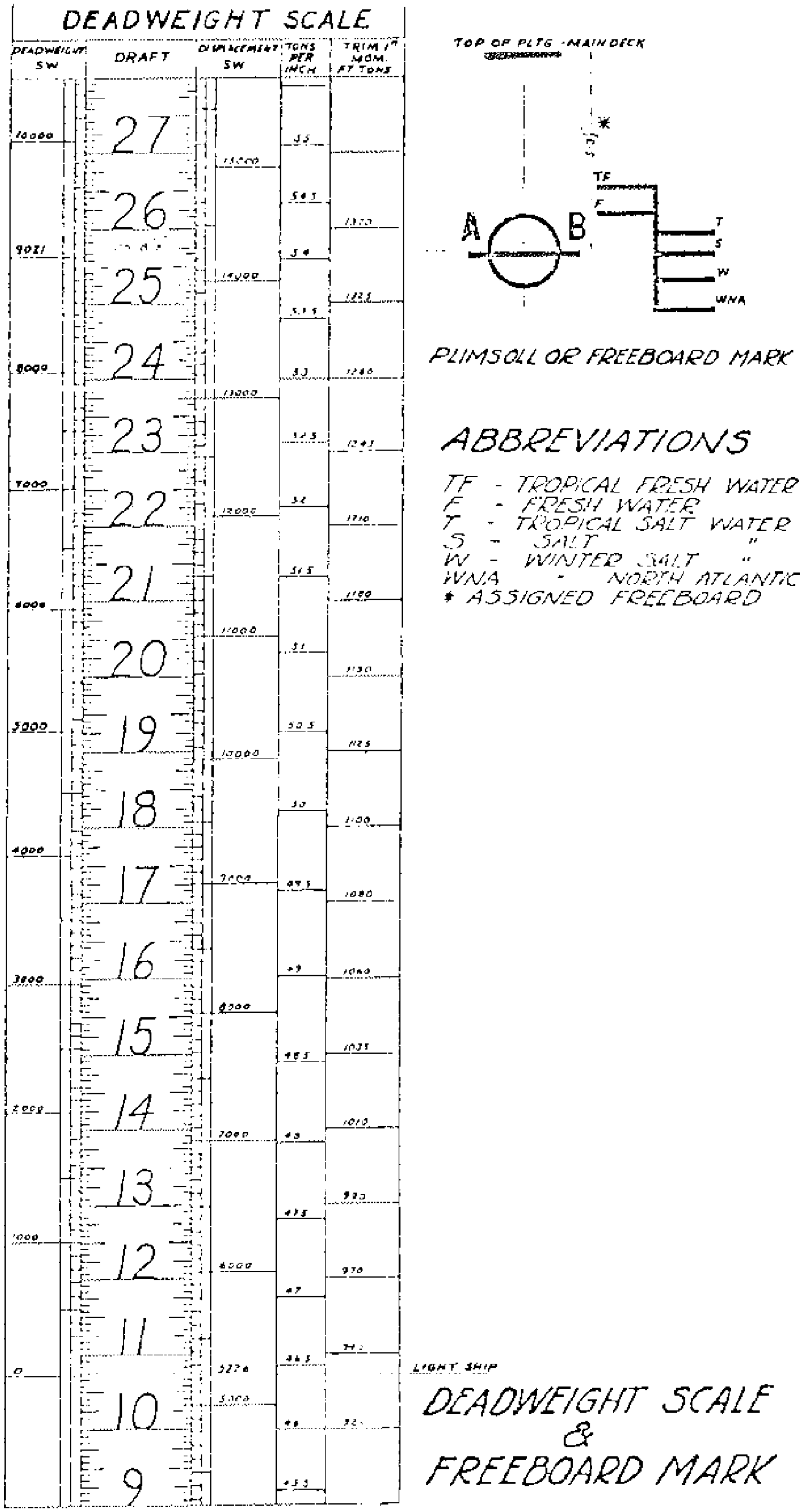


Fig. 6.7 Deadweight scale and freeboard markings.

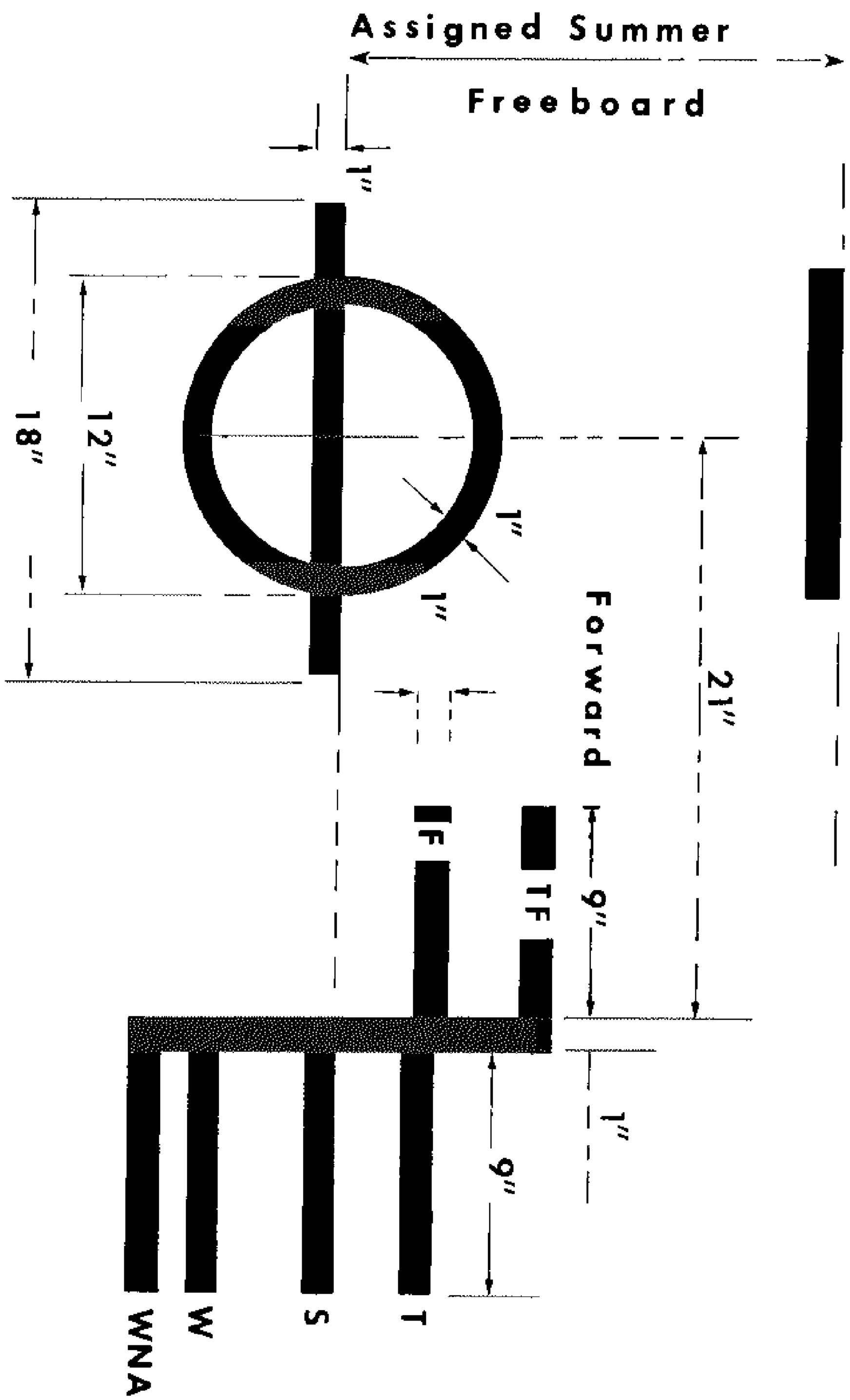


Fig. 6.8 ABS load line mark and lines to be used with this mark.

The middle body section. The middle body of a vessel is the widest part of the hull amidships.

The entrance of a vessel. The entrance of a vessel is the forward underwater portion of a vessel at or near the bow where the underwater body begins to narrow.

The run. The run is the after underwater portion of the vessel at or near the stern where the underwater body begins to narrow.

Fine lines. A vessel which has a relatively short middle body and a long and tapering entrance and run is said to have fine lines.

Base line. The base line is a line on the plans from which vertical heights are measured. For instance, the main deck may be 20 feet above the baseline. The base line is usually taken to run through the top edge of the keel plate.

Centerline. The centerline is the fore and aft middle line of the vessel and the locations of various items on the vessel are given as their horizontal displacement from the centerline.

Length, breadth, and width. The length of the vessel is given in feet. Registered length is the length of the vessel measured from the fore part of the stem to the afterside of the head of the rudder post. Length overall (LOA) is the extreme length of the vessel, measured from the foremost part of the hull to the aftermost part of the hull.

Registered breadth or width is the width of the hull at the widest part measured amidships between the outer surfaces of the shell plating. Molded breadth or width is the width of the hull at the widest part measured amidships between the inner surfaces of the shell plating.

Registered depth is the depth of the hull measured amidships between the top of the floors to the top of the upper deck beams. Molded depth is the depth of the hull measured amidships between the top of the keel and the top of the upper deck beams at the side of the vessel.

Tonnage. When a ship owner is contemplating the construction of a new vessel, the thought uppermost in his mind is the profit she will make. No man can keep a ship on the seas, indefinitely, at a loss. There must be some measure of its cargo weight carrying capacity. This measure is found by means of displacement tonnages.

The displacement tonnage of the vessel is the actual weight of the entire vessel and everything aboard her at any time in long tons (2,240 lbs).

The ship's weight alone is spoken of as the light displacement, light ship, or light weight tonnage. This weight includes: the hull and machinery and all piping. It also includes all of the steward's outfit, the dishes, the mattresses, floor coverings, and anything necessary to properly outfit the ship. The light displacement tonnage does not include any fuel, fresh water, or other consumable stores necessary for the operation of the ship.

The loaded displacement tonnage or simply loaded displacement of a vessel is the weight of the vessel fully loaded with cargo, fuel, water, stores, etc. This is the displacement of the vessel when she is loaded to the greatest draft that maritime law and insurance regulations will allow.

It should be obvious that if we subtract the weight of the vessel alone (light displacement) from the vessel and her maximum amount of fuel, water, stores, and cargo (loaded displacement), we will arrive at the maximum amount of cargo, fuel, water, stores, etc., that the vessel can carry. This is called the deadweight tonnage of the vessel.

6.5.1 Registered tonnage. We have now acquainted ourselves with two tonnages employed in rating a ship: displacement tonnage and deadweight tonnage. There is another tonnage just as important to a ship's operation as the two former tonnages. This tonnage is termed registered tonnage, and it is the oldest rating of a ship's size of the three, and the one in general use in shipping circles. Whereas displacement tonnage and deadweight tonnage are weight tonnages, registered tonnage is a volume tonnage. Registered tonnage is the measure of the volume of the ship's interior. It is the tonnage on which all of the port and canal fees are based. The ton, in the case of registered tonnage, is a unit of measure equal to one hundred cubic feet.

Registered tonnage is divided into two divisions, gross tonnage and net tonnage. Gross tonnage is a measure of the total interior volume of the vessel, less the volume of the ballast tanks, measured in units of 100 cubic feet. It is composed of the under deck tonnage and the tonnage of all superstructure, such as poop, bridge, and forecastle enclosures. The under deck tonnage is the volume of the ship under the tonnage deck less the ballast tanks volume, which is exempted. The tonnage deck is the upper deck in all ships having two decks or less, and the second deck from the keel in all ships with three decks or more.

The net tonnage is the amount of volume of the ship after all legal allowances are deducted. These allowances are machinery spaces, and all spaces given over to the ship's use such as carpenter shop, store rooms, crew quarters;in short, all spaces not available to the carriage of cargo or passengers for hire.

The tonnage of a ship is computed on the volume inside the ship's frames--the volume above her hold flooring--and below her deck beams. If cargo battens are fitted to the frames, the tonnage is computed to their inner face.

The Panama and Suez canals authorities have some variations from the usual methods of measuring, and the ship is also classed under these measurements and rated by Panama Canal Tonnage and Suez Canal Tonnage.

6.5.2 Other vessel measurements. Similar to the tonnage measurements and calculations are the measurements of grain capacity and bale capacity of the cargo holds. These measurements are not of much concern in offshore supply and crew vessels, but we shall describe them here as added information.

The measurement for grain capacity entails the calculation of volume of the cargo hold to the inner side of the ship's plating. From the total capacity of the hold is deducted the volume of all the members projecting into the hold space, such as the frames and bulkhead stiffeners. All hold stanchions or pillars are deducted, and all other objects which would not permit the stowage of grain are calculated for volume, and their cubic capacity is deducted. Where the hold happens to be the lowest one, the volume included in the hatch trunk projecting through the deck above is included in the volume of the hold below. This same volume is then deducted when the capacity of the hold above is calculated.

A careful grain capacity calculation will take into account such small items as the volume of sounding pipes and other non-structural parts of the hold. Where ceiling battens are fitted for the carriage of other cargoes, the volume of these is also deducted. As these are sometimes taken out to carry grain, the stated volume on the ship's capacity plan should specify the volume of the hold with and without ceiling battens. This may be a hair splitting requirement, but is sometimes insisted on by some ship operators.

Similar to the grain capacity of the hold is the bale capacity. This takes in the available volume of the hold inside of the ceiling battens. The deduction of bulkhead stiffeners and other obstructions to stowage of bales is taken into account as well as the availability of the hatch trunks for the stowage of the cargo, the same as in grain measurements.

The tanks aboard a ship have their own particular measurements. Tank capacities are measured by two means, soundings and ullage. The soundings are generally applied to water, or other light liquids. They are made up in tables giving either the capacity of the tank in gallons, barrels, or tons for different depths of the tank. The tables are carried aboard the ship in a booklet, or are shown on the ship's capacity plan. It is general practice to give the capacities of the peak tanks and all other ballast tanks in tons, so that the ship's personnel may readily calculate the amount of tankage necessary to trim the ship. The drinking water and other tanks are generally given in gallons.

A sounding is the actual depth of the liquid in the tank. The sounding pipes that are installed in the ship do not always run perfectly vertical through the tank, so that a rod dropped down them would read a greater sounding than actually existed. This is allowed for in the tables. Soundings are most generally taken with a jointed steel bar or a brass rod attached to a piece of rope. The rod is sometimes chalked to distinguish just how far it went into the liquid.

In an oil tank the tank tables are made up in ullages. An ullage is the actual amount of oil out of the tank, instead of in it. The ullage is measured from a plate on the hatch above the tank, to the surface of the liquid. For instance, the ullage table will show that the tank has so much liquid in it when the distance below the ullage plate is a certain figure.

6.6 Free Surface

One other important calculation that must be taken into consideration is free surface. This is a calculation made by the shipyard for all the tanks in the vessel, but must also be carefully taken into account by the designer.

When a ship is inclined, the solid weights fixed to the ship do not change their center of gravity, and therefore do not have a changing effect on the total ship center of gravity. A tank completely full of a liquid will act in the same manner as a solid weight because the shape of the volume of liquid, and therefore the center of gravity of the liquid cannot move.

However, if a tank of liquid is only partly full, a totally different situation exists. When a partly filled tank is inclined, the liquid inside moves in the same direction, thus moving its center of gravity toward the direction of the inclination. The effect of this movement of the weight of liquids must be taken into account.

The measure of the effect of this shift of weight is dependent directly on the amount of the athwartship dimension of the surface of the liquid free in the tank. Thus the term free surface. If the total hull were a series of tanks, each of which goes completely across the ship, and only partly filled with a liquid, the vessel would be completely unstable because the horizontal shift of weight would be equal to the movement of the center of buoyancy.

The free surface effect is expressed as an equivalent vertical shift of the center of gravity so that it can be deducted from the calculated GM to determine the actual stability of the vessel.

6.7 Model Testing

A very important tool of the designer is the model basin or model tank. As the name implies, this is a large basin of water in which models of ships and other vessels are tested under conditions simulating actual service conditions. Generally, when the designer completes his hull design, he needs to confirm his predictions of speed, power requirements, seaworthiness, and general behavior.

The personnel at a model basin will make an exact replica of the ship's hull and characteristics including the center of gravity and radius of gyration. The scale is generally such that the model is about twenty feet long, as this is as large as most tanks can handle.

The model is put into the water and attached to a towing carriage which can pull the model through the water at a speed proportional to the actual speed of the vessel. The carriage contains instruments to measure the speed and resistance of the hull going through the water. Some models are self-propelled so that the actual horsepower required to propel the model can be measured and then calculated to give the horsepower for the full size ship.

For studying the effects of waves on the ship, many tanks can provide waves of any specific size and frequency or random waves such as are actually encountered at sea. Some tanks can also provide confused seas, that is, waves from more than one direction, which is also a condition sometimes encountered in service. Through measurements made on the hull during these tests the designer can find out how his ship or drill rig or platform will behave under any sea condition he expects the unit to encounter.

7. CONSTRUCTION PROCEDURE

After the designer has completed his work and the owner decides that he wishes to actually build the vessel, the design is given to a number of shipyards for them to bid on on the construction of the ship. Following a period of negotiation between the owner and the builder of his choice, the vessel is constructed. The following is a description of the steps taken by the shipyard.

7.1 Estimating

The estimate is built up from material cost and labor cost plus other fixed costs of the plant. The first step is to gather together a list of all of the material needed for the vessel. This will include a complete list of the machinery, the shafting, propellers, plus a total compilation of all of the steel weight needed for the ship, in addition to all of the pipe required, electrical cable, and the paint. In other words, all of the material that must be used to build the ship. The price of each item is then gathered from the various vendors of the material. The yard will get more than one quotation for each item of material to be sure they can purchase the least expensive.

Figs. 7.1 to 7.4

The material list is also used to determine the amount of labor hours that are going to be required. The labor hours are usually directly proportional to the amount of steel, pipe, electric cable, paint, and other materials that will be used in the vessel. After the material cost is established and the labor hours that are required have been calculated, the yard will multiply the labor hours by their hourly average rate, that is, the rate paid to the average worker in the yard. They must keep in mind at this point that they have to use the average rate that will be in existence from now until the end of the contract, which may be for three to four years.

The labor needed for the first ship of a kind is generally higher than that needed for the following or duplicate ships. The estimators therefore use what they call a learning curve to figure the cost of the second, third, fourth, fifth ships of the series. The learning curve is so named because it reflects the fact that the workmen learn how to make a particular vessel on the first unit. They will make mistakes on the first unit, but they learn from these mistakes; presumably the mistakes will not be repeated in the following ships and therefore the cost will be less.

A rule of thumb for the use of the learning curve is that the labor hours should be reduced by 5 percent per ship each time the number of ships is doubled. That is, reduce the number of man hours for the second ship by 5 percent and then another 5 percent reduction for the fourth ship and another 5 percent reduction for the eighth ship and so on. Nowadays inflation of labor and material costs can easily nullify the effects of the learning curve savings, but nevertheless they must still be calculated.

Overhead is the next item to be added to the cost. This covers most of the normal yard cost that cannot be calculated in the man hours or material price. Examples of this are the costs of the administration people--accounting department, personnel department, security force, clean-up crews, the president, vice-president, and so forth. The utilities used for the yard are also included on overhead along with the cost of paid vacations for the men, social security payments, hospitalization plans, and other related items.

Now must be added certain fixed costs that are known to be needed. Insurance on the yard against mistakes, weather catastrophes, and other risks, is a known item that must be accounted for as well as tug cost for launching, any new equipment needed for this job in particular, and other items that can be attributed only to this particular ship.

After all of the costs are totaled the yard personnel then must decide on a price for the owner. The yard, of course, must make a profit on their work or they will not stay in business very long. Yet the price cannot be so high that the owner will decide to go to some other yard for the work. So the price must be carefully worked out by the yard. Sometimes the final price is arrived at by negotiation between the yard and the owner.

Once the contract is settled, and both the owner and the shipyard know exactly what is to be built, the yard is given notice to proceed.

7.2 Working Plans

The first workers to start on the ship are in the engineering department. They start making a detailed take-off of the steel in all the sizes that will be needed for the ship so that the material can be ordered. The detail drawings are then started. Each group in the department makes drawings that show where each piece of steel, pipe, electrical cable, ventilation duct, joiner bulkhead, floor covering, and other components must be placed to construct the ship.

Each group must coordinate with the other to insure that there are no interferences of one piece of material with another. For this purpose composite plans are often made. These plans show all of the steel, ventilation ducts, pipes, and any other material for location and size in three dimensions to assure that each piece clears the others.

The process of detail drawing development takes almost as long as the construction time of the ship, therefore the first drawings needed are the ones that are started first. For the structural group, the keel and bottom sections are started first and the top of the superstructure, and such things as railings and the small lines that can be put in last, are drawn last.

As with the drawings that were developed by the designer, all of the detailed drawings must be sent to the regulatory bodies for review and approval. Generally, all of the detail drawings are also sent to the owner or the owner's representative, his naval architect, for review and approval at the same time they are sent to the regulatory bodies. This saves time in the approval process. The contract generally provides that all of those people who have review responsibility must approve the drawings before any of these drawings can be used for construction.

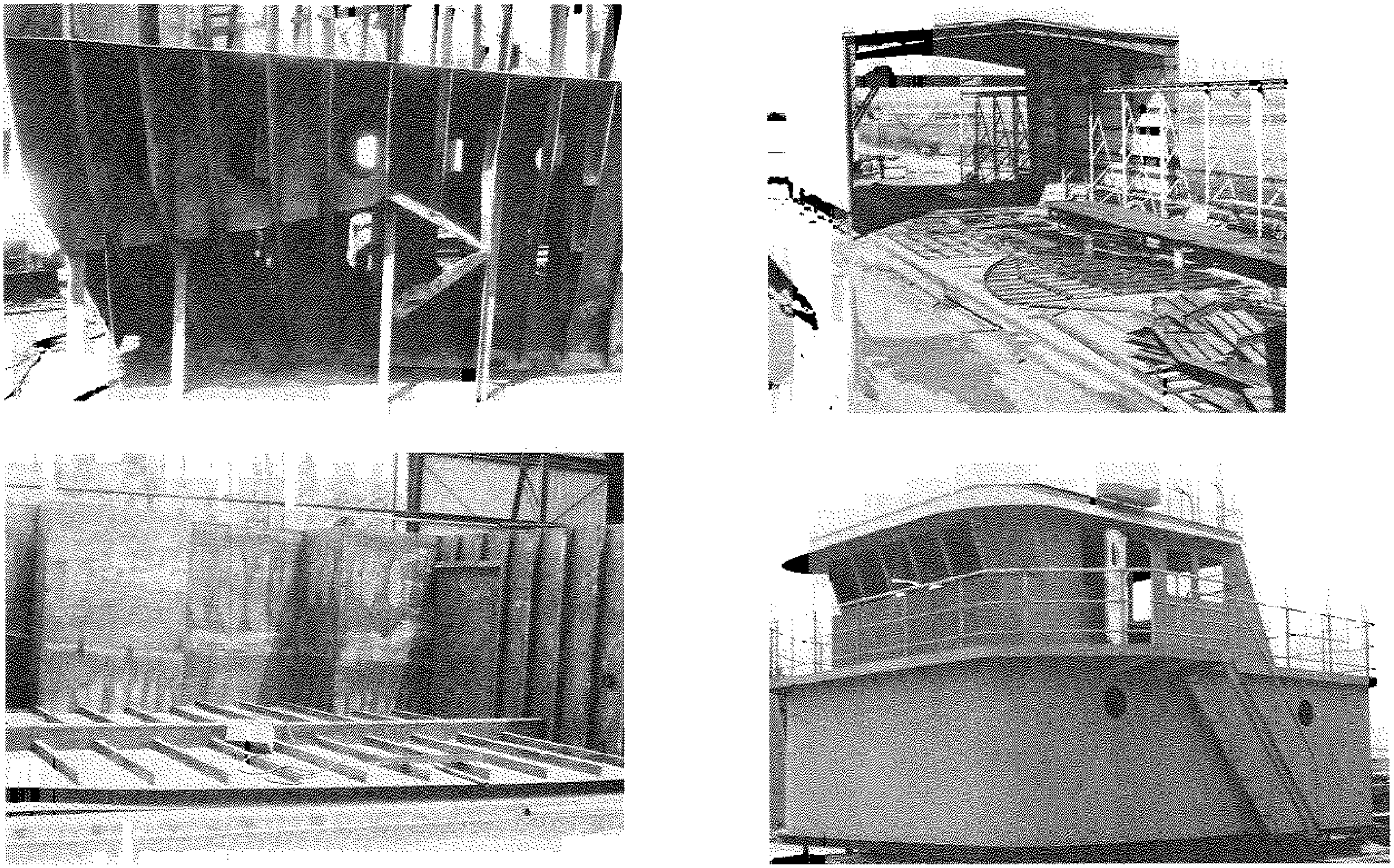


Fig. 7.1 - 7.4 Construction of the vessel begins with assembly.

During the development of the drawings, the same drawings that have been produced by the designer are again produced by the shipyard, that is, the curves of form, capacity plan, stability calculations, Bon jean curves, damage stability calculations, and so forth, are all made by the shipyard based on the actual construction dimensions and weight of the vessel. One of the biggest jobs for the shipyard's engineering department is to make a very accurate weight estimate of the ship in all its parts, that is, every piece of steel, every pipe, every piece of machinery must be included in the weight estimate and this must be submitted to the owner for his review and approval.

At the end of the construction, the engineering department must take all of the drawings that it has produced and correct them to agree with the ship "as built." These drawings, which now reflect the exact pieces of material in sizes and dimensions to which the actual ship was built, are given to the owner for his office and put aboard the ship for the use of the people there.

7.3 Production

The beginning of production is in the planning group. Planning is the most important tool of the production department. A study must be made of the man-hour estimate that had been developed by the estimating department. This study is made to determine the number of man-hours required by each craft and at what time during the production procedure they will be required. As an example, the structural people will study the number of ship fitters needed, the number of welders needed, the number of tackers, what crane services are required, and plan all of these man-hours in accordance with the time schedule intended for the construction of the hull. The pipefitting department must do the same with their man power. Each group must then plan their own operations with each of the other craft groups, so that each group will work without interfering with the other groups. Obviously, it would be impossible for all of the men to work on the ship at the same time, therefore, the planning group must lay out the time schedule so that when the structural people have finished a section, the pipefitters can then put their pipe in and that can be followed by the ventilation duct people and then again followed by the electrical people.

Figs. 7.5 to 7.8

The hull work is started in the mold loft. This work is generally done in a large space where the lines of the vessel can be laid down on the floor to full size. Then

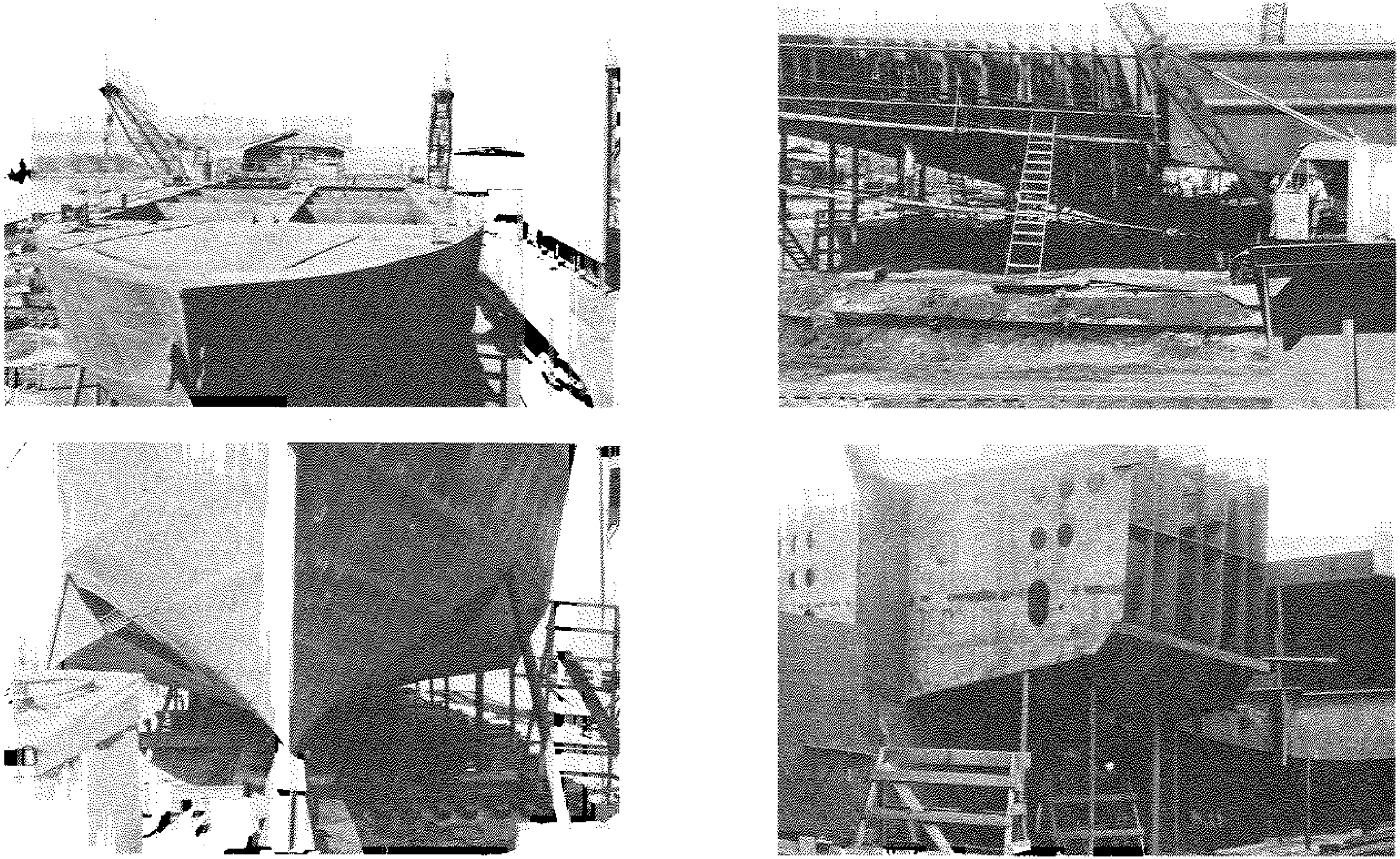


Fig. 7.5 - 7.8 The vessel begins to take shape as the various parts are assembled on the ways.

templates are made of each of the frames, each of the longitudinal girders, and often each of the plates that are going to be laid on the hull of the vessel. These templates are taken to the shops for fabrication of the pieces. After the individual pieces have been fabricated they are put into sections in accordance with the drawings that have been made by the engineering department. These sections or blocks are carried to the area in which the hull will be erected. Sections are then put together on the launching ways like building blocks. The keel section will be laid down first and then gradually each section outboard of the keel with the side sections on top of that. The deck section is then laid on top. In order to give the machinery installation people and the piping people an early start, the construction of the hull starts with the engine room. Generally the engine room is in the middle part of the ship, so that portion can be laid down first and the hull section can work forward and aft of that. Meanwhile, the machinery installation people, the piping people, and even the electrical people can be working within the machinery space.

Figs. 7.9 to 7.12

A superstructure is the last steel structure to be placed on top of the hull. Sometimes it is built in place, and sometimes it is built off to one side, in one piece, and lifted that way on top of the hull.

After the lowest section of the hull is complete, some of the other crafts begin their work within that section. The piping people will put the ballast and bilge piping into the lower inner bottom sections and as the sides come up they will put the fuel oil piping in for the fuel tanks.

7.4 Inspection

During the entire construction period all the work being done by the shipyard is carefully watched and inspected by various people, in accordance with the owner's desires. If the vessel is subject to the U.S. Coast Guard regulations, they must inspect the work. Also, if the ship is being classed by the American Bureau of Shipping and the owner wants inspection (signified by the Maltese Cross in the classification), then the ABS will have an inspector watching over the construction.

The owner can also have his own inspection staff in attendance at the yard for this purpose. Sometimes the owner will have people from his company do the inspection, but more often he will hire someone, such as his designer, to do this job. Many naval architectural firms can supply

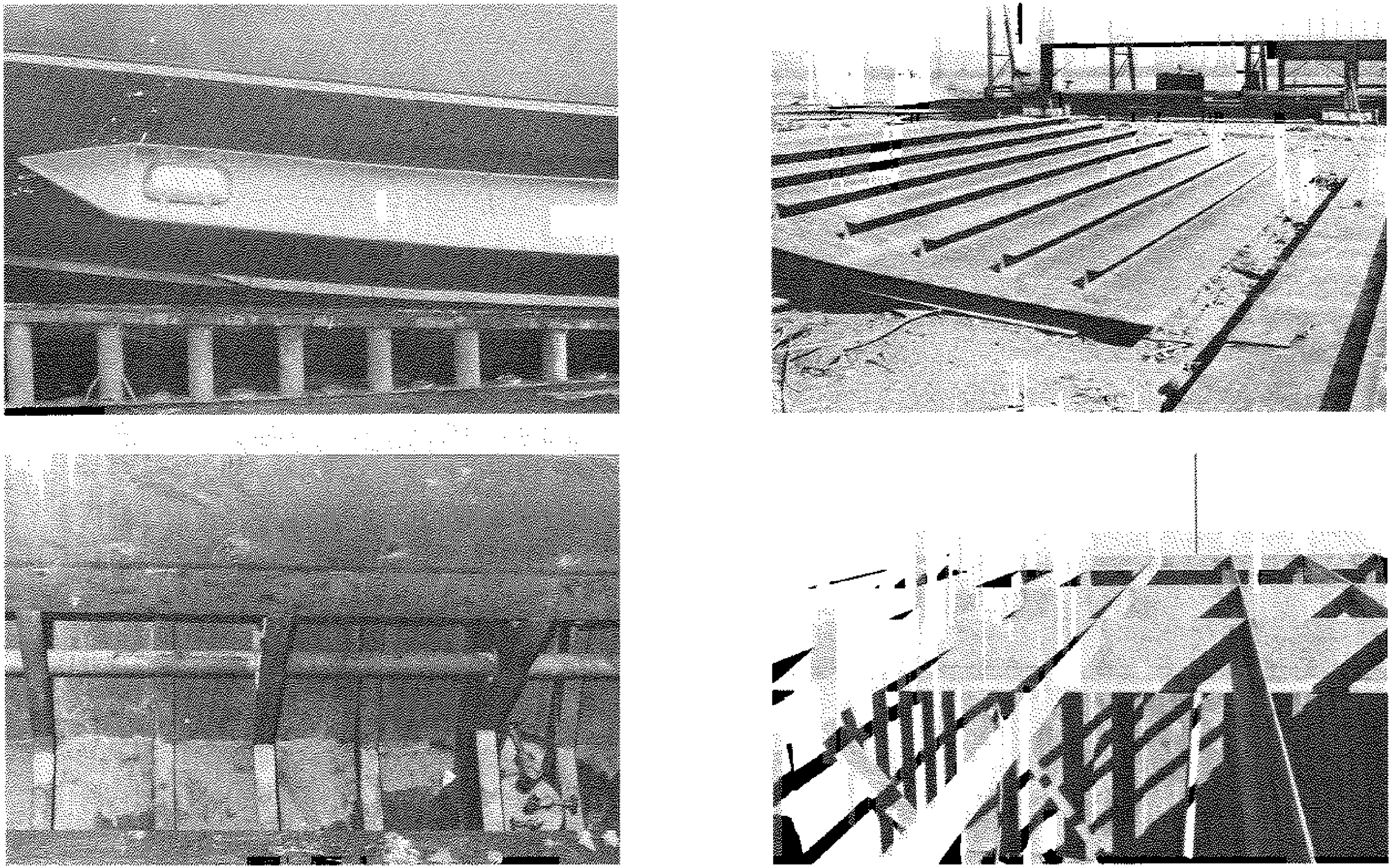


Fig. 7.9 - 7.12 Primary members of the vessel are visible as construction proceeds. 7.9: Keel cover; 7.10: Transverse frames in the engine room; 7.11: Bulkheads and stiffeners; 7.12: Girders, deckbeams, frames.

an inspection force, in addition to review of the detail plans produced by the yard.

Inspection involves a close watch of all of the building procedures, such as welding quality and methods; this includes examining X-rays of welds in critical areas of the vessel to insure the soundness of these welds. The inspector must also look for continuity of structural members to insure the steel will act in the manner it was intended. A great deal of the inspection time must also be spent in observing tests of watertight compartments, doors, and hatches. Each of the systems of the ship, piping, electrical, and ventilation, must be watched during installation.

Operating tests of all the yard-supplied equipment aboard the vessel are also observed and approved by the inspection personnel. The actual testing is generally performed by the shipyard's testing department.

One of the most important duties of the American Bureau of Shipping is to inspect certain items of material. All the steel going into a hull to be classed by ABS must be inspected and tested at the steel mill to see that it meets the physical and chemical requirements of the ABS rules. In addition, the vital machinery of the vessel, main engines, generator sets, shafting, propellers, and steering gear are all inspected by the ABS in the factories which produced the items.

During sea trials the inspection forces are kept very busy checking on all the operating equipment as well as the overall operation of the vessel.

Any time during the inspection process an inspector may call a halt to the construction of a particular item if he finds it does not meet the requirements of the drawings or specifications. If the yard agrees that it is in error then they will proceed to correct it. However, there are times when the yard will not agree with an inspector and then the matter must go to negotiation or arbitration, as may be called out in the contract for disagreements. In any case, it is the duty of each inspector to watch carefully and determine fairly the correctness of the shipyard's workmanship.

7.5 Trials and Tests

When the vessel is essentially complete and all the machinery has been checked out for its ability to operate, Figs. 7.13 to 7.16

the vessel is sent on sea trials (or river trials, if that is where it will enventually operate). The sea trials are intended to prove the overall capability of the ship to do the job it was intended to do.

Speed runs are made to check the speed of the vessel at varying horsepower outputs of the engines. Usually two or three runs are made over a measured course, going in opposite directions, for each power. The speed made in each direction will generally vary because the wind and waves will have an effect on the speed of the hull. When the vessel is going in the same direction as the wind or waves it will go faster than when it goes against them. Therefore, the speeds made both ways are averaged (added together and divided by the number of runs) to give the speed that would occur in calm water, thus eliminating the effect of the wind and waves (or river current).

Another important part of the sea trial is the endurance run. For this the vessel is run at full power for a specified time, generally four hours, and data is taken on all the main propulsion equipment to verify that the plant is operating as designed. This data would include temperatures and pressures in all the steam lines, lubricating oil lines, cooling water lines, and any other systems in the propulsion system. The horsepower output is generally measured with a horsepower meter and the fuel consumption is determined for the period of the run. This information is extremely important to the chief engineer who will be running the vessel in service so that he will know what the conditions are for the normal running of the plant.

Also, during the sea trials the vessel is run astern to determine its ability in that direction. Crash stops ahead and astern are usually done to give the owner, and particularly the captain, an idea of how fast the vessel can stop from a full power situation. Turning tests are also made to determine the minimum turning radius for the vessel. This is essential information for the operators of the vessel.

The anchor windlasses are usually given their first test on sea trials as there is never enough depth of water at the yard to lift the anchor and any appreciable amount of anchor chain. All the operating machinery is given a thorough test during the sea trials. The electronic navigation equipment, such as radar, radio direction finder, depth recorders, collision avoidance system, and gyro compass are given their first real test during these trials. Usually the compass is adjusted at this time also because it is the only time the vessel can be turned to various positions to check the effect of the steel hull on the magnetic compass.

Sea trials may be only one day in duration or they may last for 2 or 3 days. This will depend on the extent of testing to be done, and also on how long it takes to travel to the area for testing. The areas must be open enough to do all the maneuvering needed to check all the systems, and make long enough runs for good speed checks. It must also have enough water depth to be sure that there will not be any effect on the speed from shallow water. The depth of water should be at least five times the draft of the vessel.

If the sea trials are successful the ship returns to the yard and final finishing touches are put to it to make ready for delivery. If the trial is unsuccessful, if a major item did not work, or if the vessel did not perform as required, then the ship must be returned to the yard for corrective work and another trial made to prove the vessel.

8. DELIVERY

After the vessel is proven on trial and the work has been finished to the satisfaction of all the inspecting groups involved, the ship can be delivered. At this point the owner's crew, who may have been at the yard for a few weeks, and even on sea trials, to learn the operation of the ship, will take over the vessel and take it out and put it to work. Some items needed aboard are not included in the shipyard price and these must be put aboard the ship at the shipyard directly after delivery, or they may be put aboard at some local dock that is owned or used by the owner. These items include linens for the crew quarters, utensils for the galley and messrooms, food and other steward supplies, tools for the engine room, lubricating oils, spare parts, and other miscellaneous items.

The delivery of the vessel does not end the shipyard's interest in it. Most contracts will include a guarantee by the shipyard of their work for some period of time, usually six months. During this time the ship personnel will report any item that they find is not working as intended, and if the shipyard agrees that it is because of faulty installation or material used, they will fix it. Naturally accidents or crew negligence in handling the equipment or the vessel will not be accepted by the yard as a reason for them to correct an item.

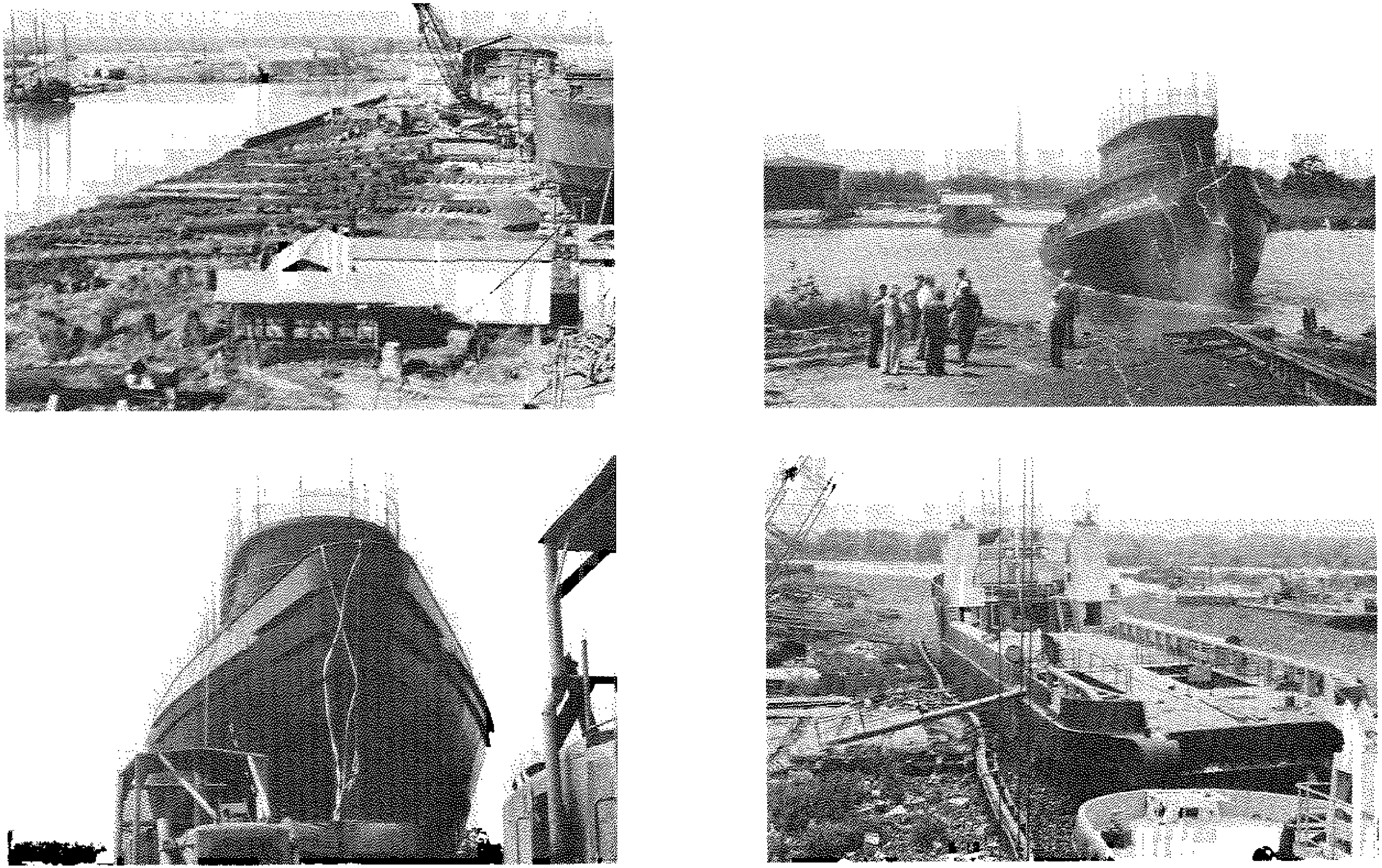


Fig. 7.13 - 7.16 The nearly completed vessel is moved to its launching ways. It enters water either sideways or stern first. Final outfitting and installation often occur after the vessel has been launched.

After the delivery of the vessel the owner can finally begin to put the unit to work for him to make a profit in his business. Up to this point he has paid out a large amount of money to get this unit to this point. Here he now must depend on his crew to successfully operate the vessel. The remainder of this book gives the reader a good idea of what is required of this crew.

9. STABILITY AND TRIM

What is stability? Anyone who has been aboard a vessel and felt it roll to the force of the waves has seen stability in action. Stability is what brings a vessel back to an upright position after it has been inclined due to the forces of the sea.

9.1 Stability

A more complete definition for the word stability would be, "Stability is the tendency of a vessel to return to its original upright position after it has been inclined due to external forces."*

The way that a vessel rolls is a good indication of her stability. If she has been loaded in such a way as to make her top heavy, she is said to be in a tender or cranky condition. Her roll is slow, and she has a weak tendency to return to her original upright position. Her stability is poor.

If she has a concentration of weight toward the bottom she is said to be in a stiff condition; she rolls quickly and has a strong tendency to return to her original upright position. She has excess stability.

A vessel should be loaded in such a way as to give her an easy rolling period, neither too fast nor too slow. When a vessel rolls too fast, the upper parts of the vessel are stressed, and such a condition also creates a very uncomfortable ride for those aboard. A vessel that rolls too slowly has poor stability and could capsize due to heavy weather or damage.

Fig. 9.1 9.1.1 Centers of gravity and bouyancy. The stability condition of a vessel is determined almost totally by the location of two points in the vessel, the center of gravity and the center of buoyancy.

All of the vertically downward forces of weight of a vessel are considered to act downward through a point known as the center of gravity. All of the vertically upward support forces (buoyancy) are considered to be concentrated at the center of buoyancy. The position of the center of buoyancy is determined by the shape of the underwater portion of the vessel because the center of buoyancy is also the center of volume of the underwater portion of the vessel.

9.12 The couple. When a boat rolls due to the force of the seas or some other outside force, the center of gravity remains fixed in position. This is always the case unless weights are free to move. If the vessel does not have a list the position of G is on the centerline of the vessel.

However, when a boat rolls, the center of buoyancy (B) moves because it is the center of volume of the part of the vessel under the water.

Fig. 9.2

This movement of B establishes a tendency for the boat to return to its original upright position. The stronger this tendency is, the more stable the vessel is.

Why does the movement of B away from its position directly under G cause a tendency for the boat to return to its upright position? The movement of B away from its position directly under G causes a tendency for the boat to return to an upright position due to something known as the couple. Whenever two equal forces are applied on a body in opposite directions and along parallel lines, a couple is formed.

To illustrate this fact, lay a book down on a flat surface. Now push the lower right corner of the book to the left and the upper left corner to the right. Be sure that you are pushing in parallel lines and that you are pushing with the same force on each finger.

What happens? The book will revolve. Next, place your fingers closer to the center of the book and push as before. Although the book will revolve, it does not do so as quickly as before. If you place your fingers at the center of the book and push, the book will not revolve. You no longer have a couple.

This couple is what rotates the ship back to an upright position.

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* LaDage, John, and Van Gemert, Lee. 1972. Stability and Trim for the Ship's Officer. 2d ed. Cornell Maritime Press, Inc., Cambridge, Md.

Fig. 9.3

The example of the book illustrates what happens when a vessel rolls. Figure 9.5 shows that when B moves, the lines of force through G and B separate. A couple has now been formed. This couple is what rotates the ship back to an upright position.

The couple has been formed by the two equal forces of weight (G) and buoyancy (B). These two forces are parallel and in opposite directions. The farther the lines through G and B move apart, the stronger is the force of the couple.

G and B are in the same vertical line as long as no external force is inclining the vessel. However, when the vessel rolls, B moves toward the low side of the vessel, and a couple is formed which tends to right the vessel.

9.1.3 Moments. All couples are expressed as a certain force (weight) times a length. This weight times a length is called a moment.

Suppose you pushed on the book with a force of two pounds with each finger and the distance between the lines of force through your fingers is one foot. Then there is a moment of two foot-pounds tending to rotate the book. The length is the distance between the two parallel lines of force and the force is equal to one of the two equal forces. In the case of a vessel, the force is the weight of the vessel and the length is equal to the perpendicular distance from G to the line of action of B. The couple is formed by multiplying the weight of the vessel (displacement) by this distance and the couple is known as the righting moment. For those who have forgotten, displacement is the total weight of the vessel and everything aboard her at any certain time.

Fig. 9.4

It is customary as shown in Figure 9.6 to label the distance between the lines of force through G and B as GZ. GZ is known as the righting arm. For a boat then, the righting moment is equal to her displacement (Δ) x her righting arm. Another way of saying this is (Δ) x (GZ) = righting moment.

For the examples below, you are given displacement of the vessel in tons and the length of GZ in feet. Figure out the tendency of the vessel to right herself. In other words, what is the total force tending to turn the vessel upright again?

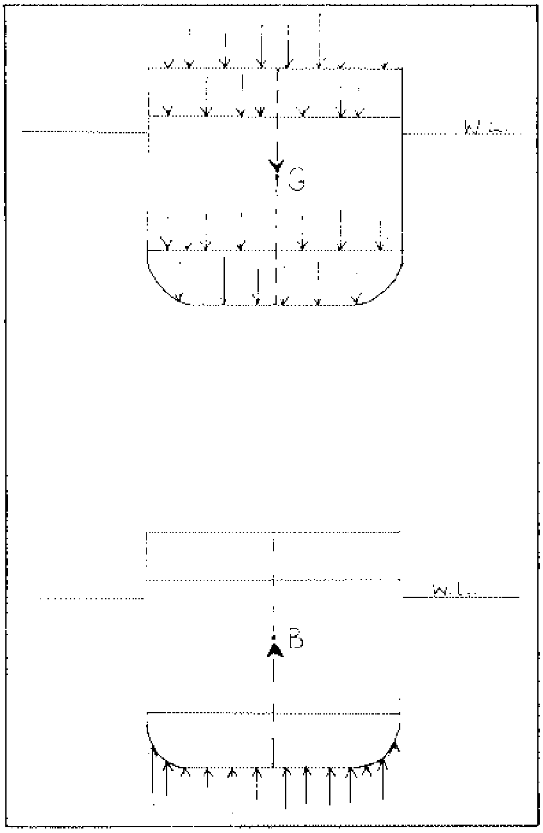

Fig. 9.1 Schematic of centers of gravity and buoyancy.

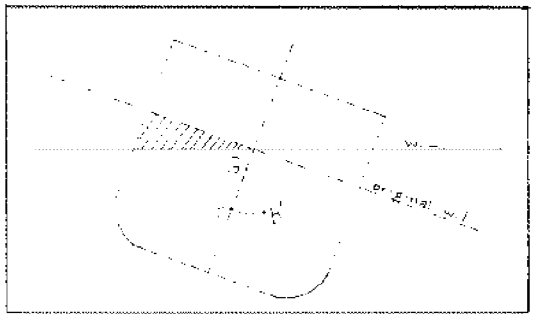

Fig. 9.2 Schematic of the movement of center of buoyancy.

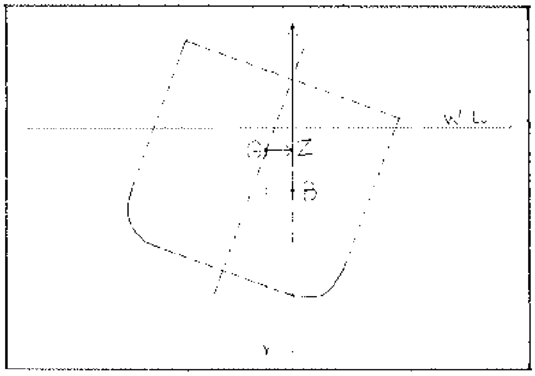

Fig. 9.4 GZ, the righting arm.

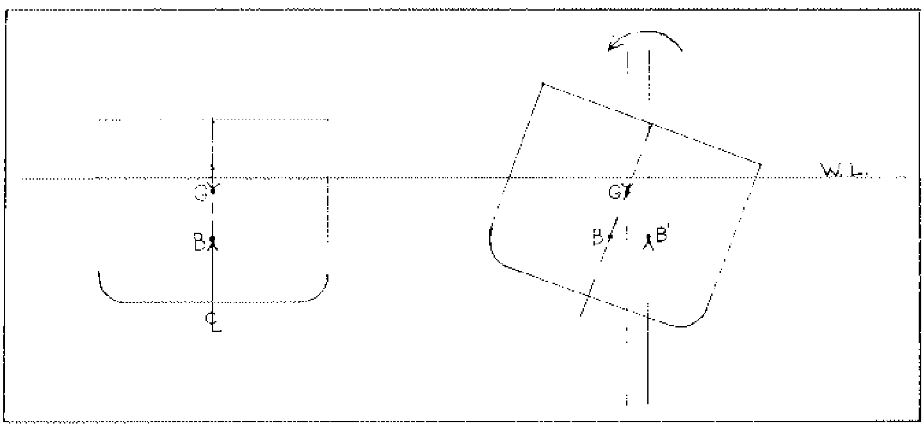

Fig. 9.3 Schematic of how a couple is formed when the vessel rolls.

Displacement	GZ	Righting Moment (ft/tons)
10,000	2	
10,000	4	
6,000	1	
200	2	
700	3	
100	4	
250	1	
600	1/2	
1,200	5	
12,000	2	

By now you should begin to realize what stability is, i.e., where the tendency to return to an erect position comes from, and upon what two things that tendency depends. The righting moment depends upon the displacement of the boat and the length of GZ. The greater the weight of the boat, the greater the righting moment.

If you have the information at hand, the righting arm (GZ) alone can be used as a very good indication of stability. This should be easy to understand. A vessel's weight does not change when she rolls. She weighs or displaces a certain number of tons. GZ does change, however. If GZ doubles, the righting moment doubles, and so forth.

9.2 Transverse Metacenter

Fig. 9.5 This section must be read in conjunction with the careful study of the drawings in Figure 9.5.

In each of the figures, a number of things remain the same. The boat is inclined to the same angle in each case, and the displacement of the boat is the same. The center of buoyancy remains at the same point in each figure because the underwater portion of the vessel is the same. The only difference is that in each drawing the boat is loaded differently, so that the center of gravity is located in a different place.

In case 1 the vessel has been loaded to have a low center of gravity (G). This produces a large righting moment due to the distance between the lines of force.

In case 2 the vessel has now been loaded in such a way as to have its center of gravity (G) higher than in the first case. Nothing else has changed except the position of G. Notice that GZ, or righting arm, has been shortened. The righting moment has been decreased.

In cases 1 and 2, the couple tends to right the vessel. The vessel is said to be in a state of stable equilibrium. She posseses positive stability, and if she rolls, she will return to an upright position.

In case 3 there is no couple. G has been raised to a point where the lines of force through G and B are the same. There is no tendency for the vessel to right herself once she rolls. If the vessel should roll to the position shown in the drawing, she would stay there. She is said to be in a condition of neutral equilibrium.

In case 4, G is located still higher. Once again the lines of force through G and B are separated. However, the righting arm, or GZ, is negative and the couple thus formed tends to upset the vessel.

The vessel is now in a state of unstable equilibrium.

Case 5 merely shows G raised even higher than in case 4. The boat is even more unstable.

In each of the drawings shown in Figure 9.5 "M" is called the transverse metacenter. Although it is a difficult sounding term, transverse metacenter simply means "that point to which G may rise and still permit the vessel to possess positive stability." *

The distance from G to M is called the metacentric height (GM). Looking at the previous drawings, you can see that the larger the GM is, the greater the stability of the vessel. This is true except where GM is negative, as it is in cases 4 and 5.

9.3 Calculating GM

As captain of a vessel, you will be mainly interested
Fig. in calculating GM to determine the stability of your vessel.
9.6 Study the drawing in Figure 9.8. A definition of each letter in the figure is:

M = transverse metacenter
G = center of gravity

* LaDage and Van Gemert (1972).

B = center of buoyancy
K = keel
GM = distance from G to M, calculated by the skipper. This is a good indication of how stable the boat is.
KG = distance from K to G, the height of the center of gravity above the keel. It must be calculated by the skipper.
KM = distance from K to M and is the height of the transverse metacenter above the keel. KM can be looked up in the stability curves of the vessel.

From Figure 9.6 and the definitions above you should be able to see that KM - KG = GM. A few examples will illustrate how this is done.

Example 1: Your vessel has a KG of 27 feet and a KM of 30 feet. What is your boat's GM?

30 - 27 = 3 feet

Example 2: Your vessel's vertical center of gravity is 33 feet above the keel. The height of the transverse metacenter above the keel is 30 feet. What is the metacentric height for your vessel?

30 - 33 = -3 feet (The vessel is in unstable condition.)

Table 9.1

At this point you might say, "Fine. I've come up with a number for GM and I know the bigger the number, the more stable my boat is. But what is a good GM for my boat?" First of all it would be wise to check the stability curves for your vessel and see what GM is required. The GM required varies with the draft of the vessel. By consulting Table 9.1 you can see what the required GM is for a 184-foot supply vessel in different conditions of load with different drafts. Notice in the table that the deeper the vessel is loaded (the greater her draft), the larger the GM required for the safety of the vessel.

9.4 KM and KG

In previous example problems you were given KM and KG. It will be your duty in practice, however, to find KM for the vessel from the stability curves and KG from your own calculations. Since KM minus KG equals GM, you must first find KM and KG before you can know what GM is.

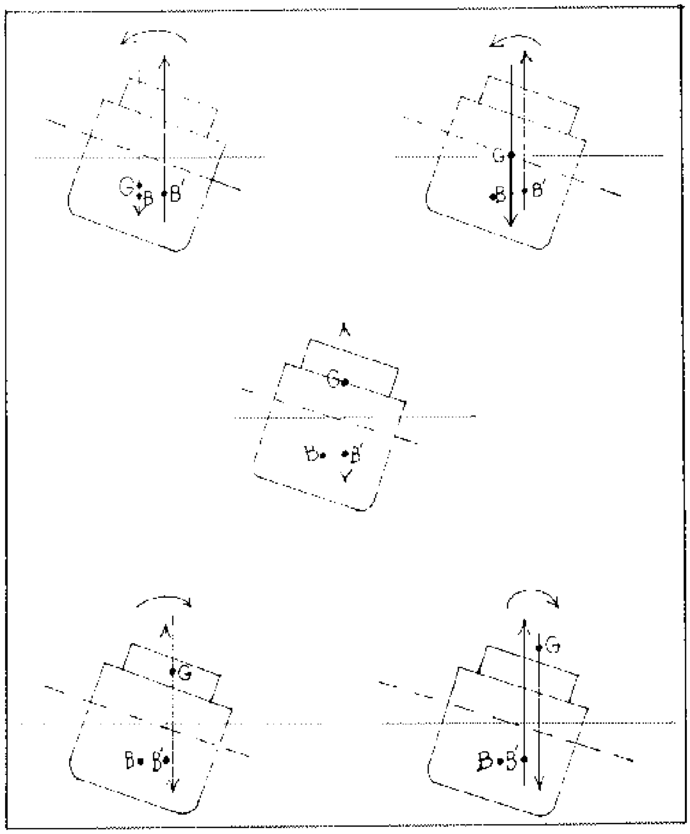

Fig. 9.5 Location of G in the righting movement.

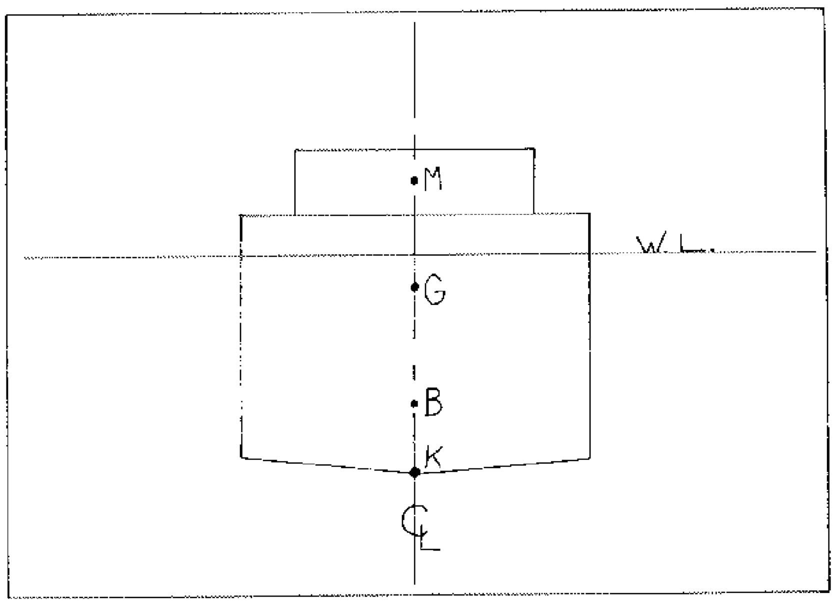

Fig. 9.6 Points that determine stability.

Table 9.1

Stability Curves
(printed separately)

9.4.1 Finding KM. In this section we will use the stability curves for the 184-foot supply vessel in Table 9.1 to find her KM for several different conditions of draft. The table is entered from the side at the appropriate draft. Continuing transversely across the table from the draft, you intersect the KM curve. From the point of intersection of the KM curve, follow a line of sight directly to the bottom of the table where you read KM, the height of the transverse metacenter above the keel. For instance, when the draft is 6 feet, the height of the transverse metacenter is 26.7 feet. When the draft is 6.5 feet, KM is 25.17 feet. What is the height of the transverse metacenter for 8 feet? For 7 feet? For 5.5 feet?

9.4.2 Finding KG. In this section we will concentrate on the methods which a competent captain must utilize to calculate KG. The height of KG (the center of gravity) varies with each different way in which the vessel is loaded.

Before a successful attempt at calculating the KG of the vessel at any particular time, the captain must first know the position of the center of gravity for the vessel in a light condition (in other words, with no cargo, passengers, fuel, water, stores, or crew aboard). Usually light KG is found at the time the vessel is built by performing the inclining experiment on the vessel at the shipyard. If information about light KG is not available to the captain, he should communicate with his superiors to obtain it.

Once loading begins, every weight that is added to the weight of the vessel affects the position of the center of gravity. To find out the change in the position of the center of gravity, the captain must ascertain, as accurately as possible, the positions of the center of gravity of every weight loaded including fuel, water, cargo and stores. He must then multiply each weight by the height of its center of gravity above the keel and divide the sum of these moments by the total weights to find the new center of gravity. We will investigate this procedure step by step.

Figs. 9.7 to 9.9

9.4.3 Using Moments to Find KG. A piece of playground equipment, the seesaw, will illustrate how it is possible to use moments to find KG. Let us suppose that we have a seesaw that is 30 feet in length. The center of gravity of the seesaw is, of course, at its midpoint (see Fig. 9.9).

We will now place a 110 pound weight on the right-hand side of the seesaw 10 feet from the fulcrum. How far from the fulcrum (on the left side of the seesaw) must another 110 pound weight be placed to make the seesaw balance (see Fig. 9.8)?

The answer is 10 feet. You may have subconsciously used the theory of moments to obtain the answer. The moment of 1,100 foot tons (10 ft x 110 lbs) on the right-hand side of the seesaw had to be matched by a moment of 1,100 foot tons on the left-hand side. The theory of moments can also be used to determine the placement of differing weights on either side of the fulcrum. For instance, suppose that you had placed a 100-pound weight on
Fig. 9.10 the right-hand side of the seesaw 16 feet from the fulcrum. How far from the fulcrum on the left-hand side would a 200 pound weight have to be placed to balance the seesaw? The answer is 8 feet. The theory of moments could be used to obtain the answer as follows: weight x distance = moment.

Weight (lbs)	Distance (ft)	Moment (foot-pounds)
100	16	1,600
200	8	1,600

The moments on each side of the fulcrum are the same and therefore the seesaw balances.

See if you can work the following two problems using the theory of moments.

1) If you placed 200 pounds on the right-hand side of the seesaw 20 feet from the fulcrum, on the left-hand side of the seesaw you would have to place 250 pounds ____ feet from the fulcrum?

2) If you placed 150 pounds 10 feet from the fulcrum on the right-side of the seesaw, you would place 75 pounds ____ feet from the fulcrum on the left-hand side of the seesaw?

Besides shifting weights there is another method of making the seesaw balance. Let us consider that we have 150 pounds on the left-hand side of a seesaw which is 10 feet from the fulcrum. On the right-hand side of the
Fig. 9.11 seesaw we place 225 pounds 10 feet from the fulcrum. Our seesaw is 40 feet long (see Fig. 9.11). How far would we have to move the fulcrum to the right to make the seesaw balance?

To figure this out, find the distance of each weight from the left-hand side of the seesaw (Fig. 9.11). The 150-pound weight is 10 feet from the left-hand side of the seesaw. The 225-pound weight is 30 feet from the left-hand side of the seesaw. Using the theory of moments: Weight x Distance = Moment.

Weight (lbs)	Distance (ft)	Moment (foot-pounds)
150	10	1,500
225	30	6,750
375 (total wts)		8,250 (total moment)

Divide the total moment by the total weight:

$$\frac{8{,}250}{375} = 22 \text{ feet (from the left end)}$$

Since the fulcrum is presently 20 feet from the left end of the seesaw, we see that we would have to move the fulcrum two feet to the right to make the seesaw balance.

When the seesaw balances, we may consider the fulcrum to represent the center of gravity of the seesaw. When we had greater weights on the right-hand side of the seesaw the center of gravity moved to the right. A ship might be considered as a vertical seesaw (see Fig. 9.12). The fulcrum of our seesaw in the boat is the center of gravity of the vessel. The left-hand side of the seesaw is the keel. When weights are added above or below the vertical center of gravity, the center of gravity (or fulcrum) will move toward the greater weight. Using the theory of moments, we can find the distance of the vertical center of gravity from the keel (left-hand side of our seesaw) using the same method as we used in the previous example. In future examples in this text we will use two terms--center of gravity and vertical center of gravity (VCG)--to mean the same thing. The two terms will be represented by the letter symbols KG, which simply means the height of the center of gravity above the keel.

Fig. 9.12

In previous examples we did not take into consideration the weight of the seesaw since it was minor. However, the weight of a vessel is considerable and we must take into account the weight of the light ship and her light vertical center of gravity (VCG) when working stability problems.

Using an example, let us now see how moments are used to find the height of a vessel's center of gravity above the keel (KG).

A ship floating at her light draft displaces (weighs) 2,000 tons. The center of gravity for the vessel in a light condition is 15 feet above the keel. 100 tons are loaded 10 feet above the keel, and 300 tons are loaded 20 feet above the keel, what will be the position of the new center of gravity? Using the theory of moments: weight x VCG = moment in foot-tons.

Weight (tons)	VCG	Moments (foot-tons)
2,000	15	30,000
100	10	1,000
300	20	6,000
2,400		37,000 foot-tons

$$\frac{37,000}{2,400} = 15.4 \text{ feet (new KG)}$$

Fig. 9.13 To illustrate the problem above, imagine a giant seesaw weighing 2,000 tons with its fulcrum 15 feet from the left-hand side (see Fig. 9.13).

Next, imagine a weight of 100 tons placed on the seesaw 10 feet from the left end. Also imagine a weight of 300 tons placed on the seesaw at a distance of 20 feet from the left end. Then work the problem the same way we worked previous examples using the seesaw.

Weight	Distance (VCG)	Moment (foot-tons)
2,000	15	30,000
100	10	1,000
300	20	6,000
2,400		37,000

$$\frac{37,000}{24,000} = 15.4 \text{ ft from left-hand side (new fulcrum position)}$$

9.5 Calculating the Shift of the Center of Gravity

In the problems we have worked thus far we have calculated the shift in the center of gravity and the position of the new center of gravity after loading or discharging a number of weights.

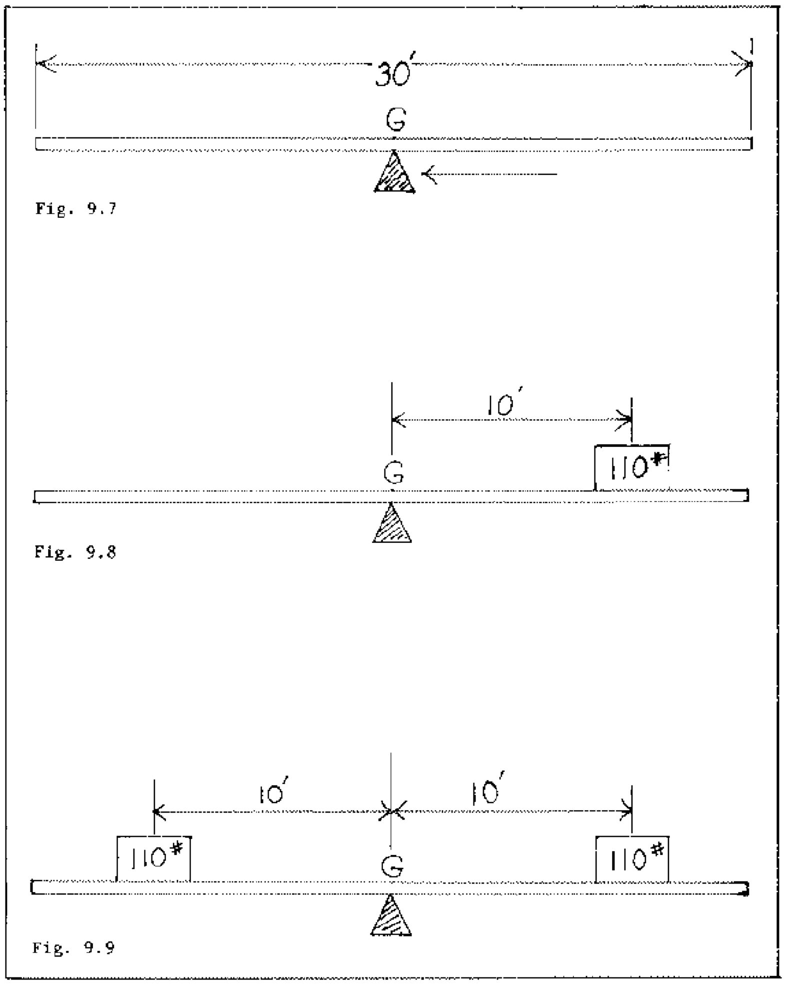

Fig. 9.7 - 9.9 Seesaw, and with weights added at one end and at both ends.

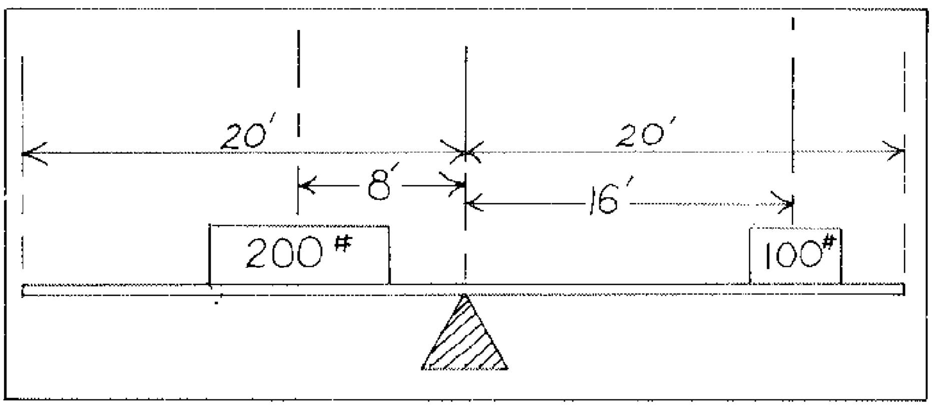

Fig. 9.10 Equal movements cause seesaw to balance.

What method should be used, however, to find the shift in the position of the center of gravity for a vessel when weight which is already on the vessel is shifted to a different position on the vessel?

For instance, let us use the following example: A vessel with a displacement of 1,500 tons and a KG of 20 feet has 500 tons of cargo shifted vertically upwards a distance of 10 feet. What will happen to the center of gravity? It is easy to understand that if weight is shifted upward, then the center of gravity for the vessel will move upward. But how far will the center of gravity move upward?

To solve this problem we will use the formula*

$$GG' = \frac{w \times d}{\text{displ.}}$$

GG' = the shift in the center of gravity
w = the weight shifted
d = the distance the weight is moved from its earlier position.

So getting back to our previous problem, the formula looks like this:

$$GG' = \frac{500 \times 10}{1,500}, \text{ which equals } \frac{5,000}{1,500}, \text{ which is } 3.33'$$

Therefore the center of gravity has shifted vertically upward a distance of 3.3 feet. The position of the new center of gravity (KG) is 20 + 3.3 or 23.3 feet.

9.6 Procedure for Finding VCG (KG) When Loading or Discharging a Vessel

In finding the VCG for a vessel which is to be completely loaded, the following steps must be taken:

1. Find the VCG for every compartment and tank on the vessel.

2. Multiply these distances by the weights in the respective compartments and tanks.

3. Add the total weights including the weight of the light ship.

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* LaDage and Van Gemert (1972).

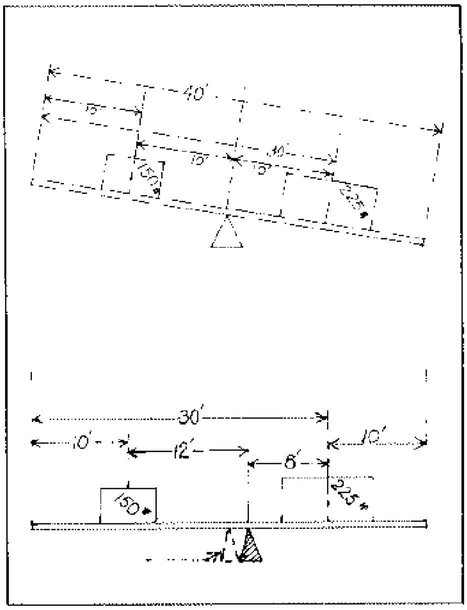


Fig. 9.11 How the movement of weights affects G.

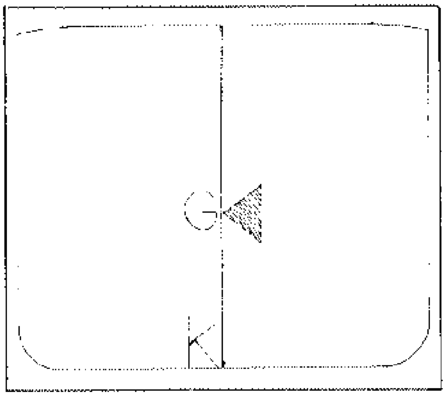


Fig. 9.12 The ship as a vertical seesaw.

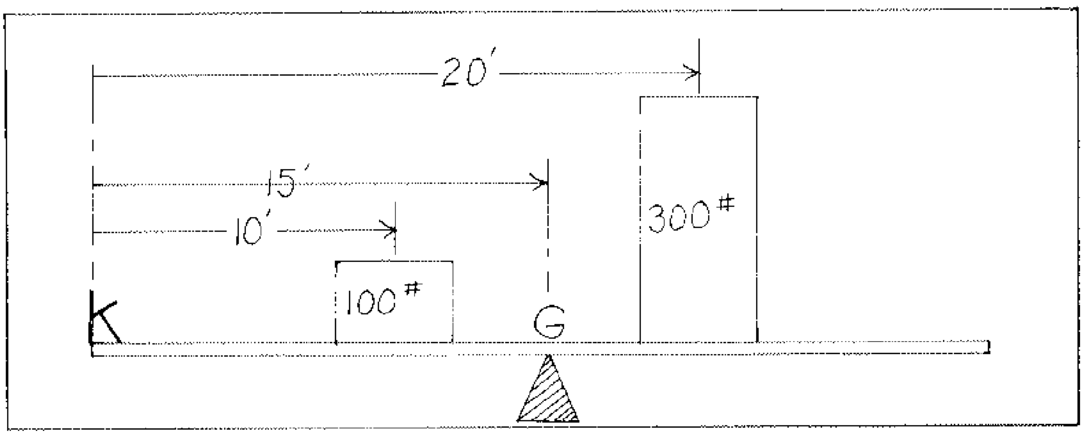


Fig. 9.13 How addition of weight affects G.

4. Add the total moment including the moment for the light ship (displ. x KG).

5. Divide the total moments by the total weights to determine the final KG.

The centers of gravity for all compartments and tanks are found on the vessel's capacity plan, Summary of Tank Characteristics (Table 9.2). If this plan is not aboard the vessel, make an attempt to obtain a copy from the office. Should you be told that this plan is not available, your only choice is to estimate the center of gravity for each space. In rectangular compartments and tanks, the center of gravity is in the center of the tank, halfway between the top and the bottom. In other locations in the vessel--where the sides of the compartment gradually widen toward the top, a close approximation is to figure that the center of gravity is slightly over half the height of the compartment.

Let us take an example of how the above process works:

The light displacement of our 184-ft supply vessel is 608.0 tons. Her light KG is 11.9 feet. It is calculated that three tons of crew and baggage will have a VCG of 18 feet; 10 tons of stores are loaded with a VCG of 24 feet above the keel. No. 3 and 4 ballast tanks port and starboard are filled. No. 16 ballast tanks port and starboard are filled. What is the KG of the vessel? Weight x VCG = Moment.

Weight	VCG	Moment
608.0	11.9	7,235.2
3.0	18.0	54.0
10.0	24.0	240.0
176.6	8.42	1,487.0
220.6	7.36	1,623.6
47.4	11.34	537.5
1,065.6		11,177.3

Dividing total moments by total weight:

$$\frac{11,177.3}{1,065.6} = 10.48$$

Therefore the new KG for the vessel is 10.48 feet.

Note: The weights for Nos. 3, 4, and 16 ballast tanks and their VCGs came off the capacity plan for the vessel in Table 9.2.

Table 9.2 Summary of Tank Characteristics (capacity plan)

Designation and Location	Liquid	100% FULL U.S. Gallons	100% FULL Long Tons	100% FULL Kg (ft)	⊠ G(ft) -Fwd +Aft	96% FULL U.S. Gallons	96% FULL Long Tons	Free Surface Corrections (ft-tons)
No. 7 Fuel Oil Fr. 26-40 P&S (ea)		10,696	34.4	8.35	+27.04	10,268	33.0	3.5
No. 8 Fuel Oil Fr. 40-52 P&S (ea)		11,834	38.0	8.27	- 1.50	11,361	36.5	3.8
No. 9 Fuel Oil* Fr. 52-58 P&S (ea)	No. 2 Diesel	4,733	15.2	8.27	-22.50	4,544	14.6	1.5
No. 13 Fuel Oil Fr. 69-77 P&S (ea)	Oil	5,626	18.1	10.29	-56.92	5,401	17.4	6.1
No. 14 Fuel Oil Fr. 69-77 P&S (ea)	41.6 ft^3 / L.Ton	12,891	41.4	9.33	-57.05	12,375	39.8	39.9
No. 15 Fuel Oil Fr. 77-87 P&S (ea)		3,997	12.8	12.33	-72.54	3,837	12.3	7.6
No. 10 Pot. Water Fr. 62-66 P&S (ea)	36.0 ft^3 / L.Ton	3,013	11.2	8.56	-40.45	2,892	10.8	1.2
No. 11 Lube Oil Fr. 67-69 Port		1,340	4.2	9.24	-48.42	1,287	4.0	0.5
No. 11 Lube Oil Fr. 67-68 St'Bd	43.0 ft^3 / L.Ton	695	2.2	9.05	-47.50	667	2.1	0.2
No. 12 Lube Oil Fr. 68-69 St'Bd		667	2.1	9.27	-49.46	640	2.0	0.2
No. 1 Forepeak Bal. Fr. 3 1/2-10 ℄		4,666	17.8	10.91	+76.54	4,479	17.1	39.9
No. 2 Ballast Fr. 10-18 P&S (ea)		8,510	32.5	7.22	+63.29	8,169	31.2	36.4
No. 3 Ballast Fr. 18-26 P&S (ea)	Salt Water	23,114	88.3	8.42	+48.98	22,189	84.8	142.9
No. 4 Ballast Fr. 26-40 P&S (ea)		28,873	110.3	7.36	+27.45	27,718	105.9	225.0
No. 5 Ballast Fr. 40-45 P&S (ea)	35.0 ft^3 / L.Ton	22,275	85.1	7.83	+ 5.50	21,384	81.7	88.6
No. 6 Ballast Fr. 45-52 P&S (ea)		19,491	74.5	7.83	- 9.50	18,711	71.5	77.5
No. 16 Ballast Fr. 77-83 P&S (ea)		6,206	23.7	11.34	-69.36	5,958	22.8	35.6
No. 17 Aftpeak Bal. Fr. 87-88 ℄		9,774	37.3	12.65	-85.90	9,383	35.8	850.8

*Day Tank

9.7 Stability vs. Stowage

At times it is necessary to compromise between the desired stability and stowage considerations of the cargo being carried. The nature of the cargo may make it necessary to place the heavier cargo at the bottom of the storage compartment and the lighter cargo on top. Or you may wish to separate a wet, dripping cargo from cargo which might be severely damaged by contact with moisture. In situations such as this you should do all within your power to obtain the best stability that you can under the circumstances.

Ideally, stability calculations should be made while the stowage plan is being made up. If you are operating an offshore supply vessel, this stowage plan is usually made up by the company which has chartered the vessel.

Typically, you (as captain) are consulted very little about what is to be loaded on your vessel and sometimes you are not asked about where the cargo should be stowed. Usually, however, you are asked to sign papers verifying that the cargo has arrived aboard and has been stowed and secured properly. Remember, it will be your responsibility if something happens to the cargo or the vessel due to improper stowage. So ask to see the list of cargo scheduled for loading aboard your vessel before it is loaded and have the cargo placed where you desire. Usually the dock force will cooperate in meeting your requirements as they do not wish to jeopardize either the safety of the vessel or her crew.

It is always best to make stowage changes on paper before the ship is loaded to produce good stability. If calculations are made while the vessel is being loaded, or after she is loaded, it may be too late to correct for poor stability. Many skippers try to do this by pumping water ballast overboard. All they accomplish is to raise the VCG since the weight they remove is stowed lower than the weights loaded on deck. Raising the center of gravity decreases the stability of a vessel.

9.8 Complete Solution of the Stability Problem

We have learned that KM - KG = GM. We have learned how to calculate KG for a vessel. Previously you practiced reading KM from the stability curves in Table 9.1. The table was entered with the draft of the vessel to find KM.

It is now time to put our knowledge of KG and KM to work to find GM because GM is our indication of the stability of our vessel.

Before we do this, however, there is still one curve in Table 9.1 which we must learn to use. As mentioned above, to find KM you have to know the draft of the vessel. However, if you are figuring stability for the vessel before the actual loading begins, how do you know what the draft will be?

9.8.1 Using Curves to Find Draft and KM. This problem is once again solved nicely by the Stability Curves in Table 9.1. On the stability curves you can find out what the draft of the vessel will be for any given displacement. Displacement is simply the total weight of the vessel and everything aboard her at any given time. So, if we know what the expected displacement of the vessel will be, then we can determine what the expected draft of the vessel will be. Draft is then used to find KM.

9.8.2 The Complete Stability Problem. In these two final problems you are to assume that you as captain are responsible for determining the stability condition of a 184 ft supply vessel. Information for use in solving the problems is contained in Tables 9.1 and 9.3 which you have already had practice in using.

1. Your 184 ft supply vessel has a light displacement of 608 tons and a light KG of 11.9 feet. No. 5 port and starboard ballast tanks are filled. No. 1 ballast tank is filled.

    a) What will be the new KG for the vessel?
    b) What will be the displacement of the vessel after loading?
    c) What will be KM for the vessel?
    d) What will be GM for the vessel after loading?

2. Preparing for this voyage, the supply vessel is loaded as follows: No. 10 port and starboard potable water tanks are filled. No. 3 port ballast tank is filled. No. 5 starboard ballast tank is filled.

    a) What is the new KG for the vessel?
    b) What is the new displacement of the vessel?
    c) What is the draft of the vessel after loading?

d) What is KM for the vessel at her new draft?
e) What is GM after loading?

9.9 Relationship Between GM (Metacentric Height) and Rolling Period

For those familiar with square root, it is interesting to note the formula discussed in this section.

The GM of a vessel has a definite relationship to the rolling of the vessel. A vessel with a large GM is "stiff" and rolls quickly. A vessel with a small GM is "tender" and rolls slowly.

The ship's officer, once he has calculated GM, can determine the rolling period of the vessel. The rolling period is the amount of time it takes the vessel to roll from one side to the other and back again.

The formula to be used is:

$$T = \frac{.44 \times B}{\sqrt{GM}}$$

T = the full rolling period in seconds
B = the beam of the vessel

For example, a vessel with a GM of 4 feet and a beam of 50 feet would have a rolling period of 11 seconds. A vessel with a GM of 16 and a beam of 50 feet would have a rolling period of 5.5 seconds. Notice that the larger GM, the quicker the ship rolls.

10. STABILITY AND TRIM

10.1 Trim Calculations

Trim may be defined as "the difference in draft forward and aft." If a vessel has a greater draft astern than forward she is said to be down by the stern or to have a trim by the stern. If the vessel has a greater draft forward, she is down by the head or trimmed by the head.

Example: Forward draft 20 feet. After draft 22 feet. The vessel has a 2 foot trim by the stern.

Example: Forward draft 6 feet. After draft 8 feet. The vessel has a 2 foot trim by the stern.

Example: Forward draft 16 feet. After draft 12 feet. The vessel has a 4 foot trim by the head.

Example: Forward draft 8 feet. After draft 8 feet. There is zero trim. The vessel is on an even keel or has an even trim.

When weights are shifted forward or aft on a vessel, or if weights are added forward or aft, the trim of the vessel may change. To determine the change of trim, the mariner may observe the forward and after drafts prior to loading the cargo, and then observe the new forward and after drafts after loading. If the trim prior to loading and the trim after loading, are both by the head or both by the stern, the change in trim is determined by subtracting the lesser from the greater. If the trims before and after loading are different, in other words one by the head and the other by the stern, add the two trims to determine the change of trim. Study the following examples.

	Fwd	Mean	Aft	Trim	Change of Trim
Initial drafts	11-00	13-00	15-00	4' by stern	
Final drafts	12-00	13-00	14-00	2' by stern	2 ft
Initial drafts	21-00	19-00	17-00	4' by head	
Final drafts	26-00	26-06	27-00	1' by stern	5 ft
Initial drafts	40-00	40-09	41-06	1' 6" by stern	
Final drafts	36-00	37-00	38-00	2' by stern	6 inches
Initial drafts	14-06	16-09	19-00	4' 6" by stern	
Final drafts	23-07	25-10	28-01	4' 6" by stern	none

You, as captain of the vessel, will be interested mainly in answering two questions related to trim:

1. What will be the change of trim of my vessel due to the loading discharging of weight?

2. Where and how much weight must I load or discharge to obtain my desired mean draft and trim?

Information is provided on the vessel's curves of form and on the capacity plan to help you answer these questions. In many ways your calculations will be similar to those used in calculating the position of the vertical center of gravity. Let's go back for a moment to our old friend--the seesaw. We found previously that we could balance the seesaw by the theory of moments. As long as the moments on

Fig. 10.1

one side of the seesaw were equal to the moments on the other side, the seesaw was level and would balance. Remember--a moment is a certain weight times a certain distance. Let us consider our vessel a seesaw balanced on a fulcrum. The fulcrum for the vessel is called the "tipping center" or the "longitudinal center of flotation." If weight is shifted on the fore and aft direction, or if weight is loaded or discharged forward or aft of the vessel's tipping center, the vessel will trim about the tipping center in the same way that a seesaw trims about its fulcrum.

If weight is loaded or discharged exactly at the LCF, the vessel's trim will not change. It would have the same effect as placing a weight over the fulcrum of the seesaw.

The tipping center (longitudinal center of flotation) is the center of the waterplane at any particular draft. Since the shape of the waterplane changes according to the draft of the vessel, the longitudinal center of flotation does not remain in the same position. The position of the longitudinal center of flotation is given for various drafts on the hydrostatic curves or curves of form for the vessel.

The value of the trimming moment for a vessel is the weight loaded, discharged, or shifted times the distance it was loaded or discharged from the LCF, or the distance it was shifted.

Example: 100 tons is loaded 10 feet from the LCF. What is the trimming moment? 100 x 10 = 1000 foot tons trimming moment.

Example: 20 tons is loaded 50 feet from the tipping center (LCF). What is the trimming moment? 20 x 50 = 1000 foot tons trimming moment.

Example: 15 tons is shifted 5 feet in a fore and aft direction (longitudinally). What is the trimming moment created? 15 x 5 = 75 foot tons trimming moment.

10.2 Moment to Change Trim One Inch

The moment required to change the trim of the vessel one inch (MT1) is given for various drafts of the vessel on the curves of form and on the deadweight scale of the vessel. When shifting weight longitudinally all the mariner needs to do to find the change of trim is to divide the total trimming moment by the MT1.

Example: The forward draft of a vessel is 23 feet, the after draft is 21 feet; 100 tons of sea water are pumped from No. 1 ballast tank to No. 8 ballast tank--a distance of 100 feet. The mariner wishes to find the change of trim and the new drafts for the vessel.

Solution: The mariner first figures the mean draft of the vessel. Using the mean draft (22 feet), he finds the MT1 for that draft on the vessel's deadweight scale, or on the curves of form. MT1 is 500 foot tons.

The mariner then calculates the trimming moment. 100 x 100 = 10,000 foot tons.

$$\frac{\text{Trimming Moment}}{\text{MT1}} = \text{Change of Trim (in inches)}$$

$$\frac{10{,}000}{500} = 20 \text{ inches change of trim}$$

Since the weight was moved aft, the forward draft will decrease and the after draft will increase. Half the change of trim is applied to the forward draft and half to the after draft.

	Fwd	Mean	Aft
Initial draft	23-00	22-00	21-00
Change of trim	00-10		00-10
Final draft	22-02	22-00	21-10

Example: The drafts of a vessel prior to the shifting of a weight are 9 feet forward and 10 feet 6 inches aft; 300 tons are shifted forward a distance of 20 feet. MT1 at the mean draft again is 500 foot tons. Find the change of trim and the new drafts.

Solution: Assuming that the mariner had not been given MT1, he would calculate the mean draft--which is 9 feet 3 inches. Using this he would use the curves of form to find MT1--500 foot tons.

$$\frac{\text{Trimming Moment}}{\text{MT1}} = \text{Change of Trim}$$

$$\frac{300 \times 20}{500} = \frac{6{,}000}{500} = 12 \text{ inches change of trim}$$

	Fwd	Mean	Aft
Initial drafts	8-00	9-03	10-06
Change of trim	06		06
Final draft	8-06	9-03	10-00

Using the curves of form for our 184-foot supply vessel in Table 9.1, find MT1 for the following mean drafts.

	MT1
6 ft	88 foot tons
8 ft	104.2 foot tons
9 feet 6 inches	122.5 foot tons
11 feet	166.5 foot tons

In actual practice, no one will be standing next to you in the wheelhouse to tell you MT1 so you will have to use your vessel's mean draft as you did above to find MT1. Also, no one will help you determine how far or how much weight has actually been shifted.

10.3 Finding How Far Weight Has Been Shifted

Fig. 10.2

Let us say that you pumped the contents of No. 1 forepeak ballast tank which was full on our supply vessel to No. 17 afterpeak ballast tank, which was empty. How much weight has been shifted and how far has it been shifted? Let us look at the Summary of Tank Characteristics in Table 9.2. You will notice that the full contents of No. 1 forepeak ballast tank are equivalent to 17.8 tons, so this is the weight which has been shifted.

Now, just how far has the weight been shifted? Looking once again at the Summary of Tank Characteristics you will see that the center of gravity of each tank is given forward or aft of amidships. For No. 1 forepeak tank the longitududinal center of gravity is 76.5 feet forward of amidships. For No. 17 afterpeak ballast tank the longitudinal center of gravity is 85.9 feet aft of amidships. Adding the two distances together you determine how far the weight has been shifted.

$$\begin{array}{r} 76.5 \\ \underline{85.9} \\ 162.4 \text{ ft} \end{array}$$

Example: Our vessel's mean draft is 11 feet, with a forward draft of 9 feet and an after draft of 13 feet. The

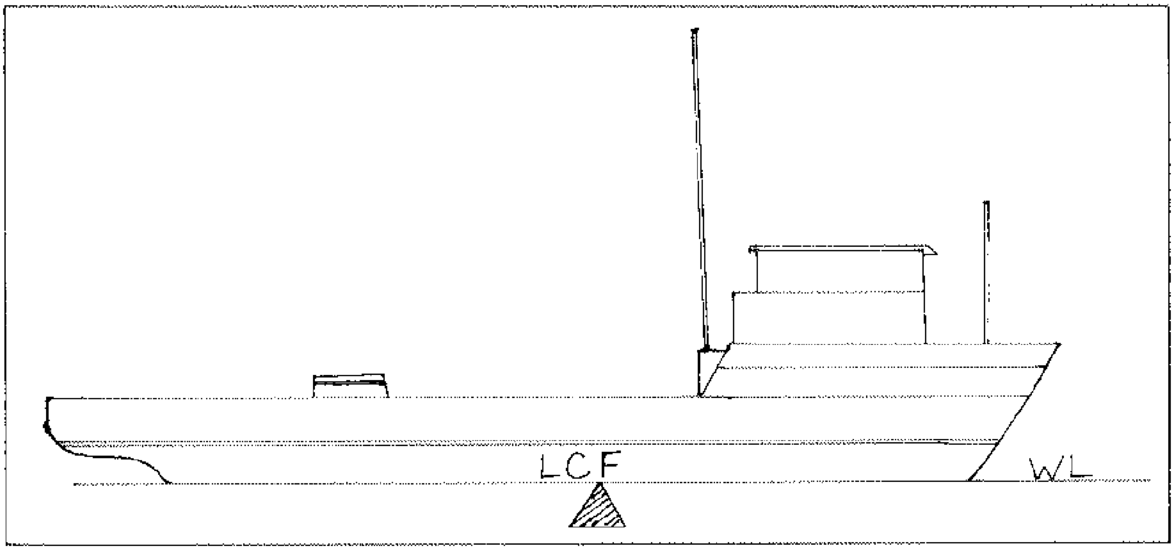


Fig. 10.1 Longitudinal center of flotation.

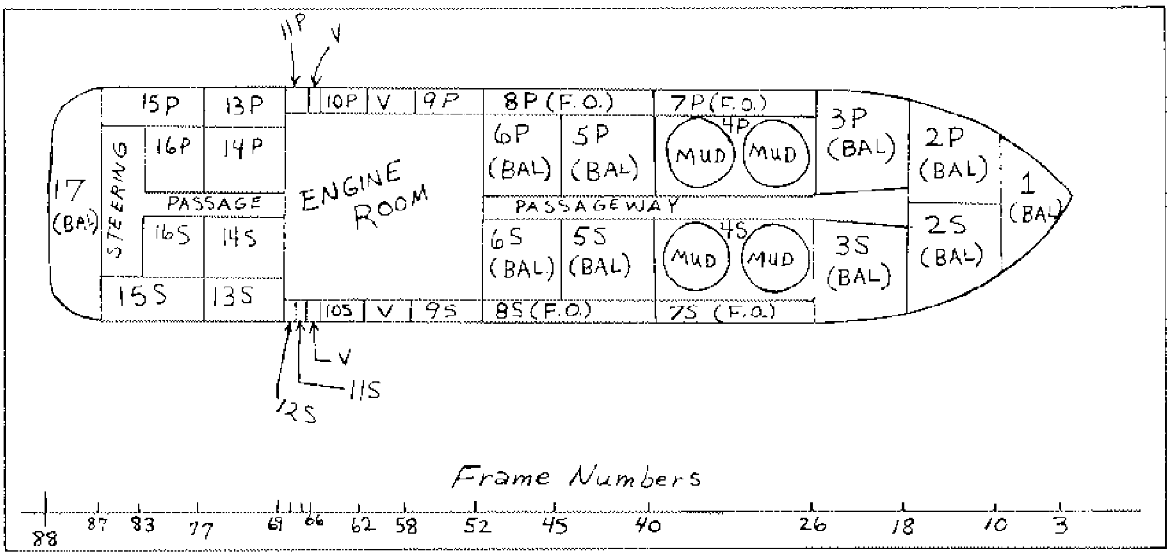


Fig. 10. 2 Tank plan. Each tank is identified by number and the letters: P (port), S (starboard); FO (fuel oil); Bal (ballast), and V (void, an empty space).

contents of No. 16 ballast tank which is full are pumped to No. 2 ballast tank which is empty. Find the change of trim and the new drafts for the vessel.

1. Find how much weight has been shifted on the Summary of Tank Characteristics. No. 16 P & S = 47.4 tons.

2. How far has the weight been shifted?

$$\begin{array}{r} 69.4 \\ \underline{63.3} \\ 132.7 \text{ ft} \end{array}$$

3. What is the trimming moment? w x d = 47.4 x 132.7 = 6290 ft tons.

4. Using the curves of form, find MT1 at your mean draft.

   MT1 = 166.5 ft tons

5. $\frac{\text{Trimming Moment}}{\text{MT1}}$ = Change of Trim = $\frac{6,290}{166.5}$ = 37.8 inches

6.

	Fwd	Mean	Aft
Inital draft	9-00	11-00	13-00
Change of trim	18.9		18.9
Final draft	10-06.9	11-00	11-05.1

10.4 Loading or Discharging Weight

When weight is loaded or discharged rather than merely being shifted from one point on the vessel to another, our calculations of necessity are somewhat different. The mariner first assumes that the weight is loaded at the tipping center. Remember, the only thing that happens if weight is loaded or discharged at the tipping center is that the mean draft of the vessel will change. Trim is not affected. Using TPI (tons per inch immersion), the mariner calculates exactly what the new mean draft will be. He then uses this mean draft to find MT1 as before. As before, trimming moments divided by MT1 equals the change of trim. Trimming moments are calculated as the weight times the distance it is loaded or discharged from the tipping center.

Example: Prior to loading, the forward draft of our 184-ft supply vessel is 7 feet; after draft is 9 feet; 100 tons are loaded 15 feet aft of the tipping center. Find the change of trim and the new drafts for the vessel.

Solution: 1) The mariner first assumes that the weight is loaded at the tipping center (LCF). Using the curves of form the mariner determines that the TPI at his original mean draft of 8 feet is 12.1 tons per inch. In other words, if 12.1 tons is loaded the vessel will sink 1 inch deeper in the water. He is loading 100 tons. How much will the vessel's mean draft change? $\frac{100}{TPI} = \frac{100}{12.5} = 8.3$ inches.

Mean draft	8 ft
Change of mean draft	8.3 inches
New mean draft	8-08.3

2) The mariner then imagines that the weight is shifted to its actual position; 100 tons is shifted 15 feet aft of the tipping center. What is the total trimming moment created? w x d = 100 x 15 = 1500 foot tons.

3) Remembering that $\frac{\text{Trimming Moment}}{\text{MT1}}$ equals the change of trim, the mariner finds MT1 for his new mean draft of 8 feet 8.3 inches--111.0 foot tons.

$$\frac{\text{Trimming Moments}}{\text{MT1}} = \frac{1,500}{111} = 13.5 \text{ inches change of trim}$$

4) The mariner now proceeds as in the previous examples.

	Fwd	Mean	Aft
Initial drafts	7-00	8-00	9-00
Change of mean draft	8.3"	8.3"	8.3"
	7-01.5	8-08.3	10-03.1
Change of trim	6.8		6.8
Final drafts	6-06.7	8-08.3	10-09.9

As mentioned earlier, you will have to find all the required information necessary for the solution of the trim problem. You have done this in the previous example all except for one thing. You were given how far the weight was loaded from the tipping center. For any particular tank or compartment filled you will have to determine how far the weight is placed forward or aft of the tipping center. As mentioned earlier, the position of the tipping center (longitudinal center of flotation) changes with changes in draft. On the curves of form of the vessel is given the position of the LCF for a number of mean drafts. If you know the position of the LCF in relation to amidships, and the position of the longitudinal center of gravity of the tank or compartment in relation to amidships, finding the distance from the tipping center is a simple matter.

10.5 Stability at Large Angles of Inclination

Previously we have studied initial stability, i.e., stability at small angles of inclination. We calculated GM and used this as an indication of the stability of our vessel. GM as an indicator of the stability of the vessel loses validity as the vessel rolls to large angles, say, 20 degrees.

A more proper criteria to use for examining the stability of a vessel at large angles of heel is GZ. If you will remember, and as illustrated in Figure 9.4, GZ is known as the righting arm and is the distance between the lines of force through G (center of gravity) and B (center of buoyancy).

Generally, the greater the heel of the vessel, the greater GZ. However a point is reached where GZ begins to decrease with any further angle of roll. The angle at which GZ is largest and the angle at which GZ begins to decrease is usually at the point at which the edge of the deck on the low side of the vessel is immersed or covered with water. This angle is called the "angle of deck edge immersion," or the "angle of maximum righting arm."

Fig. 10.3 Offshore supply vessels have a high initial GM. Shown below is comparison of initial GM (GM for inclinations up to 10 degrees) for a typical offshore supply boat and a large oceangoing cargo vessel.

At first glance it appears that the offshore supply boat possesses much greater stability than the conventional cargo vessel. But remember, GM is a good indicator only for small angles of inclination. The high initial GM of offshore supply vessels led to two pitfalls. First of all, it covered up the need for a more complete stability analysis. Second, it very likely caused poor operating practices. Capsized vessels were commonly found to have had many slack tanks and to have open cross connections between tanks. This could very possibly have been an attempt by the operator of the vessel to produce a more comfortable ride. Because as we have mentioned, a high GM results in a stiff, uncomfortable vessel.

In 1959, eleven lives were lost due to the capsizing of the offshore supply vessel National Pride. In January 1963, the uninspected supply vessel Diversity capsized in heavy weather with the loss of the lives of all five crew members. On November 25, 1968, the 160 foot supply vessel Triple Crown, while engaged in picking up anchors and chain for a drilling rig off Santa Barbara, Calif., capsized with the loss of nine crew members. It is known that the vessel had little freeboard at the stern (easily understood because when handling anchors, supply vessels are pumped down at the stern so that the stern roller is partially in the water), and that flooding of the engine room occurred through a stack door which was blocked open by an anchor.

This points out a basic fact--that the best criteria of overall stability is GZ or righting arm. This information is provided the captain on the stability curves of the vessel. These curves may be presented in two different ways: by statical stability curves, and by cross curves of stability. The cross curves of stability are shown in Table 9.2 for our 184-foot supply vessel. Before looking at them however, let us go back to our previous comparison of the supply boat and the conventional large cargo vessel. Shown in Figure 10.4 is the same graph which we used earlier to compare the GM of the two vessels. Drawn on this graph now are the statistical stability curves for the two vessels. GZ at any angle of roll is the vertical distance from the base line to the curve.

Table 9.3

Fig. 10.4

Notice the large value of the righting arms for the large cargo vessel and the relatively smaller righting arms for the offshore supply vessel. Notice that the angle of maximum righting arm for the supply vessel is approximately 18 degrees while for the conventional cargo vessel, this angle is approximately 42 degrees.

On the statical stability curves the baseline is the angle of the roll. A number of curves are drawn for selected displacements of the vessel. On the cross curves of stability, the baseline is the displacement of the vessel and a number of curves are drawn for different angles,of inclination, or roll. On both presentation, GZ in feet forms the left-hand vertical measure.

Table 9.3

Cross Curves of Stability
(printed separately)

You can learn a number of things by analyzing the stability curves for your vessel. We shall concentrate on analyzing the cross curves of stability shown in Table 9.3.

10.6 Stability Characteristics--An Analysis

10.6.1 Initial Stability. The initial stability of the vessel is indicated by GM which closely follows the statical stability curve for the first 10 degrees of roll. The sharper the slope, the greater the initial stability.

10.6.2 Maximum Righting Arm. The maximum righting arm is the maximum vertical distance from the baseline to the curve.

10.6.3 Maximum Righting Moment. To find the maximum righting moment for the vessel, simply multiply the displacement by maximum GZ.

10.6.4 Angle of Maximum Stability. This angle is equal to the angle at which the maximum righting arm is developed and is approximately equal to the angle of deck edge immersion mentioned previously. The angle at which the deck edge will be immersed is dependent upon the freeboard
Fig. 10.5 of the vessel. Study Figure 10.5 in which two vessels are shown, one with little freeboard and one with a lot of freeboard. This shows why freeboard is such an important factor in the stability of a vessel.

10.6.5 Angle of Maximum List. The angle of maximum list corresponds approximately to the angle of deck edge immersion. When a ship is listed to any particular angle, she is in equilibrium. In other words she is listed to a certain angle and the lines of force through G and B are on the same line and G and B are vertically under each other. This is different from a vessel which rolls to a certain angle where the lines of force through G and B are separate and parallel lines. When a vessel is listed over due to some reason such as the way that her cargo is stowed, she is in equilibrium; there is no tendency for her to return to an upright position, and neither is there any tendency for her to continue inclining. If a ship lists her deck edge under, she will probably capsize. Remember, we are not speaking of a vessel which rolls and immerses her deck edge.

10.6.6 Angle of Dangerous List. If your vessel is listing over and continuing to take on water, then continues to list farther and farther over, what do you consider a

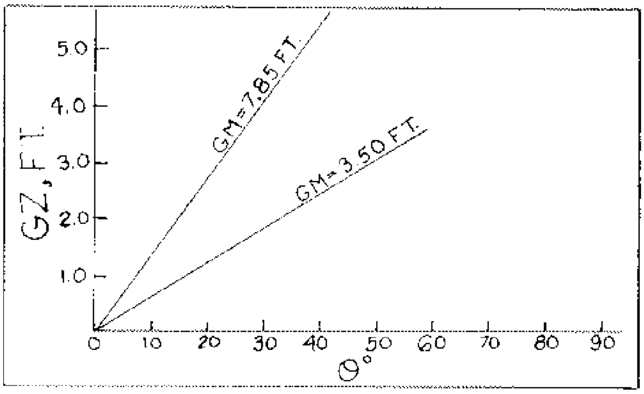


Fig. 10.3 Comparison of GM.

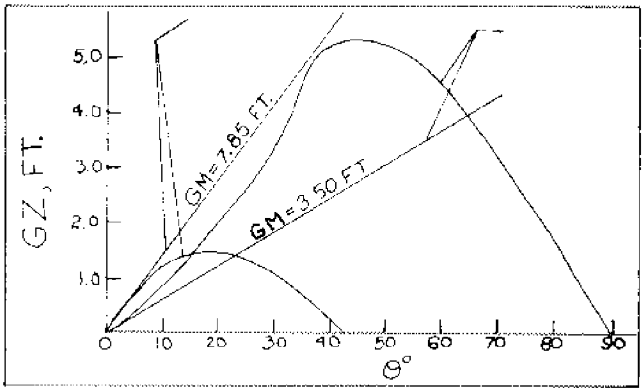


Fig. 10.4 Comparison of GZ.

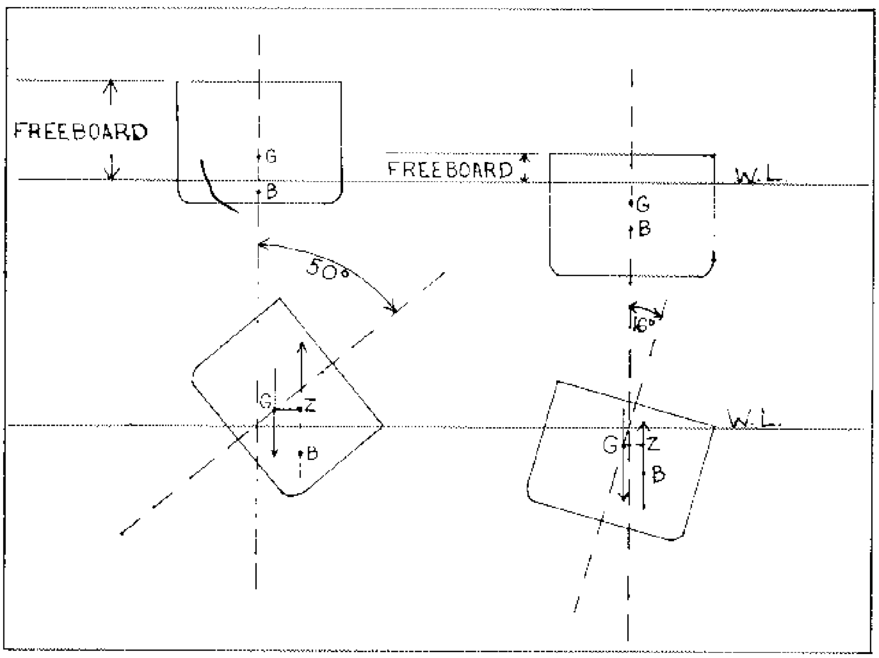


Fig. 10.5 How freeboard affects stability.

dangerous list? In other words, when should you abandon ship? We could go into a lot of discussion about this but the final decision made depends upon various factors such as the master's knowledge of his ship and weather conditions. However, it is generally accepted that an angle of dangerous list is the angle which is one-half the angle of deck edge immersion.

10.6.7 Angle of Dangerous Roll. The angle of dangerous roll which should be feared by any captain with any sense, corresponds to the angle of maximum stability. In other words, it corresponds to the angle of deck edge immersion. If your vessel is rolling her deck edge under, you had better take corrective action if possible, or prepare for the worst!

10.6.8 Angle of Maximum Roll. The angle of maximum roll is the angle at which there is no longer a righting arm. In Figure 10.5 we have drawn this angle at approximately 42 degrees. In other words, when the supply vessel pictured rolls to 42 degrees, there is no longer any tendency for her to return to an upright position. GZ (righting arm) has vanished. This angle of maximum roll is also known as the "vanishing point."

11. MATERIALS AND METHODS OF CONSTRUCTION

The captain of a vessel should know something of the vessel's construction. He should know the purpose of every valve and fitting. This knowledge will serve him well in the operation of his vessel and in the wise use of vessel equipment. In the event of an emergency such as damage to the underwater hull, he should know which measures to take and how to describe the damage over the radio. If the company owner sends him to a shipyard to represent the company during the construction of new vessels, he must know what to look for and know the desirable arrangement of equipment, pipes, fittings, and other gear.

Throughout the history of shipping many different materials and methods of construction have been used. As knowledge and techniques have advanced, the material used has changed from wood to steel.

11.1 Materials

11.1.1 Wood. Wood was the first shipbuilding material used. Supplies were abundant and it was easy to work.

However, the drawbacks of wood prompted the switch to other materials. Wood is not uniform in strength and is combustible. Furthermore, the length of vessels built of wood is limited by the fact that they sag in the middle and there is difficulty of tying the joints together which causes leaks. One other notable point is that wood is heavier than steel of the same strength.

11.1.2 Wrought Iron. The first metal to be used in ship construction was wrought iron. Wrought iron is strongly resistant to corrosion and some vessel hulls of over 50 years in age are still in operational condition. The development of the steel making industry caused the discontinuance of the use of wrought iron because steel is stronger and cheaper.

11.1.3 Concrete. In the past, concrete has also been used as a shipbuilding material. The strength of the hull was provided by steel rods within the concrete. Because the concrete hull in a large vessel is heavy and relatively easily damaged, concrete has never been commercially feasible as a material for construction of larger vessels.

11.1.4 Steel. With the notable exception of aluminum used in crewboat construction, steel is the material now used for the construction of most vessels. Although steel is more susceptible to rust and corrosion than wrought iron, it is stronger and can be easily worked. Steel must be carefully painted and maintained to prevent corrosion.

There are many different types of steel. A special, although very expensive type, called Corrosion Resistant Steel (CRS), is often used in places susceptible to great corrosive action. Armor steel finds application in military vessels where the hard outside surface of the plate breaks the head of a projectile while the somewhat softer and tough inside of the plate absorbs the energy of the shell.

11.2 Methods of Forming Steel

Some means must be employed to put the steel into the correct shape desired for its place in the vessel. The two major processes used are forging and casting.

11.2.1 Forgings. Forgings are used where great strength and toughness are required. They are made by heating the steel white hot and then beating it into shape. Some examples of forged materials on the vessel are the rudder stocks, crankshafts, and propeller shafts.

11.2.2 Castings. As the word "castings" suggest, the steel is poured or cast into a mold in this method of forming steel. A wooden pattern is made to the exact shape of the piece desired with a slightly larger dimension to allow for shrinking as the steel cools. The wooden pattern is then placed into special casting sand. After the casting sand hardens, the pattern is removed and the molten steel is poured into the hole left. The stern frame, rudder frame, struts, hawsepipes, and anchors are all examples of pieces aboard a boat which are cast.

11.3 Strength of Materials

A ship and its component parts must be built to resist various stresses which will be placed upon it by the weight of its cargo and the forces of the sea. There are three basic types of stress which we will discuss here.

11.3.1 Tension. Tension (or tensile stress) is the stress which occurs between two parts of a body when each tends to draw the other toward itself (see Fig. 11.1).

Fig. 11.1

11.3.2 Compression. Compression (or compressive stress) occurs between two parts of a body when each is pushed toward the other (see Fig. 11.1).

11.3.3 Shearing stress. Shearing stress occurs when one part of a body has a tendency to slide over another part (see Fig. 11.1).

The vessel's structure must be strong enough to resist each of the above stresses. In discussing the strength of a vessel we must consider both the strength of each particular piece or part of the vessel and also the strength of the vessel as a whole. The strength of any one particular component of the vessel is known as local strength. The strength of the ship as a whole is known as hull girder strength.

The term "hull girder strength" comes from the fact that each part of the vessel contributes to the total strength of the ship. The entire ship structure must be able to meet and endure the stresses placed upon it by rolling, pitching, and the pounding of the seas. For calculating just how well the ship will hold up under these stresses, the hull of the ship is often considered to be a gigantic box girder. The bottom of the box is the bottom of the hull. The top is the deck of the ship and the sides of the girder are the sides of the ship.

11.3.4 Hog and sag. To illustrate just how stresses can be placed on the structure of the hull as a unit, two different situations and their probable results are shown in Figures 11.2 and 11.3, when the vessel is overstressed.

Fig. 11.2 In Figure 11.2 the bow and stern of the ship are supported on the crests of waves. The vessel is said to be in the sagging condition.

Fig. 11.3 In Figure 11.3 the vessel is supported primarily amidships by the crest of a wave. The vessel is said to be in the hogging condition.

Even though we can, when considering hull girder strength, picture the hull as a simple beam for illustration, the idea should not be conceived that the ship's hull is only a beam and need only face hogging and sagging stress. The ship's hull must stand up as it drives through heavy seas, rapidly picking up speed only to slam into another wave and have its direction changed, being further stressed by internal vibration from its own propulsion machinery and propellers.

11.4 Factors of Safety

When he designs a ship structure, the naval architect must first calculate as accurately as possible just what loads the structure will have to bear. It would be extremely hazardous to build the ship only as strong as needed to support this load, for it is conceivable that the unexpected may occur, and the vessel will be called upon to meet a stress or load far over its normal load. For this reason the vessel is built to support loads far greater than what is normally expected. A factor of safety is decided upon and the vessel is built using this safety factor. Let us imagine for an instant that the deck on a particular vessel will normally be called upon to bear a load of 250 tons. Let us also say that the naval architect wishes to use a safety factor of 4. This means that the vessel will be built to handle a load four times as large as that normally expected (250 x 4 = 1,000 tons), or 1,000 tons.

Another term usually comes up when discussing safety factors. This is breaking strength. Breaking strength (BS) simply means the amount of load which must be applied to a material before it will break. In other words, if you had a bar of steel which would break when you placed a load of 20 tons on it, its breaking strength would be 20 tons. You would never in practice push a material to its breaking strength because this is an unsafe practice. Instead you use the safety factor (SF) to determine what would be a safe load to place on the material under ordinary working conditions. This is called the safe working load (SWL). Let's say that you have a steel cable which will support a load of 20 tons before it will break. You wish to observe or use a safety factor of 4. What would be the safe working load for the steel cable using a safety factor of 4? The answer is obtained by dividing the breaking strength (20 tons) by the safety factor (4). Twenty divided by four equals 5. So to observe a safety factor of 4 you would never load the cable over 5 tons. The relationship between breaking strength, safety factor and safe working load can be expressed as follows: BS = SF x SWL. Breaking strength equals the safety factor times the safe working load. This holds true no matter what material you are working with--wood, steel, cable, fiber rope, etc. Safety factors of 6 are now uncommon in ship construction, especially for items which are critical to the safety of the vessel and her personnel.

Safety factors for merchant ships and the scantlings (sizes) of the various components for merchant vessels are generally specified by various classification societies (see Section 5.3).

11.5 Beams

A beam is an athwartship, horizontal member of the vessel supporting a deck or a flat. One example of a beam would be a deck beam. The size of the beams is determined largely by five factors:

11.5.1 The type and amount of load. The larger the load the stronger the beam must be. A beam which would have to support a 5 ton load would not have to be as large as a beam supporting a 50 ton load. The type of load is also an influencing factor. If the load is concentrated in one point, the beam must bellarger than if the load is spread out over the length of the beam.

11.5.2 The distance between supports. A beam which must run 50 feet between supports must be larger than a beam which runs only 5 feet between supports. The more supports, the more the load must be before the beam will bend.

11.5.3 Type of end connections. A beam which has the ends stoutly secured can support a greater load than a beam which is not secured at both ends. For this reason, the better the end connections, the smaller the beam can be.

11.5.4 Number of supports. The fewer the number of supports, the larger the beam must be to support a given load.

11.5.5 Material. Perhaps the most obvious factor influencing the size of a beam is the material of which it is made. The stronger the material, the smaller the beam may be for a given load.

11.6 Plates

Plates are sheets of steel rolled to a uniform thickness of 1/4" or more (usually 1/4" to 1 1/4"). Plates, because they are in some manner supported at the ends and support loads, act as a beam. In building a vessel, the naval architect must determine the thickness of the plate to be used. Here he must make a compromise between weight and strength. Thicker plates possess more strength but they are heavier than lighter plates. Stiffeners are used to stiffen plate or make it stronger. If stiffeners are used, thin plate can be made as strong as thick plate. However, there is a point at which we must stop adding stiffeners to reduce plate thickness because weight saving gained by using the thinner plate is more than offset by the added weight of the stiffeners. The naval architect must be very careful to see that he uses the proper ratio of stiffeners to plate weight so that he can get the required strength with the least weight.

11.6.1 Types of plate. Plate may be flat, rolled or furnaced. This depends upon the way in which the plate is
Fig. 11.4 made. Most of the plates in the vessel are flat plates and are made with no curvature. Plates which have curvature in one direction only--such as those found at the turn of the bilge, are rolled plates. These plates are cold rolled by a machine. At some points in the vessel, such as at the bow and stern, plates which possess curvature in two directions must be used. These plates are called furnaced plates and they are heated and hammered to the correct shape using a special shaped steel form.

11.7 Shapes Found in Vessel Construction

Various shapes may be found when looking at the structure of a vessel. These shapes are each designed to serve a special purpose. Imagine that you are looking at the end of a long steel bar and seeing each of these shapes in turn.

11.7.1 Plain Angle. Plain angles are used for frames, beams, and stringers. They are also used to connect together two other members of the vessel at right angles. The parts of an angle are shown in Figure 11.5. If the angle is connected as shown in Figure 11.5(3), it is known as an inverted angle. Inverted angles provide greater strength than plain angles.

Fig. 11.5

11.7.2 Bulb Angle. Bulb angles are used only in riveted construction. They are simply plain angles which have a bulb of material added to the toe of the angle at the point of greatest stress. They are much stronger than the plain angle.

11.7.3 T-Bar. The T-Bar is an angle--one leg of which has been centered on the other. It will not fall over or "trip" as easily as a plain angle. When used it may be inverted. When inverted, the side of the vessel or other structure to which it is attached forms another flange and the T-Bar then acts as an I-Beam and becomes a strong and rigid stiffener.

11.7.4 T-Bulb Bar. The T-Bulb Bar is simply a T-bar which has had a bulb of material added to the bottom of the stem to increase its strength.

11.7.5 Channels. Channels are used for side frames, deck beams, bulkhead stiffeners, and pillars.

11.7.6 I-Beam. A rolled shape which has a cross section like the letter I is called an I-Beam. The I-beam is used chiefly for deck beams and girders.

11.7.7 H-Beam. When the flanges of an I-Beam are as wide as the web, it is called an H-Beam. H-beams are used chiefly as columns or pillars.

11.8 Welding vs. Riveting

In the early days of shipbuilding, all metal ships were built using riveted construction. Today most construction methods utilize welding. The disadvantage of riveted construction is that leaks often develop because it is too difficult to obtain absolute tightness. Welding is the art of uniting two pieces of metal at the melting point, without using another metal having a lower melting point to make the joint. When two pieces of steel are welded together, the two become one piece as strong as the original two pieces.

Where two pieces of metal are joined together by welding or riveting, this is called a seam. Riveting is still used in places on some vessels because it possesses one major advantage. This advantage is related to the seam previously mentioned. Imagine four steel plates. Two of the plates are welded together. Two are riveted together. If a crack begins in one of the two plates welded together, it can continue from one plate all the way through the seam and into the next plate. If a crack begins in one of the two plates riveted together, the crack may continue to the seam but will not continue past the seam because the two plates are still separate pieces. At places on a ship where cracks are prone to begin, such as in areas of high stress, riveted seams are sometimes employed to limit the damage. Such a device used to prevent a crack from spreading is called a crack arrestor. Another method which may also be used to prevent a crack from spreading is used after the crack has started. A small hole may be drilled at the end of the crack. The crack will usually stop at the hole. Then at a later opportunity the plates are replaced.

11.9 Terms

Before proceeding further, study the following terms in the glossary at the end of this book: forward, aft, fore and aft, amidships, athwartship, centerline, beam, below, bow, frame, inboard, intercostal, midship, outboard, overboard, panting, plating, stem, stern, stow, bracket, girder, bilge.

12. VESSEL MEMBERS

12.1 Keel

The keel is the backbone of the vessel's frame. It is the principal fore and aft member of a ship's frame. The keel runs along the bottom and connects the stem and the stern,and the frames of the vessel are connected to it. Because the keel is the bottom structure of the box girder formed by the hull, it must be strong enough to resist longitudinal stresses and the concentrated pressures due to grounding, drydocking, and cargo.

There are two main types of keel, the bar keel and the flat plate keel.

12.1.1 Bar keel. The bar keel may be thought of as a heavy flat bar of steel which runs fore and aft along the centerline and protrudes through the bottom of the vessel. The bar keel was very common in the early days of shipping. It protected the bottom of the vessel in the event of grounding on a hard bottom and also served somewhat to reduce the roll of the vessel. The main disadvantage of the bar keel is the fact that it increases the draft of the vessel. Let us assume that for a particular vessel, 100 tons of cargo must be loaded to increase the draft of the vessel one inch. Let us also assume that this particular vessel is now being loaded at the dock and that she has a bar keel extending 10 inches down from the bottom of the hull. In order to leave the harbor, the vessel must pass over a bar. A similar vessel without a bar keel will just skim the top of the bar when passing out to sea. Our vessel with the bar keel must be 10" higher out of the water in order to cross over the bar. How much cargo must be unloaded to permit the ship to rise 10" out of the water: 100 tons x 10" = 1,000 tons. So, our vessel with the bar keel can carry 1,000 tons less than the vessel without the bar keel. This represents a sizable loss of money to our vessel's owner because of the lost freight on the cargo which could not be carried.

Fig. 12.1

12.1.2 Flat plate keel. The flat plate keel was developed to provide a backbone for the vessel without increasing the draft of the vessel. It is basically a fore and aft row of flat plates increased in thickness. This row of plates runs along the bottom of the ship from stem to stern.

Fig. 12.2

The flat plate keel is reinforced by the center vertical keel, vertical flat plates running fore and aft on the centerline. When the rider plate is placed atop the center vertical keel, the structure formed is a rigid and powerful I-beam. The rider plate is a fore and aft row of flat plates placed atop the center vertical keel.

The center vertical keel may run fore and aft in one continuous piece or it may be intercostal to the floors which are to be discussed below.

12.1.3 Bilge keel. Another type of keel which is not used for the same purpose as the bar keel or the flat plate keel is the bilge keel. The bilge keel is a fin-like piece of steel fitted to the vessel at the turn of the bilge to reduce the rolling of the vessel in a seaway.

Fig. 12.3

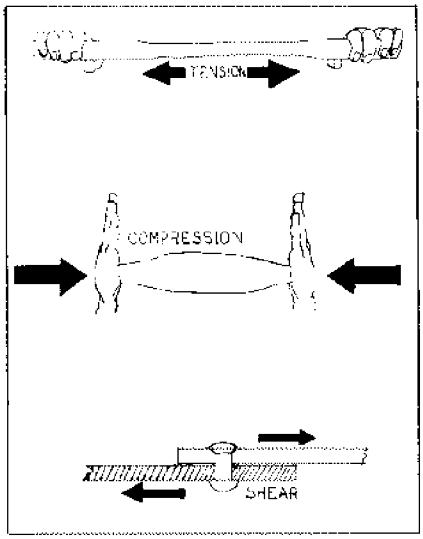


Fig. 11.1 Compression, tension, shearing stress.

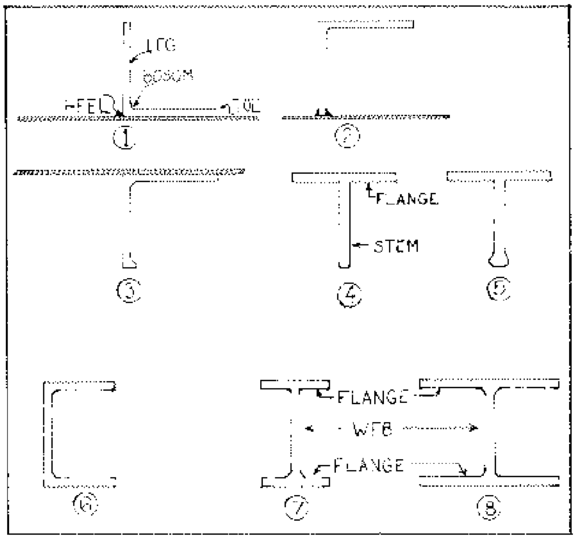


Fig. 11.5

Fig. 11.4 Types of plate: (A) Furnaced; (B) Rolled; (C) Flat.

Fig. 11.5 Various shapes in vessel construction: (1) plain angle; (2) inverted angle; (3) bulb angle; (4) T-bar; (5) T-bulb bar; (6) channel; (7) I-beam; (8) H-beam.

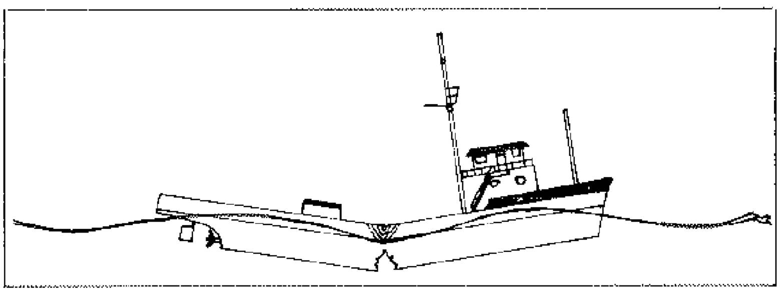


Fig. 11.2 Excessive sagging stress.

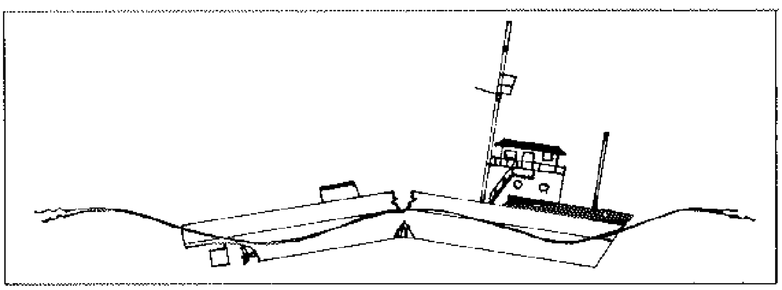


Fig. 11.3 Excessive hogging stress

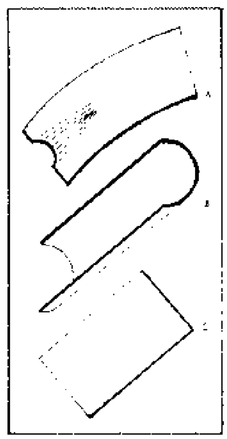


Fig. 11.4

12.2 Floors

Fig. 12.4 A floor is a plate placed vertically in the bottom of a vessel, usually on every frame, and running athwartship from bilge to bilge. Its purpose is to give additional strength and stiffness to the vessel's structure.

Fig. 12.5 The vertical height of the floors is determined chiefly by the height of the center vertical keel. Floors may be of solid construction or open construction.

12.2.1 Openings in the floors. Open floors are built up of structural members as opposed to a solid floor which is made up of plate. Solid floors are not, however, watertight. Solid floors do have openings in them called limber, lightening, and air holes.

Limber holes allow water or other liquids to drain between floors.

Lightening holes serve the purpose of lightening the plate used in construction of the floors. The lightening holes also serve the invaluable purpose of providing access between floors during construction and for necessary maintenance. For this reason they are sometimes called access holes.

Air holes are cut in the floors to prevent an air lock from forming and thus prohibiting the free flow of liquid between the floors.

Under the engine room the floors are heavier to provide for the extra load and vibration at this point. As mentioned earlier, the floors may be continuous and the center vertical keel intercostal, or vice versa.

12.3 Bottom Longitudinals

Bottom longitudinals are longitudinal members of the vessel which prevent the floors from tripping or falling over. They run fore and aft along the bottom of the vessel parallel to the keel.

The keel, floors, and bottom longitudinals divide the inner bottom of the vessel into rigid cell-like compartments which add significantly to the hull girder strength of the vessel.

12.4 Double Bottoms

Fig. 12.6 The double bottoms, sometimes called the double bottom tanks, are the compartments at the bottom of the vessel between the inner and outer bottoms. The outer bottom is formed by the bottom shell plating of the vessel. The inner bottom is formed by the rider plate and the strakes or rows of plating parallel to the rider plate which are laid over the top of the floors. Inside the double bottoms are the center vertical keel, the floors, and the bottom longitudinals. The depth of the double bottoms is determined by the height of the center vertical keel. However, the double bottoms must always be deep enough to allow access and to provide the required strength.

In the early days of shipping, ballast in the form of sand and stones or other weight material was loaded directly into the bottom of the holds in order to bring the vessel down deeper in the water when necessary. Upon arrival at a loading port, the ballast then had to be removed before cargo could be loaded. This was a long and costly process. The development of double bottom tanks did away with this process. Now ballast, in the form of liquids, can be pumped into or out of the double bottom tanks as necessary, swiftly and easily. The double bottoms also serve other purposes. One of the most noticeable is that because of the cell-like construction, they add great strength to the structure of the vessel. The double bottom tanks can also be used to carry fuel, water, or oil. In the event the bottom of the vessel (outer bottom) is torn open by grounding, the inner bottom provides a valuable "second skin" which prevents the seawater from flooding the vessel. If the double bottoms have been loaded with liquid prior to grounding, no change in trim will result after a hole is ripped in the outer bottom due to the fact that no seawater can enter.

12.5 Frames and Framing Systems

Fig. 12.7 Frames are the "ribs" of the ship in much the same way that the keel is the backbone of the ship.

Two main types of framing systems are found in vessels, the transverse framing system and the longitudinal framing system.

Fig. 12.8 12.5.1 Transverse framing system. The various members of the transverse framing system are shown in Figure 12.8. Transverse means athwartship, at right

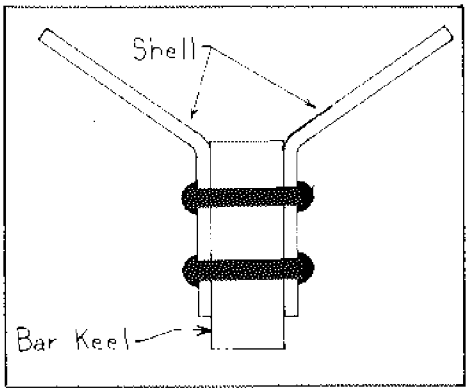


Fig. 12.1 Bar keel.

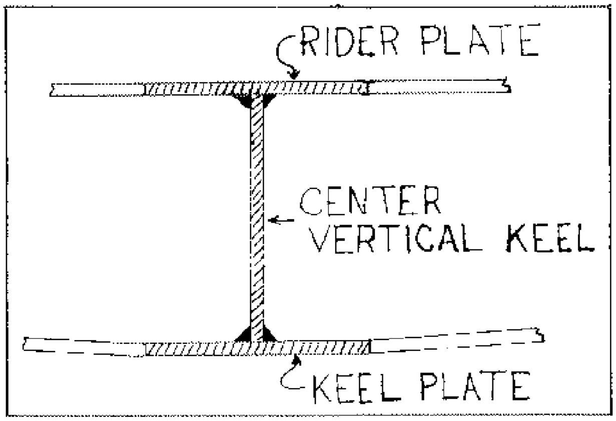


Fig. 12.2 Flat-plate keel.

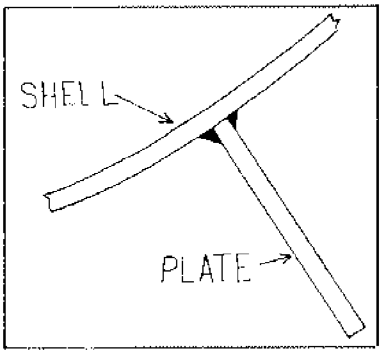


Fig. 12.3 Bilge keel.

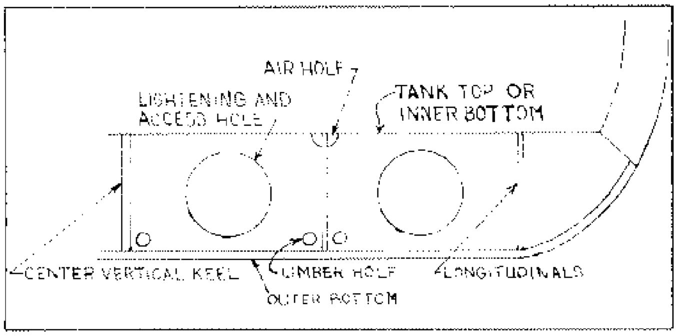


Fig. 12.4 The floors.

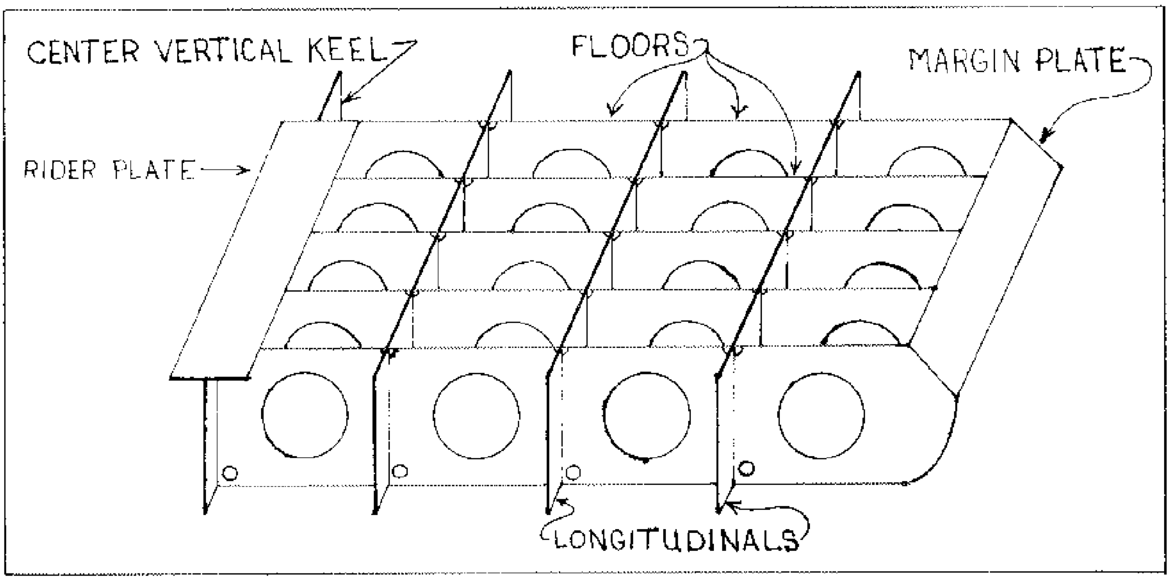


Fig. 12.5 Arrangement of floors.

angles to the keel. The main elements or parts of the transverse framing system are:

a) Floors. As described earlier, the floors are vertical plates running athwartship from bilge to bilge.

b) Bottom longitudinals. As described earlier, the bottom longitudinals are members which run in a fore and aft direction. They add strength and keep the floors from "tripping."

c) Transverse frames. The transverse frames act as the ship's ribs. They radiate outward transversely from the keel and are attached to the shell plating.

d) Deep web frames. The deep web frames are massive, built up frames fitted into the hull to add strength and rigidity at points of special stress. They support the side stringers which in turn support the transverse frames. Fitted in areas such as the engine room they absorb vibration and add strength.

e) Stringers. Stringers are fore and aft members used to give longitudinal strength to the shell plating.

f) Pillars. Pillars, sometimes called stanchions, are vertical members used to support the deck girders.

g) Girders. A girder is a continuous member which runs in a fore and aft direction under the deck for the purpose of supporting the deck beams and the deck.

h) Deck beams. The deck beams run athwartship and are supported by the girders. They act to support deck loads and the deck plating. They prevent wrinkling of the deck plate and act as a tie to keep the sides of the vessel in place.

i) Brackets. A bracket is a triangular plate used to join two or more members together.

12.5.2 Longitudinal framing system. The longitudinal
Fig. 12.9 framing system differs from the transverse framing system in that the shell plating and the bottom plating are supported by closely spaced longitudinal frames which run

fore and aft. These longitudinal frames are supported by widely spaced deep web frames. The longitudinal framing system is favored for tankers and barges whereas the transverse framing system is favored in tugs, crewboats, supply boats and other oilfield vessels.

One result of the longitudinal framing system is that the deep web frames used protrude into cargo holds and hinder the stowage of cargo in vessels such as oceangoing freighters. This is not a factor in vessels which carry liquid cargoes such as tankers and tank barges where the longitudinal framing system is used to advantage. Vessels are sometimes built with a combination of the longitudinal and transverse framing systems. The transverse framing system is more effective in preventing damage to the hull when it comes in contact with docks, piers, and platforms.

12.6 Shell Plating

Shell plating refers to the plating on the hull of the vessel. One fact that may surprise you is that merchant vessels in general possess heavier plating than naval vessels. The reason for this is that they usually receive rougher treatment and less care than naval vessels.

Fig. 12.10

12.6.1 Methods of plating. According to the way it is put on the hull, plating may be in and out, clinker, flush, or joggled. All of these methods are used in riveted construction.

In the in and out method of plating the inner plate is laid flush against the frame. The next plate laps over the edge of the inner plate and the next plate is again placed flush against the frame. In this method a steel liner is used to fill the space left between the outside plates and the frames.

The clinker system of plating in appearance looks somewhat similar to the outside weatherboarding used on a house. Here again liners must be used. One end of each plate is laid against the frame while the other end laps over the next plate.

In the joggled system, each end of the outer plate is joggled or offset so that the center of the plate may be laid flush against the frame. The inner plates are laid flush against the frame. No liners are required by this method of plating.

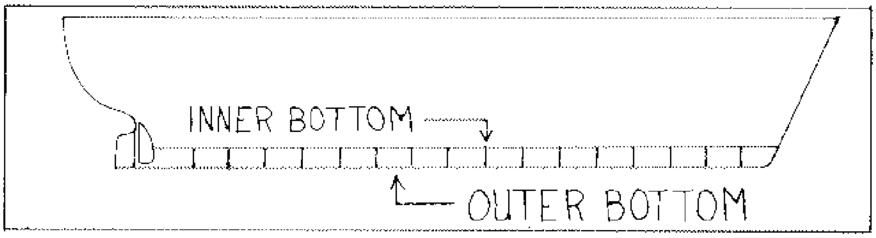


Fig. 12.6 Double-bottom tank.

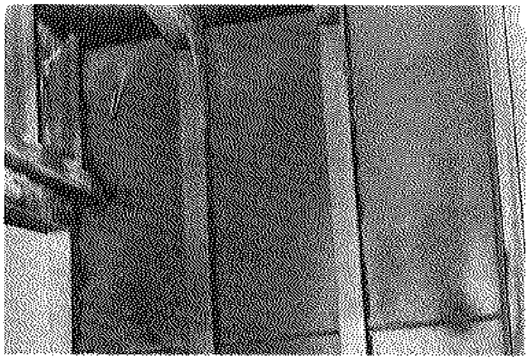


Fig. 12.7 Transverse frames.

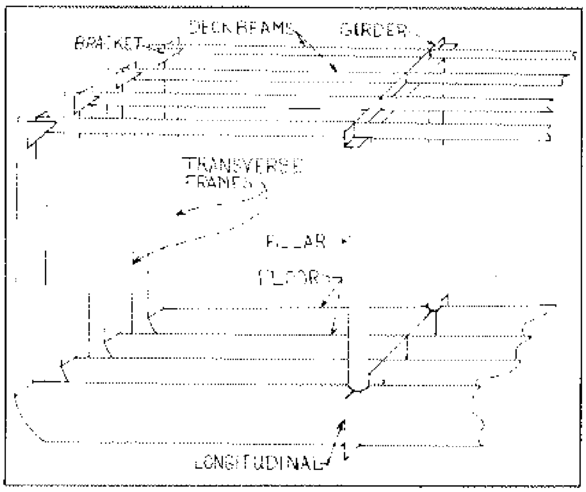


Fig. 12.8 Transverse framing system.

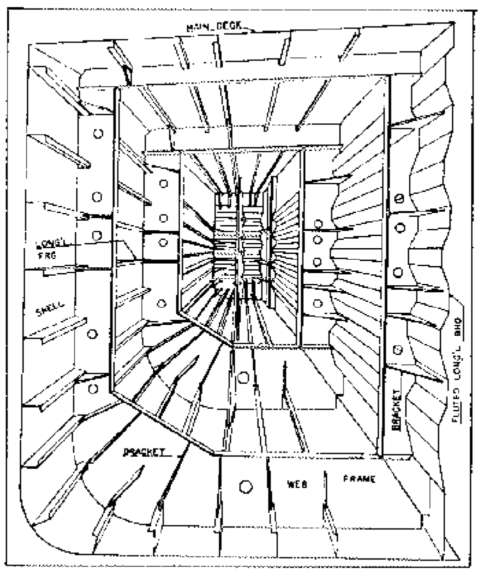


Fig. 12.9 Longitudinal framing, steel construction.

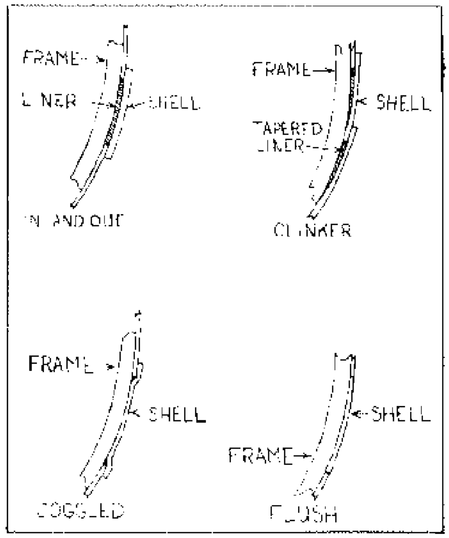


Fig. 12.10 Methods of plating.

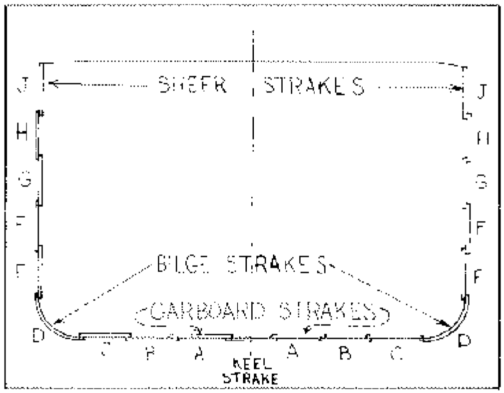


Fig. 12.11 Sheer strakes.

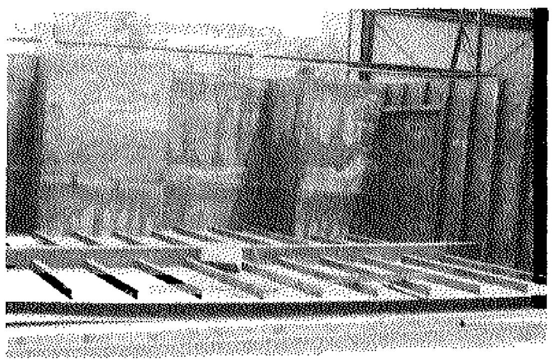


Fig. 12.12 Bulkhead stiffeners.

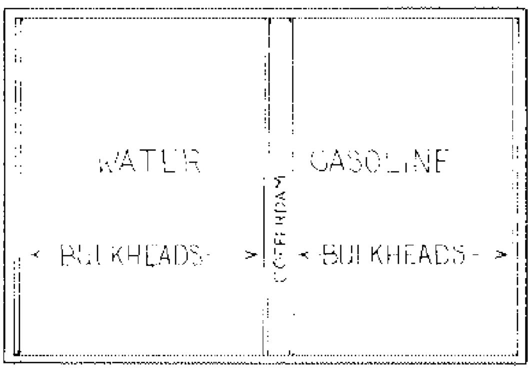


Fig. 12.13 Cofferdam.

In the flush system all plates are laid flush on the frames and welded together.

12.6.2 Types of plating. As mentioned previously plate may be flat, rolled, or furnaced according to its location on the hull.

12.6.3 Strakes. Shell plating is laid in long fore and aft rows called strakes. We speak of a strake of plating meaning a course or row of plates. Some strakes of plating start at the bow and run all the way aft to the stern. These are called through strakes. Because the body of the vessel tapers and narrows as you approach the bow or the stern, some strakes of plating are not carried all the way through from bow to stern. They are discontinued in lieu of another strake at some point. These are called drop strakes.

Fig. 12.11

Each strake of plating is given a letter for identification except the keel strake. This method of identification is shown in Figure 12.12. You will notice that "i" is not used. The reason for this is that each plate in a strake is numbered starting with 1 for the plate closest to the stem and continuing aft in the strake. If the letter i were used it might lead to confusion with the number 1. Thus a particular hole in the shell plating may be identified as damage to plate H3, J18, and so on.

Certain strakes of plating are also given special identifying names. The keel strake is the strake of plating which runs fore and aft on the center line of the vessel. The garboard strakes are the strakes of plating on either side of the keel strake. The bilge strakes are the strakes of plating at the turn of the bilge where the body of the vessel begins to turn upward. The sheer strakes are the topmost strakes of plating on the hull of the vessel.

12.6.4 Doubler plates. Wherever there is an opening in the shell plating, or any other plating aboard the vessel, it is necessary that the plating around the opening be of a greater thickness to compensate for the loss of strength caused by the hole. The plating used may be thicker or a doubler plate may be placed around the opening. A doubler plate is a plate placed on top of another to add extra strength and stiffness. As an example, doubler plates are placed around the portholes and where the hawse pipe comes through the deck and shell plating.

12.7 Bulkheads

A bulkhead is a vertical steel partition corresponding to the wall of a room. Landlubbers use the term "wall." A sailor uses the term "bulkhead." Bulkheads may run either athwartship or fore and aft. They serve many purposes:

1) They prevent water from passing from one compartment to another.

2) They act as fire checks to stop the spread of fire.

3) In fighting a fire, they allow various parts of the vessel to be flooded.

4) They strengthen the hull of the vessel.

12.7.1 Spacing. Generally the spacing of the bulkheads is used as a criteria by classification societies to determine the safety of a vessel. The closer the bulkheads are spaced the less chance there is of flooding the entire vessel through a single hole in the shell plating. A subdivision of space or room in a ship formed and bounded by bulkheads is known as a compartment. Vessels are commonly described as one compartment ships, two compartment ships, and so on (see Section 6.4.4).

12.7.2 Collision bulkhead. The forward collision bulkhead, usually referred to simply as the collision bulkhead is the foremost or first watertight bulkhead in the bow of the vessel. Required by the ABS, this bulkhead runs athwartship and water cannot pass from one side of the bulkhead to the other. The main purpose of the collision bulkhead is to prevent flooding of the vessel in the event of damage to the bow. It acts as a "second bow."

12.7.3 Watertight bulkhead. A watertight bulkhead is a bulkhead having absolutely no openings. Water cannot pass through the bulkhead. The forward collision bulkhead is one example of a watertight bulkhead. In some vessels there are also watertight bulkheads running athwartship in other locations. The after collision bulkhead runs athwartship at the stern of the vessel. Machinery space bulkheads running athwartship at the forward and after ends of the machinery spaces prevent water from damaging the propulsion equipment.

Longitudinal watertight bulkheads are also employed in some vessels. With these types of bulkheads some means must be provided to let water pass from one side of the bulkhead to the other. The reason for this is easily understood. Can you imagine what would happen if only one side of a vessel was flooded? This is known as "unsymetrical" flooding and its danger was first brought to everyone's attention when the S.S. Empress of Ireland capsized due to the flooding of one engine room compartment, and caused the loss of 1,000 lives. These openings usually take the form of valves which may be opened from outside the compartment to let water pass from one side of the vessel to the other.

12.7.4 Bulkhead stiffeners. Bulkhead stiffeners are angle bars, T-bars, or channels, used to stiffen the bulkhead plating. Bulkhead stiffeners usually run vertically although they may be placed horizontally. The size of the stiffeners is usually decreased toward the top of the bulkhead due to the reduced water pressure.

Fig. 12.12

12.7.5 Cofferdams. A cofferdam is the space between two bulkheads formed by placing them a few feet apart. Their purpose is to prevent leakage from one compartment to another. For instance, a particular vessel may be carrying water in one tank and fuel in the tank adjacent. If the two tanks share a common bulkhead and a leak develops in the bulkhead, the water will be contaminated by the fuel and the fuel will be contaminated by the water. If a cofferdam is placed between the two compartments, leakage will drain into the cofferdam and not into the next compartment. Cofferdams also serve the purpose of permitting inspection of the bulkheads and access for quick repairs.

Fig. 12.13

13. STEM, BOW, AND STERN

13.1 The Stem

The stem is the extreme (most forward part) bow of the ship. It is like an extension of the keel and gives strength and rigidity to the hull structure.

Fig. 13.1

The stem is fastened to the keel and connects the two sides of the shell plating at the bow. It can be a forged or cast piece of metal, or it can be rounded plate.

The stem must be similar in strength and size to the keel, because it encounters the pounding of heavy seas and the impact of obstructions. One particular experience comes to mind which illustrates the strength of the stem in a vessel. A particularly large ship had taken a pilot aboard in Saigon harbor. After all moorings had been cast off, the vessel was in the process of turning around with the assistance of tugs and its own propulsion. All of a sudden, power was lost due to boiler failure on the ship. Before the anchor could be dropped the vessel's bow swung around and completely crumpled the bridge wing and part of the wheelhouse of a vessel tied up at the dock. Damage to the stem--a 1/4" dent.

13.2 The Bow

Fig. 13.2

13.2.1 Plumb bow. The plumb bow cuts through the water rather than riding over the waves. The fact that the plumb bow possesses very little flare sometimes causes difficulties when raising the anchor as the anchor may foul on the shell plating as it comes up.

13.2.2 Clipper bow. The clipper bow possesses a lot of flare and a lot of rake. The large amount of flare causes the deck to remain drier because the flared sides throw the water aside. More room is also provided for the deck machinery because, due to the flare, the sides of the vessel move rapidly apart as the deck level is approached. Because of the flare the anchor can also be raised without fouling the shell plating.

An unusual feature of clipper type bows is that they cause less damage in a collision. Due to their extreme rake, they penetrate the upper portion of the hull of another vessel first and the underwater hull may be left intact. If every vessel on the water possessed a clipper bow with a soft nosed stem there would be far fewer sinkings due to collision.

13.2.3 Spoon bow. The spoon bow is a very seaworthy design because it rises to the waves. Ice breakers are often equipped with spoon bows because the bow of the vessel rides up on top of the ice where the weight thus brought to bear allows the vessel to crash down through the ice and break a path.

13.2.4 Innui or bulbous bow. The innui bow, often called the bulbous bow, has a bulb at the lower portion of the stem. This bulb can be used to carry cargo or ballast, however, its main advantage lies in the fact that it enables the vessel to attain greater speeds at or near full power than vessels without it.

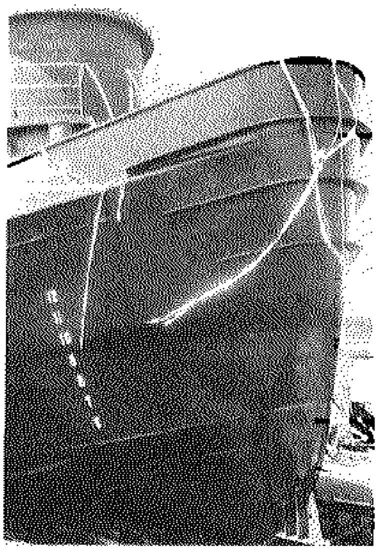


Fig. 13.1 Tugboat stem.

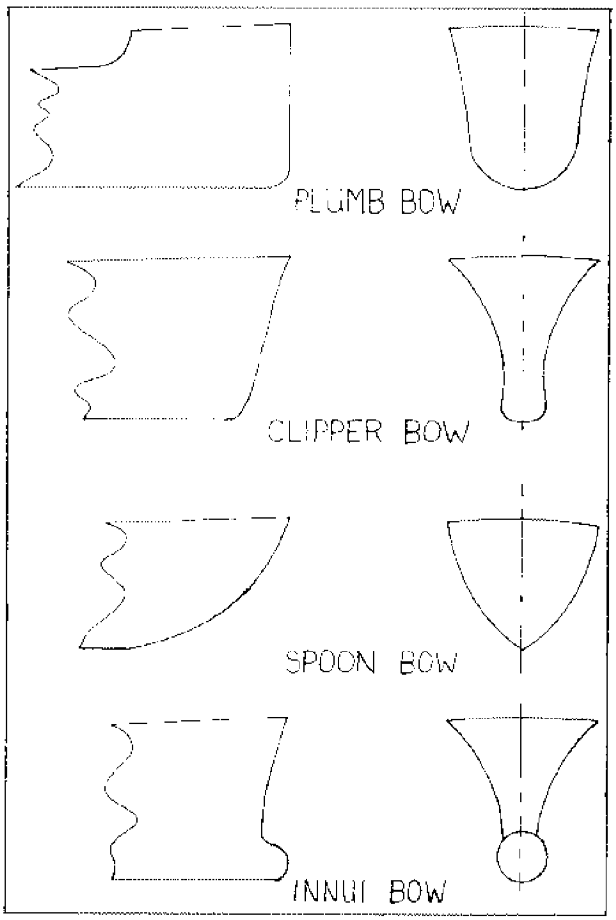


Fig. 13.2 Bow shapes.

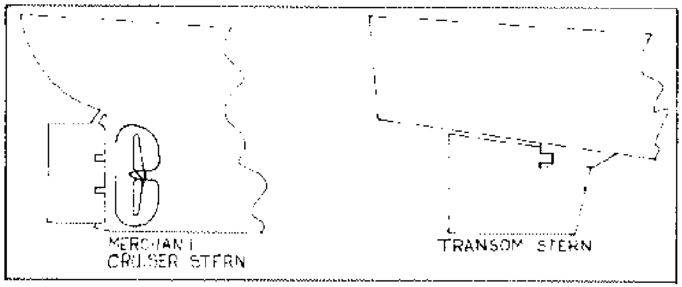


Fig. 13.3 Stern shapes.

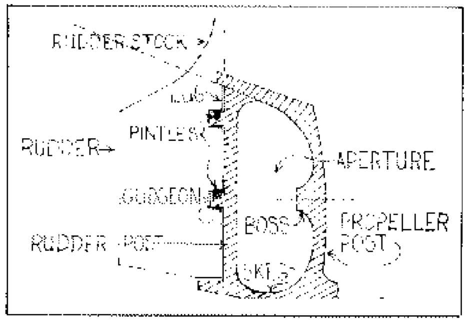


Fig. 13.4 Stern frame for a single-screw vessel.

13.3 The Stern

13.3.1 Stern shapes. Although there are many variations in stern shape we shall discuss only two--the merchant cruiser stern and the transom stern. The merchant cruiser stern is rounded. The transom stern, which is sometimes known as the "barndoor" stern, is most common on offshore crew and supply vessels. It is broad and fairly flat underneath. It prevents "squat" at high speeds and decreases resistance 3 to 5 percent. Squat is readily visible as the force which causes the stern of a vessel to sink down in shallow water at high speeds. You may have noticed this effect yourself at one time or another.

Fig. 13.3

13.3.2 Stern frame. The stern frame is the large casting or forging attached to the after end of the keel to form the ship's stern. This definition is very appropriate for single screw vessels; however, it is somewhat inaccurate when discussing twin or triple screw vessels.

Fig. 13.4

13.3.3 Single screw installation. The stern frame consists of two posts, the propeller post and the rudder or stern post. It can be considered a vertical extension of the keel, like the stem. It connects the two sides of the shell plating at the stern and supports the propeller and rudder. The stern frame in a single screw vessel consists of:

a) The rudder. A large heavy fitting that is hinged to the stern frame and used for steering the vessel.

b) The lugs. Projections cast or fitted to the forward edge of the rudder to which the pintles are attached.

c) Pintles. Hinge pins on the rudder which project from the lugs.

d) Gudgeons. Projections on the sternpost drilled to accept the pintles.

e) Aperture. The opening between the sternpost and the propeller post for the propeller.

f) The skeg. A shoe which forms the bottom of the stern frame.

g) The propeller post. The post in the stern frame through which the propeller passes.

h) Boss. The swelled up portion of the propeller post through which the shaft passes.

i) The rudder post. Also called the stern post, the rudder post is the after post of the stern frame and is the post on which the rudder is hinged.

j) The rudder stock. The shaft of the rudder which extends up through the hull of the vessel.

Fig. 13.5 Fig. 13.6

13.3.4 Twin or triple screw installation. The rudder may be hinged on a rudder post or may simply hang down from the hull supported by a huge bearing inside the hull. The propeller shaft is supported by struts which extend down from the lower hull. A skeg may or may not be present. Other parts of the stern frame are similar to those in a single screw vessel.

13.4 Rudders

Fig. 13.7

The rudder is the means by which the vessel is steered. Flat-blade rudders which are the same thickness all the way through are found only on older vessels and small boats. Modern rudders are streamlined in shape, being broader forward and tapering aft to a point. The forward part of a rudder is called the leading edge. The after side of the rudder is called the trailing edge.

Rudders may be either single or double plate rudders. A single plate rudder is made up of a single heavy piece of steel cut to the desired shape. This type of rudder is very inefficient at its job and modern vessels generally use double plate rudders. The double plate rudder consists of an interior frame upon which steel plates are welded. The thickness of the rudder decreases from the leading edge to the trailing edge because stress on the rudder decreases toward the trailing edge. The leading edge is comparatively wide and rounded. Streamlining a rudder in such a fashion may in some cases reduce the total resistance of a vessel by as much as 5 percent. The interior of double plate rudders is usually hollow. This reduces their weight. Small plugs are fitted on the bottom of the rudder for draining and for pressure testing for leaks.

Fig. 13.8

13.4.1 Rudder shapes. Three common types of rudders according to shape are: the unbalanced rudder, the semi-balanced rudder (sometimes called a balanced rudder), and the spade rudder.

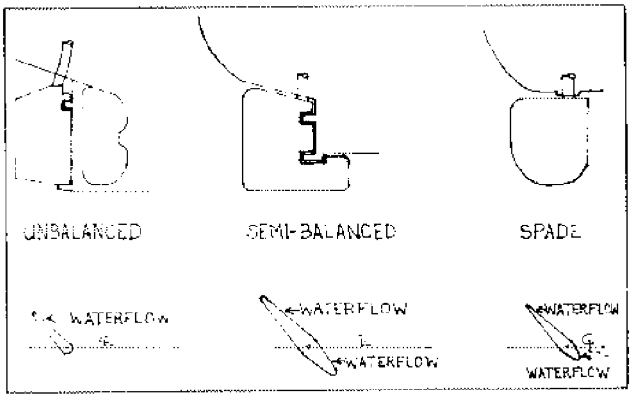


Fig. 13.8 Unbalanced, semibalanced, and spade rudders.

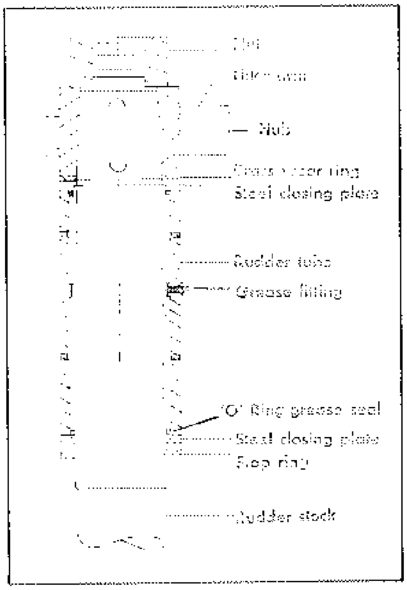


Fig. 13.9 Rudder-tube arrangement.

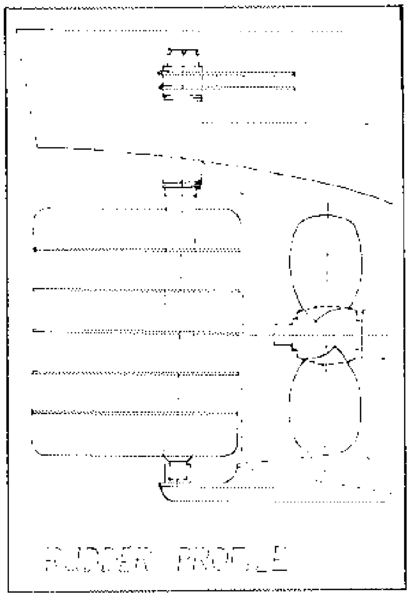


Fig. 13.5 Rudder profile for a twin-screw vessel.

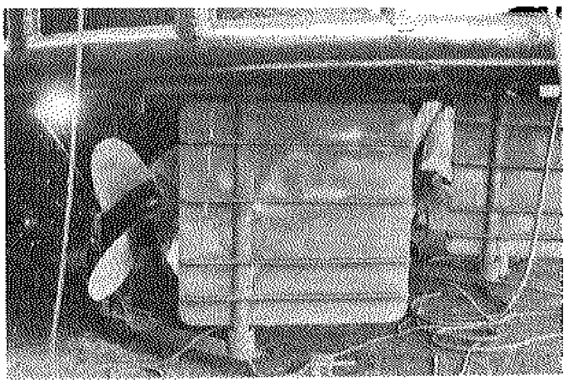


Fig. 13.6 Typical stern frame of a twin-screw vessel.

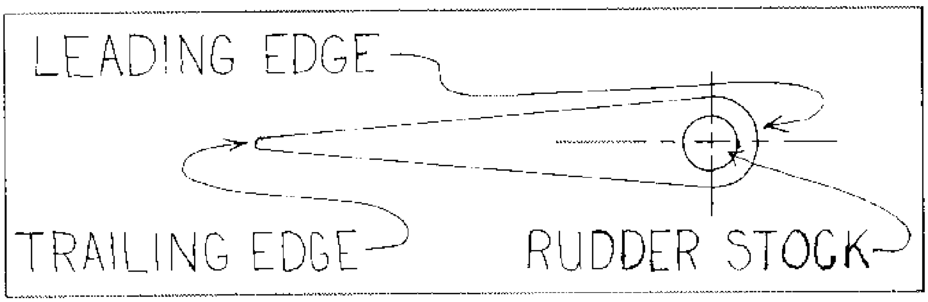


Fig. 13.7 Streamlined, double-plate rudder.

The unbalanced rudder has all of its effective area aft of the rudder's pivot point. The effective area of a rudder is the part of the rudder which assists in turning the vessel. The pivot point of the rudder is the point about which the rudder turns.

The semibalanced rudder has part of the blade extended forward of the pivot point. Although this rudder is sometimes called a "balanced" rudder, it is impossible to have a truly balanced rudder and the term is incorrect. The semibalanced rudder requires less force to turn because the waterflow acts on the forward part of the rudder when it is put over to help turn the rudder. Approximately 25 percent of the rudder blade is forward of the pivot point in a semibalanced rudder.

When seen from the side, the spade rudder looks like the blade of a shovel. The spade rudder is fairly common on oilfield vessels.

13.4.2 Rudder bearings. Although the rudder is hinged on pins called pintles, the rudder bearing acts to carry the main portion of the weight of the rudder. The rudder bearing is enclosed within the hull of the vessel and is placed above the sternpost. The inside of the rudder bearing is cylindrical and the rudder stock passes up through the bearing. A carrier is welded or bolted to the upper part of the rudder stock and carries the weight of the rudder. All rudder-bearing surfaces are lined with nonfriction metal and must be well lubricated. Where the rudder stock passes up through the hull of the vessel, it is enclosed in a watertight shaft packed to prevent water from entering the rudder compartment.

It should be noted that in most smaller offshore vessels rudder bearing and carrier arrangements are usually not as elaborate or as sophisticated as in larger vessels. Because of this they need frequent checking and lubrication. It is not uncommon to see a small circular plate or disc welded or bolted to the rudder stock as the carrier. This "carrier" may rest directly, metal to metal, on the top of the rudder bearing. Grease zircs are usually provided for the purpose of squirting grease between the carrier and the top of the rudder bearing. When this arrangement is left to itself without maintenance, it is not uncommon for vibration to eventually cause the carrier to become separated from the rudder stock and allow the rudder to drop down or be lost completely. Such an accident can cause, at the least, loss of maneuvering power, and at the worst, flooding of the vessel and damage to steering gear.

13.4.3 Rudder stops. Stops in the form of metal bars are usually provided on offshore crew and supply vessels to limit the angle through which the rudder may be turned. These stops are placed either side of the rams or quadrants inside the rudder compartment. It has been proven that the maximum effective rudder angle is between 30 and 35 degrees from the centerline of the vessel. In other words, when the rudder is turned hard over or all the way over to one side, the rudder will be turned only 35 degrees off the fore and aft centerline of the vessel. Turning the rudder to any greater angle, say 50, 60, or 90 degrees, will not allow the vessel to turn any faster or in a shorter circle. As a matter of fact, it would hinder the turning ability of the vessel.

14. DECKS AND DECK FITTINGS

14.1 Decks

The decks of a vessel correspond to the floors in a building. Although decks may be made of wood or steel, they all serve the following purposes:

1) The upper deck increases the seaworthiness of the vessel by forming a watertight covering to the hull.

2) Decks contribute to the strength of the vessel.

3) They serve as working platforms.

4) They provide living space.

The decks of the vessel are supported by the deck beams which are in turn supported by the girders, frames, pillars, stanchions, and bulkheads. When steel plating is used for a deck covering, it is fitted in wide fore and aft strakes. The outer strake of deck plating on each side of the deck is called the stringer plate. The stringer plate receives the most stress of all the deck plating and is usually of a larger size than the rest of the deck plating. In the past, some vessels have been completely lost due to cracks which developed in the outside strake of deck plating and carried all the way across the deck and down through the sides of the hull.

14.1.1 Camber. Decks possess camber. Camber is the athwartship curvature of the deck. The deck rises to a crown or high point at the centerline and then slopes down to the stringer strake at the sides of the deck. Camber permits water shipped on deck to drain outboard to scuppers and drains and thus overboard. A vessel whose decks possess a lot of camber is usually allowed to load to a deeper draft than similar vessels with little camber in the decks.

14.1.2 Sheer. Sheer is the fore and aft curvature of a deck. Simply, it is the slope upward of the deck as you approach the bow. Sheer allows a vessel to ride the waves with a drier deck for water drains aft. Freeboard regulations also allow a vessel with sheer to load to a deeper draft than one without sheer.

14.1.3 Sheathing. The vessel's decks are often sheathed or covered with wood in some places. Sheathing serves several functions:

a) Sheathing distributes the weight of cargo loaded on deck and prevents damage to the deck plating from loads which are dropped on the deck. This is an important function of the afterdeck sheathing on offshore supply boats as loads are usually placed on deck offshore by a crane operator sitting as much as 70 feet above the water.

b) Sheathing increases the stiffness of the deck.

c) Sheathing insulates the deck and compartment below.

d) Sheathing prevents sweating in compartments below deck due to rapid temperature changes.

e) Cargo placed on a deck sheathed with wood will not slide around as it would on a bare steel deck.

14.2 Terms and Deck Fittings

We have now covered most of the basic structure of the vessel. In addition to this basic structure, there are many miscellaneous structures and fittings which need to be investigated. Study the following terms in the glossary of terms at the end of the book:

Ballast
Berth
Booby hatch
Boat deck
Block
Bridge
Bitts
Bulwark
Bulwark stay
Cleat
Chock
Chain locker
Coaming
Crow's nest
Charley Noble
Capstan
Dead light
Dog
Davit
Ensign staff
Engine order telegraph
Forecastle
Forecastle deck
Freeing port
Fairlead
Fixed light
Flag staff
Funnel
Gasket
Gangway
Galley
Gate
Hatch
Hull
Locker
Ladder
Mast
Poop deck
Pad eye
Port
Porthole
Quaters
Rails
Superstructure
Swash plates
Strongback
Shroud
Stay
Sounding pipe
Scupper
Tween decks
Tackle
Ventilator pipe
Voice tube
Wind scoop
Wheelhouse
Weather deck
Yard
Yardarm

15. GROUND TACKLE

Ground tackle is the name given to the ship's anchor, the anchor chain, the anchor windlass, and the associated equipment used in raising and lowering the anchor.

151. The Anchor

At one time ships used huge stones or blocks of concrete for anchors. The modern anchor is quite different from its earlier counterparts. Basically it consists of a shank with flukes attached which bite into the bottom. The desirable characteristics of an anchor are that it be capable of holding the vessel, that it be lightweight, and that it can be conveniently stowed once it has been weighed.

Fig. 15.1

There are many different types of anchors including the grapnel, the mushroom, the stockless, and the old-fashioned anchor. We shall discuss the properties of each of these anchors in the chapter on seamanship.

Before the anchor is placed aboard a vessel, it is tested in accordance with classification society rules. In the drop test, the anchor is dropped from a certain height and then inspected to check for damage. In the proof test, a sample of the same piece of metal used in construction of the anchor is put to the test in a machine which stresses the metal until it yields or breaks. The load at which the metal yielded is then noted. The anchor is then stamped or marked with certain information including:

1) The anchor's number (e.g., 24195)

2) The inspector's initials (e.g., EGP)

3) The date of inspection (e.g., 11/75)

4) The proof test applied (e.g., 76,440)

5) The classification society that witnessed the test (e.g., ABS)

6) The weight of the anchor (e.g., 4,200)

Anchors may be named according to their use or location on the vessel. The bower anchors are the anchors in place on either side of the bow. The spare bower achor is carried on deck, usually behind the forecastle and is used as needed to replace one of the bower anchors. The spare bower is sometimes called the sheet anchor. Usually it is the same size as the bowers. The stream anchor is an anchor carried at the stern of some vessels and used to keep the boat from swinging around in restricted waters. A stern anchor is any anchor carried at the stern of a vessel. A kedge anchor is a small anchor used for kedging. Kedging is moving a vessel a little at a time by taking the kedge anchor out with another vessel or one of the ship's boats, dropping the anchor and then heaving on the anchor chain.

15.2 Anchor Chain

Anchor chain is also known as chain cable or anchor cable. The Chinese were apparently the first mariners to use anchor chain for handling a ship's anchors. In the year 2200 B.C. Chinese vessels used two chains forward and two aft to steady and stop the vessel. Alexander the Great equipped the vessels of his fleet with chain cables so that enemies could not swim out in the darkness and cut his vessels adrift.

In England in 1634, Phillip White patented a method of heating and tempering iron for the purpose of making anchor chain. This was the real birth of anchor chain. However, most vessels were still not equipped with anchor chain. In 1771, Bougainville, a French explorer, complained that he had lost six anchors in nine days due to the fact that his vessels were not equipped with iron chain.

In 1808, Robert Flinn, an Englishman, became the first to make improved iron anchor chains which received widespread recognition and success. Studs to stiffen the chain links appeared in 1812. The links had now developed to their present form. Studs in anchor chain links prevent the link from elongating, prevent the chain from fouling when being paid out or taken in, and add approximately 15 percent to the strength of each link.

The U.S. Navy recognized the advantage of anchor chain, and in 1816 a 2 1/4" iron stud link chain was installed on the U.S.S. Constitution. By 1817 a chain-making plant was constructed at the Washington Navy Yard for the purpose of replacing the hemp anchor cables then in use.

Anchor chain found wide use in the merchant service by 1836, and its superiority was well known. Insurance underwriters stopped charging higher insurance rates for vessels using iron chain. In 1846 Lloyds Register of Shipping changed its rules to require that thereafter all anchor chains for classed vessels would be proof tested and stamped on each end to indicate the load applied. In 1853 Lloyds Rules made it mandatory that in order for a vessel to be classed, a certificate must be produced showing the test of the anchor chain and in 1858 issued rules stipulating the length and size of anchor chain.

The anchor chain is connected to the jew's harp or ring of the anchor by means of a bending shackle. To prevent the chain from fouling on any other piece of ground tackle when the anchor is let go, the bow of the bending shackle should always face outboard in the chain.

Anchor chain is measured in shots, usually a 15-fathom length. Offshore supply vessels may have an equal amount of chain attached to both the port and starboard bower anchors, or one anchor may possess more chain than the other. The weather anchor should possess more chain than the other. In the northern hemisphere the weather anchor is the port anchor. The reason for designating a weather anchor is that in strong winds you may wish to moor the vessel with both the port and starboard anchor. Because with time, the wind usually veers, or shifts clockwise in the northern hemisphere, having more chain on the weather anchor will prevent twists or crossing of the chain as the wind shifts.

The size of the anchor chain varies with the size of the vessel, and, of course, with the size of the anchor. The size of the anchor chain is the diameter of one link of chain at the side. In 1778, George Washington had a buoyed barrier chain constructed to prevent passage of the British Fleet at West Point, N.Y. It took six weeks for seventeen American blacksmiths to forge a 1,700 foot chain of 3 1/2" diameter. Each link weighed 275 pounds.

There are different methods of manufacturing anchor chain. In the drop forge process, each link is forged or bent to the correct shape with a press or forge and then welded. The next link is passed through the first and forged and welded and so on. Cast chain is made by casting several links of chain in a mold. When the links come out of the mold, they are already connected. Di-lok chain is formed by connecting the male and female ends of a single link. The cold male section, which consists of two stems, is inserted into the two openings on the heated female section of the link and the joint is then struck to seal the connection.

Fig. 15.2

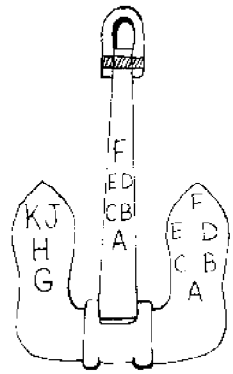
Most anchor chain has a stud or crosspiece in each link. Studs in anchor chain links prevent the link from elongating, prevents the chain from fouling when being paid out or taken in, and adds approximately 15 percent to the strength of each link.

Fig. 15.3

Any link of chain which connects two shots of chain is called a connecting link. The most common type of connecting link is the detachable link. The parts of the detachable link are shown in Figure 15.3. A forelock pin locks the link in the closed position and a lead pellet is placed on top of the pin to prevent it from backing out. These links can be easily opened with the proper equipment. When the anchor has been dropped and the chain is being veered (paid out), the most favorable point to stop and secure the chain is at a point where you have the connecting link on deck. In this manner you may easily slip or release the anchor and chain if you cannot recover the anchor for some reason.

One point not often realized by the student is that the weight of the anchor chain itself contributes greatly to the holding power of the ground tackle. The more chain you have out, the more weight there is under the water and on the bottom holding the vessel.

15.2.1 Anchor chain markings. When the anchor is let go, the chain picks up speed and begins running out at a



A. The number of the certificate (furnished by the surveyor)
B. The initials of the surveyor who witnesses the proff test
C. Month and year of test
D. Proff test applied
E. Signifying that the testing machine is recognized by the Committee of the American Bureau of Shipping
F. The weight of the anchor
G. Signifying that the anchor head has been tested by a surveyor of the American Bureau of Shipping
H. The weight of the anchor head
J. The initials of the surveyor who witnesses the drop test
K. Month and year of drop test

Fig. 15.1 Typical oil field boat anchor.

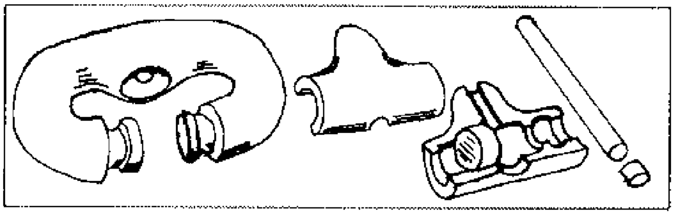


Fig. 15.3 Detachable link.

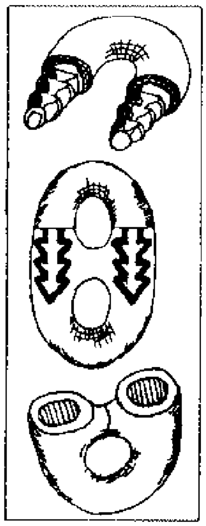


Fig. 15.2 Di-lok anchor chain.

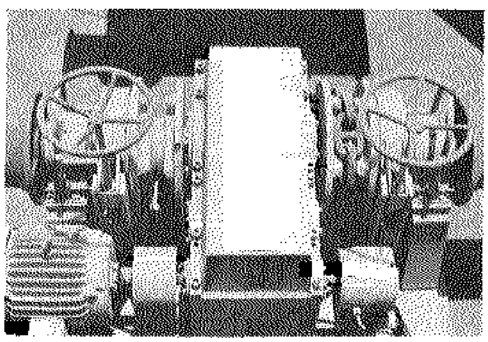


Fig. 15.4 Anchor windlass with stripping bar.

swift rate. It is desirable that some method be available of knowing how much chain is out and how close to the end Table 15.1 of the anchor chain you are. For this reason a marking system of paint and wire markings is employed. The wire markings allow you to determine how many shots are out if the paint markings have become worn off or covered with mud or rust. This marking system is shown in Table 15.1.

15.2.2 Connecting the bitter end of the chain. As one end of the anchor chain is attached to the anchor, the other end must be secured aboard the vessel in some manner. Most commonly, the bitter end of the chain is shackled to a padeye in the bottom of the chain locker. This is a somewhat difficult arrangement because, with chain piled on top of it, it is hard to get at this connection if it is desired to release the anchor chain. The pin on this shackle should never be welded so that it cannot come loose, but may be keyed or bolted. Another method of securing the chain is to connect the bitter ends of the chain from the port and starboard anchors together through the bulkhead between the port and starboard chain locker. Still another method and perhaps the best method is to pass the bitter end of the chain through a ring at the bottom of the chain locker. The bitter end of the chain is then brought up and secured to a padeye at the top of the chain locker. Thus the fittings securing the bitter end of the chain in the chain locker can be periodically inspected to determine whether they are in good condition, and by reaching through the manhole opening into the chain locker the chain may be slipped easily and swiftly from outside the chain locker.

15.3 Anchor Windlass

The heavy winch used for heaving in or paying out the anchor chain is called the anchor windlass. The anchor Fig. 15.4 chain is engaged by a sprocketed wheel on the anchor windlass termed the wildcat. A stripping bar or chain stripper is fitted on the windlass directly under the wildcat to strip the chain links off the wildcat should they become stuck. When the wildcat is engaged the anchor chain may be taken in or walked out slowly with the windlass motor. When the wildcat is disengaged it is allowed to free wheel and the anchor chain pays out rapidly. Disengaging the wildcat on the anchor windlass also allows use of the gypsyheads on the anchor windlass for heaving in on lines without moving the anchor chain. A brake is fitted on the windlass to lock the wildcat from turning and thus preventing the chain from paying out.

Table 15.1 Merchant Service Markings or Anchor Chain Markings

Fathom	Wire Marking	Paint Marking
15	1 turn of wire on 1st stud from each side of connecting link	White paint on one-half the stud on each side of connecting link
30	2 turns of wire on 2nd stud from each side of shackle	White paint on one and one-half links on each side of connecting link
45	3 turns of wire on 3rd stud from each side of connecting link	White paint on two and one-half links on each side of connecting link
60	4 turns of wire on 4th stud from each side of connecting link	White paint on three and one-half links on each side of connecting link
75	5 turns of wire on 5th stud from each side of connecting link	White paint on four and one-half links on each side of connecting link
90	6 turns of wire on 6th stud from each side of connecting link	White paint on five and one-half links on each side of connecting link

The anchor chain passes from the wildcat into the chain locker through an opening in the deck called a spill pipe. Most chain lockers on modern vessels are "self-stowing." In other words, they are narrower at the bottoms to cause the chain to fall into place without piling up and becoming tangled. The anchor chain passes down through the deck through the hawse holes into the hawse pipe and then out through the hull. Buckler plates are provided so that the hawse pipe may be covered up on deck to prevent water from coming up on deck through the hawse pipe and also to prevent serious injury to seamen from stepping accidently into the hawse pipe.

Fig. 15.5

A number of different type fittings may be employed on the vessel to secure the anchor and chain. A riding chock is placed on the forecastle deck between the hawse pipe and the anchor windlass. The chain rides in this chock which acts to fairlead the chain to the wildcat and prevent it from jumping around on deck. Fitted on the riding chock is the riding pawl. When the anchor is being let go, the riding pawl is raised up so that it does not rest on the chain. When the anchor is being weighed or when the anchor is on the bottom, the riding pawl rests on the chain. It thus prevents the passage of any links to the hawse pipe. The devil's claw is a two pronged metal hook which is attached to a padeye on deck by means of a turnbuckle. When the anchor is secured the devil's claw is hooked into a link of chain and thus prevents the chain from paying out.

On long voyages some means must be employed to prevent water shipped on deck from entering the chain locker through the spill pipe. In some instances plates are provided for this purpose. A better seal may be obtained, however, by jamming sticks into the opening, covering the sticks with burlap and pouring a thin layer of cement over the burlap. Upon arrival at destination, the cement is easily broken out.

The chain locker may be drained by a drain in the outboard corner of the chain locker. The problem with such an arrangement is that significant amounts of mud collect in the chain locker from the anchor chain and the drain may become plugged. A more desirable arrangement is to have an eductor fitted in the chain locker. The principle of the eductor involves water pressure that is usually provided from the ship's fire main. Because this allows no mud to pass through a pump, the eductor is an ideal method for pumping out the chain locker.

Fig. 15.6

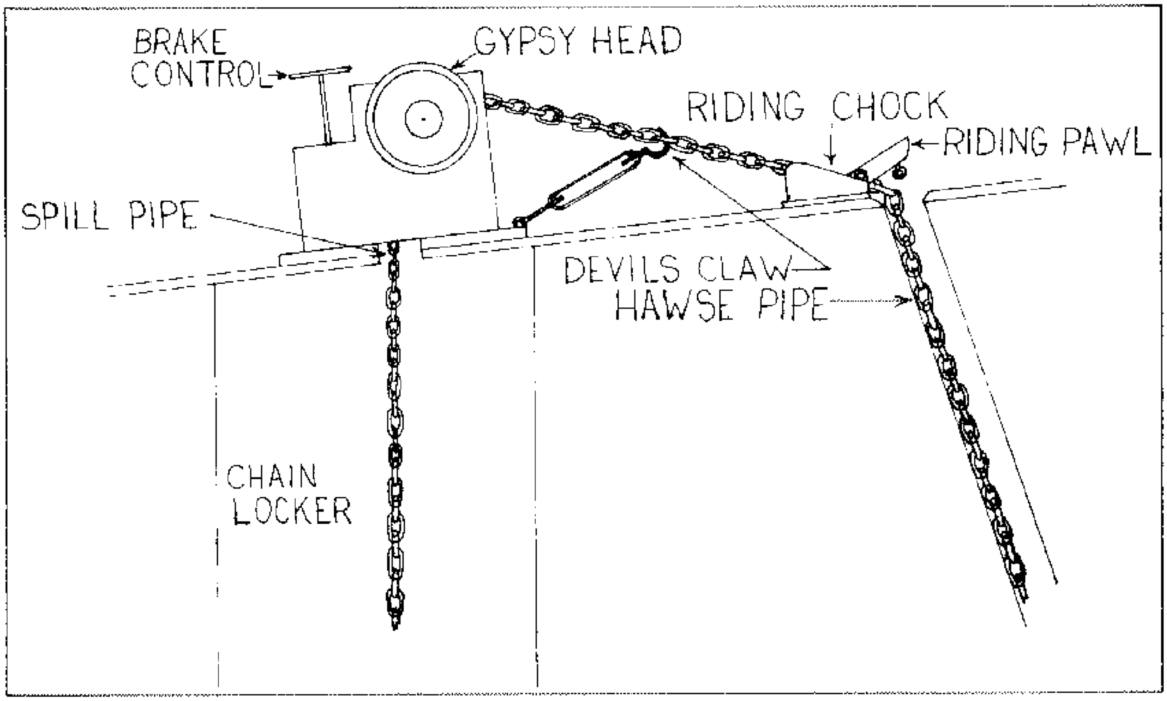


Fig. 15.5 Arrangement of ground tackle.

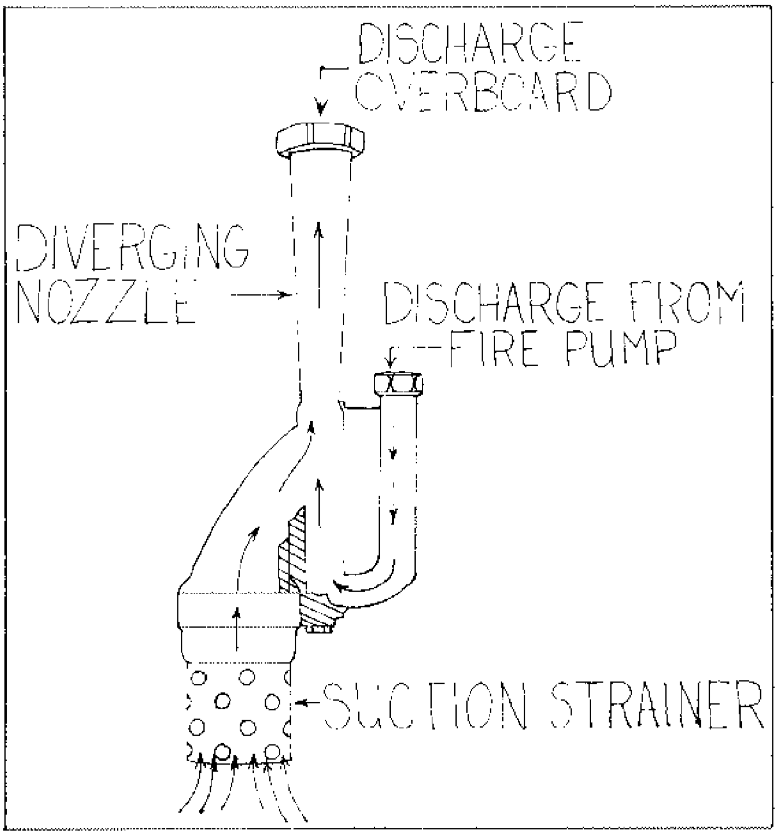


Fig. 15.6 Eductor operation.

16. VESSEL SYSTEMS

There are many systems incorporated within a vessel and each of them must work properly if the vessel is to perform her job. We shall briefly investigate six of these systems: the propulsion system, the steering system, the bilge and ballast system, the fuel oil system, the potable water system, and the sanitary water system.

16.1 Propulsion

Propulsion may be defined as "the means used to move a vessel through the water." There are various types of propulsion employed on marine craft with which you are familiar.

16.1.1 Oars. Oars are of course the earliest method used to propel vessels.

Fig. 16.1

16.1.2 Sails. The sail operates on the principle of pressure, similar to the wing on an airplane. The fact that the air on the convex side of the sail has farther to travel than the air on the back or concave side of the sail causes it to flow at a faster speed. This causes an area of low pressure on the forward side of the sail which actually draws the sail and the boat forward.

Square rigs were the first type of sail rigs used. These square sails worked very well when the vessel was sailing before the wind (with the wind coming from behind) and they were used to advantage in the trade winds. However, they were of little use when sailing to windward.

Fore and aft rigs with the sails set fore and aft were thus developed and overcame the disadvantage of the square sail when sailing to windward. Close hauled, a fore and aft rigged boat can sail to within four points of the wind.

There are two general types of fore and aft rigs. The jib headed or Bermuda rig sports triangular sails and is the original prototype of the now much evolved modern sail rigs. The gaff rig utilizes four-sided sails but this rig is seen today only on the traditional or "character" boats.

The mainsail is the main or largest sail on the vessel. The foresail is the sail on the most forward mast, called the foremast, on the vessel if she is schooner rigged. A boom or long wooden or light metal spar is used to hold the bottom edge of the sail secure. The various cables and ropes aboard a sailboat which cannot be moved and are securely fastened into place are known as standing rigging. The movable lines aboard the vessel are termed running rigging.

Fig. 16.2 A jib is the name given to a small triangular sail extending forward from the foremast. The jib tunnels the wind past the mainsail and can add as much as 50 to 75 percent more pull to the sails.

When a sailboat is sailing as close into the wind as she can sail, this is known as sailing close hauled. When sailing with the wind at any point between close hauled and astern, she is reaching. When the sailboat is sailing with the wind astern, she is said to be running free. Running free as meant in the Rules of the Road means sailing with the wind abaft the beam, and would include a vessel on a broad reach. When changing course by swinging her head through the wind, she is coming about, or tacking. Tacking is more often used to mean sailing a series of courses, close hauled with the wind alternately on each side to make good a course to windward. When she changes course, swinging her stern across and through the wind, she is wearing. When the wind is on or forward of the starboard beam, a sailboat is on the starboard tack. When the wind is on or forward of the port beam, a sailboat is on the port tack.

16.1.3 Paddle wheels. Paddle wheels are an effective method of propulsion when the vessel is operating in shallow, protected waters. There is no propeller projecting down into the water which may be damaged by obstructions. However, in rough water, paddle wheels lose their effectiveness. Paddle wheel towboats operated until relatively recently upon the Mississippi and other inland river systems.

16.1.4 Jet propulsion. A water jet is formed by housing the propeller in a long tunnel open at each end. This method of propulsion has not been commercially successful on larger vessels. One of its drawbacks is that logs, trash, and debris may clog the tunnel and jam the propeller.

Fig. 16.3 16.1.5 Propeller. The propeller, also called the wheel or screw, is the most universally employed method of marine propulsion. The action of a propeller is similar to that of a pump--it generates thrust by pushing the water.

Fig. 16.4

A propeller may have three or more blades. The forward part of the blade is termed the leading edge, the after edge is called the trailing edge. The forward side of a propeller is called the back or suction side. The after side of the blade is known as the face or pressure side. The blades of the propeller are attached to a hub. On some propellers the blades are permanently affixed to the hub while on others they may be moved or taken off.

Adjustable pitch propellers are constructed with detachable blades capable of being twisted when the ship is in drydock. Controllable pitch propellers are constructed with detachable blades capable of being twisted by a hub mechanism controlled from within the pilothouse.

Pitch is the distance which the propeller would advance in one revolution if it were acting as a fixed nut. In other words, if you turn a nut on a bolt one revolution, the distance it moves up the bolt would be similar to the pitch of the propeller. However, you must remember that both the propeller and the water are moving and the propeller does not operate exactly like a fixed nut. Theoretically, a propeller should advance in one revolution a distance equal to the pitch. This never happens, however, due to a phenomenon known as slip. Slip is the loss of efficiency of a propeller due to the movement aft of the water pushed by the propeller.

To reduce vibration caused by the turning of the propeller to a minimum, the hull clearance from the propeller tip should be at least one sixth the diameter of the propeller.

Propeller wake or prop wash is used by the mariner to denote the swirling mass of water trailing aft of, and caused by, the propeller.

Propeller performance is affected by the following things:

1) The number of blades on the propeller.

2) The location of the propeller. We have already mentioned tip clearance. The propeller should also be located far enough aft of the propeller post for the water coming in from both sides of the hull to come together before flowing to the propeller.

3) The material of the propeller. Most propellers are of manganese bronze which is a tough, corrosion resistant material.

It can also be highly polished. Cast iron blades are cheaper but corrode rapidly. They do, however, possess the advantage that when an obstruction is met, the cast iron will break easier than a bronze blade and thus prevent the shock of collision from being transmitted up the shaft where it may damage shafting and machinery.

4) The number of screws. A single propeller may not be able to absorb all the power required. Multiple screw vessels also possess better maneuvering properties. There is also the added advantage of a backup in the case of damage to one propeller.

5) The pitch of the propeller.

The loss of propeller efficiency in a propeller is in two main parts:

1) The loss due to movement of the column of water pushed by the propeller aft.

2) The loss due to the frictional drag of the blades through the water.

The first effect can be reduced by moving a large amount of water at a slow speed rather than the fast movement of a small amount of water. Larger blades and slower turning propellers accomplish this. You are of course aware that the propeller on a vessel does not turn as fast as the flywheel on the engine. Can you imagine a propeller turning at 1,800 revolutions per minute? Reduction gears fitted between the engine and the propeller shaft reduce the rpms out of the engine to a slower rate of revolution for the propeller.

The second effect may be reduced by using narrow blades, but the narrower the blade, the more the increase in pressure to the square inch of blade surface. Because of this, it is usually favorable to increase the number of propeller blades as the blades become narrower.

If a propeller turns so fast and develops so much thrust that the blades push the water aft faster than water can flow into the back or suction side of the propeller, small bubbles or cavities will form on the back of the blades. This effect is known as cavitation. It causes the propeller to lose thrust and efficiency. Cavitation deteriorates the structure of the propeller blade and can cause holes or gaps in the blades.

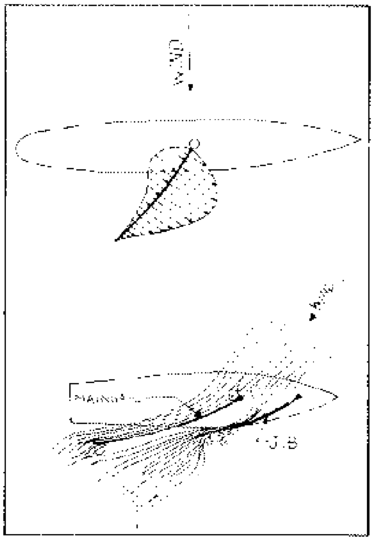


Fig. 16.1 How a sail works.

Fig. 16.2 A jib adds to the efficiency of the sail.

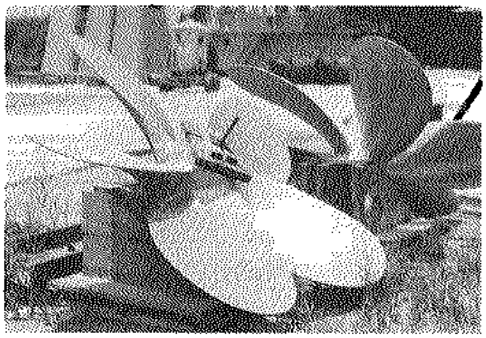


Fig. 16.3 Propellor before installation.

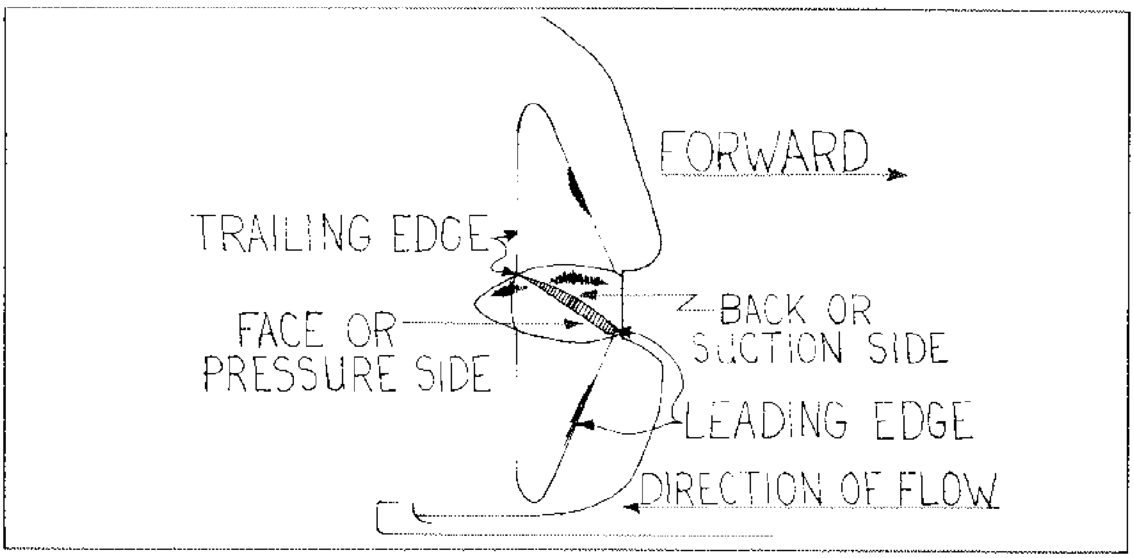


Fig. 16.4 Parts of the propellor.

Cavitation can also cause racing of the engines which is very harmful to machinery. To prevent cavitation the blades may be increased in diameter or width.

16.2 The Steering System

Fig. 16.5

16.2.1 Components. The devices which are used to transmit movement from the wheel to the rudder, including the wheel and the rudder, are termed the steering gear. The basic components of the steering gear are: the wheel, the steering engine connecting devices, the steering engine, the helm or tiller, and the rudder.

The steering wheel is a wooden or metal wheel having its spokes extended through the rim for handholds and used to control the rudder.

The steering engine connecting devices consist of the shafting or ropes led through guides and fairleads, or the electrical, pneumatic, or hydraulic lines used to transmit the movement of the wheel to the steering engine.

The steering engine is simply the name given to the devices which actually turn the helm (or tiller). On most offshore supply and crew vessels, the steering engine consists of the steering pumps, a reservoir and valves, and the required piping. On many vessels there is no steering engine. Cables are led directly from the wheel to the tiller.

The helm or tiller is connected to the rudder stock. By pushing the helm to port or starboard the rudder is turned. Some vessels possess a quadrant rather than a tiller.

On vessels with both a port and starboard rudder, it is necessary that both rudders move together and maintain the same angle. In some cases interconnecting cables are used. In other cases a ram is utilized to connect together both tillers. Rudder quadrants and tillers are fitted directly above the rudder carrier.

16.2.2 Types of steering gear. We shall classify steering gear in two main categories--hand-powered steering, and power-assisted steering.

Fig. 16.6

Hand-powered steering gear was the only type of steering gear before the advent of the motor. In this type of steering system, power to turn the rudder is provided by the man at the wheel. There are no motors involved, and shafting, rope, or cables are used to connect the wheel to the tiller or quadrant. Fairleads in the form of sheaves are used to guide the cables aft to the rudder compartment. It is extremely important that the cables and sheaves in this system be frequently greased and inspected.

In power-assisted steering, power to turn the rudder is provided by motors. The major types of power-assisted steering are electric steering, hydraulic steering, and air (pneumatic) steering, or combinations of the foregoing such as electro-hydraulic steering. In electric steering, electrical cable is run from the wheelhouse to the steering engine and transmits the signal to turn the rudder. In hydraulic steering, oil under high pressure in hoses transmits the signal to turn the rudder to the steering engine. In pneumatic steering, air under pressure in pipes turns the rudder. In electro-hydraulic steering, the steering engine connecting devices are electrical cables and the lines from the steering engine to the tiller are oil bearing hoses. In most steering systems in offshore vessels and tugs, where hydraulic lines run from the steering engine to the rudder, hydraulic cylinders connected to the tiller turn the rudder. The ends of the hydraulic cylinders are connected securely to the deck while the other ends with the piston are attached to the tiller.

With hand-powered steering the rudder only turns as far as the wheel is turned because the wheel is connected directly by cable or shafting to the rudder. With power-assisted steering there must also be some method employed for telling the rudder just how much to turn, for instance 15 degrees, and for telling the wheel just how far the rudder has moved. The moving liquid in the lines must turn the rudder just so far and then stop turning the rudder. This is accomplished by means of a piece of equipment called the follow-up. This control allows you to spin or turn the wheel as fast as you desire to any angle. The rudder then follows and stops at the correct angle.

16.2.3 Manual vs. automatic steering. Manual steering needs a man at the wheel to steer. Automatic steering makes use of an autopilot to steer the vessel. A nickname for the autopilot is the iron mike. If you ask who is steering and someone tells you Mike is at the wheel, he means the vessel is on the autopilot.

An autopilot is a mechanical-electrical apparatus which will steer a ship automatically on course. It gets its directive force or instructions from a magnetic or gyro compass.

In order that the autopilot can be useful under all conditions, facilities are provided in the equipment to take care of variable factors which influence the steering of the vessel such as weather conditions and the characteristics of the vessel itself. These two adjustments are the weather adjustment and the rudder adjustment. Both of the adjustments can be manually applied by controls on the autopilot.

The weather adjustment is designed to compensate for yaw, pitch, and roll and prevents the continual movement of the rudders back and forth as the vessel moves off course.

Yaw is the movement of the vessel's head to port or starboard of the course line.

Pitch is the up and down movement of the bow and stern of the vessel.

Roll is the rocking, side to side, movement of the vessel about the vessel's centerline.

In calm weather, the vessel's head may vary only part of a degree to the port or starboard of the desired course. In rough weather, however, especially with seas on the quarter, the vessel's head may swing suddenly four or five degrees off course due to wave and swell action. However, the vessel's head generally comes back, crosses the course line and then goes off course four to five degrees on the opposite side of the course line. This action continually occurs and an experienced wheel man doesn't fight this action any more than necessary. If the vessel should be thrown off course to port of the desired course, he does not turn the wheel sharply to starboard because the next thing that the vessel will naturally do is come back to starboard. This in combination with a sharp turn of the wheel to starboard will cause the vessel to come flying back to starboard, and go even farther off the course to starboard.

The autopilot is told by the compass when the vessel is off course. If the weather adjustment is set to one degree, when the vessel has swung off course one degree the autopilot will turn the rudder to bring the vessel back on course. In rough weather a one degree setting of the weather adjustment would cause the autopolot to continually move the rudders back and forth to bring the vessel back on course and its action would be like that of an inexperienced wheelman overcompensating for yaw. So the weather adjustment may be set to three or four degrees, or whatever is desired. This means that the vessel would have to swing a certain amount of degrees off her course before the autopilot took corrective action.

The rudder adjustment varies the amount of rudder applied for a given amount of departure from the set course. This adjustment is designed to take into account the condition of load of the vessel. A deeply loaded vessel will move off course more slowly than a vessel in the light condition, but once it begins moving or swinging it is harder to stop, and it takes a sharper turn of the rudder in the opposite direction of the swing to bring the vessel back on course. Thus, if the vessel were deeply loaded and the weather adjustment was set to two degrees and the rudder adjustment was set to five degrees, when the vessel had swung two degrees off course, the autopilot would immediately turn the rudder five degrees in the opposite direction to counter and stop the swing of the vessel. After the initial correction of five degrees the rudder movement decreases if more is needed to bring the vessel back on course.

16.2.4 Meeting and checking. To check the vessel means to stop the swing of the vessel off course. To meet the vessel means to turn the rudder so as to stop the movement of the vessel as she swings back to the proper course so that she does not go off course to the opposite side of the course line.

16.2.5 Steering requirements. Besides inspection of pipes and pumps for structural defects and leaks, two other general standards are set for steering systems:

1) In most vessels, two steering motors and two steering pumps are required.

2) In all vessels, the steering gear must be capable of moving the rudder from hard over on one side to hard over on the other side in not more than 30 seconds.

16.2.6 Turning the vessel. In conjunction with the steering gear it is desirable that the mariner know something of the turning characteristics of his vessel. To determine the turning characteristics of any vessel, the vessel is turned in a number of circles during sea trials to determine her handling characteristics under different circumstances.

The pivot point is the point about which the ship turns when the rudder is put over. The position of the pivot point depends upon the underwater hull shape of the vessel and on how the vessel is loaded. It moves forward when the vessel is trimmed down by the head. It moves aft when the vessel is trimmed down by the stern. Generally, however, the pivot point is located approximately 1/3 of the length of the vessel back from the bow.

Fig. 16.7 The turning circle is the path followed by the pivot point during a 180 degree turn or change of course. Various terms are associated with the turning circle:

Kick is the distance the ship moves sideways from the original course away from the direction of the turn when the rudder is first put over.

Advance is the distance gained in the direction of the original course when the vessel has turned through 90 degrees.

Transfer is the distance gained at right angles to the original course when the vessel has turned through 90 degrees.

Tactical diameter is the distance gained to the right or left of the original course when a turn of 180 degrees has been made.

Final diameter is the distance perpendicular to the original course between the 180 degree turn and the 360 degree turn.

Knowing the turning characteristics of his vessel assists the mariner in the proper handling of his vessel in avoiding other vessels and dangers.

16.3 The Bilge and Ballast System

The bilge and ballast system pumps overboard waste or drainage water which collects in the bilges of the vessel. Ballast is usually liquid in the form of water which is used to trim the vessel, or to sink the vessel deeper in the water.

Any particular vessel may have a separate bilge pump and a separate ballast pump, or one pump may serve both purposes.

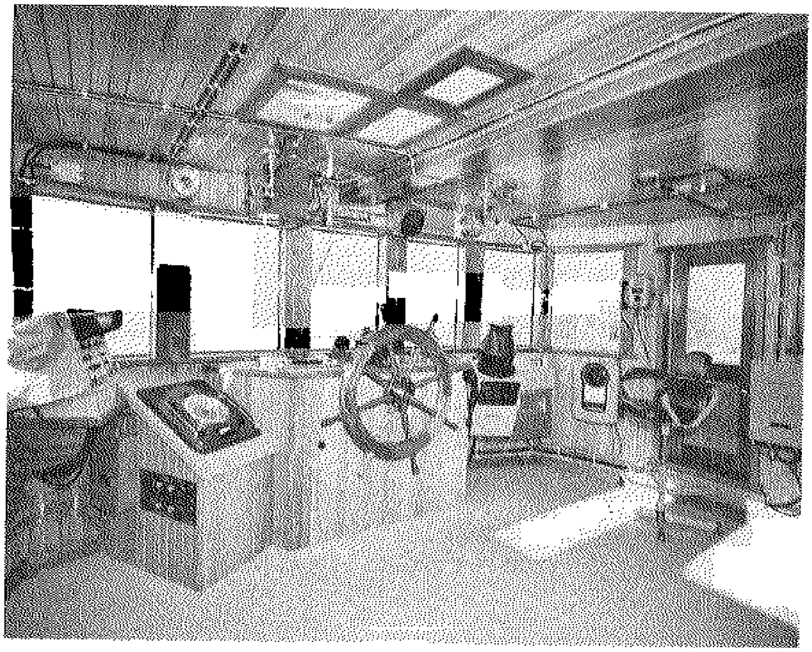


Fig. 16.5 Steering controls in wheelhouse.

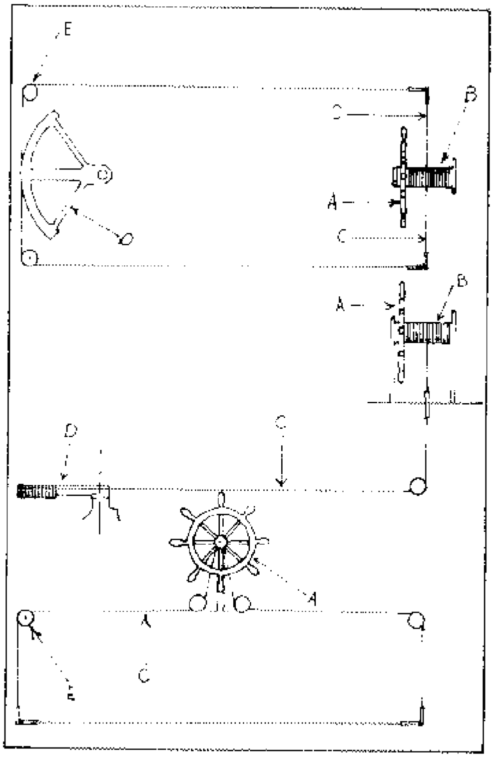


Fig. 16.6 Handpowered steering arrangement.

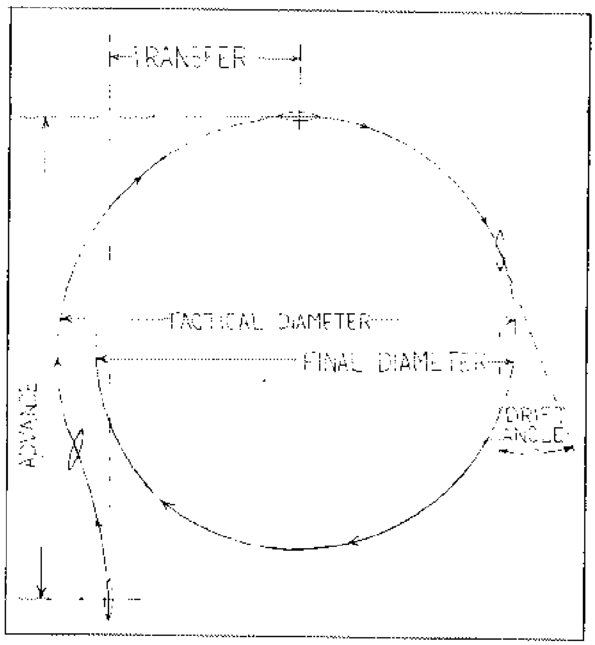


Fig. 16.7 Turning circle. The sideways movement is slighter than illustrated but has been exaggerated for clarity.

Manifolds are used in the system to direct the flow of liquid in the proper direction. Manifolds are a system of pipes and valves. Suction lines carry liquid to a pump while discharge lines carry liquid away from a pump. There is usually a mud basket installed between the manifold and the suction side of the pump. This mud basket contains a strainer to prevent solid or semi-solid materials from clogging the pump.

The end of a suction line is termed the suction foot. It is usually located in the after inboard side of the compartment which it services because this is the lowest point in the compartment and all drainage will flow to it. The suction foot is usually enclosed in a strum box (also called a rose box) inside the compartment. This is a boxlike structure with one or more perforated sides. The idea here again is to prevent solid materials from being sucked up in the suction line. The suction foot may also be enclosed in what is termed a drain well. The drain well is similar to the rose box except that its top is flush with the bottom of the compartment. The top of the drain well is covered by a metal plate with holes in it to strain out solid materials.

The sea suction is the line which takes in seawater through the hull of the vessel. The end of the sea suction line is enclosed in a structure called the sea chest. The sea suction runs from the pump to the sea chest which is constructed of solid metal plate except for the side of the sea chest which exits to the side of the vessel. This side of the sea chest is composed of a metal grating or strainer. Attached to the top of the sea chest inside the vessel is a blowdown plug. When the sea chest becomes clogged, an air line may be attached to this plug to blow the trash in the sea chest out through the hull.

The overboard discharge is an opening in the hull of the vessel through which liquid is pumped out of the vessel.

16.3.1 Valves. Various types of valves are installed in the bilge and ballast system. A gate valve has a gate inside which is raised and lowered by turning the valve stem. The butterfly valve has a partition inside which is turned to either block or permit the flow of water. A check valve is a valve which permits the flow of water in one direction only. Check valves are installed in various critical places. For instance there is a check valve between the overboard discharge and the pump. There are check valves installed on the discharge sides of pressure tanks so that water once pumped out will not slowly drain

Fig. 16.8, a-e

back into the tank. A pressure-relief valve is installed and set to a certain pressure. Once the pressure on the valve becomes too great it releases and "dumps" the liquid or air creating the pressure. This prevents the rupture of tanks and pipes and prevents damage to pumps.

Where valves are inaccessible and cannot be reached for opening and closing, reach rods are installed. A reach rod is essentially a long metal rod which may be thought of as an extension of the valve stem. The reach rod extends from the valve to a location from which it may be operated from outside the compartment. Where reach rods pass through a deck, they should be enclosed in a watertight packing. Reach rods should never be disconnected, and they should be maintained in good operating condition.

When a valve is opened it should be turned completely counterclockwise and then closed one quarter turn. This will prevent "freezing" of the valve in the open position. When a valve is closed it should be closed completely, quickly opened one quarter turn and then closed again completely. This action is designed to flush out any particles which may have become jammed in the valve gate that would prevent a tight seal.

16.3.2 Sounding tubes. Sounding tubes, otherwise known as sounding pipes, are long hollow metal tubes which extend from the deck down into the compartment for the purpose of "sounding" the tank to determine how much liquid is in the tank. A chalked tape or line with a weight on the end is dropped through the sounding tube until it strikes the bottom of the tank and is then pulled out to determine the depth of the liquid in the tank. At the bottom of the sounding tube is a steel plate called a striking plate. The striking plate is not a part of the sounding tube because the sounding tube does not run all the way to the bottom of the tank. This striking plate is designed to prevent the weight used in sounding the tank from eventually wearing a hole in the metal in the bottom of the tank underneath the sounding tube. At the top of the sounding tube is the sounding plug. This is a threaded plug which caps the sounding tube and prevents water from entering the tank through the sounding tube. These plugs are usually recessed in the deck and are opened with a special wrench. Never allow cargo to be placed on top of these plugs! If you desired to sound the tank in an emergency, when you wished to determine if you were taking on water through a hole in the hull, you would not be able to do so. These plugs are usually of brass and their threads are extremely delicate. Don't throw them around carelessly or you may damage the threads. Be certain when tightening them that you have cleaned all the dirt from the threads, and do not strip them by taking up on them too much when tightening.

16.3.3 Fill lines and vent pipes. Fill line is the name given any line which may be used to fill a tank or compartment with liquid. Vent pipes are those pipes used to prevent a buildup of pressure and vapors within a tank. A gooseneck vent is a vent pipe with an 180 degree turn in the end of it. In other words, it turns back toward the deck.

Fig. 16.9 16.3.4 Bilge and ballast system requirements. The following requirements must be met by installation piping:

1) All sounding tubes must be not less than one and one half inches in diameter.

2) Sounding tubes are to be installed on all tanks which are not at all times readily accessible.

3) Sounding tubes must extend to within two inches of the bottom of the tank which they serve.

4) Every tank must be fitted with at least one vent pipe.

5) Vent pipe diameter shall be not less than two and one half inches.

6) Where the tanks are to be filled by pump pressure, the total area of the vents shall be at least equal to the area of the filling line.

7) All vent and overflow pipes should terminate by way of a U-bend.

8) The height of the end of vent pipes from the deck shall be at least 36 inches on the main deck and 18 inches on superstructure decks.

9) Vent outlets must be fitted with corrosion resistant wire gauze and a satisfactory means of closing in an emergency. This means of closing may consist simply of a wooden plug. Some vent pipes have a ball valve on the end to prevent water from entering the vent pipe. On many offshore vessels, cut rubber inner tubes have been used on the end of vent pipes to the fuel tanks to prevent water from entering.

10) Vent pipes are to be led as directly as possible, and their inclination is not to be less than 30 degrees from the horizontal.

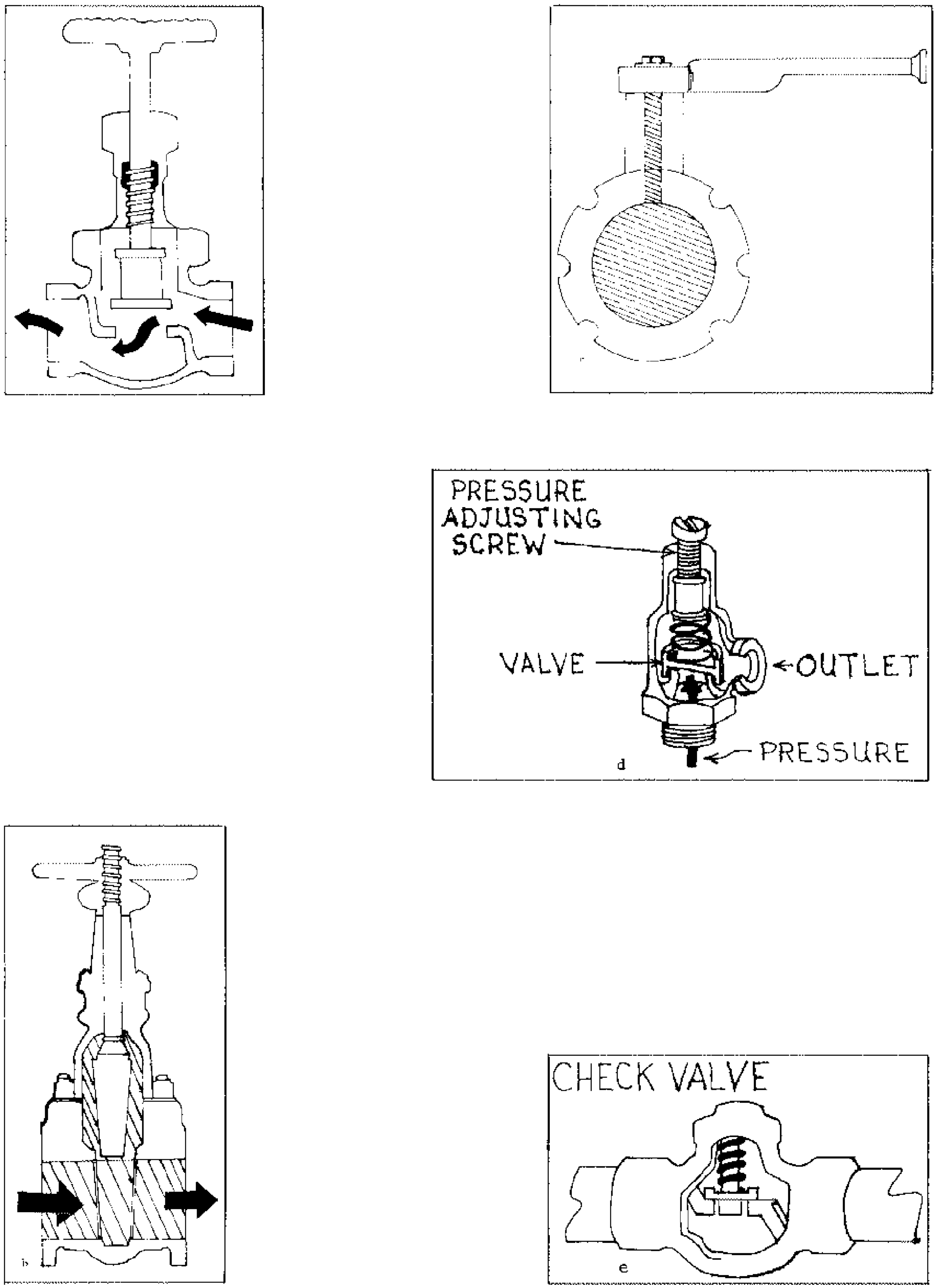


Fig. 16.8 a-e Valve types: (a) globe valve; (b) gate valve; (c) butterfly valve; (d) check valve; (e) pressure-relief valve.

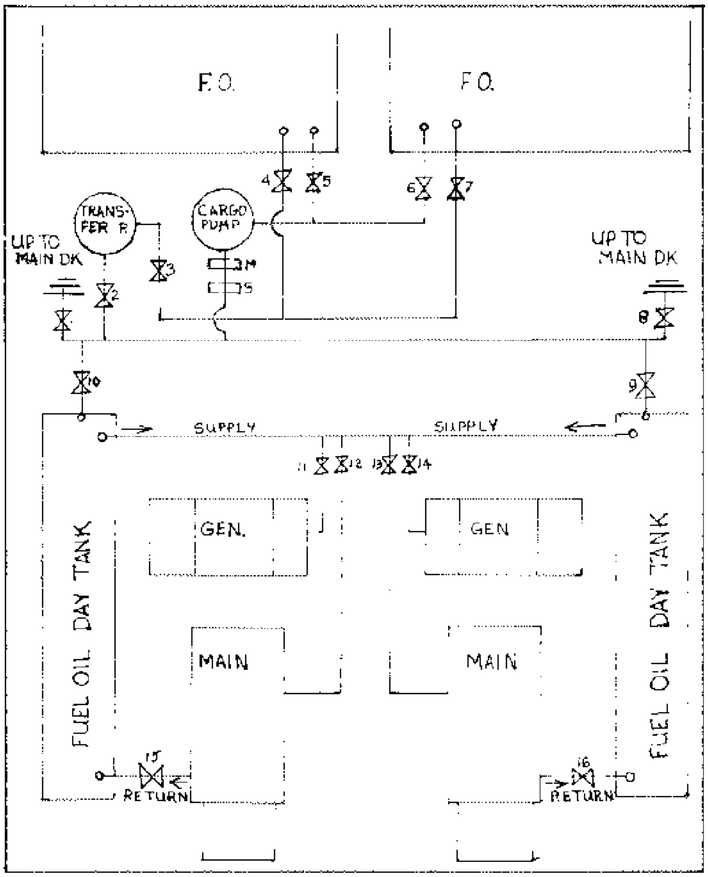


Fig. 16.9 General layout of fuel oil system aboard offshore vessel: FO (fuel oil); oil); M (main engine); CP (cargo pump); G (generator); TP (transfer pump). All valves are numbered: 3 and 4 are check valves; near valves 1 and 9, pipeline passes up through deck where a fuel hose (usually painted red) is connected to transfer the fuel.

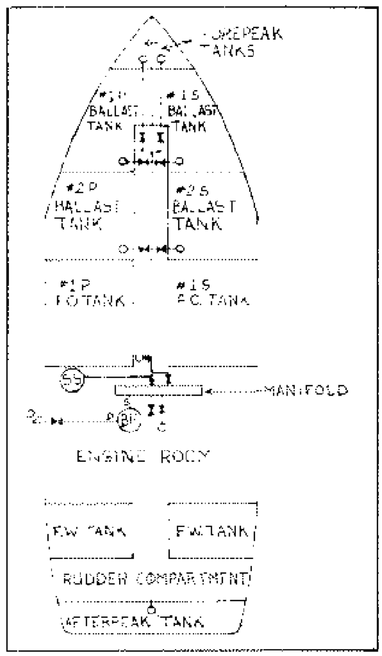


Fig. 16.10 Simplified arrangement of tanks and lines aboard an offshore supply vessel bilge and ballast system: SS (sea suction); FW (fresh water); D (discharge); BP (bilge pump); FO (fuel oil); S (suction); O (suction foot); (valve).

16.4 The Fuel Oil System

Fig. 16.10

The fuel oil system aboard offshore crew and supply vessels is designed to serve both the needs of the vessel's own engines and to supply fuel oil to offshore drilling rigs, platforms, and other vessels. Fuel oil tanks aboard offshore supply vessels are commonly designed to carry in the neighborhood of 100,000 gallons of fuel.

Fuel oil day tanks are installed in the system for both the port and starboard main engines and generators. Fuel oil is pumped from the fuel oil tanks to the fuel oil day tanks where trash and water gravitate to the bottom. From the fuel day tanks the fuel is supplied to the engines.

Fuel flows to the main engines and generators through supply lines and unburned fuel returns to the day tanks by means of a return line. Fuel oil pumps on the diesel engines draw or suck fuel oil from the day tanks.

Fuel filters are installed at various locations in the system to strain out impurities. Water traps are also installed near the day tanks to separate water from the fuel. Water should be drained from these traps frequently and the filters changed when necessary. The fuel oil day tanks are equipped with sight glasses which allow you to determine visually the level of the fuel in the tank.

The fuel oil cargo pump is used to pump fuel oil from the vessel's tanks to platforms, rigs, and other boats. This pump is equipped with a meter which allows the engineer to monitor the number of gallons which he has transferred. A strainer is also placed by this pump to clean the fuel oil before it passes to another vessel.

The fuel oil transfer pump is used to transfer fuel from the fuel tanks to the fuel oil day tanks. The day tanks are pumped up as needed.

The fuel oil day tanks and the fuel oil tanks are usually separated from the side of the hull by a void or cofferdam to prevent leakage of water into the tanks should the hull be punctured.

16.5 Fresh Water System

Fig. 16.11

The fresh water system of the vessel provides water for drinking, showering, cleaning, and cooking. This system is also known as the potable water system. By law, this system is required to be independent of and separate from all other systems aboard the vessel.

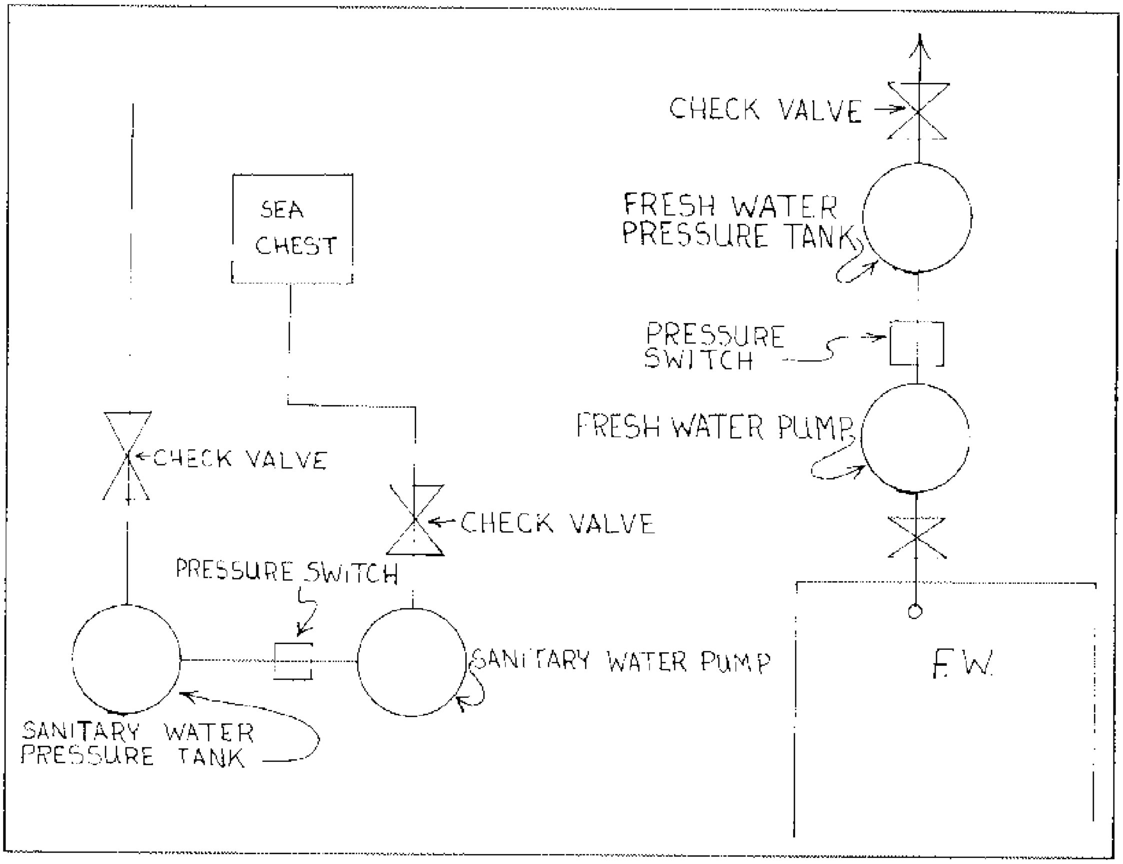


Fig. 16.11 Sanitary and freshwater piping system.

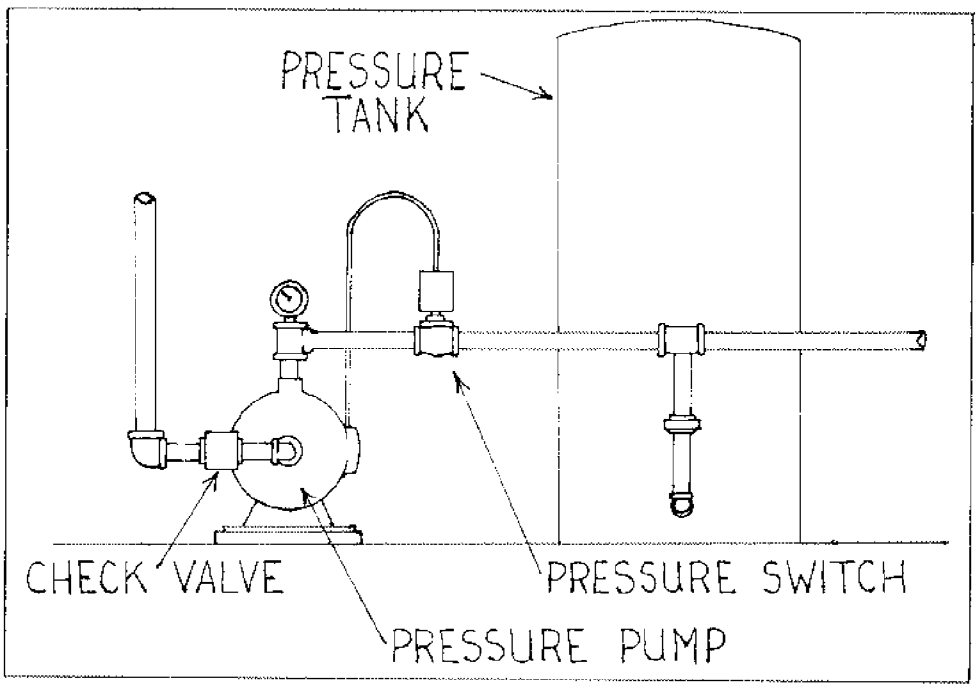


Fig. 16.12 Freshwater pump and pressure tanks.

Fig. 16.12 The main function of the fresh water pump is to pull water by suction from the fresh water tanks into its mechanism and then deliver the water under pressure to a storage or pressure tank. A pressure switch on the storage tank tells the pump when to run. This pressure switch can be set by an adjusting screw to the desired pressure (usually 35 to 40 pounds) and when the pressure in the storage tank drops due to the use of water, the switch kicks on the pump. As soon as the pressure is back up to the desired level, the switch cuts the pump off. From the pressure tank, the water flows under pressure to a faucet whenever the faucet is opened.

A check valve is installed on the suction side of the pump to prevent water once pumped into the storage tank from draining back into the fresh water tanks. A pressure relief valve is usually installed on the pressure tank to prevent rupture of the tank, damage to the pump, or damage to the piping should pressure become too high. In addition, on most pressure tanks a screw cap is located on the side so that air can be bled out of the tank. Don't stand behind this plug when removing it because it may fly off under pressure. Unscrew it slowly and let the air bleed off gradually.

16.6 The Sanitary Water System

The sanitary water system takes suction from the sea chest and delivers sea water to the sanitary facilities of the vessel. A sanitary water pump pulls water from the sea chest and delivers it under pressure to the sanitary water pressure tank.

In general, the installation of pressure switches and check valves is similar to that of the fresh water system.

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APPENDIX A
GLOSSARY

access hole - Opening in any part of the ship's plating used as a passageway while ship is under construction.

accomodation ladder - A portable set of steps suspended over the ship's side for the accommodation of people boarding from small boats or a pier.

added weight method - A method of solving for damage stability where the water which enters the vessel is considered as an added weight.

aft - Toward, at, or near the stern (adverb).

after - Toward, at, or near the stern (adjective).

afterpeak - The compartment in the narrow part of the stern, aft of the last watertight bulkhead.

afterpeak bulkhead - Watertight bulkhead farthest aft.

after perpendicular - A line perpendicular to the base line, intersecting the after edge of the sternpost at the design water line on fantail stern ships. On ships with a cruiser stern, it is usually taken at the end of the waterline. This also applies to merchant cruiser sterns. The after perpendicular usually passes through center of rudder stock when vessel does not have a sternpost.

air-escape hole - An aperture cut in the top of floors or in tanks to prevent air lock from inhibiting the free flow of a liquid.

air port - A circular window with hinged glass in the ship's side or deckhouse, for light or ventilation; also called "porthole."

amidships - In the vicinity of the middle portion of a ship, as distinguished from the ends.

angle clip - A short piece of angle bar used for attachment.

anneal - To relieve locked-up stresses by heating and gradual cooling.

anti-rolling devices - These include the bilge keel, or rolling chocks, anti-rolling tanks, gyro stabilizer, and stabilizing fins.

aperture - The space provided between rudderpost and propeller post for the propeller.

assemble - To put together sections of the ship's structure on the skids, in advance of erection on the ways.

athwartship - Across the ship, at right angles to the fore-and-aft center line of a vessel.

auxiliaries - Various winches, pumps, motors, and other small engines required on a ship.

B - Symbol for buoyancy.

backing angle - A short piece of angle for reinforcing the butt joint or splice of two angles, placed behind the angles joined.

ballast - Any weight or weights used to keep the ship from becoming topheavy or to increase its draft or trim. In some designs which may be too stable and therefore ride too hard when light, ballast may be placed high in the vessel to reduce stiffness.

ballast tank - Watertight compartment to hold water ballast.
base line - A fore-and-aft datum line from which vertical heights are measured. On riveted hulls it is usually parallel to the top edge of the garboard strakes. On welded hulls it is usually parallel to the top edge of the flat plate keel. However, as the location of this reference line is a designer's option, the lines plan should be checked to determine its exact location.
beam - An athwartship horizontal member supporting a deck or flat. Also, the extreme width of the ship.
beam bracket - A triangular flat plate welded or riveted to the shell frame and the deck beam where they terminate.
beam-draft ratio - Ratio of beam to draft. This ratio has an important bearing on the height and movement of "M."
below - Below a deck or decks (corresponding to "downstairs").
bending rolls - A machine in which power-driven steel rollers are used to give cylindrical curvature to plates.
bending slabs - Heavy cast-iron perforated slabs arranged to form a large floor on which frames, etc., are bent, after heating in a furnace.
berth - A place where a ship is docked or tied up. 2: A place to sleep; a bunk.
between decks - The space between any two continuous decks; also called "tween decks."
bevel - The angle between the flanges of a frame or other member. (Greater than right angle, open bevel; less, closed bevel.)
bilge - Curved section between the bottom and the side of a ship; the recess into which all water drains.
bilge bracket - A flat plate welded or riveted to the tank top or margin plate and to the frame in the area of the bilge, sometimes called "margin bracket."
bilge keel - 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 welding or by angle bars. It helps materially in steadying a ship and does not add much to the resistance to propulsion if fitted in the streamline flow. Sometimes called "rolling chocks."
bilge pump - Pump for removing bilge water.
bilge strake - Course of plates at the bilge.
bilge water - Water collecting in the bottom of a ship owing to leaks, sweat, etc.
binnacle - A stand or box for holding and illuminating a compass so that it may be conveniently observed by the steersman.
bitt - Tie post for making lines fast on deck.
bitumastic - An elastic bituminous cement used in place of paint to protect steel.
block - An encased roller revolving on a pin. Sometimes called a "pulley."
block coefficient - A coefficient of fineness which expresses the relationship between the volume of displacement and a block having the length, breadth, and draft of the vessel.

BM - Symbols for metacentric radius; distance between B and M.
boat deck - Deck on which lifeboats are kept.
booby hatch - Watertight covering over an opening on deck of a ship for a stairway or ladder.
boom - A long, round, heavy spar pivoted at one end, ordinarily used for hoisting cargo.
bosom piece - 1: A short piece of angle riveted inside a butt joint of two angles. 2: A butt strap for angle bars; splice piece.
boss - The curved swelling portion of the ship's hull around the propeller shaft.
boss frame - Hull frame that is bent for clearing propeller shaft tube.
boss plate - Shell plate covering curved portion of hull where propeller shaft passes outboard.
bow - The forward end of a ship.
bracket - A triangular plate used to connect rigidly two or more parts, such as deck beam to frame or frame to margin plate.
braze - To join certain metals by the use of a hard solder.
breasthook - A flanged plate bracket joining port and starboard side stringers at their forward end at the point of the stem.
bridge - 1: Platform extending athwartship at pilothouse. 2: An amidships superstructure.
bridge deck - Deck at top of bridge superstructure.
brow plate - Any ramped sloping plate around an access opening which facilitates the handling of cargo over an obstruction.
building slip - Place where the ship is built before launching.
bulb angle - Angle shape reinforced at one toe.
bulb plate - Narrow plate reinforced on one edge.
bulb tee - T-bar with toe of web reinforced.
bulkhead - A vertical steel partition corresponding to the wall of a room, extending either athwartship or fore-and-aft.
bulwark - The strake of shell plating above a weather deck. It helps to keep the deck dry and also serves as a guard against losing deck cargo or men overboard.
bunker - A compartment used for the stowage of coal or other fuel.
buoyancy - Ability to float; upward force of water pressure. It is equal to the weight of the displaced liquid.
buoyancy reserve - The additional buoyancy that would result if that part of the vessel's hull which is above the load water line were immersed.
butt - The joint formed when two parts are placed edge to edge; the end joint between two plates.
buttock - The intersection of a fore-and-aft vertical plane with the molded form of the ship.
butt strap - A strip or strap that overlaps both pieces, serving as a connecting strap between the butted ends of plating.

camber - The rise or crown of a deck, athwartship.
cant frame - A frame not square to the center line, usually at the counter of the vessel.

capsize - To "turn turtle" due to loss of transverse stability.
capstan - A revolving device with axis vertical, used for heaving-in mooring lines.
cargo - The freight carried by a ship.
cargo batten - Strip of wood used to keep cargo away from steel hull.
cargo boom - Heavy boom used in loading cargo.
cargo hatch - Large opening in a deck to permit loading of cargo into holds.
cargo port - Opening in a ship's side for loading and unloading cargo.
carling (also called "carlines") - Fore-and-aft member at side of hatch, extending across ends of beams where cut to form hatch; also placed between beams to stiffen areas under points of great stress such as under winches.
casting - An object made by pouring molten metal into a mold and allowing it to cool.
caulk (calk) - To make a joint watertight.
ceiling - A surface, usually of wood, placed over the tank top for protection.
center line - The fore-and-aft middle line of the ship, from stem to stern.
center of buoyancy - That point at which all the vertically upward forces of buoyancy are considered to be concentrated; the center of volume of the immersed portion of the vessel.
center of flotation - The center of gravity of the waterplane; the point around which a vessel trims.
center of gravity - That point at which all the vertically downward forces of weight are considered to be concentrated; the center of the mass of the vessel.
chafing plate - Bent plate for minimizing chafing of ropes, as it hatches.
chain locker - Compartment in forward lower portion of ship in which anchor chain is stowed.
chain pipe - Pipe for passage of chain from windlass to chain locker.
change of trim - The algebraic sum of the initial trim and the trim after weight has been shifted, loaded, or discharged.
chart house - Small room adjacent to steering wheel for charts and navigational instruments.
chock - A heavy fitting through which ropes or hawsers may be led; saddle or seat of wood or metal.
classification society - An institution that supervises the construction of vessels under established rules, witnesses all tests on materials for hulls, machinery, and boilers, proof-tests all anchors and chains, and issues a certificate of classification. The major institutions are American Bureau of Shipping (ABS), United States; Lloyd's Register (LR), Great Britain; British Corporation (BC), Scotland; and Norwegian Veritas (NV), Norway. Numerous other small societies exist.

cleat - A fitting having two arms or horns around which ropes may be made fast. A clip on the frames of a ship to hold the cargo battens in place.
coaming - The vertical boundary of a hatch or skylight.
cofferdam - Narrow empty space between two bulkheads that prevents leakage into adjoining compartments.
collision bulkhead - First watertight bulkhead from bow of ship.
companion way - An access hatchway in a deck, with a ladder leading below, generally for the crew's use.
compartment - A subdivision of space or room in a ship.
compartment standard - The number of compartments in any location which can be flooded up to the margin line without causing the vessel to sink. Based on a certain permeability, usually 63 percent for cargo spaces and 80 percent for machinery space.
compass - A device for indicating the magnetic north, by means of a magnetized bar or needle, or the true north, through the action of a gyroscope.
compression - Stress caused by pushing.
Contraguide - a trade name usually referring to the Gold schmidt patented contraguide rudder, rudderpost and stern frame "from which the vessel receives a forward push from the rotation of the water in the propeller race which is lost energy unless the contraguides are fitted." (Words in quotations are claimed.)
counter - Overhang of stern of a ship.
countersink - The taper of a rivet hole for a flush rivet.
couple moment - Created by two equal forces exerted in opposite directions along parallel lines. In stability, the forces through G and B.
cowl - Hood-shaped top of ventilator pipe.
crack arrestor - A slot cut or hole bored near an area of probable high stress to stop a crack should one start in the stressed area. The theory being that the intense stresses in the apex of a crack will lessen when the apex becomes a slot or circular hole.
cradle - 1: A form on which furnaced plates are shaped. 2: The support in which a ship lies during launching, called "launching cradle."
cranky ship - A vessel with small metacentric height; topheavy.
criterion of service numeral - A number (usually between 23 and 123) based on the dimensions and service in which the vessel is engaged, which is used to obtain the subdivision requirements for a vessel.
cross curves of stability - Curves for various angles of inclination up to 90 degrees. The ordinates are displacements. Intersection of ordinates with curves produce the abscissas (righting arms).
crow's nest - An elevated lookout station on a ship, usually attached to forward side of foremast.
curves of form - See "hydrostatic curves."
curves of statical stability - See "statical stability curves."

damage stability - Stability of a vessel after flooding.

davit - A crane arm for handling anchors, lifeboats, stores, etc.

dead flat - The portion of a ship's form or structure that has the same transverse shape or the same area as the midship section.

dead rise - Rise or slant up athwartship of the bottom of a ship from the keel to the bilge; the distance the bottom rises in one half the beam.

deadweight - The total weight of cargo, fuel, water, stores, passengers and crew, and their effects, that a ship can carry.

deadweight scale - A scale of values of TPI, MTI, displacement, and deadweight, for all drafts.

deck - The deck on a ship, corresponding to the floor in a building.

deck beam - Athwartship support of deck.

deck, bulkhead - The uppermost continuous deck to which all the main transverse watertight bulkheads are carried. This deck should be watertight to prevent any compartment that is open to the sea from flooding the one adjacent to it.

deck, freeboard - 1: Deck to which freeboard is measured. 2: Deck above which bulkheads need not be watertight. 3: The watertight deck; also called "bulkhead deck."

deck house - Shelter built on deck, not extending to the sides.

deck, main - The principal deck, usually the freeboard deck.

deck, orlop - A partial deck in the hold.

deck, shelter - A complete weather deck above the freeboard deck is suitable for carrying cargo, although it is exempt from tonnage measurements since the deck is theoretically nonwatertight. Since this is the uppermost through deck, it is sometimes the strength deck.

deck stringer - The strake of plating that runs along the outer edge of a deck.

deck, weather - Full deck with no overhead protection; water tight except in case of a shelter deck.

deep tank - A tank usually used for carrying sea-water ballast, but also used for carriage of fuel oil and cargo.

deflection - The amount of bending.

degree of subdivision - A relative term expressing the relation of actual subdivision to required compartment standard.

density - The weight per unit volume of a substance.

derrick - A device for hoisting heavy weights, cargo, etc.

die - 1: A tool having several cutting edges, used for cutting threads. 2: In drop-forging work, a template tool used to stamp out a piece of work in one operation.

displacement - The total weight of the ship when afloat, including everything on board, equals weight of water displaced. Displacement may be expressed in either cubic feet or long tons. A cubic foot of sea water weighs 64 lb, and one of fresh water 62.5 lb; consequently, one long ton is equal to 35 cu ft of sea water or 35.9 cu ft of fresh water. One long ton equals 2,240 lbs.

docking keel - Keel on each side, and in place of regular keel, used to distribute the weight in dry dock as in the case of large ships. (Seldom used except on largest naval ships and now almost extinct.)
dog - 1: A small metal fitting used to hold doors, hatch covers, manhole covers, etc., closed. 2: A bent bar of round iron used for holding shapes on the bending slab.
double bottom - Compartments at bottom of a ship between inner-and-outer bottoms, used for ballast tanks, oil, water, fuel, etc.
doubling plate - A plate fitted outside or inside of and facing (touching) against another to give extra strength or stiffness.
draft marks - The numbers painted at the bow and stern of a vessel to indicate how much water she draws. These marks are 6 inches high and spaced 12 inches from the bottom of one number to the bottom of the next number.
drift pin - A small tapered tool driven through rivet holes and used to draw adjoining plates or bars into alignment with each other.
drop strake - A strake that is terminated before it reaches the bow or stern. The number of strakes dropped depends on the reduction of girth between the midship section and the ends.
dry dock - A dock in which a ship's hull may be kept out of water during construction or repair. Three types are used: (a) the graving dock, a basin excavated near a waterway, with a gate to exclude the water after pumping out; (b) the floating dock, a hollow structure of wood or steel, which is sunk to receive the ship to be docked and is pumped out to lift it from the water; and (c) the marine railway, a cradle of wood or steel on which the ship may be hauled out of water along inclined tracks leading up the bank of a waterway.
dutchman - Any piece used to connect two or more pieces or a piece to fill in the gap between members.
dynamical stability - The energy which a vessel possesses to right herself due to the work performed in inclining her.

ensign staff - A flagstaff at stern of vessel from which the national ensign may be flown.
equilibrium - Vessel is in a state where there is no movement; G must be in the same vertical line with B.
erect - To hoist into place and bolt up on the ways fabricated and assembled parts of a ship's hull, preparatory to riveting or welding.
escape trunk - A vertical trunk usually located in the after end of the shaft alley to permit the engine room personnel or anyone trapped in the shaft alley a means of escape.
even keel - A ship is said to be on an even keel when the keel is level or parallel to the surface of the water and the hull is not listed, or tipped, sideways.

expansion trunk - Upper portion of a tank on an oil tanker, used to allow for the expansion of oil when the temperature rises, and for contraction upon cooling without permitting a large area of free surface.

eyebrow - A plate shaped around the top of an opening to prevent drainage from entering the opening.

fabricate - To process hull material in the shops prior to assembly or erection. In hull work fabrication consists of shearing, shaping, punching, drilling, countersinking, scarfing, rabbeting, beveling, etc.

factor of subdivision - A number less than one obtained from curves of factor of subdivision which, when multiplied by floodable length produces permissible length of compartment. It is the reciprocal of the compartment standard.

fair (fair up) - 1: To correct or fair up a ship's lines on mold-loft floor. 2: To assemble the parts of a ship so that they will be fair, i.e., without kinks, bumps, or waves. 3: To bring rivet holes into alignment.

fairlead - Any ringbolt, eye, loop, or sheave which guides a rope in the required direction.

fantail - 1: Fan-shaped plate on center line of ship on overhanging stern. 2: Plates forming overhang at stern.

fathom - A measure of length, equivalent to six linear feet, used for depths of water and lengths of rope or chain.

faying surface - The surface between two adjoining parts.

fender - Heavy strip of wood or steel attached to the side of the vessel, running fore-and-aft, at the water line, for the purpose of preventing rubbing or chafing of the hull.

fidley hatch - Hatch around smokestack and uptake for ventilating the boiler room.

fixed light - Circular window with fixed glass in side of ship, door, skylight cover, etc.

flatstaff - A light spar or pole from which a flag may be displayed.

flange - Portion of a plate or shape at (or nearly at) right angles to main portion; to flange is to bend over to form such an angle.

flare - The outward curvature of a ship's side.

floodable length - At any point of a ship, the length of the space having its center at that point, which can be flooded without causing the ship to sink.

floor - A plate placed vertically in the bottom of a ship, usually on every frame, and running athwartship from bilge to bilge.

floor plate - Vertical plate in bottom (see "floor").

fore-and-aft - In line with the length of the ship; longitudinal.

forecastle - The forward upper portion of the hull, usually used for rope, paint, and boatswain's stores.

forefoot - The part of the stem that curves aft to meet the keel.

forepeak - A narrow compartment, or tank, at the bow in the lower part of the ship forward of the collision bulkhead.

forward - Near, at, or toward the bow of the ship.

forward perpendicular - A line perpendicular to the base line, intersecting the forward edge of the stem at the designed water line.

foundations, main - Supports for boilers and engines.

foundations, auxiliary - Supports for small machinery such as winches, condensers, heaters, etc.

founder - To sink due to loss of reserve buoyancy.

frame - One of the ribs forming the skeleton of a ship.

frame spacing - The fore-and-aft distance between heel and heel of adjacent transverse frames along the center line.

frame, web - Heavy side or continuous frame, made with web plate between its members.

freeboard - The distance from the water line to the top of freeboard deck at side.

freeing port - An opening in the bulwarks, close to the deck and fitted with a flap cover which opens outboard, or with rods, to allow water shipped upon the deck to free itself from the vessel rapidly but without carrying any crew members with it.

free surface - Condition existing when a liquid is free to move in the tank or compartment of a vessel. Causes a virtual rise of the ship's center of gravity.

funnel - Smokestack of a vessel.

furnace - Heater or large forge for heating plates or shapes for bending. To furnace is to bend after heating in a furnace.

G - Symbol for center of gravity.

galley - A cookroom or kitchen on a ship.

galvanizing - Coating metal parts with zinc for protection against rust.

gangway - A passageway, ladder, or other means of boarding a ship.

gasket - Flexible material used to pack joints in machinery, piping, doors, hatches, etc., to prevent leakage of liquids or gases.

GG' - Distance that the center of gravity moves due to weight movement or free surface of liquid.

girder - A continuous member running in a fore-and-aft direction under the deck for the purpose of supporting the deck beams and deck. The girder is generally supported by widely spaced pillars.

girth - Distance around a vessel's shell from gunwale to bilges, to keel, to bilge, to gunwale.

GM - Metacentric height; distance from the center of gravity to the metacenter.
grating - A structure built out of wooden strips or metal bars, to form a walkway across a deck or opening without interference with light, drainage, or ventilation.
gross tonnage - A figure obtained by dividing the total volume of the ship, in cubic feet by 100, after the omission of all spaces exempted from measurement by law.
ground ways - Timbers fixed to the ground, under the hull on each side of the keel, on which ship slides during launching.
gudgeons - Bosses on sternpost drilled for pins (pintles) for rudder to swing on.
gunwale - Junction of deck and shell at top of sheer strake.
gunwale bar - Angle bar that connects deck stringer plate and shell plates at weather deck.
gusset plate - Triangular plate that connects members or braces.
GZ - Righting arm or lever. Distance between lines of force through G and B.

hatch - Opening in deck for passage of cargo, etc.
hatch beam - Portable beam across the hatch to support covers.
hawse pipe - Casting extending through deck and side of ship for passage of anchor chain, for stowage of anchor in most cases.
header - A member added for local strength which is not parallel to the main strength members of the vessel. Usually used to deliver the load from some strength member which has been cut to other strength members in the area.
heel - The transverse angle of inclination of a vessel.
heeling - 1: Tipping of a vessel to one side. 2: Listing.
heeling moment - The moment tending to heel the vessel; opposed by the righting moment.
helm - A term used to designate the rudder's position as controlled by the tiller, wheel, or steering gear.
heterogeneous cargo - Cargo of a varied nature; general cargo.
hogging - Straining of the ship that tends to make the bow and stern lower than the middle portion (see "sagging").
hold - 1: The spaces below deck allotted for the stowage of cargo. 2: The lowermost cargo space.
homogeneous cargo - Cargo of the same density throughout.
horseshoe plate - Small horseshoe-shaped plate around rudder-stock on shell of ship, for the purpose of preventing water from backing up into the rudder trunk.
hull - The body of a ship, including shell plating, framing, decks, and bulkheads.

hydrostatic curves - Curves based on the form of the immersed portions of a vessel. They include: coefficients of fineness, TPI, displacement, increase of displacement for one foot trim by the stern.

I - Symbol for inertia.
inboard - Inside the ship; toward the center line.
inclining experiment - Experiment, which by inclining a vessel a few degrees, produces with the aid of a formula the metacentric height (GM) and the position of the center of gravity of a vessel.
initial stability - Stability of a vessel for small angles of inclination (up to 15 degrees).
inner bottom - Plating forming the top of the double bottom; also called "tank top."
intact buoyancy - Intact space below the surface of a flooded area.
intercostal - Made in separate parts, between successive frames or beams; the opposite of "continuous."
inverted angle - An angle with the toe welded to a plate, thus, in effect, in conjunction with a portion of the plate adjacent to the toe, forming a channel.

jack staff - A flagpole at bow of vessel, from which the union jack may be displayed.
joggle - To offset a plate or shape to save the use of liners.

K - Symbol for keel.
KB - Linear distance from the keel to the center of buoyancy (when vessel is upright).
keel - The principal fore-and-aft member of a ship's frame, which runs along the bottom and connects the stem and to which are attached the frames of the ship. The backbone of the ship's frame.
keel, bar - A keel that protrudes through the bottom.
keel blocks - Heavy blocks on which ship rests during construction.
keel, flat - A fore-and-aft row of flat plates end to end on the center line, running along the bottom of the ship from stem to stern, the forward and after plates being dished up into a U shape to fit the stem and stern casting.
keelson, side - Fore-and-aft member placed on each side of the center vertical keel.
keel, vertical - Vertical plate on center line, used as reinforcement for longitudinal flat keel; sometimes called "center keelson."
KG - Height of center of gravity above keel.
king post - A stub mast, outboard from center line, to carry cargo booms; also called "Samson post."
KM - Height of metacenter above keel.

knot - A speed measurement of one nautical mile per hour, a nautical mile being about one and one-seventh land miles (6,080 ft or one-sixtieth degree at the equator).
knuckle - A sharp bend in a plate or shape.
knuckle plate - A plate bent to form a knuckle.

ladder - Vertical or inclined steps aboard ship, taking the place of stairs.
lap - A joint in which one part overlaps the other, the use of a butt strap being thus avoided.
laminated plate - A rolled piece of steel which looks more sandwich-like than solid when viewed edgewise. Laminated steel is invariably condemmed.
launching - The operation of placing the hull in the water by allowing it to slide down the launching ways. During launching the weight of the hull is borne by the cradle and sliding ways, which are temporarily attached to the hull and slide with it down the ground ways.
laying off - Marking plates, shapes, etc., for fabrication.
length between perpendiculars - The length of a ship measured from the forward perpendicular to the after perpendicular.
length over all - The length of a ship measured from the forwardmost point of the stem to the aftermost point of the stern.
lift - To "lift" a template is to make it from measurements taken from the job.
light displacement - Weight in long tons of vessel in a light condition.
lightening hole - A hole cut in a structural member to reduce its weight.
limber hole - A hole of a few inches diameter cut in a floor plate near the bottom to allow water to drain to lowest point of tank.
liner - A flat or tapered strip placed under a plate or shape to bring it in line with another part that it overlaps; a filler.
lines - The plans of a ship that show its form.
list - Transverse angle of inclination of a vessel.
listing - See "heeling."
load displacement - Weight of vessel in long tons when fully loaded.
load water line - Line of surface of water on a ship when loaded to maximum allowance in salt water in the summertime.
longitudinal - A fore-and-aft structural member running parallel or nearly parallel to the center vertical keel, along the inner bottom, shell, or deck.
longitudinal stability - Tendency of a vessel to return to its original longitudinal position. Longitudinal stability terms: longitudinal metacenter, GM_L, center of buoyancy, center of gravity.

M - Symbol for metacenter.
main deck - See "deck, main."

manhole - A round or oval-shaped hole cut in a ship's divisional plating, large enough for a man to pass through.

manifold - A box casting containing several valves to which pipelines are led to or from various compartments and pumps on a ship, thus allowing any tank to be connected to one or more pumps.

margin - 1: Usually a plate or a shape attached to an outer edge. 2: an allowance for error plus or minus.

margin angle - Angle bar connecting margin plate to shell.

margin bracket - A bracket connecting the frame to the margin plates. Sometimes called "bilge bracket" or "wing bracket."

margin plate - Any one of the outer row of plates of the inner bottom, connecting with the shell plating at the bilge.

mast - A large long spar, placed nearly vertical on the center line of a ship.

mean draft - That draft midway between the draft forward and draft aft.

mess room - Dining room for crew.

metacenter - The highest point to which "G" may rise and still permit the vessel to have positive stability. Found at the intersection of the line of action of "B" when the ship is erect with the line of action of "B" when the ship is given a small inclination.

metacentric height - Distance between "G" and "M". Used as a measure of initial stability.

metacentric radius - Distance between "B" and "M."

midship - Center of ship, located at the midpoint between the forward and after perpendiculars.

midship section - A plan showing a cross section of the ship through the middle, or amidships. This plan shows sizes of frames, beams, brackets, etc., and thicknesses of plating.

mold - 1: A light pattern of a part of a ship, usually made of thin wood or paper. 2: A template.

mold loft - A building with a large smooth floor for laying down the lines of a vessel to actual size to be used for making templates from them for the structural work entering the hull.

moment - Created by a force or weight moved through a distance.

mooring - securing a ship in position by several lines or cables so that she cannot move or swing.

mooring ring - A round or oval casting inserted in the bulwark plating of a ship, through which the mooring lines, or hawsers, are passed.

moment to trim one inch (MTI) - The moment necessary to change the trim of the vessel one inch.

negative stability - Exists when "G" is above "M," that is, when there exists a negative "GM" or "GZ."

net tonnage - A figure obtained by making deduction from the gross tonnage for space not available for carrying cargo or passengers.

neutral equilibrium - exists when "G" coincides with "M." The vessel does not tend to return to an upright position if inclined, nor to continue it's inclination if the inclining force is removed.

oiltight - Riveted, caulked, or welded to prevent oil leakage.

outboard - Away from the center line, toward the side of a ship.

overboard - Outside, over the side of a ship, in the water.

overhang - Portion of the hull over and unsupported by the water.

oxter plate - 1: A bent shell plate that fits around upper part of sternpost. 2: A tuckplate. (Now practically obsolete.)

packing - 1: Material put between plates or shapes to make them watertight. 2: Wooden blocks and wedges supporting ship on sliding ways.

panting - The in-and-out movements of the frames and shell plating due to variation of wave pressure, most noticeable in the bow and stern.

parallel sinkage - Vessel increases her draft so that the drafts forward and aft are increased by the same amount.. Increase of draft without change of trim.

paravane - An object shaped like a small airplane. Two paravanes attached to steel cables are lowered into position on the paravane skeg--one port and one starboard, which trail out at 45-degree angles. When the anchoring cable of a mine strikes the paravane cable, the mine travels to the paravane where it is cut loose.

paravane skeg - A finlike protuberance at the bottom of the stem which allows the paravane crotch to ride at the lowest point of the stem.

peak - The space at the extreme lower bow or stern.

permeability - The percentage of the volume of a compartment which can be occupied by water if flooded.

permeability of surface - The percentage of the surface of a flooded compartment which is occupied by water.

permissible length - Maximum length permitted between main, transverse bulkheads. Found by multiplying factor of subdivision by floodable length.

pillar - 1: Vertical member or column giving support to a deck girder. 2: Stanchion.

pilothouse - Deckhouse containing steering wheel, compass, charts, etc., used for navigation of a ship. It is generally placed forward, near navigating bridge.

pintles - The pins or bolts that hinge the rudder to the gudgeons on the sternpost.

pipe tunnel - A longitudinal or transverse metal box through which pipes are run.

planking - Wood covering for decks, etc.

platen - Skids plated over, on which structural welded parts are assembled.

platform - A flat deck, without camber or sheer.

plating - The plates of a hull, a deck, a bulkhead, etc.

Plimsol mark - A mark scribed and painted on the side of a vessel, designating the depth to which the ship may be loaded.

poop - The after upper portion of the hull, usually containing the steering gear.

port - 1: The left-hand side of a ship looking toward the bow. 2: An opening in the side of a ship for loading cargo, etc.

porthole - A circular opening in the ship's side. See "air port."

profile - Side elevation or fore-and-aft centerline section of a ship's form or structure.

propeller - A revolving device that drives the ship through the water, consisting of three, four or more blades, resembling in shape those of an electric fan. Sometimes called a "screw" or "wheel."

propeller post - Forward post of stern frame, through which propeller shaft passes.

quadrant - A casting, forging, or built-up frame on the rudderhead, to which the steering chains are attached.

quarter deck - That portion of the weather deck nearest the stern.

quarters - living or sleeping rooms.

rabbet - A depression or offset of parallel depth designed to take some other adjoining part, as, for example, the rabbet in the stem to take the shell plating.

racking - Straining of a ship that tends to make the decks and bottom no longer square with the sides.

rail - The rounded section at the upper edge of the bulwarks, or a horizontal pipe forming part of a railing fitted inside of a bulwark.

range of stability - The end of the range of stability is reached at an angle of inclination when the righting arm is equal to zero. Practically, the range of stability is ended shortly after deck edge immersion in most vessels.

reaming - Enlarging a rivet hole by means of a revolving cylindrical, slightly tapered, tool with cutting edges along its sides.

reserve buoyance - The volume of all intact space above the waterline.

ribband - 1: A fore-and-aft wooden strip or heavy batten used to support the transverse frames temporarily after erection and to keep them in a fair line. 2: Any similar batten for fairing a ship's structure.

rigging - Ropes, wire ropes, lashings, etc., used to support masts, spars, booms, etc., and also for handling and placing cargo on board ship.
righting arm - The distance between the line of force through "B" and the line of force through "G," when there is positive stability.
righting moment - The product of the weight of the vessel (displacement) and the righting arm (GZ).
rivet - A short, round metal connection used to fasten two or more members together by clinching after heating red-hot. Certain alloys of aluminum rivets are driven ice-cold.
roller chock - See "chock, roller."
rolling period - The time it takes a vessel to make a complete roll, that is, from port to starboard and back to port again.
rose box - A galvanized iron box with the sides perforated by small holes, the combined areas of which equal at least twice the area of the bilge suction pipe. The purpose is to prevent refuse from clogging the pumps when pumping bilge water.
rough bolt - To bolt a plate or frame temporarily in place until it can be faired for reaming.
rudder - A large heavy fitting hinged to the stern frame used for steering the ship.
rudder lug - A projection cast or fitted to the forward edge of the rudder frame for the purpose of taking the pintle.
rudderpost - 1: After post of stern frame to which rudder is hung. 2: Sternpost.
rudderstock - Shaft of rudder, which extends through counter of ship.
rudder stop - Lug on stern frame or a stanchion at each side of quadrant, to limit the swing of the rudder to approximately 34 degrees port or starboard.

sagging - Straining of the ship that tends to make the middle portion lower than the bow and stern (see "hogging").
Samson post - 1: A heavy vertical post that supports cargo booms. 2: Kingpost.
scantlings - The dimensions of the frames, girders, plating, etc., that go into a ship's structure. For merchant ships these dimensions are taken from the classification society rules.
scarf - A connection made between two pieces by tapering their ends so that they will mortise together in a joint of the same breadth and depth as the pieces connected. It is used on bar keels, stem and stern frames, and other parts.
screen bulkhead - A bulkhead, dusttight but not watertight, usually placed between engine and boiler rooms.

scupper - Drain from weather decks to carry off sea and rain water. Usually called "drain" when it evacuates water from enclosed spaces.

scupper pipe - Pipe that drains free moisture from scuppers through side of a ship, or to the bilges.

scuttle - A small opening, usually circular, generally fitted in decks to provide access, or to serve as a manhole or opening for the stowage of fuel, water, and small stores.

scuttlebutt - 1: A drinking fountain aboard ship. 2: The Navy term for "rumors" aboard ship.

sea chest - A casting fitted to shell of a vessel for the purpose of supplying water from the sea to the condenser and pumps.

seam - Fore-and-aft joint of shell plating, deck and tank-top plating, or lengthwise side joint of any plating.

seam strap - Strap connecting plates to form a flush seam.

serrated member - A rolled section in which the web has been cut alternately long and short. The longer web pieces are welded to the plating leaving the shorter section clear of the plating for drainage. By the serrated cutting of a 12 inch I beam, two 7 inch tees are produced.

settlers - Tanks used for "settling" fuel oil before using.

shaft - Long, round, heavy forging connecting engine and propeller, or other rotating machinery to its parts.

shaft alley (shaft tunnel) - A watertight casing covering propeller shaft, large enough to walk in, extending from engine room to afterpeak bulkhead, to provide access and protection to shaft in way of after cargo holds.

shape - Bar of constant cross section throughout its entire length, such as a channel, T-bar, or angle bar.

shear - A stress that tends to cause the adjacent parts of a body to slide over each other.

shear line - Line to shear or cut to.

shears - Large machine for cutting plates and shapes.

sheave - A grooved roller revolving on a pin. When encased complete with a shackle, it is called a "block."

sheer - Fore-and-aft curvature of a deck.

sheer plan - Side elevation of a ship's form; a profile.

sheer strake - Top full course of shell plates at strength deck level.

shell expansion - A plan showing details of all plates of the shell.

shell landings - Points on the frames showing where the edges of shell plates come.

shell plating - The plates forming the outer skin of the hull.

shelter deck - See "deck, shelter."

shore - A brace or prop.

skeg - A deep finlike projection on the bottom of a vessel usually toward the stern, installed (a) to support the lower edge of the rudder, and (b) to prevent erratic steering in seaway.
skids - A skeleton framework used to hold assemblies off ground to permit riveting or welding (see "platen").
skylight - An opening in a deck to give light and air to the compartment below, usually fitted with hinged covers having fixed lights.
slack tank - Tank which is not completely filled or empty.
sliding ways - See "launching."
slop chute - Chute for dumping garbage overboard.
smokestack - A metal chimney or passage through which the smoke and gases are led from the boiler uptakes to the open air.
sounding pipe - Pipe in oil or water tank used to measure depth of liquid in tank.
spar - A long, round, wooden timber used to carry rigging.
split frame - A channel or "Z" bar frame split at the bilge so that one flange may connect to the shell plating and the other to the tank top.
sponsons - Bulges on the upper sides of canoes and other small boats which add breadth when the boat inclines.
stable equilibrium - Exists when "M" is above "G." A vessel will tend to return to an erect position if inclined to a small angle.
stability - Tendency of a ship to return to her original position when inclined away from that position by an exterior force.
stability tables - Tables which show the proper and improper distribution of weights and their effect on the "GM" and rolling period of a vessel.
stabilogauge - A device which automatically calculates "GM" when actuators indicating weights loaded or discharged are turned.
stanchion - A pillar or upright post; a vertical rail post.
staple angle - A piece of angle bent in the shape of a staple or other irregular shape.
stapling - Collars, forged of angle bars, to fit around continuous members passing through bulkheads for water-tightness (now obsolete).
starboard - Right side of a ship looking forward.
statical stability curves - Curves for various displacements up to and past load displacement. The ordinates are angles of inclination. Intersection of ordinates with curves produces the abscissas (righting arms).
stay - A guy line.
stealer - A plate extending into an adjoining strake in the case of a drop strake. Stealer plates are located in the bow and stern, where the narrowing girth compels a reduction in the number of strakes.

steering gear - Apparatus for controlling the rudder.
steering wheel - Wooden or metal wheel having its spokes extended through the rim for handholds and used to control rudder by rope leads, or otherwise, through steering engine.
stem - Forging, casting, or rounded plate forming extreme bow of ship, extending from keel to forecastle deck.
step - To set in place, as applied to a mast.
stern - After end of a ship.
stern frame - Large casting or forging attached to after end of keel to form ship's stern. Includes rudderpost, propeller post, and aperture for propeller.
sternpost - 1: After part of a stern frame to which rudder is attached. 2: Rudderpost.
stern tube - Tube through stern through which propeller shaft passes.
stiffener - An angle bar, T-bar, channel, built-up section, etc., used to stiffen plating of a bulkhead, etc.
stiff ship - Vessel with low center of gravity and large metacentric height.
stopwater - Canvas soaked in red lead or other material, fitted between two metal parts to make a watertight joint.
storm valve - A check valve in a pipe opening above water line on a ship.
stow - To put away.
stowage - Equipment for support and fastening of articles to be stowed, as anchor or boat stowage.
strain - Alteration in shape or dimensions resulting from stress.
strake - A course, or row, of shell or other plating.
stress - Force per unit area.
stringer - A fore-and-aft member used to give longitudinal strength to shell plating. According to location, stringers are called "hold stringers," "bilge stringers," "side stringers," etc.
stringer plate - 1: Deck plate outboard edge of deck, connected to the shell of a ship by welding or with an angle. 2: Web of built-up side stringers.
strongback - 1: Portable supporting girders for hatch covers. 2: A rig used in straightening bent plates. 3: A bar for locking cargo ports. 4: A central girder to support covers of wood, metal, or canvas.
strum box - The enlarged terminal on the suction end of a pipe and forming a strainer that prevents the entrance of material likely to choke the pipe. See "rose box."
strut - Outboard support for propeller tail shaft, used on ships with more than one propeller.
superstructure - A structure extending across the ship, built immediately above the uppermost complete deck.
swash bulkhead - Longitudinal bulkhead, with or without lightening holes, installed for the purpose of reducing free surface effects.

swash plate - Baffle plate in tank to prevent excessive movement of the contained liquid.
sweat batten - A plank attached to the inboard surface of the frames to prevent cargo touching the shell which may be damp due to the difference in temperature of the water outside and the air in the hold.
synchronous rolling - Occurs when the rolling period of the vessel is the same as the wave period; a condition to be avoided.

table of stability - See "stability tables."
tail shaft - Short section of propeller shaft extending through stern tube and carrying propeller.
tangency bracket - A bracket whose inner face is curved rather than straight to distribute the stress over the face of the bracket rather than concentrate it in the corners.
tank - Compartment for liquid or gas, either built into ship's structure or independent of it and supported by an auxiliary foundation.
tank top - The inner-bottom plating.
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 and size of laps is indicated. Common types are made of paper or thin boards.
tender ship - See "crank ship."
tension - Stress caused by pulling.
thrust - Push or driving force.
thrust bearing - Bearing on propeller line shaft, which relieves the engine from the driving force of the propeller and transfers this force to the structure of the ship.
tie plank - 1: The fastening which keeps the ship from sliding down the ways. 2: Solepiece.
tie plate - A single fore-and-aft course of plating attached to deck beams under a wood deck to give extra strength.
tiller - Arm attached to rudderhead for operating the rudder.
tipping center - See "center of flotation."
tons per inch (TPI) - Number of tons necessary to change to mean draft of a vessel one inch; varies with draft.
transom - The aftermost transverse frame.
transverse - Athwartship; at right angles to the keel.
transverse frames - Athwartship members forming the ship's "ribs."
transverse metacenter - See "metacenter."
trim - To shift ballast to make a ship change its position in the water (noun). The trim is the excess of draft forward or aft.
trim calculator - A device which calculates quickly the trim of a vessel after loading or discharging.

trimming tables - Tables which calculate change of mean draft and change of trim after loading, discharging, or shifting of weights.
trimming tanks - The forward and after peak tanks.
tripping bracket - A small piece of steel placed beside a plate or shape to prevent its collapsing or folding over. A more correct name would be "antitripping."
trunk - Steel casing passing through deck and forming an enclosure for ladders or cargo hatches.
tumble home - Slant inboard of a ship's side above the bilge.
'tween decks - 1: The space between any two continuous decks. 2: "Between decks."

unstable equilibrium - Exists when "G" is above "M." Vessel does not tend to return to an erect position after being inclined but, for small angles, tends to continue inclination.
uptake - A metal casing connecting the boiler smokebox with the base of the smokestack. It conveys the smoke and hot gases from the boiler to the stack.

vertical center of gravity (VCG) - The vertical height of the center of gravity of a compartment above its bottom, or of the center of gravity of a vessel above its keel.
vertical keel - Row of vertical plates extending along center of flat plate keel. Sometimes called "center keelson."
virtual rise of G - Caused by the "swinging" motion of water in a slack tank.
voice tube - Large speaking tube.

warping bridge - 1: Bridge at after end of hull, used while docking a ship. 2: Docking bridge.
water line - The line of the water's edge when the ship is afloat; technically, the intersection of any horizontal plane with the molded form of the ship.
waterplane - The plane defined by the intersection of the water in which a vessel is floating with the vessel sides.
waterplane coefficient - A coefficient of fineness which expresses the relationship between the area of the waterplane and a rectangle having the length and breadth of the vessel at that waterplane.
watertight - So constructed as to prevent the passage of water.
watertight flat - Short section of watertight deck, forming a step in a bulkhead or the top of a watertight compartment or water tank.
waterway - 1: A narrow passage along the edge of the deck for the drainage of the deck. 2: A gutter.
ways - Structure on which a ship is built and launched.

weather deck - See "deck, weather."
web - The vertical portion of a beam, the athwartship portion of a frame, etc.
web frame - A built-up member consisting of a web plate, to the edges of which are attached single or double bars if riveted, or a face plate, if welded.
welding - Making a joint of two metal parts by fusing the metal in between them or by forging together at welding heat.
well - Space in bottom of a ship to which bilge water runs so that it may be pumped out.
wheel - 1: Nickname for propeller. 2: Steering-gear control.
winch - A small hoisting engine, usually used in connection with the cargo gear.
windlass - The machine used to hoist the anchors.
wind sail - A tabular canvas ventilator open at the bottom and with a slot at the top. At each side of the slot are two large canvas flaps which direct the wind into the slot and down into the space to be ventilated.
wind scoop - A device used to divert air into a compartment of a ship through an air port.
wing ballast tank - Tank, usually located in the upper 'tween deck on either side of the engine room casing, which is especially valuable in raising the center of gravity of a light ship. These tanks also serve to dampen the period of roll of a vessel. Any weights "winged out" increase the "mass moment of inertia" of a vessel, thus dampening rolling.

APPENDIX B
EXERCISES

Work the following problems in displacement tonnages:

1. A vessel's light displacement is 6,000 tons. The vessel's deadweight tonnage is 5,000 tons. What is her loaded displacement?

2. A vessel's light displacement is 900 tons. She is loaded with 50 tons of bulk cement, 100 tons of bulk mud, 100 tons of fuel oil, and 10 tons of pipe. What is her displacement?

3. A vessel can carry 600 tons of cargo, fuel, and stores when she is loaded to capacity. What is her deadweight tonnage?

4. A Japanese vessel with a loaded displacement of 10,000 tons is loaded to her capacity. She then proceeds to New York where she offloads 6,000 tons of cargo. What is her displacement?

5. The M/V Jesse Mechem has a light displacement of 980 tons. She has a loaded displacement of 11,000 tons. What is her deadweight tonnage?

6. A vessel has a displacement of 6,780 tons. Her light displacement is 5,364 tons. How much cargo, fuel, and stores is she carrying?

7. The deadweight tonnage of the S/S Orient Express is 11,250 tons. How many tons of fuel, cargo, and stores can she carry when fully loaded? Her light displacement is 22,000 tons.

8. The light displacement of the M/V Miss Maggie is 1,000 tons. Her loaded displacement is 1,800 tons. What is her deadweight tonnage?

9. The M/V John Clark has a displacement of 100 tons. Her light displacement is 75 tons. a) How many tons of cargo, fuel, and stores is she carrying? b) The John Clark's deadweight tonnage is 38 tons. Referring to (a) above, answer the following question: The rig pusher would like to load a 15-ton cement tank on her stern. Should the captain okay this?

10. The Itco has a loaded displacement of 150 tons. The light displacement of the vessel is 98 tons. She is carrying a cargo of 40 tons. How much more cargo can she load?

EXERCISES IN REGISTERED TONNAGE

1. The gross tonnage of the M/V Bo Truc 19 is 198 tons. Her net tonnage is 123 tons. How much space on the Bo Truc 19 cannot be used to carry passengers or cargo?

2. The internal volume of the M/V Magcobar Mercury is 19,800 cubic feet. What is the gross tonnage?

3. The M/V Ida Cadies has a gross tonnage of 199 tons. Her total internal volume which cannot be utilized for the carriage of freight or passengers is 5,900 cubic feet. What is her net tonnage?

4. The S/S Nubiko Maru has a volume of 155,000 cubic feet, which may be used for the carriage of cargo and passengers. What is her net tonnage?

5. The net tonnage of a vessel is 530 tons. Her gross tonnage is 870. How many cubic feet of her internal volume is not used for the carriage of freight or passengers?

EXERCISES IN CALCULATING GM

To become proficient in using tables such as Table 9.1, work the following problems. The first two are done for you.

	Draft (mean ft)	Required GM (ft)
1.	9.1	2.2
2.	10.0	2.4
3.	8.5	
4.	11.0	
5.	12.0	
6.	11.5	
7.	9.8	
8.	10.6	
9.	12.9	
10.	10.5	

The GM's which you found above were the required GM in each case for the vessel in question, for reasons of safety. If the vessel had already been loaded, the skipper might have found later, by consulting the curves, that GM was either greater or smaller than that required. However, keep in mind that GM should be at least equal to the required GM for reasons of safety. Any GM of a greater value than that required by the curves in Table 9.1 would have been all right. However, remember, too large a GM makes the ship "stiff." She will ride uncomfortably and stress the upper parts of the vessel due to her sharp roll.

EXERCISES IN FINDING KM AND KG

For each of the problems below, find KM, height of the transverse metacenter, using the curves in Table 9.1.

	Draft (ft)	KM
1.	8.0	
2.	7.9	
3.	6.3	
4.	8.9	
5.	10.0	
6.	11.0	

For each of the problems below you are given draft and KG, the height of the center of gravity above the keel. Using the formula KM - KG = GM, find GM.

	Draft (ft)	KG (ft)	GM
1.	6.0	26.0	
2.	6.5	24.83	
3.	8.0	22.0	
4.	7.0	21.0	
5.	5.5	24.8	

Exercises using the theory of moments: weight x VCG = moments in foot-tons.

1. A certain vessel has a light displacement of 608 tons. Her light KG is 12 feet. Some 34 tons of fuel oil are loaded 8.2 feet above the keel, and 100 tons of ballast are loaded 3.5 feet above the keel.

   a) Do you expect the center of gravity to shift up or down?
   b) What is the new VCG (KG) of the vessel?
   c) What has been the change in the position of the center of gravity?

2. A vessel has a light displacement of 1000 tons and a light ship VCG of 22 feet; 200 tons of cargo are loaded 30 feet above the keel; 100 tons of cargo are loaded 25 feet above the keel.

   a) Do you expect the center of gravity to move up or down?
   b) What is the new VCG (KG) for the vessel?
   c) What has been the shift in the position of the VCG?

3. A vessel has a light displacement of 500 tons and in the light condition her VCG is 14 feet. 100 tons of bananas are loaded 15 feet above the keel; 100 tons of monkeys in cages are loaded 13 feet above the keel.

   a) Do you expect the center of gravity of the vessel to move up or down?
   b) What is the new VCG (KG)?
   c) What has been the shift in the position of the VCG?

4. A vessel has a light displacement of 500 tons and her VCG in the light condition is 14.0 feet; 100 tons of bananas are loaded 15 feet above the keel; 200 tons of gorillas are loaded 13 feet above the keel.

a) Do you expect the center of gravity to shift up or down?
b) What will be the new VCG (KG)?
c) What has been the shift in the center of gravity?

5. A vessel floating at her light condition displaces (weighs) 5,000 tons. The center of gravity is located 20 feet above the keel; 300 tons are loaded 10 feet above the keel; 700 tons are loaded 5 feet above the original center of gravity.

   a) What will be the new VCG (KG)?

6. The boat in problem 5 now has the following weights removed from the locations listed: 200 tons from a position 10 feet above the keel and 400 tons from a position 2 feet above the keel.

   a) What will be the new VCG (KG)?

7. A certain boat has a displacement of 7,000 tons and a VCG of 30 feet. The following weights are discharged (offloaded): 1,000 tons from a position 20 feet above the keel; 500 tons from a position 2 feet above the keel.

   a) What is her new VCG?
   b) If KM is 36.4, then what is GM?
   c) Is the boat in stable equilibrium or unstable equilibrium? Why?

EXERCISES IN CALCULATING THE SHIFT IN THE CENTER OF GRAVITY

Work the example problems below and check your answers with those at the end of the exercise.

1. A boat with a displacement of 608 tons and a KG of 15 feet has 38 tons shifted downward a distance of 5 feet. What will be the shift in the VCG and what will be the position of the new center of gravity?

2. A boat with a displacement of 10,000 tons and a KG of 30 feet has 200 tons of cargo shifted vertically upwards a distance of 10 feet. What will be the shift in the center of gravity and what will be the position of the new center of gravity of the vessel?

3. Some 300 tons of cargo are shifted vertically upward a distance of 5 feet. The vessel has a displacement of 6000 tons and a KG of 20. What will be the position of the new VCG?

4. On a ship with a displacement of 500 tons and a KG of 20, 50 tons of wheat are shifted from their position 5 feet above the keel to a position 15 feet above the keel. What will be the shift in the center of gravity and what will be the new KG for the ship?

5. A vessel has a displacement of 12,000 tons and a KG of 23. Some 600 tons of raw hides are shifted from a position 28 feet above the keel to a position 23 feet above the keel. What will be the shift in the center of gravity and what is the new KG?

6. On a vessel with a displacement of 1,000 tons and a KG of 15 feet, 60 tons of cargo with a VCG of 10 are shifted vertically downward a distance of 6 feet. What will be the shift in the center of gravity and what will be the vessels new KG?

Answers: (1) .31 ft, 14.69 ft (2) .2 ft, 30.2 ft (3) .25 ft, 20.25 ft (4) 1 ft, 21 ft (5) .25 ft, 22.75 ft (6) .36 ft, 14.64 ft

Work the following problems to find the KG for the 184-foot supply vessel. Information concerning tank capacities and VCGs may be found in Table 9.2. Light ship displacement and KG taken from the stability curves for the 184-foot vessel in Table 9.1 are 608 tons and 11.9 ft respectively.

1. Our 184-ft supply vessel is now loaded in the following manner: Nos. 8 and 9 fuel oil tanks port and starboard are loaded. No. 3 port and starboard ballast tanks are half filled. No. 4 ballast tank is completely filled on both the port and starboard sides. No. 6 port ballast tank is completely filled. What is the new KG for the vessel?

2. The supply boat (problem 1) is now loaded in the following manner: No. 7 port and starboard fuel oil tanks are filled. No. 10 potable water tanks port and starborad are filled half full. What is the new KG for the vessel?

3. The supply boat during her next stay at the dock is loaded in the following manner: No. 1 forepeak ballast tank is filled. No. 14 port fuel oil tank is filled. What is the new KG for the vessel?

4. The supply boat is loaded during her next voyage in the following way: No. 11 port and starboard lube oil tanks are filled. No. 4 ballast tank port is loaded half full. What is the new KG for the vessel?

Using Curves to Find Draft and KM

Use the curves in Table 9.1 to find draft of the vessel for the given displacements.

Displacements (tons)	Draft
620	
650	
720	
920	
1,140	

Use the curves in Table 9.1 to find KM for the drafts found in each of the problems above.

Draft (ft)	KM
5.9	
6.1	
6.6	
9.0	
9.5	

For the following mean drafts find the position of the longitudinal center of flotation forward or aft of the amidships.

Mean Draft (ft)	
7.0	.3 ft forward of amidships
5.5	1.75 ft forward of amidships
8.0	.8 ft aft of amidships
10.1	6.2 ft aft of amidships

For the following problems determine how far forward or aft of the tipping center the weights have been loaded.

1. Mean draft is 7 feet. No. 2 ballast tanks are filled.

Longitudinal center of gravity No. 2	+63.3 ft
Tipping center from amidships	+ .3 ft
Distance from tipping center	63.0 ft

Note: Plus signs are used to designate distances forward of amidships. Minus signs are used to designate distances aft of amidships.

2. Mean draft is 5.5 feet. No. 8 fuel oil tanks are discharged.

Longitudinal center of gravity No. 8	-1.5 ft
Tipping center from amidships	+1.7 ft
Distance from tipping center	3.2 ft

3. Mean draft is 10.1 feet. No. 4 ballast tanks are filled.

Longitudinal center of gravity No. 4	+27.5 ft
Tipping center from amidships	- 6.2 ft
Distance from tipping center	33.7 ft

Example: Our 184-foot supply vessel has a forward draft of 10 feet and an after draft of 8 feet; 150 tons of ballast are taken in ballast tanks No. 6 P & S. Find the change of trim and the new drafts.

Solution: 1) Mean draft is 9 feet. Find TPI from the curves of form. TPI is 12.6 tons per inch.

2) Determine how much mean draft will change if 150 tons are loaded at the tipping center. Weight = change of mean draft = $\frac{150}{12.6}$ = 11.9 inches.

3) Determine the new mean draft. 9' + 11.9" = 9-11.9.

4) Using the new mean draft, find MT1. MT1 = 133.5 ft tons (from the curves of form).

5) In order to find the total trimming moments you must find the weight and the distance it has been loaded from the tipping center.

You already know the weight--150 tons. Find the position of the tipping center at the mean draft of 9-11.9 and also find the position of the longitudinal center of gravity of No. 6 ballast tanks.

Longitudinal center of gravity No. 6	-9.5 ft
Tipping center from amidships	-5.2 ft
Distance from tipping center	4.3 ft

6) Find trimming moment. w x d 150 x 4.3 = 645 ft tons

7) Find change of trim. $\frac{\text{Trimming Moment}}{\text{MT1}} = \frac{645}{133.5} =$ 4.8 inches

8) Find new drafts:

	Fwd	Mean	Aft
Initial drafts	10-00	9-00	8-00
Change of mean draft	11.9	11.9	11.9
	10-11.9	9-11.9	8-11.9
Change of trim	2.3		2.4
Final drafts	10-09.5	9-11.9	9-02.3

Example: The supply vessel is floating at a forward draft of 9 feet and an after draft of 11 feet. No. 1 forepeak ballast tank is filled with sea water and No. 17 afterpeak ballast tank which was full is pumped overboard. Find the change in trim and the new drafts.

Solution: 1) Mean draft is 10 feet. Find TPI at this draft from the curves of form. TPI is 12.2 tons per inch.

2) Determine how much mean draft will change for 17.8 tons (No. 1 F.P.) loaded at the tipping center and 37.3 tons (No. 17 A.P.) offloaded at the tipping center.

37.3
17.8
19.5 tons aggregate offloaded

$\frac{19.5}{12.2}$ = 1.6 inches change in mean draft

3) Determine the new mean draft. Since you took off an aggregate total of 19.5 tons by pumping No. 17 overboard the vessels, draft will decrease.

Initial mean draft	10.0 ft
Change of mean draft	1.6 inches
New mean draft	9 ft 0.4 inches

4) Using the new mean draft, find MT1. From the curves of form, MT1 = 131 ft tons.

5) In order to find the total trimming moments you must find the weight and the distance it has been loaded or discharged from the tipping center. You know that 17.8 tons have been loaded in No. 1 and that 37.3 tons have been discharged from No. 17. Find the position of the tipping center at the mean draft of 9 ft 10.4 inches and also find the position of the longitudinal center of gravity for No. 1 forepeak and No. 17 afterpeak tanks.

Longitudinal center of gravity No. 1	+76.5 ft
Tipping center from amidships	- 4.8 ft
Distance from tipping center	81.3 ft

Longitudinal center of gravity No. 17	-85.9 ft
Tipping center of amidships	- 4.8 ft
Distance from tipping center	81.1 ft

6) Find the total trimming moment.

17.8 tons x 81.3 ft =	1,447.1 ft tons (forward
37.3 tons x 81.1 ft =	3,025.0 ft tons (forward)
Net trim moment	4,472.1 ft tons (forward)

Note: Since weight was discharged at the stern it could be considered that the weight was loaded forward or that the trimming moment acted to depress the bow of the vessel as shown in the calculations above.

7) Find the change of trim.

$$\frac{\text{Trimming Moment}}{\text{MT1}} = \frac{4,472.1}{131} = 34.1 \text{ inches}$$

8) Find the new drafts.

	Fwd	Mean	Aft
Initial drafts	9-00	10-00	11-00
Change of mean draft	01.6	01.6	01.6
	8-10.4	9-10.4	10-10.4
Change of trim	17.0		17.0
Final drafts	10-03.4	9-10.4	9-05.4