# Ship Construction Handbook

Lyle Gore

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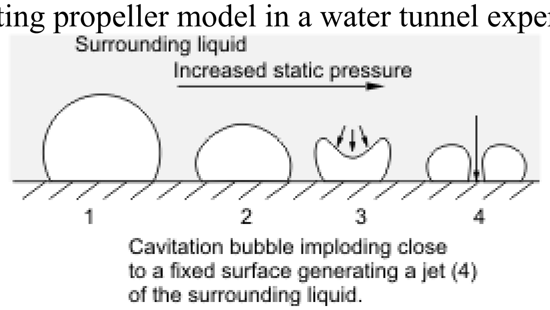
# Cavitation

Cavitating propeller model in a water tunnel experiment.




High speed jet of fluid impact on a fixed surface.

Cavitation damage on a valve plate for an axial piston hydraulic pump.

**Cavitation** is the formation of gas bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapor pressure. Cavitation occurs when a liquid is subjected to rapid changes of pressure causing the formation of gas or vapor bubbles in the lower pressure regions of the liquid. When entering high pressure areas these bubbles collapse on a metal surface continuously, they cause cyclic stressing of the metal surface. This results in surface fatigue of the metal causing a type of wear called cavitation. The most common examples of this kind of wear are pump impellers and bends when a sudden change in the direction of liquid occurs. Cavitation is usually divided into two classes of behavior: inertial (or transient) cavitation, and non inertial cavitation.

Inertial cavitation is the process where a void or bubble in a liquid rapidly collapses, producing a shock wave. Inertial cavitation occurs in nature in the strikes of mantis shrimps and pistol shrimps, as well as in the vascular tissues of plants. In artifacts, it can occur in control valves, pumps, propellers and impellers.

Non inertial cavitation is the process in which a bubble in a fluid is forced to oscillate in size or shape due to some form of energy input, such as an acoustic field. Such cavitation is often employed in ultrasonic cleaning baths and can also be observed in pumps, propellers, etc.

Since the shock waves formed by cavitation are strong enough to significantly damage moving parts, cavitation is usually an undesirable phenomenon. It is specifically avoided in the design of machines such as turbines or propellers, and eliminating cavitation is a major field in the study of fluid dynamics.

## *Inertial cavitation*

Inertial cavitation was first studied by Lord Rayleigh in the late 19th century, when he considered the collapse of a spherical void within a liquid. When a volume of liquid is subjected to a sufficiently low pressure, it may rupture and form a cavity. This phenomenon is termed *cavitation inception* and may occur behind the blade of a rapidly rotating propeller or on any surface vibrating in the liquid with sufficient amplitude and acceleration. A fast-flowing river can cause cavitation on rock surfaces, particularly when there is a drop-off, such as on a waterfall.

Other ways of generating cavitation voids involve the local deposition of energy, such as an intense focused laser pulse (optic cavitation) or with an electrical discharge through a spark. Vapor gases evaporate into the cavity from the surrounding medium; thus, the cavity is not a perfect vacuum, but has a relatively low gas pressure. Such a low-pressure cavitation bubble in a liquid begins to collapse due to the higher pressure of the surrounding medium. As the bubble collapses, the pressure and temperature of the vapor within increases. The bubble eventually collapses to a minute fraction of its original size, at which point the gas within dissipates into the surrounding liquid via a rather violent mechanism, which releases a significant amount of energy in the form of an acoustic shock wave and as visible light. At the point of total collapse, the temperature of the vapor within the bubble may be several thousand kelvin, and the pressure several hundred atmospheres.

Inertial cavitation can also occur in the presence of an acoustic field. Microscopic gas bubbles that are generally present in a liquid will be forced to oscillate due to an applied acoustic field. If the acoustic intensity is sufficiently high, the bubbles will first grow in size and then rapidly collapse. Hence, inertial cavitation can occur even if the rarefaction in the liquid is insufficient for a Rayleigh like void to occur. High-power ultrasonics usually utilize the inertial cavitation of microscopic vacuum bubbles for treatment of surfaces, liquids, and slurries.

The physical process of cavitation inception is similar to boiling. The major difference between the two is the thermodynamic paths that precede the formation of the vapor. Boiling occurs when the local vapor pressure of the liquid rises above its local ambient pressure and sufficient energy is present to cause the phase change to a gas. Cavitation inception occurs when the local pressure falls sufficiently far below the saturated vapor pressure, a value given by the tensile strength of the liquid.

In order for cavitation inception to occur, the cavitation "bubbles" generally need a surface on which they can nucleate. This surface can be provided by the sides of a container, by impurities in the liquid, or by small undissolved microbubbles within the liquid. It is generally accepted that hydrophobic surfaces stabilize small bubbles. These pre-existing bubbles start to grow unbounded when they are exposed to a pressure below the threshold pressure, termed Blake's threshold.

The vapor pressure here differs from the meteorological definition of vapor pressure, which describes the partial pressure of water in the atmosphere at some value less than 100% saturation. Vapor pressure as relating to cavitation refers to the vapor pressure in equilibrium conditions and can therefore be more accurately defined as the equilibrium (or saturated) vapor pressure.

### *Noninertial cavitation*

Noninertial cavitation is the process in which small bubbles in a liquid are forced to oscillate in the presence of an acoustic field, when the intensity of the acoustic field is insufficient to cause total bubble collapse. This form of cavitation causes significantly less erosion than inertial cavitation, and is often used for the cleaning of delicate materials, such as silicon wafers.

### *Cavitation damage*

Cavitation damage to a Francis turbine.

Cavitation is, in many cases, an undesirable occurrence. In devices such as propellers and pumps, cavitation causes a great deal of noise, damage to components, vibrations, and a loss of efficiency.

When the cavitation bubbles collapse, they force energetic liquid into very small volumes, thereby creating spots of high temperature and emitting shock waves, the latter of which are a source of noise. The noise created by cavitation is a particular problem for military submarines, as it increases the chances of being detected by passive sonar.

Although the collapse of a cavity is a relatively low-energy event, highly localized collapses can erode metals, such as steel, over time. The pitting caused by the collapse of cavities produces great wear on components and can dramatically shorten a propeller or pump's lifetime.

After a surface is initially affected by cavitation, it tends to erode at an accelerating pace. The cavitation pits increase the turbulence of the fluid flow and create crevasses that act as nucleation sites for additional cavitation bubbles. The pits also increase the components' surface area and leave behind residual stresses. This makes the surface more prone to stress corrosion.

## *Hydrodynamic cavitation*

Hydrodynamic cavitation describes the process of vaporisation, bubble generation and bubble implosion which occurs in a flowing liquid as a result of a decrease and subsequent increase in pressure. Cavitation will only occur if the pressure declines to some point below the saturated vapor pressure of the liquid. In pipe systems, cavitation typically occurs either as the result of an increase in the kinetic energy (through an area constriction) or an increase in the pipe elevation.

Hydrodynamic cavitation can be produced by passing a liquid through a constricted channel at a specific velocity or by mechanical rotation through a liquid. In the case of the constricted channel and based on the specific (or unique) geometry of the system, the combination of pressure and kinetic energy can be created when the hydrodynamic cavitation cavern downstream of the local constriction generating high energy cavitation bubbles.

The process of bubble generation, subsequent growth and collapse of the cavitation bubbles results in very high energy densities, resulting in very high temperatures and pressures at the surface of the bubbles for a very short time. The overall liquid medium environment, therefore, remains at ambient conditions. When uncontrolled, cavitation is damaging; however, by controlling the flow of the cavitation the power is harnessed and non-destructive. Controlled cavitation can be used to enhance chemical reactions or propagate certain unexpected reactions because free radicals are generated in the process due to disassociation of vapors trapped in the cavitating bubbles.

Orifices and venturi are reported to be widely used for generating cavitation. A venturi, because of its smooth converging and diverging sections, has an inherent advantage, over the orifice, that it can generate a higher velocity at the throat for a given pressure drop across it. On the other hand, an orifice has an advantage that it can accommodate more number of holes (larger perimeter of holes) in a given cross sectional area of the pipe.

Hydrodynamic cavitation can improve industrial processes. For instance, cavitated corn slurry show higher yields in ethanol production compared to uncavitated corn slurry in dry milling facilities.

This is also used in the mineralization of bio-refractory compounds which otherwise would need extremely high temperature and pressure conditions since free radicals are generated in the process due to the dissociation of vapours trapped in the cavitating bubbles, which results in either the intensification of the chemical reaction or may even result in the propagation of certain reactions not possible under otherwise ambient conditions.

### *Chemical engineering applications*

In industry, cavitation is often used to homogenize, or mix and break down, suspended particles in a colloidal liquid compound such as paint mixtures or milk. Many industrial mixing machines are based upon this design principle. It is usually achieved through impeller design or by forcing the mixture through an annular opening that has a narrow entrance orifice with a much larger exit orifice. In the latter case, the drastic decrease in pressure as the liquid accelerates into a larger volume induces cavitation. This method can be controlled with hydraulic devices that control inlet orifice size, allowing for dynamic adjustment during the process, or modification for different substances. The surface of this type of mixing valve, against which surface the cavitation bubbles are driven causing their implosion, undergoes tremendous mechanical and thermal localized stress; they are therefore often constructed of super-hard or tough materials such as stainless steel, Stellite, or even polycrystalline diamond (PCD).

Cavitating water purification devices have also been designed, in which the extreme conditions of cavitation can break down pollutants and organic molecules. Spectral analysis of light emitted in sonochemical reactions reveal chemical and plasma-based mechanisms of energy transfer. The light emitted from cavitation bubbles is termed sonoluminesence.

Hydrophobic chemicals are attracted underwater by cavitation as the pressure difference between the bubbles and the liquid water forces them to join together. This effect may assist in protein folding.

### *Biomedical application*

Cavitation plays an important role for the destruction of kidney stones in shock wave lithotripsy. Currently, tests are being conducted as to whether cavitation can be used to transfer large molecules into biological cells (sonoporation). Nitrogen cavitation is a method used in research to lyse cell membranes while leaving organelles intact. Cavitation plays a key role in non-thermal noninvasive fractionation of tissue for treatment of a variety of diseases. Cavitation also probably plays a role in HIFU, a thermal noninvasive treatment methodology for cancer.

Ultrasound is sometimes used to increase bone formation, for instance post-surgical applications. Ultrasound treatments and/or exposure can create cavitation that can potentially "result in a syndrome involving manifestations of nausea, headache, tinnitus, pain, dizziness, and fatigue.".

### *Cleaning application*

In industrial cleaning applications, cavitation has sufficient power to overcome the particle-to-substrate adhesion forces, loosening contaminants. The threshold pressure required to initiate cavitation is a strong function of the pulse width and the power input. This method works by generating controlled acoustic cavitation in the cleaning fluid, picking up and carrying contaminant particles away so that they do not reattach to the material being cleaned.

### *Pumps and propellers*

Major places where cavitation occurs are in pumps, on propellers, or at restrictions in a flowing liquid.

As an impeller's (in a pump) or propeller's (as in the case of a ship or submarine) blades move through a fluid, low-pressure areas are formed as the fluid accelerates around and moves past the blades. The faster the blades move, the lower the pressure around it can become. As it reaches vapor pressure, the fluid vaporizes and forms small bubbles of gas. This is cavitation. When the bubbles collapse later, they typically cause very strong local shock waves in the fluid, which may be audible and may even damage the blades.

Cavitation in pumps may occur in two different forms:

#### Suction cavitation

Suction cavitation occurs when the pump suction is under a low-pressure/high-vacuum condition where the liquid turns into a vapor at the eye of the pump impeller. This vapor is carried over to the discharge side of the pump, where it no longer sees vacuum and is compressed back into a liquid by the discharge pressure. This imploding action occurs violently and attacks the face of the impeller. An impeller that has been operating under a suction cavitation condition can have large chunks of material removed from its face or very small bits of material removed, causing the impeller to look spongelike. Both cases will cause premature failure of the pump, often due to bearing failure. Suction cavitation is often identified by a sound like gravel or marbles in the pump casing.

In automotive applications, a clogged filter in a hydraulic system (power steering, power brakes) can cause suction cavitation making a noise that rises and falls in synch with engine RPM. It is fairly often a high pitched whine, like set of nylon gears not quite meshing correctly.

### Discharge cavitation

Discharge cavitation occurs when the pump discharge pressure is extremely high, normally occurring in a pump that is running at less than 10% of its best efficiency point. The high discharge pressure causes the majority of the fluid to circulate inside the pump instead of being allowed to flow out the discharge. As the liquid flows around the impeller, it must pass through the small clearance between the impeller and the pump housing at extremely high velocity. This velocity causes a vacuum to develop at the housing wall (similar to what occurs in a venturi), which turns the liquid into a vapor. A pump that has been operating under these conditions shows premature wear of the impeller vane tips and the pump housing. In addition, due to the high pressure conditions, premature failure of the pump's mechanical seal and bearings can be expected. Under extreme conditions, this can break the impeller shaft.

Discharge cavitation in joint fluid is thought to cause the popping sound produced by bone joint cracking, for example by deliberately cracking one's knuckles.

## *Control valves*

Cavitation can occur in control valves. If the upstream pressure is just above the vapor pressure, then it is possible that the pressure will drop below the vapor pressure as the fluid flows through the valve. If the pressure recovers after the valve to a pressure that is once again above the vapor pressure, then cavitation will occur.

## *Cavitation on spillways*

When water flows over a dam spillway, the irregularities on the spillway surface will cause small areas of flow separation in a high speed flow, and, in these regions, the pressure will be lowered. If the velocities are high enough the pressure may fall to below the local vapor pressure of the water and vapor bubbles will form. When these are carried downstream into high pressure region the bubble collapses giving rise to high pressures and possible cavitation damage.

Experimental investigations show that the damage on concrete chute and tunnel spillways can start at clear water velocities of between 12 to 15 m/s, and, up to velocities of 20 m/s, it may be possible to protect the surface by streamlining the boundaries, improving the surface finishes or using resistant materials.

When some air is present in the water the resulting mixture is compressible and this damps the high pressure caused by the bubble collapses. If the velocities near the spillway invert are sufficiently high, aerators (or aeration devices) must be introduced to prevent cavitation. Although these have been installed for some years, the mechanisms of air entrainment at the aerators and the slow movement of the air away from the spillway surface are still challenging.

The spillway aeration device design is based upon a small deflection of the spilway bed (or sidewall) such as a ramp and offset to deflect the high velocity flow away from the spillway surface. In the cavity formed below the nappe, a local subpressure beneath the nappe is produced by which air is sucked into the flow. The complete design includes the deflection device (ramp, offset) and the air supply system.

## *Cavitation in engines*

Some larger diesel engines suffer from cavitation due to high compression and undersized cylinder walls. Vibrations of the cylinder wall induce alternating low and high pressure in the coolant against the cylinder wall. The result is pitting of the cylinder wall, which will eventually let cooling fluid leak into the cylinder and combustion gases to leak into the coolant.

It is possible to prevent this from happening with the use of chemical additives in the cooling fluid that form a protective layer on the cylinder wall. This layer will be exposed to the same cavitation, but rebuilds itself. Additionally a regulated overpressure in the cooling system (regulated and maintained by the coolant filler cap spring pressure) prevents the forming of cavitation.

From about the 1980s, new designs of smaller petrol (gasoline) engines also displayed cavitation phenomenon. One answer to the need for smaller and lighter engines was a smaller coolant volume and a correspondingly higher coolant velocity. This gave rise to rapid changes in flow velocity and therefore rapid changes of static pressure in areas of high heat transfer. Where resulting vapor bubbles collapsed against a surface, they had the effect of first disrupting protective oxide layers (of cast aluminum materials) and then repeatedly damaging the newly formed surface, preventing the action of some types of corrosion inhibitor (such as silicate based inhibitors). A final problem was the effect that increased material temperature had on the relative electrochemical reactivity of the base metal and its alloying constituents. The result was deep pits that could form and penetrate the engine head in a matter of hours when the engine was running at high load and high speed. These effects could largely be avoided by the use of organic corrosion inhibitors or (preferably) by designing the engine head in such a way as to avoid certain cavitation inducing conditions.

## *Vascular plants*

Cavitation occurs in the xylem of vascular plants when the tension of water within the xylem becomes so great that dissolved air within the water expands to fill either the vessel elements or tracheids. Plants are generally able to repair cavitated xylem in a number of ways. For plants less than 50 cm tall, root pressure can be sufficient to redissolve air. For larger plants, they must repair cavitation by importing solutes into the xylem; this causes water to enter as well, which can then redissolve the air. In some trees, the sound of the cavitation is clearly audible, particularly in summer, when the rate of evapotranspiration is highest. Deciduous trees shed leaves in the autumn partly because cavitation increases as temperatures decrease.

## *Marine life*

Just as cavitation bubbles form on a fast-spinning boat propeller, they may also form on the tails and fins of aquatic animals. The effects of cavitation are especially important near the surface of the ocean, where the ambient water pressure is relatively low and cavitation is more likely to occur.

For powerful swimming animals like dolphins and tuna, cavitation may be detrimental, because it limits their maximum swimming speed. Even if they have the power to swim faster, dolphins may have to restrict their speed because collapsing cavitation bubbles on their tail are too painful. Cavitation also slows tuna, but for a different reason. Unlike dolphins, these fish do not feel the painful bubbles, because they have bony fins without nerve endings. Nevertheless, they cannot swim faster because the cavitation bubbles create an air film around their fins that limits their speed. Lesions have been found on tuna that are consistent with cavitation damage.

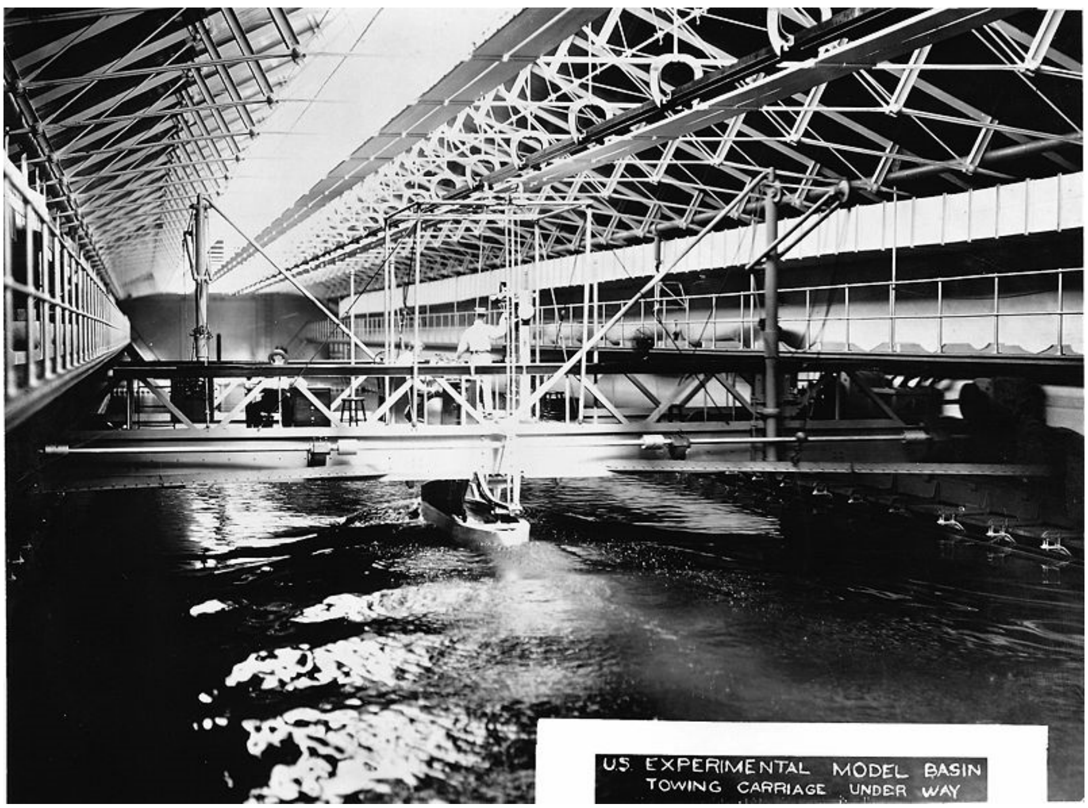
Cavitation is not always a limitation for sea life; some animals have found ways to use it to their advantage when hunting prey. The pistol shrimp snaps a specialized claw to create cavitation, which can kill small fish. The mantis shrimp (of the *smasher* variety) uses cavitation as well in order to stun, smash open, or kill the shellfish that it feasts upon. Their knees do wear out as a result, which is not a problem because the animal moults every three months.

## *Coastal erosion*

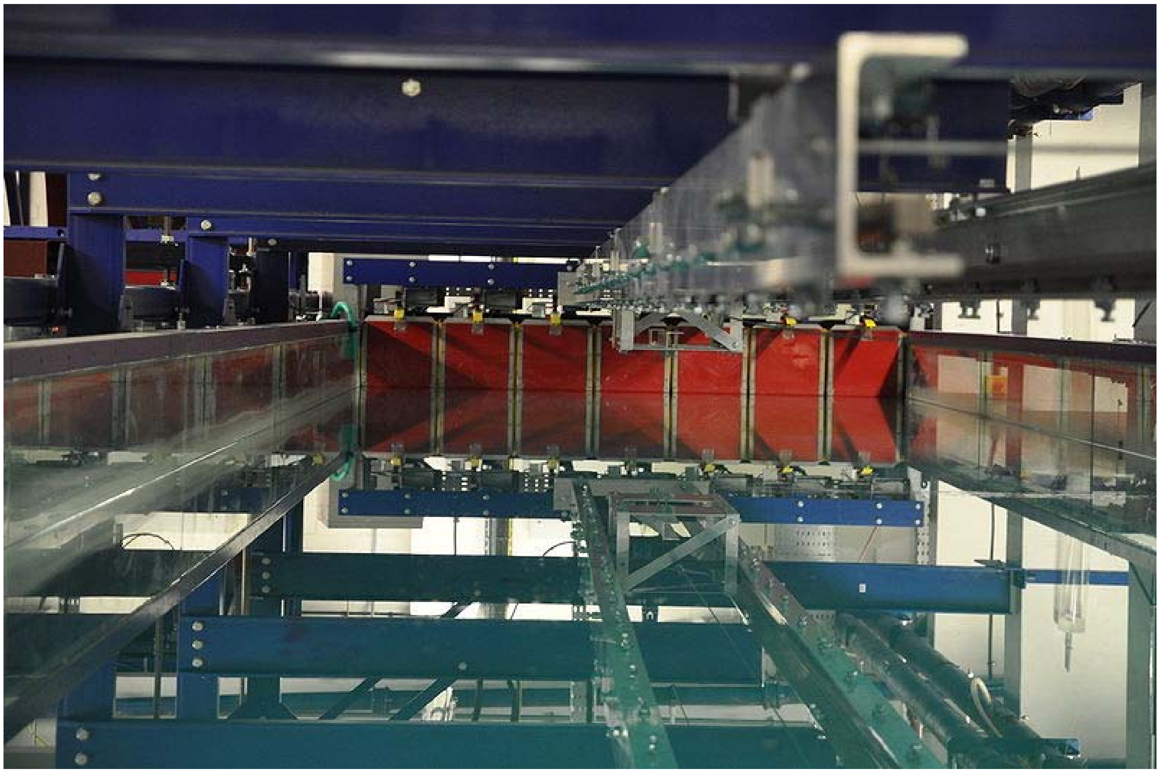
In the last half-decade, coastal erosion in the form of inertial cavitation has been generally accepted. Air pockets in an incoming wave are forced into cracks in the cliff being eroded, then the force of the wave compresses the air pockets until the bubble implodes, becoming liquid, giving off various forms of energy that blast apart the rock.

Chapter 2

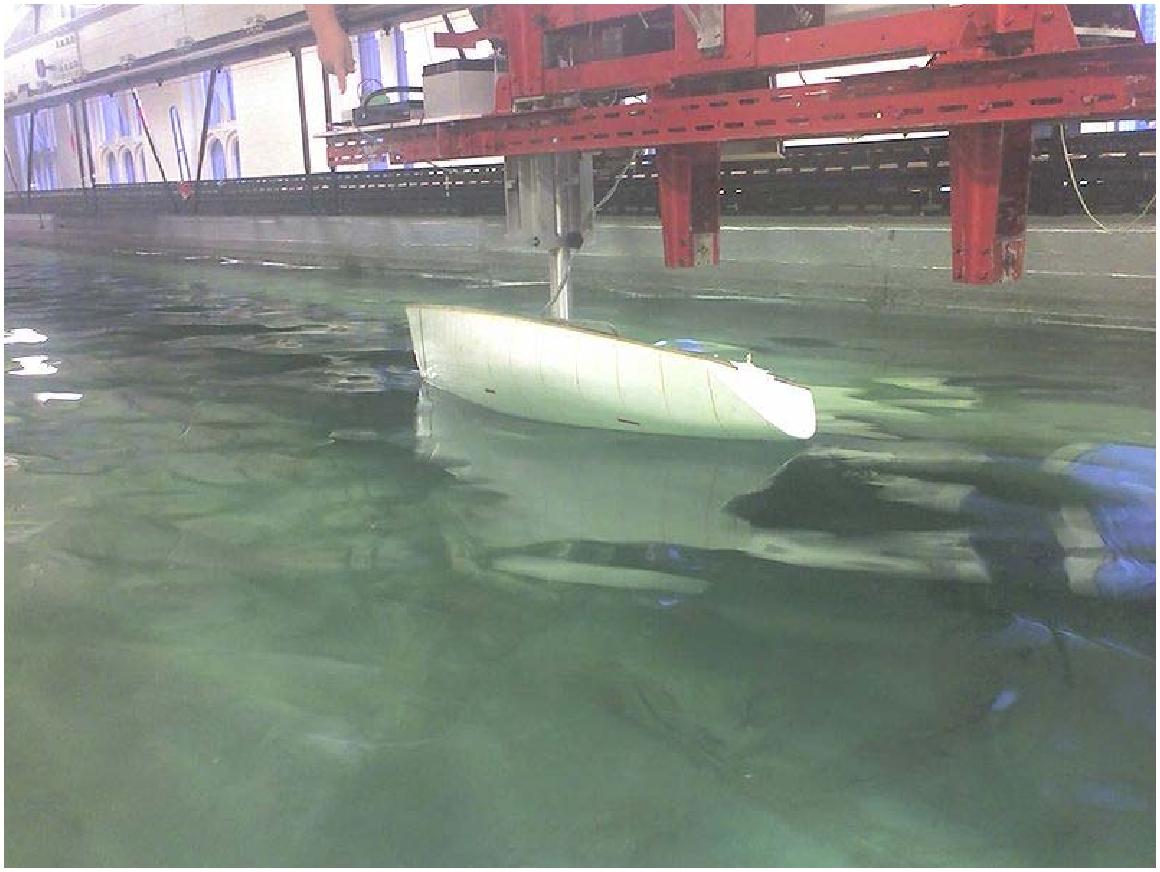
# Ship Model Basin




US Experimental Model Basin, circa 1900



The Ocean Towing Tank - with both towing and wave making facilities - at University College London



A model being tested in the Towing Tank of Newcastle University.

Cavitation tunnel of the Versuchsanstalt für Wasserbau und Schiffbau in Berlin

Cavitating propeller in a water tunnel experiment at the David Taylor Model Basin

A **ship model basin** may be defined as one of two separate yet related entities, namely:

- a physical basin or tank used to carry out hydrodynamic tests with ship models, for the purpose of designing a new (full sized) ship, or refining the design of a ship to improve the ship's performance at sea;
- the organization (often a company) that owns and operates such a facility.

In the second meaning, the company or authority is an engineering firm. that acts as a contractor to the relevant shipyards, and provides hydrodynamic model tests and numerical calculations to support the design and development of ships and offshore structures.

The hydrodynamic test facilities present at a model basin site include at least:

- A **towing tank:** This is a basin, several meters wide and hundreds of meters long, equipped with a towing carriage that runs on two rails on either side. The towing carriage can either tow the model or follow the self-propelled model, and is equipped with computers and devices to register or control, respectively, variables such as speed, propeller thrust and torque, rudder angle etc. The towing tank serves for resistance and propulsion tests with towed and self-propelled ship models to determine how much power the engine will have to provide to achieve the speed laid down in the contract between shipyard and ship owner. The towing tank also serves to determine the maneuvering behavior in model scale. For this, the self-propelled model is exposed to a series of zig-zag maneuvers at different rudder angle amplitudes. Post-processing of the test data by means of system identification results in a numerical model to simulate any other maneuver like Dieudonné spiral test or turning circles. Additionally, a towing tank can be equipped with a PMM (planar motion mechanism) or a CPMC (computerized planar motion carriage) to measure the hydrodynamic forces and moments on ships or submerged objects under the influence of oblique inflow and enforced motions. The towing tank can also be equipped with a wave generator to carry out seakeeping tests, either by simulating natural (irregular) waves or by exposing the model to a wave packet that yields a set of statistics known as *response amplitude operators* (acronym *RAO*), that determine the ship's likely real-life sea-going behavior when operating in seas with varying wave amplitudes and frequencies (these parameters being known as *sea states*). Modern seakeeping test facilities can determine these RAO statistics, with the aid of appropriate computer hardware and software, in a single test.

- A **cavitation tunnel** to investigate propellers. This is a vertical water circuit with large diameter pipes. At the top, it carries the measuring facilities. A parallel inflow is established. With or without a ship model, the propeller, attached to a dynamometer, is brought into the inflow, and its thrust and torque is measured at different ratios of propeller speed (number of revolutions) to inflow velocity. A stroboscope synchronized with the propeller speed serves to visualize cavitation as if the cavitation bubble would not move. By this, one can observe if the propeller would be damaged by cavitation. To ensure similarity to the full-scale propeller, the pressure is lowered, and the gas content of the water is controlled.

- **Workshops**: Ship model basins manufacture their ship models from wood or paraffin with a computerized milling machine. Some of them also manufacture their model propellers. Equipping the ship models with all drives and gauges and manufacturing equipment for non-standard model tests are the main tasks of the workshops.

Some ship model basins have further facilities, for example:

- A **maneuvering and seakeeping basin**. This is a test facility that is wide enough to investigate arbitrary angles between waves and the ship model, and to perform maneuvers like turning circles, for which the towing tank is too narrow. However, some important maneuvers like the spiral test still require even more space and still have to be simulated numerically after system identification.

- An **Ice Tank**: To develop ice breaking vessels, this tank fulfills similar purposes as the towing tank does for open water vessels. Resistance and required engine power as well as maneuvering behavior are determined depending on the ice thickness. Also ice forces on offshore structures can be determined. Ice layers are frozen with a special procedure to scale down the ice crystals to model scale. Also tests in brash ice are performed.

Additionally, these companies or authorities have CFD software and experience to simulate the complicated flow around ships and their rudders and propellers numerically. Today's state of the art does not yet allow software to replace model tests in their entirety by CFD calculations. One reason, but not the only one, is that elementization is still expensive. Also the lines design of some of the ships is carried out by the specialists of the ship model basin, either from the beginning or by optimizing the initial design obtained from the shipyard. The same applies to the design of propellers.

The ship model basins worldwide are organized in the ITTC (International Towing Tank Conference) to standardize their model test procedures.

Some of the most significant ship model basins are the David Taylor Model Basin and the Davidson Laboratory at Stevens Institute of Technology in the United States, The High Speed Towing Tank facility at Naval Science and Technological Labs at Vizag India, The Institute for Ocean Technology in St. Johns, Canada, FORCE Technology in Lyngby, Denmark, SSPA, in Gothenburg, Sweden, the Maritime Research Institute Netherlands (MARIN) in Wageningen, the Netherlands, the INSEAN in Rome, Italy, the HSVA in Hamburg, Germany, the "Bassin d'essai des carènes" in Val de Reuil , France and CEHIPAR in Madrid, Spain, CTO S.A. in Gdansk, Poland

**Chapter 3**

# Shipbuilding

**Shipbuilding** is the construction of ships. It normally takes place in a specialized facility known as a shipyard. **Shipbuilders**, also called **shipwrights**, follow a specialized occupation that traces its roots to before recorded history.

Shipbuilding and ship repairs, both commercial and military, are referred to as the "naval engineer". The construction of boats is a similar activity called boat building.

The dismantling of ships is called ship breaking.

## *History*

### Prehistory

Archaeological evidence indicates that humans arrived on New Guinea at least 60,000 years ago, probably by sea from Southeast Asia during an ice age period when the sea was lower and distances between islands shorter. The ancestors of Australian Aborigines and New Guineans went across the Lombok Strait to Sahul by boat over 50,000 years ago.

### 4th millennium BC

Evidence from Ancient Egypt shows that the early Egyptians knew how to assemble planks of wood into a ship hull as early as 3000 BC. The Archaeological Institute of America reports that some of the oldest ships yet unearthed are known as the Abydos boats. These are a group of 14 discovered ships in Abydos that were constructed of wooden planks which were "sewn" together. Discovered by Egyptologist David O'Connor of New York University, woven straps were found to have been used to lash the planks together, and reeds or grass stuffed between the planks helped to seal the seams. Because the ships are all buried together and near a mortuary belonging to Pharaoh Khasekhemwy, originally they were all thought to have belonged to him, but one of the 14 ships dates to 3000 BC, and the associated pottery jars buried with the vessels also suggest earlier dating. The ship dating to 3000 BC was 75 feet long and is now thought to perhaps have belonged to an earlier pharaoh. According to professor O'Connor, the 5,000-year-old ship may have even belonged to Pharaoh Aha.

## 3rd millennium BC

Early Egyptians also knew how to assemble planks of wood with treenails to fasten them together, using pitch for caulking the seams. The "Khufu ship", a 43.6-meter vessel sealed into a pit in the Giza pyramid complex at the foot of the Great Pyramid of Giza in the Fourth Dynasty around 2500 BC, is a full-size surviving example which may have fulfilled the symbolic function of a solar barque. Early Egyptians also knew how to fasten the planks of this ship together with mortise and tenon joints.

The oldest known tidal dock in the world was built around 2500 BC during the Harappan civilisation at Lothal near the present day Mangrol harbour on the Gujarat coast in India. Other ports were probably at Balakot and Dwarka. However, it is probable that many small-scale ports, and not massive ports, were used for the Harappan maritime trade. Ships from the harbour at these ancient port cities established trade with Mesopotamia. Shipbuilding and boatmaking may have been prosperous industries in ancient India. Native labourers may have manufactured the flotilla of boats used by Alexander the Great to navigate across the Hydaspes and even the Indus, under Nearchos. The Indians also exported teak for shipbuilding to ancient Persia. Other references to Indian timber used for shipbuilding is noted in the works of Ibn Jubayr.

## 2nd millennium BC

The ships of Ancient Egypt's Eighteenth Dynasty were typically about 25 meters (80 ft) in length, and had a single mast, sometimes consisting of two poles lashed together at the top making an "A" shape. They mounted a single square sail on a yard, with an additional spar along the bottom of the sail. These ships could also be oar propelled.

The ships of Phoenicia seems to have been of a similar design. The Greeks and probably others introduced the use of multiple banks of oars for additional speed, and the ships were of a light construction for speed and so they could be carried ashore.

## 1st millennium BC

The naval history of China stems back to the Spring and Autumn Period (722 BC–481 BC) of the ancient Chinese Zhou Dynasty. The Chinese built large rectangular barges known as "castle ships", which were essentially floating fortresses complete with multiple decks with guarded ramparts.

## Early 1st millennium AD

The ancient Chinese also built ramming vessels as in the Greco-Roman tradition of the trireme, although oar-steered ships in China lost favor very early on since it was in the 1st century China that the stern-mounted rudder was first developed. This was dually met with the introduction of the Han Dynasty junk ship design in the same century.

## Medieval Europe, Sung China, Abbasid Caliphate, Pacific Islanders

Viking longships developed from an alternate tradition of clinker-built hulls fastened with leather thongs. Sometime around the 12th century, northern European ships began to be built with a straight sternpost, enabling the mounting of a rudder, which was much more durable than a steering oar held over the side. Development in the Middle Ages favored "round ships", with a broad beam and heavily curved at both ends. Another important ship type was the galley which was constructed with both sails and oars.

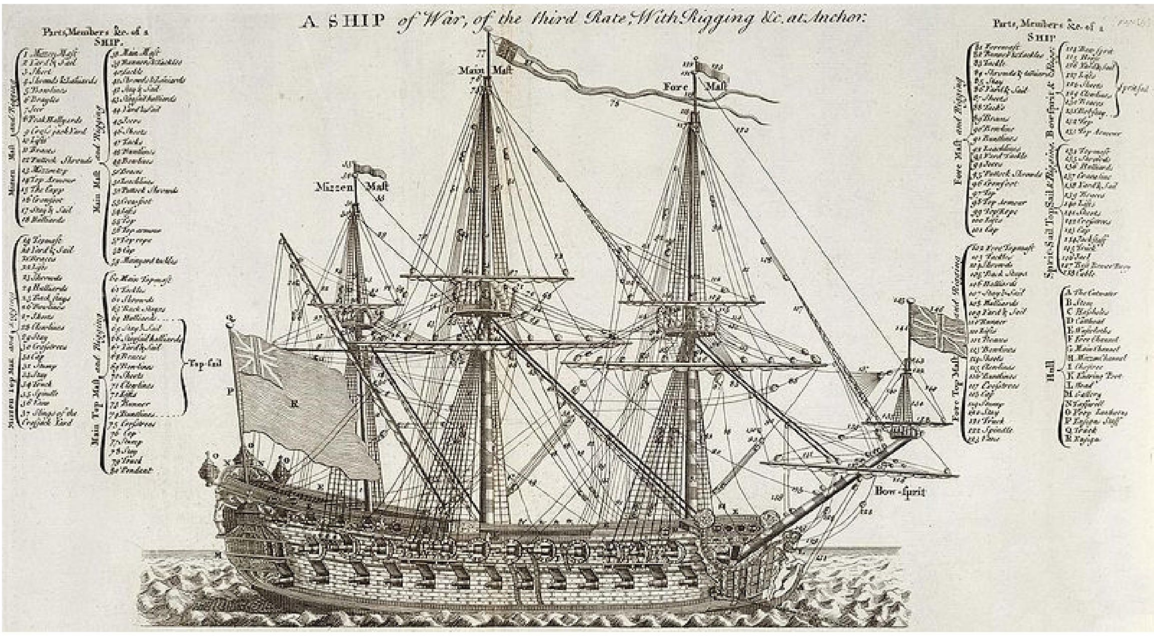
An insight into ship building in the North Sea/Baltic areas of the early medieval period was found at Sutton Hoo, England, where a ship was buried with a chieftain. It was nearly 90 feet long and, at its wides, 14 feet wide. Upward from the keel, the hull was made by overlapping nine planks on either side with rivets fastening the oaken planks together.In its days on the whale-road it could hold upwards of thirty men.

The first extant treatise on shipbuilding was written ca. 1436 by Michael of Rhodes, a man who began his career as an oarsman on a Venetian galley in 1401 and worked his way up into officer positions. He wrote and illustrated a book that contains a treatise on ship building, a treatise on mathematics, much material on astrology, and other materials. His treatise on shipbuilding treats three kinds of galleys and two kinds of round ships.

Outside Medieval Europe, great advances were being made in shipbuilding. The shipbuilding industry in Imperial China reached its height during the Sung Dynasty, Yuan Dynasty, and early Ming Dynasty, building commercial vessels that by the end of this period were to reach a size and sophistication far exceeding that of contemporary Europe. The mainstay of China's merchant and naval fleets was the junk, which had existed for centuries, but it was at this time that the large ships based on this design were built. During the Sung period (960–1279 AD), the establishment of China's first official standing navy in 1132 AD and the enormous increase in maritime trade abroad (from Heian Japan to Fatimid Egypt) allowed the shipbuilding industry in provinces like Fujian to thrive as never before. The largest seaports in the world were in China and included Guangzhou, Quanzhou, and Xiamen.

In the Islamic world, shipbuilding thrived at Basra and Alexandria, the dhow, felucca, baghlah and the sambuk, became symbols of successful maritime trade around the Indian Ocean; from the ports of East Africa to Southeast Asia and the ports of Sindh and Hind (India) during the Abbasid period.

At this time islands spread over vast distances across the Pacific Ocean were being colonised by the Melenesians ans Polynesians, who built giant canoes and progressed to great catamarans.




18th century perspective: 148 ship parts, 18 labeled hull sections (from Cyclopaedia, Volume 2, 1728).

## Early Modern

With the development of the carrack, the west moved into a new era of building the first regular ocean going vessels. These were of unprecedented size, complexity and cost. Shipyards became large industrial complexes and the ships built were financed by consortia of investors.

These considerations led to the documentation of design and construction practices in what had previously been a secretive trade run by master shipwrights, and ultimately led to the field of naval architecture, where professional designers and draughtsmen played an increasingly important role, although this is often overlooked. Even so, construction techniques changed only very gradually. The ships of the Napoleonic Wars were superior to those of the Spanish Armada of two centuries earlier but were still built more or less to the same basic plan.

Nevertheless, there were many subtle changes in ship design and construction in this period. Ships incorporated new design features. One example was tumblehome, a narrowing of the hull as it rises further from the waterline. Another example, is that fundamental to the strength of any boat or ship is the type and composition of the fastenings used to secure the timbers. Often these remained hidden beneath paints, protective coatings or sheathing. In the early modern period, in some circumstances, iron gave way to copper and later to hardened copper for use in fastenings below the waterline. This was in response to the advent of copper sheathing as a deterrent to shipworm and to fouling with weed and barnacles.

## Industrial Revolution

Other than its widespread use in fastenings, Iron was gradually adopted in ship construction, initially in discrete areas in a wooden hull needing greater strength, (e.g. as deck knees, hanging knees, knee riders and the like). Then, in the form of plates rivetted together and made watertight, it was used to form the hull itself. Initially copying wooden construction traditions with a frame over which the hull was fastened, Isambard Kingdom Brunel's *Great Britain* of 1843 was the first radical new design, being built entirely of wrought iron. Despite her success, and the great savings in cost and space provided by the iron hull, compared to a copper sheathed counterpart, there remained problems with fouling due to the adherence of weeds and barnacles. As a result composite construction remained the dominant approach where fast ships were required, with wooden timbers laid over an iron frame (the *Cutty Sark* is a famous example). Later *Great Britain's* iron hull was sheathed in wood to enable it to carry a copper-based sheathing. Brunel's *Great Eastern* represented the next great development in shipbuilding. Built in association with John Scott Russell, it used longitudinal stringers for strength, inner and outer hulls, and bulkheads to form multiple watertight compartments. Steel also supplanted wrought iron when it became readily available in the latter half of the 19th century, providing great savings when compared with iron in cost and weight. Wood continued to be favored for the decks, and is still the rule as deckcovering for modern cruise ships. Scotts Shipbuilding & Engineering Co. Ltd, Greenock, Scotland is a superb example of a shipbuilding firm that lasted nearly 300 years.

### *Modern worldwide shipbuilding industry*

MS Oasis of the Seas, the world's second-largest passenger ship, was built by STX Europe in Turku, Finland. STX Europe is a subsidiary of South Korean shipbuilder STX Offshore & Shipbuilding.


A TI class supertanker built by Daewoo Shipbuilding & Marine Engineering in Okpo, South Korea.

In the 20th century, shipbuilding (which encompasses the shipyards, the marine equipment manufacturers, and many related service and knowledge providers) grew as an important and strategic industry in a number of countries around the world. This importance stems from:

- The large number of skilled workers required directly by the shipyard, along with supporting industries such as steel mills and engine manufacturers; and
- A nation's need to manufacture and repair its own navy and vessels that support its primary industries

Historically, the industry has suffered from the absence of global rules and a tendency towards (state-supported) over-investment due to the fact that shipyards offer a wide range of technologies, employ a significant number of workers, and generate foreign currency income (as the shipbuilding market is both global and dollar-based).

Shipbuilding is therefore an attractive industry for developing nations. Japan used shipbuilding in the 1950s and 1960s to rebuild its industrial structure; South Korea started to make shipbuilding a strategic industry in the 1970s, and China is now in the process of repeating these models with large state-supported investments in this industry.

As a result, the world shipbuilding market suffers from over-capacities, depressed prices (although the industry experienced a price increase in the period 2003–2005 due to strong demand for new ships which was in excess of actual cost increases), low profit margins, trade distortions and widespread subsidisation. All efforts to address the problems in the OECD have so far failed, with the 1994 international shipbuilding agreement never entering into force and the 2003–2005 round of negotiations being paused in September 2005 after no agreement was possible.

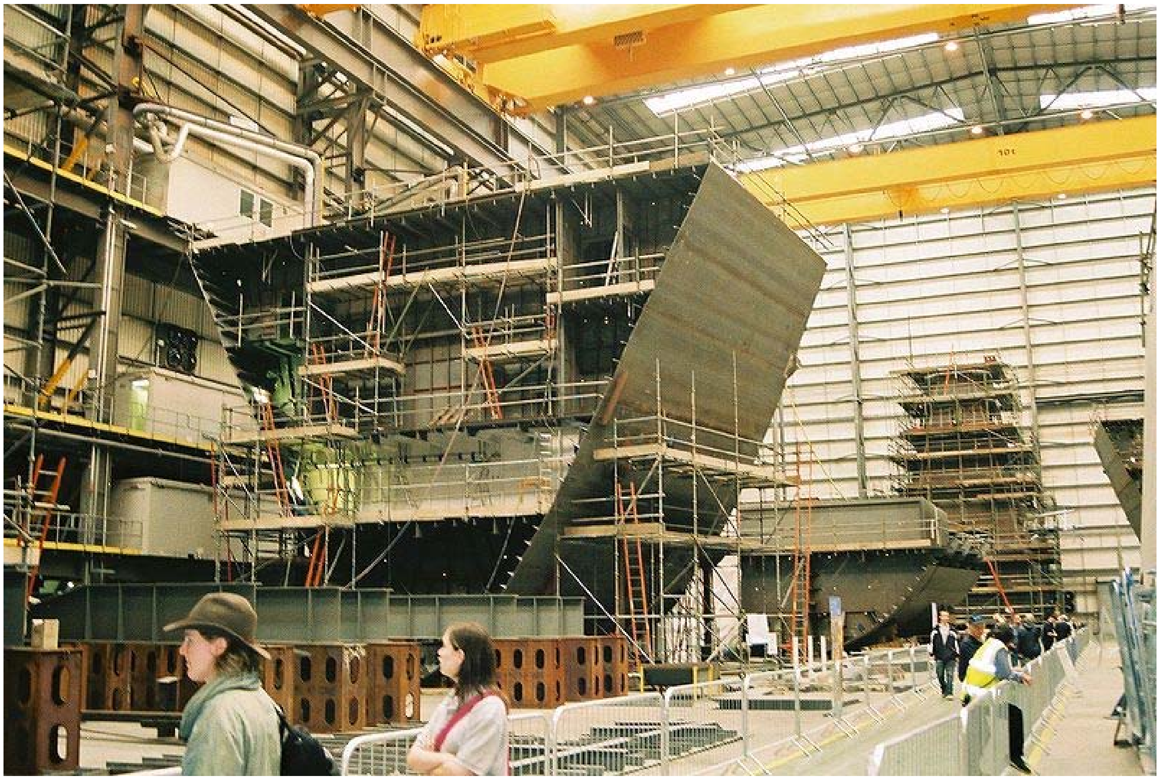
Where state subsidies have been removed and domestic industrial policies do not provide support, in high-cost nations shipbuilding has usually gone into steady, if not rapid, decline. The British shipbuilding industry is one of many examples of this. From a position in the early 1970s where British yards could still build the largest types of sophisticated merchant ships, British shipbuilders today have been reduced to a handful specialising in defence contracts and repair work. In the U.S.A., the Jones Act (which places restrictions on the ships that can be used for moving domestic cargoes) has meant that merchant shipbuilding has continued, but such protection has failed to penalise shipbuilding inefficiencies. The consequence of this is contract prices that are far higher than those of any other nation building oceangoing ships.

## World shipbuilding industry in the 21st century

China is the largest shipbuilder in the world in terms of compensated gross tons of ships as of 2010, at a total of 15.9 million tons, followed by South Korea with 11.77 million compensated gross tons. In terms of monetary value of the ships, South Korea is still the largest shipbuilder in the world as of 2010, followed by China, at a total value of $30.61 billion.

Japan lost its leading position in the industry to South Korea in 2004, and its market share has since fallen sharply. The entire European market share has fallen to only a tenth of South Korea's, and the outputs of the United States and the rest of the world have become negligible.

## Modern shipbuilding manufacturing techniques



Construction of prefabricated module blocks of HMS *Dauntless* at BAE's Portsmouth Shipyard.

Modern shipbuilding makes considerable use of prefabricated sections. Entire multi-deck segments of the hull or superstructure will be built elsewhere in the yard, transported to the building dock or slipway, then lifted into place. This is known as "block construction". The most modern shipyards pre-install equipment, pipes, electrical cables, and any other components within the blocks, to minimize the effort needed to assemble or install components deep within the hull once it is welded together. This was first introduced by Alstom Chantiers de l'Atlantique when they built the largest Ocean Liner in the world Cunard's RMS Queen Mary 2.

Ship design work, also called naval architecture, may be conducted using a ship model basin. Modern ships, since roughly 1940, have been produced almost exclusively of welded steel. Early welded steel ships used steels with inadequate fracture toughness, which resulted in some ships suffering catastrophic brittle fracture structural cracks. Since roughly 1950, specialized steels such as ABS Steels with good properties for ship construction have been used. Although it is commonly accepted that modern steel has eliminated brittle fracture in ships, some controversy still exists. Brittle fracture of modern vessels continues to occur from time to time as the use of grade A and grade B steel of unknown toughness or fracture appearance transition temperature (FATT) in way of ships' side shells can be less than adequate for all ambient conditions.

## Ship repair industry

All ships need maintenance and repairs. A part of these jobs must be carried out under the supervision of the Classification Society. A lot of maintenance it is carried out while at sea or in port by ship's staff. However a large number of repair and maintenance works can only be carried out while the ship is out of commercial operation, in a Shiprepair Yard. Prior to undergoing repairs, tankers must dock at a Deballasting Station for if necessary completing the tank cleaning operations and pumping ashore its slops (dirty cleaning water and hydrocarbon residues) ashore.

**Chapter 4**

# Anchor

An **anchor** is a device, normally made of metal, that is used to connect a vessel to the bed of a body of water to prevent the vessel from drifting due to wind or current.

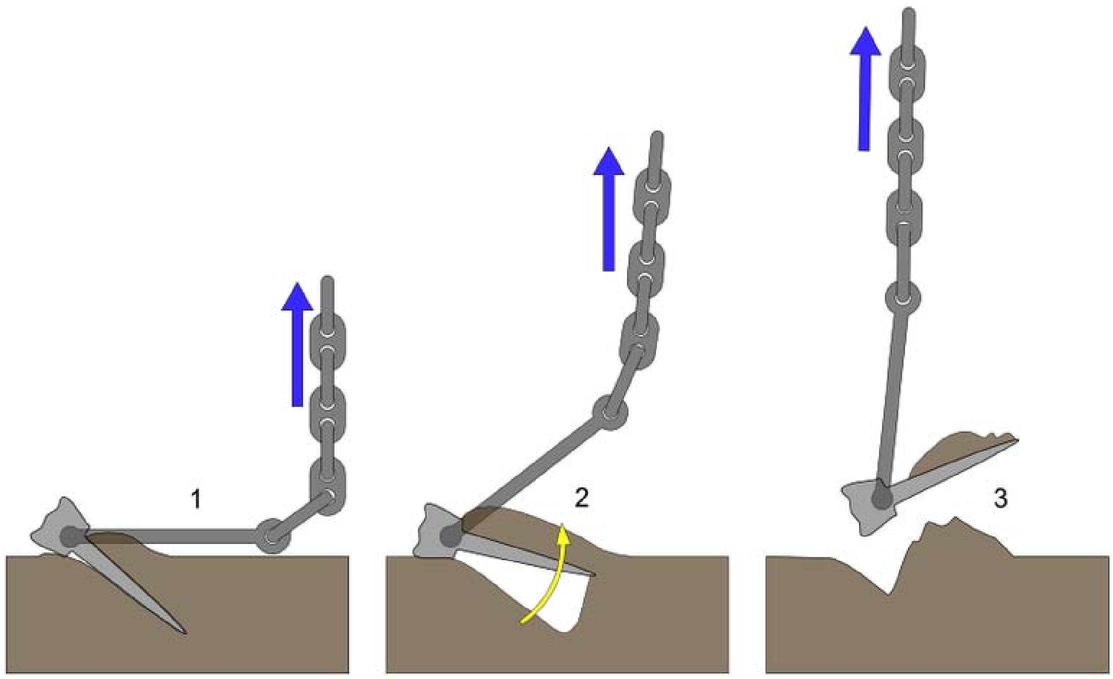
Anchors can either be temporary or permanent. A permanent anchor is used in the creation of a mooring, and is rarely moved; a specialist service is normally needed to move or maintain it. Vessels carry one or more temporary anchors which may be of different designs and weights.

A sea anchor is an unrelated device: a drogue used to control a drifting vessel.

## *Overview*

Anchors achieve holding power by "hooking" into the seabed, via sheer mass, or a combination of the two. Permanent moorings use large masses (commonly a block or slab of concrete) resting on this seabed. Semi-permanent mooring anchors (such as mushroom anchors) and large ship's anchors derive a significant portion of their holding power from their mass, while also hooking or embedding in the bottom. Modern anchors for smaller vessels have metal flukes which hook on to rocks on the bottom or bury themselves in soft bottoms.

The vessel is attached to the anchor by the rode which is made of chain, cable, rope (or a combination of these). The ratio of the length of rode to the water depth is known as the scope. Anchoring with sufficient scope and/or heavy chain rode brings the direction of strain close to parallel with the seabed. This is particularly important for light modern anchors designed to bury in the bottom, where ratios of 5-7 to 1 are common, whereas heavy anchors and moorings can use 3 to 1 or less.




Stockless anchor being broken out

Since all anchors that embed themselves in the bottom require the strain to be along the seabed, anchors can be broken out of the bottom by shortening the rode until the vessel is directly above the anchor. If necessary, motoring slowly around the location of the anchor also helps dislodge it. Anchors are sometimes fitted with a tripping line attached to the crown, by which they can be unhooked from rocks or coral.

An interesting element of anchor jargon is the term *aweigh*, which describes the anchor when it is hanging on the rode, not resting on the bottom; this is linked to the term *to weigh anchor*, meaning to lift the anchor from the sea bed, allowing the ship or boat to move. An anchor is described as *aweigh* when it has been broken out of the bottom and is being hauled up to be *stowed*. *Aweigh* should not be confused with *under way*, which describes a vessel which is not *moored* to a dock or *anchored*, whether or not it is moving through the water. Thus, a vessel can be under way (or underway) with no way on (i.e., not moving).

## *Evolution of the Anchor*

The earliest anchors were probably rocks and many rock anchors have been found dating from at least the Bronze Age. Many modern moorings still rely on a large rock as the primary element of their design. However, using pure mass to resist the forces of a storm only works well as a permanent mooring; trying to move a large enough rock to another bay is nearly impossible.

The ancient Greeks used baskets of stones, large sacks filled with sand, and wooden logs filled with lead, which, according to Apollonius Rhodius and Stephen of Byzantium, were formed of stone; and Athenaeus states that they were sometimes made of wood. Such anchors held the vessel merely by their weight and by their friction along the bottom. Iron was afterwards introduced for the construction of anchors, and an improvement was made by forming them with teeth, or "flukes", to fasten themselves into the bottom.

## Admiralty Pattern

An Admiralty Pattern anchor

The Admiralty Pattern, "A.P.", or simply "Admiralty", and also known as "Fisherman", is the most familiar among non-sailors. It consists of a central shank with a ring or shackle for attaching the rode. At one end of the shank there are two arms, carrying the flukes, while the stock is mounted to the other end, at ninety degrees to the arms. When the anchor lands on the bottom, it will generally fall over with the arms parallel to the seabed. As a strain comes onto the rode, the stock will dig into the bottom, canting the anchor until one of the flukes catches and digs into the bottom.

The basic design remained unchanged for centuries, with the most significant changes being to the overall proportions, and a move from wooden stocks to those of iron. Since one fluke always protrudes up from the set anchor, there is a great tendency of the rode to foul the anchor as the vessel swings due to wind or current shifts. When this happens, the anchor may be pulled out of the bottom, and in some cases may need to be hauled up to be re-set. In the mid-1800s, numerous modifications were attempted to alleviate these problems, as well as improve holding power, including one-armed mooring anchors. The most successful of these *patent anchors*, the Trotman Anchor, introduced a pivot where the arms join the shank, allowing the "idle" arm to fold against the shank.

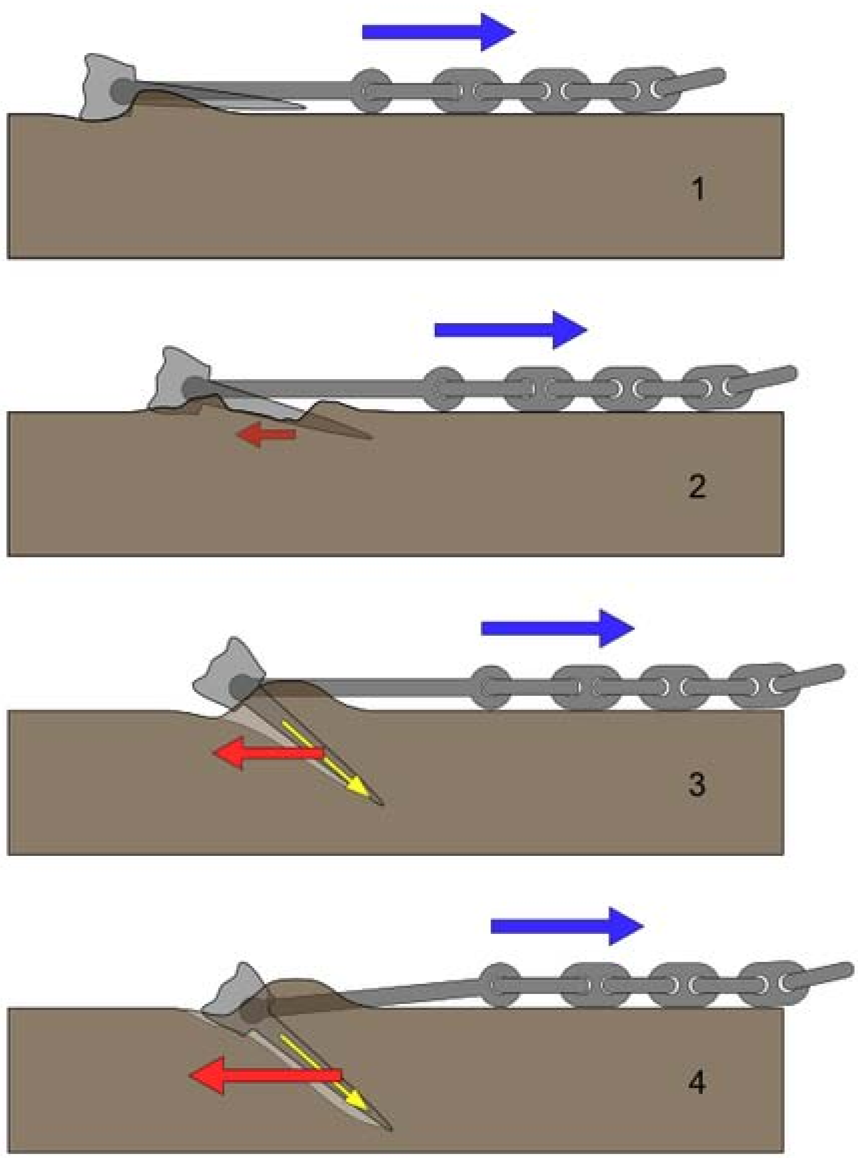
Handling and stowage of these anchors requires special equipment and procedures. Once the anchor is hauled up to the hawsepipe, the ring end is hoisted up to the end of a timber projecting from the bow known as the cathead. The crown of the anchor is then hauled up with a heavy tackle until one fluke can be hooked over the rail. This is known as "catting and fishing" the anchor. Before dropping the anchor, the fishing process is reversed, and the anchor is dropped from the end of the cathead.

## Stockless or Navy Pattern Anchor

Stockless Anchor

Developed in the late 1800s, stockless anchors represented the first significant departure in anchor design in centuries. Though their holding power to weight ratio is significantly lower than admiralty pattern anchors, their ease of handling and stowage aboard large ships led to almost universal adoption. In contrast to the elaborate stowage procedures for earlier anchors, stockless anchors are simply hauled up until they rest with the shank inside the hawsepipes, and the flukes against the hull (or inside a resess in the hull).

While there are numerous variations, stockless anchors consist of a set of heavy flukes connected by a pivot or ball and socket joint to a shank. Cast into the crown of the anchor is a set of tripping palms, projections that drag on the bottom, forcing the main flukes to dig in.




The action of a stockless anchor being set

## *Small Boat Anchors*

Until the mid-20th century, anchors for smaller vessels were either scaled-down versions of admiralty anchors, or simple grapnels. As new designs with greater holding power to weight ratios, a great variety of anchor designs has emerged. Many of these designs are still under patent, and other types are best known by their original trademarked names.

### Grapnel

A traditional design, the grapnel is merely a shank with four or more tines. It has a benefit in that no matter how it reaches the bottom one or more tines will be aimed to set. In coral it is often able to set quickly by hooking into the structure, but may be more difficult to retrieve. A grapnel is often quite light, and may have additional uses as a tool to recover gear lost overboard; its weight also makes it relatively easy to carry onboard.

Grapnels rarely have enough fluke area to develop much hold in sand, clay, or mud. It is not unknown for the anchor to foul on its own rode, or to foul the tines with refuse from the bottom, preventing it from digging in. On the other hand, it is quite possible for this anchor to find such a good hook that, without a trip line from the crown, it is impossible to retrieve. The shape is generally not very compact, and is difficult to stow, although there are a few collapsing designs available.

### Herreshoff anchor

Designed by famous yacht designer L. Francis Herreshoff, this is essentially the same pattern as an admiralty anchor, albeit with small diamond shaped flukes or palms. The novelty of the design lay in the means by which it could be broken down into three pieces for stowage. In use, it still presents all the issues of the admiralty pattern anchor.

### Northill anchor

Originally designed as a lightweight anchor for seaplanes, this design consists of two plow-like blades mounted to a shank, with a folding stock crossing through the crown of the anchor.

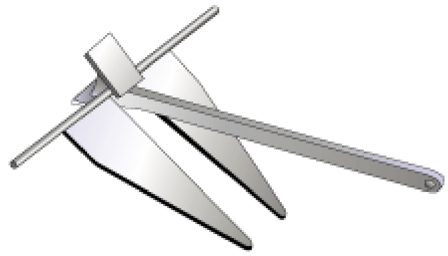
## CQR (Clyde Quick Release) Plough anchor

CQR anchor

So named due to its resemblance to a traditional agricultural plough (or more specifically two ploughshares), many manufacturers produce a plough-style design, all based on or direct copies of the original CQR (Secure), a 1933 design by mathematician Geoffrey Ingram Taylor. Ploughs are popular with cruising sailors and other private boaters. They are generally good in all bottoms, but not exceptional in any. The CQR design has a hinged shank, allowing the anchor to turn with direction changes rather than breaking out, while other plough types have a rigid shank. Plough anchors are usually stowed in a roller at the bow.

Owing to the use of lead or other dedicated tip-weight, the plough is heavier than average for the amount of resistance developed, and may take a slightly longer pull to set thoroughly. It cannot be stored in a hawse pipe.

## Danforth or Fluke anchor



A fluke-style anchor

American Richard Danforth invented the Danforth pattern in the 1940s for use aboard landing craft. It uses a stock at the crown to which two large flat triangular flukes are attached. The stock is hinged so the flukes can orient toward the bottom (and on some designs may be adjusted for an optimal angle depending on the bottom type). Tripping palms at the crown act to tip the flukes into the seabed. The design is a burying variety, and once well set can develop high resistance. Its light weight and compact flat design make it easy to retrieve and relatively easy to store; some anchor rollers and hawsepipes can accommodate a fluke-style anchor.

The fluke anchor has difficulty penetrating kelp and weed-covered bottoms, as well as rocky and particularly hard sand or clay bottoms. If there is much current or the vessel is moving while dropping the anchor it may "kite" or "skate" over the bottom due to the large fluke area acting as a sail or wing. Once set, the anchor tends to break out and reset when the direction of force changes dramatically, such as with the changing tide, and on some occasions it might not reset but instead drag.

## Bruce/ Claw

Bruce anchor

This claw shaped anchor was designed by Peter Bruce from the Isle of Man in the 1970s. Bruce gained its early reputation from the production of large scale commercial anchors for ships and fixed installations such as oil rigs. The Bruce and its copies, known generically as "claws", have become a popular option for small boaters. It was intended to address some of the problems of the only general-purpose option then available, the plough. Claw-types set quickly in most seabeds and although not an articulated design, they have the reputation of not breaking out with tide or wind changes, instead slowly turning in the bottom to align with the force.

Claw types have difficulty penetrating weedy bottoms and grass. They offer a fairly low holding power to weight ratio and generally have to be over-sized to compete with other types. On the other hand they perform relatively well with low rode scopes and set fairly reliably. They cannot be used with hawse pipes.

## Recent designs

Rocna anchor

In recent years there has been something of a spurt in anchor design. Primarily designed to set very quickly, then generate high holding power, these anchors (mostly proprietary inventions still under patent) are finding homes with users of small to medium sized vessels.

- The German designed bow anchor, **Bügelanker** (or **Wasi**), has a sharp tip for penetrating weed, and features a roll-bar which allows the correct setting attitude to be achieved without the need for extra weight to be inserted into the tip .
- The **Bulwagga** is a unique design featuring three flukes instead of the usual two. It has performed well in tests by independent sources such as American boating magazine *Practical Sailor* .
- The **Spade** is a French design which has proved successful since 1996. It features a demountable shank and the choice of galvanized steel, stainless steel, or aluminium construction, which means a lighter and more easily stowable anchor .
- The New Zealand designed **Rocna** has been produced since 2004. It too features a sharp toe like the Bügel for penetrating weed and grass, sets quickly , and has a particularly large fluke area. Its roll-bar is also similar to that of the Bügel. The Rocna obtained the highest averaged holding power in SAIL magazine's comparison testing in 2006 .

### Other Temporary Anchors

- **Mud weight**: Consists of a blunt heavy weight, usually cast iron or cast lead, that will sink into the mud and resist lateral movement. Suitable only for very soft silt bottoms and in mild conditions. Sizes range between 5 and 20 kg for small craft. Various designs exist and many are home produced from lead or improvised with heavy objects. This is a very commonly used method on the Norfolk Broads in England.

## *Permanent anchors*

These are used where the vessel is permanently sited, for example in the case of lightvessels or channel marker buoys. The anchor needs to hold the vessel in all weathers, including the most severe storm, but only occasionally, or never, needs to be lifted, only for example if the vessel is to be towed into port for maintenance. An alternative to using an anchor under these circumstances may be to use a pile driven into the seabed.

Permanent anchors come in a wide range of types and have no standard form. A slab of rock with an iron staple in it to attach a chain to would serve the purpose, as would any dense object of appropriate weight (e.g., an engine block). Modern moorings may be anchored by sand screws which look and act very much like over-sized screws drilled into the seabed, or by barbed metal beams pounded in (or even driven in with explosives) like pilings, or a variety of other non-mass means of getting a grip on the bottom. One method of building a mooring is to use three or more conventional anchors laid out with short lengths of chain attached to a swivel, so no matter which direction the vessel moves one or more anchors will be aligned to resist the force.

## Mushroom


Mushroom Anchor on the Lightship Portsmouth in Virginia.

The mushroom anchor is suitable where the seabed is composed of silt or fine sand. It was invented by Robert Stevenson, for use by an 82 ton converted fishing boat, *Pharos*, which was used as a lightvessel between 1807 and 1810 near to Bell Rock whilst the lighthouse was being constructed. It was equipped with a 1.5 ton example.

It is shaped like an inverted mushroom, the head becoming buried in the silt. A counterweight is often provided at the other end of the shank to lay it down before it becomes buried.

A mushroom anchor will normally sink in the silt to the point where it has displaced its own weight in bottom material, thus greatly increasing its holding power. These anchors are only suitable for a silt or mud bottom, since they rely upon suction and cohesion of the bottom material, which rocky or coarse sand bottoms lack. The holding power of this anchor is at best about twice its weight unti it becomes buried, when it can be as much as ten times its weight. They are available in sizes from about 10 lb up to several tons.

### Deadweight

This is an anchor which relies solely on being a heavy weight. It is usually just a large block of concrete or stone at the end of the chain. Its holding power is defined by its weight underwater (i.e. taking its buoyancy into account) regardless of the type of seabed, although suction can increase this if it becomes buried. Consequently deadweight anchors are used where mushroom anchors are unsuitable, for example in rock, gravel or coarse sand. An advantage of a deadweight anchor over a mushroom is that if it does become dragged, then it continues to provide its original holding force. The disadvantage of using deadweight anchors in conditions where a mushroom anchor could be used is that it needs to be around ten times the weight of the equivalent mushroom anchor.

### Screw

Screw anchors can be used to anchor permanent moorings, floating docks, fish farms, etc. These anchors must be screwed into the seabed with the use of a tool, so require access to the bottom, either at low tide or by use of a diver. Hence they can be difficult to install in deep water without special equipment.

Weight for weight, screw anchors have a higher holding than other permanent designs, and so can be cheap and relatively easily installed, although may not be ideal in extremely soft mud.

### *Anchoring gear*

Naval anchor incorporated into HMAS Canberra (1927) memorial, Canberra, Australia

The elements of anchoring gear include the anchor, the cable (also called a *rode*), the method of attaching the two together, the method of attaching the cable to the ship, charts, and a method of learning the depth of the water.

Vessels may carry a number of anchors: *Bower Anchors* (formerly known as *Sheet Anchors*) are the main anchors used by a vessel and normally carried at the bow of the vessel. A *Kedge Anchor* is a light anchor used for kedging, or more commonly on yachts for mooring quickly. or in benign conditions. A *Killick Anchor* is a small, possibly improvised, anchor.

Charts are vital to good anchoring. Knowing the location of potential dangers, as well as being useful in estimating the effects of weather and tide in the anchorage, is essential in choosing a good place to drop the hook. One can get by without referring to charts, but they are an important tool and a part of good anchoring gear, and a skilled mariner would not choose to anchor without them.

The depth of water is necessary for determining *scope*, which is the ratio of length of cable to the depth measured from the highest point (usually the anchor roller or bow chock) to the seabed. For example, if the water is 25 ft (8 m) deep, and the anchor roller is 3 ft (1 m) above the water, the scope is the ratio between the amount of cable let out and 28 ft (9 m). For this reason it is important to have a reliable and accurate method of measuring the depth of water.

A cable or rode is the rope, chain, or combination thereof used to connect the anchor to the vessel. Neither rope nor chain is fundamentally superior to a cable.

## Anchoring techniques

Anchor winch on RV Polarstern

Colored plastic inserts on a modern anchor chain show the operator how much chain has been paid out. This knowledge is very important in all anchoring methods

The basic anchoring consists of determining the location, dropping the anchor, laying out the scope, setting the hook, and assessing where the vessel ends up. The ship will seek a location which is sufficiently protected; has suitable holding ground, enough depth at low time and enough room for the boat to swing.

The location to drop the anchor should be approached from down wind or down current, whichever is stronger. As the chosen spot is approached, the vessel should be stopped or even beginning to drift back. The anchor should be lowered quickly but under control until it is on the bottom. The vessel should continue to drift back, and the cable should be veered out under control so it will be relatively straight.

Once the desired scope is laid out, the vessel should be gently forced astern, usually using the auxiliary motor but possibly by backing a sail. A hand on the anchor line may telegraph a series of jerks and jolts, indicating the anchor is dragging, or a smooth tension indicative of digging in. As the anchor begins to dig in and resist backward force, the engine may be throttled up to get a thorough set. If the anchor continues to drag, or sets after having dragged too far, it should be retrieved and moved back to the desired position (or another location chosen.)

With the anchor set in the correct location, everything should be reconsidered.

Some other techniques have been developed to reduce swing, or to deal with heavy weather.

- Using an anchor weight, kellet or sentinel
- Forked moor
- Bow and Stern
- Bahamian moor
- Backing an anchor

## Protection

A good anchorage offers protection from the current weather conditions, and will also offer protection from the expected weather. The anchorage should also be suitable for other purposes; for example, proximity to shore is beneficial if the crew plans to land.

## Seabed

Charts should indicate the type of bottom, and a sounding lead may be used to collect a sample from the bottom for analysis. Generally speaking, most anchors will hold well in sandy mud, mud and clay, or firm sand. Loose sand and soft mud are not desirable bottoms, especially soft mud which should be avoided if at all possible. Rock, coral, and shale prevent anchors from digging in, although some anchors are designed to hook into such a bottom. Grassy bottoms may be good holding, but only if the anchor can penetrate the foliage.

## Depth and tides

If the anchorage is affected by tide, tide ranges, as well as the times of high and low water, should be known. Enough depth is needed so that low tide does not present obstacles to where the vessel might swing. This is also important when determining scope, which should be figured for high tide and not the current tide state.

## Swing range

If the anchorage is affected by tide, one should keep in mind that the swing range will be larger at low tide than at high tide. However, no matter where the vessel is anchored, the largest possible swing range should be considered, as well as what obstacles and hazards might be within that range. Other vessels' swing ranges may overlap, presenting a further variable. Boats on permanent moorings, or shorter scope, may not swing as far as expected, or may swing either more rapidly or more slowly (all-chain cables tend to swing more slowly than all-rope or chain-and-rope cables.)

There are techniques of anchoring to limit the swing of a vessel if the anchorage has limited room.

**Using an anchor weight, kellet or sentinel**

Lowering a concentrated, heavy weight down the anchor line – rope or chain – directly in front of the bow to the seabed, behaves like a heavy chain rode and lowers the angle of pull on the anchor. If the weight is suspended off the seabed it acts as a spring or shock absorber to dampen the sudden actions that are normally transmitted to the anchor and can cause it to dislodge and drag. In light conditions, a kellet will reduce the swing of the vessel considerably. In heavier conditions these effects disappear as the rode becomes straightened and the weight ineffective. Known as a "anchor chum weight" or "angel" in the UK.

**Forked moor**

Using two anchors set approximately 45° apart, or wider angles up to 90°, from the bow is a strong mooring for facing into strong winds. To set anchors in this way, first one anchor is set in the normal fashion. Then, taking in on the first cable as the boat is motored into the wind and letting slack while drifting back, a second anchor is set approximately a half-scope away from the first on a line perpendicular to the wind. After this second anchor is set, the scope on the first is taken up until the vessel is lying between the two anchors and the load is taken equally on each cable.

This moor also to some degree limits the range of a vessel's swing to a narrower oval. Care should be taken that other vessels will not swing down on the boat due to the limited swing range.

**Bow and stern**

Not to be mistaken with the **Bahamian moor**, below.

In the *Bow and Stern* technique, an anchor is set off each the bow and the stern, which can severely limit a vessel's swing range and also align it to steady wind, current or wave conditions. One method of accomplishing this moor is to set a bow anchor normally, then drop back to the limit of the bow cable (or to double the desired scope, e.g. 8:1 if the eventual scope should be 4:1, 10:1 if the eventual scope should be 5:1, etc.) to lower a stern anchor. By taking up on the bow cable the stern anchor can be set. After both anchors are set, tension is taken up on both cables to limit the swing or to align the vessel.

**Bahamian moor**

Similar to the above, a *Bahamian moor* is used to sharply limit the swing range of a vessel, but allows it to swing to a current. One of the primary characteristis of this technique is the use of a swivel as follows: the first anchor is set normally, and the vessel drops back to the limit of anchor cable. A second anchor is attached to the end of the anchor cable, and is dropped and set. A swivel is attached to the middle of the anchor cable, and the vessel connected to that.

The vessel will now swing in the middle of two anchors, which is acceptable in strong reversing currents but a wind perpendicular to the current may break out the anchors as they are not aligned for this load.

### Backing an anchor

Also known as *Tandem anchoring*, in this technique two anchors are deployed in line with each other, on the same rode. With the foremost anchor reducing the load on the aft-most, this technique can develop great holding power and may be appropriate in "ultimate storm" circumstances. It does not limit swinging range, and might not be suitable in some circumstances. There are complications and the technique requires careful preparation and a level of skill and experience above that required for a single anchor.

## Kedging

*Kedging* is a technique for moving or turning a ship by using a relatively light anchor known as a *kedge*.

In yachts, a kedge anchor is an anchor carried in addition to the main, or bower anchors, and usually stowed aft. Every yacht should carry at least two anchors – the main or *bower* anchor and a second lighter *kedge* anchor. It is used occasionally when it is necessary to limit the turning circle as the yacht swings when it is anchored, such as in a very narrow river or a deep pool in an otherwise shallow area.

For ships, a kedge may be dropped while a ship is underway, or carried out in a suitable direction by a tender or ship's boat to enable the ship to be winched off if aground or swung into a particular heading, or even to be held steady against a tidal or other stream.

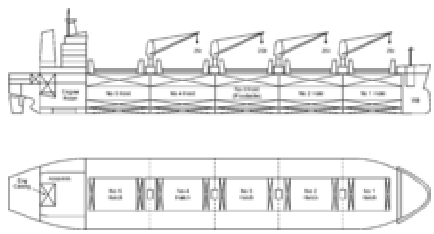
Historically, it was of particular relevance to sailing warships which used them to out-maneuver opponents when the wind had dropped but might be used by any vessel in confined, shoal water to place it in a more desirable position, provided she had enough manpower.

### Club hauling

Club hauling is an archaic technique, and may be considered a variety of kedging: when a sailing vessel is in a narrow channel or on a lee shore so that there is no room to tack the vessel in a conventional manner an anchor attached to the lee quarter may be dropped from the lee bow. This is deployed when the vessel is head to wind and has lost headway. As the vessel gathers sternway the strain on the cable pivots the vessel around what is now the weather quarter turning the vessel onto the other tack. The anchor is then normally cut away as it cannot be recovered.

# Chapter 5

# Engine Room



Location of a ship's engine room.

Main engine deck of a cargo vessel

On a ship, the **engine room**, or **ER**, commonly refers to the machinery spaces of a vessel. To increase the safety and damage survivability of a vessel, the machinery necessary for operations may be segregated into various spaces, the engine room is one of these spaces, and is generally the largest physical compartment of the machinery space. The engine room houses the vessel's prime mover, usually some variations of a heat engine - diesel engine, gas or steam turbine. On some ships, the machinery space may comprise more than one engine room, such as forward and aft, or port or starboard engine rooms, or may be simply numbered.

On a large percentage of vessels, ships and boats, the engine room is located near the bottom, and at the rear, or aft, end of the vessel, and usually comprises few compartments. This design maximizes the cargo carrying capacity of the vessel and situates the prime mover close to the propeller, minimizing equipment cost and problems posed from long shaft lines. The engine room on some ships may be situated mid-ship, especially on vessels built from 1900 to the 1960s. With the increase use of diesel electric propulsion packages, the engine room(s) may be located well forward, low or high on the vessel, depending on the vessel use.

The engine compartment of a locomotive may be described as an engine room.

## *Equipment*

### Engines

The engine room of a Severn class lifeboat

The engine room of a motor vessel typically contains several engines for different purposes. Main, or propulsion engines are used to turn the ship's propeller and move the ship through the water. They typically burn diesel oil or heavy fuel oil, and may be able to switch between the two. There are many propulsion arrangements for motor vessels, some including multiple engines, propellers, and gearboxes.

Large engines drive electrical generators that provide power for the ship's electrical systems. Large ships typically have three or more synchronized generators to ensure smooth operation. The combined output of a ship's generators is well above the actual power requirement to accommodate maintenance or the loss of one generator.

On a steamship, power for both electricity and propulsion is provided by a large boiler. Superheated steam from the boiler is used to spin powerful turbines for propulsion and turbo generators for electricity. Besides propulsion and auxiliary engines, a typical engine room contains many smaller engines, including generators, air compressors, feed pumps, and fuel pumps. Today, these machines are usually powered by small diesel engines or electric motors, but may also use low-pressure steam.

### Engine cooling

The engine(s) get required cooling from liquid-to-liquid heat exchangers connected to fresh seawater or divertible to recirculate through tanks of seawater in the engine room. Both supplies draw heat from the engines via the coolant and oil lines. Heat exchangers are plumbed in so that oil is represented by a yellow mark on the flange of the pipes, and relies on paper type gaskets to seal the mating faces of the pipes. Sea water or brine, is represented by a green mark on the flanges and internal coolant is represented by blue marks on the flanges.

### Thrusters

In addition to this array of equipment is the ships thruster system, typically operated by electric motors controlled from the bridge. These thrusters are laterally mounted propellers that can suck or blow water from port to starboard (i.e. left to right) or vice versa. They are normally used only in maneuvering, e.g. docking operations, and are often banned in tight confines, e.g. drydocks.

Thrusters, like main propellers, are reversible by hydraulic operation. Small embedded hydraulic motors rotate the blades up to 180 degrees to reverse the direction of the thrust.

## *Safety*

### Fire precautions

Engine rooms are hot, noisy, sometimes dirty, and potentially dangerous. The presence of flammable fuel, high voltage (HV) electrical equipment and internal combustion engines (ICE) means that a serious fire hazard exists in the engine room, which is monitored continuously by the ship's engineering staff and various monitoring systems.

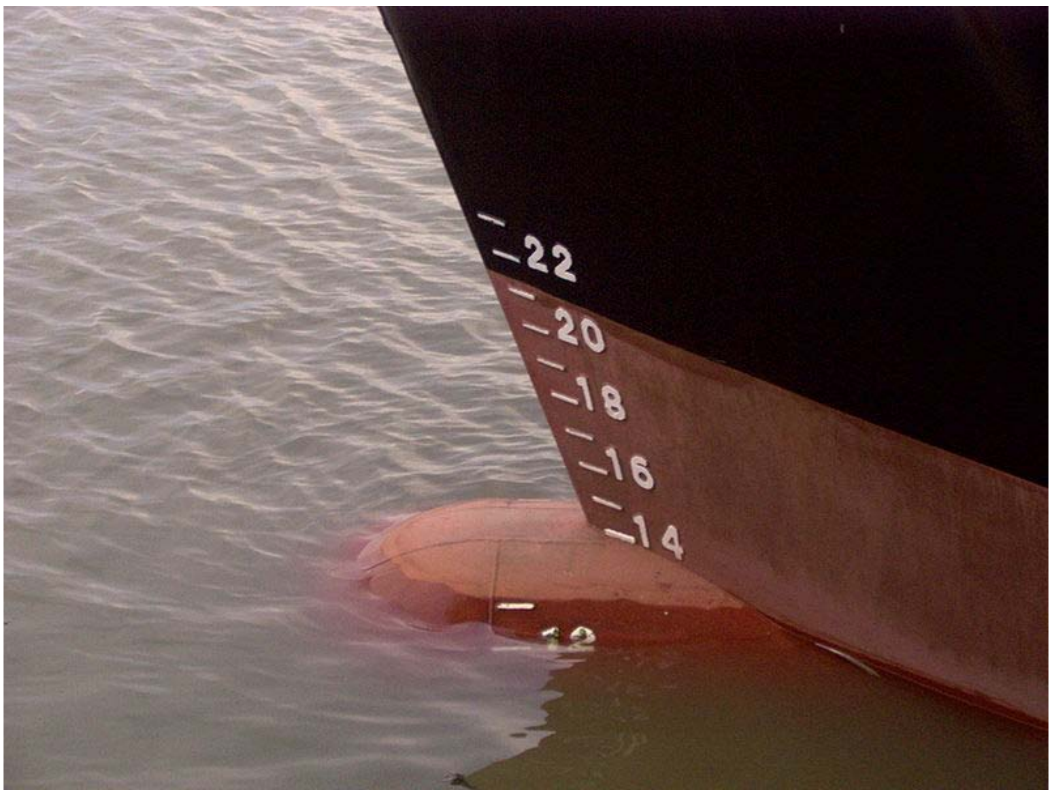
## Ventilation

Engine room of the SS Shieldhall

If equipped with internal combustion or turbine engines, engine rooms employ some means of providing air for the operation of the engines and associated ventilation. If individuals are normally present in these rooms, additional ventilation should be available to keep engine room temperatures to acceptable limits. If personnel are not normally in the engine space, as in many pleasure boats, the ventilation need only be sufficient to supply the engines with intake air. This would require an unrestricted hull opening of the same size as the intake area of the engine itself assuming the hull opening is in the engine room itself. Commonly screens are placed over such openings and if this is done, airflow is reduced by approximately 50% so the opening area is increased appropriately. The requirement for general ventilation and the requirement for sufficient combustion air are quite different. A typical arrangement might be to make the opening large enough to provide intake air plus 1000 Cubic Feet per Minute (CFM) for additional ventilation. Engines pull sufficient air into the engine room for their own operation. However, additional airflow for ventilation usually requires intake and exhaust blowers.

**Chapter 6**

# Displacement (Ship)




As weight is added to a ship, it submerges. Designated displacement is the ship's weight when fully loaded and submerged to her load lines.

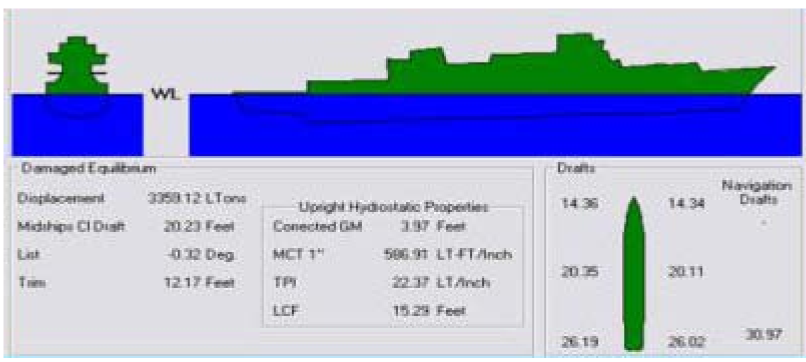
A ship's **displacement** is its mass at any given time, generally expressed in metric tons or long tons. The term is often used to mean the ship's mass when it is loaded to its maximum capacity. A number of synonymous terms exist for this maximum mass, such as **loaded displacement**, **full load displacement** and **designated displacement**. Displacement is a measurement of mass, and should not be confused with similarly named measurements of volume or capacity such as net tonnage, gross tonnage, or deadweight tonnage.

The word displacement refers to the mass of the water that the ship displaces while floating. Another way of thinking about displacement is the amount of water that would spill out of a completely filled container were the ship to be placed into it. A floating ship always displaces an amount of water of the same mass as the ship.

The density (mass per unit of volume) of water can vary. For example, the average density of seawater at the surface of the ocean is 1025 kg/m³ (10.25 lb/ga, 8.55 lb/US gallon), fresh water on the other hand has a density of about 1000 kg/m³ (10.00 lb/ga, 8.35 lb/US gallon). Consider a 100-ton ship passing from a saltwater sea into a freshwater river. It always displaces exactly 100 tons of water, but it has to displace a greater volume of fresh water to amount to 100 tons. Therefore it would sit slightly lower in the water in the freshwater river than it would in the saltwater sea.

It can be useful to know a ship's displacement when it is unloaded or partially loaded. Terms for these measurements include **light displacement**, **standard displacement**, and **normal displacement**. These terms are defined fully below.

## *Calculation*




Shipboard stability programs are often used to calculate a ship's current displacement.

The traditional method for determining a ship's actual displacement is by use of draft marks. A merchant vessel has six sets of draft marks: forward, midships, and astern on both the port and starboard sides. These drafts can allow the determination of a ship's displacement to an accuracy of 0.5%. First, the individual drafts are averaged to find a mean draft. Then the mean draft is entered into the ship's hydrostatic tables, giving a displacement.

Computers have been used to assist in hydrostatic calculations, such as determining displacement, since the 1950s. The first were mechanical computers, similar to slide rules which could convert cargo levels to values such as deadweight tonnage, draft, and trim. Since the 1970s, personal computer-based programs have been developing to meet these needs.

## *Displacement under special conditions*

A number of measurements of displacement are defined when the ship is in a special state, such as when it is completely full or completely empty. These special types of displacement are discussed below.

### Full or deep load or loaded displacement

Full load displacement and loaded displacement have almost identical definitions.

Full load displacement is defined as the displacement of a vessel when floating at her greatest allowable draft as established by the classification societies. For warships, an arbitrary full load condition is established. Deep load condition means full ammunition and stores, with most available fuel capacity used.

Loaded displacement is defined as the mass of the ship including cargo, passengers, fuel, water, stores, dunnage and such other items necessary for use on a voyage, which brings the ship down to her load draft.

### Standard displacement

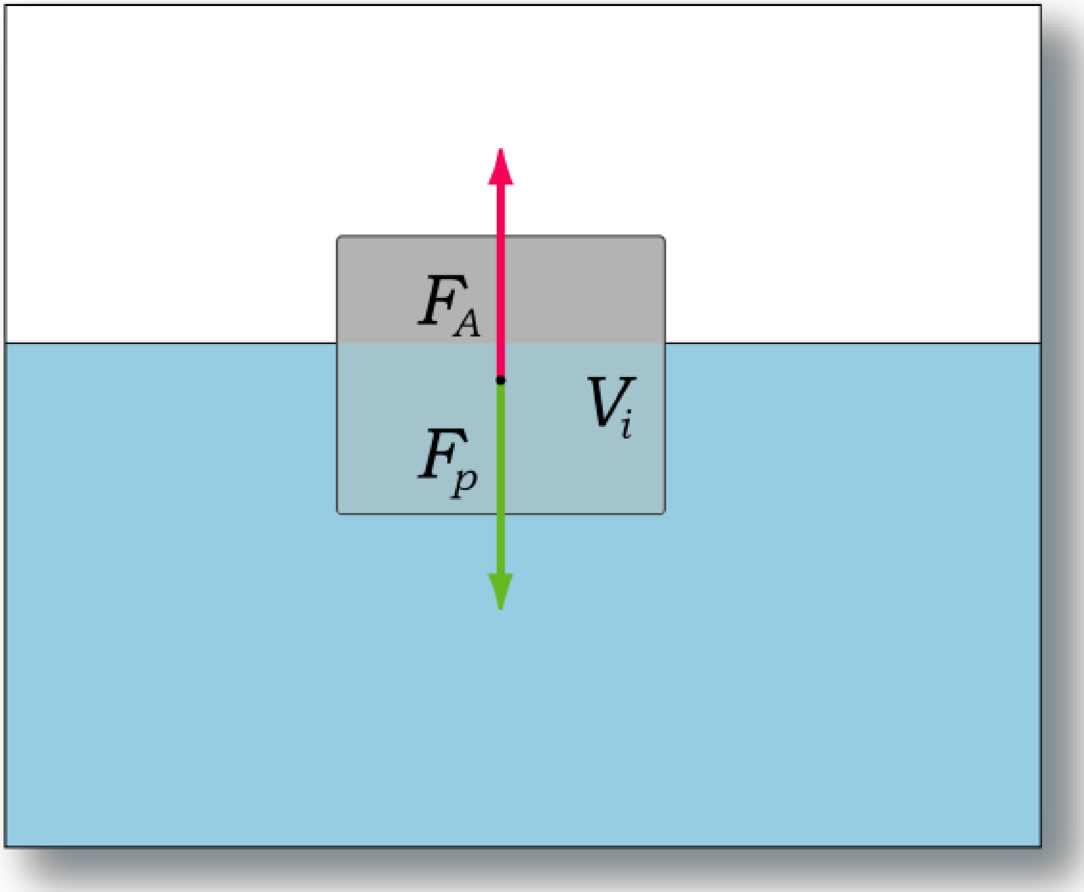
The standard displacement, also known as Washington disp, is a term defined in the Washington Naval Treaty. It is defined as the displacement of the ship complete, fully manned, engined, and equipped ready for sea, including all armament and ammunition, equipment, outfit, provisions and fresh water for crew, miscellaneous stores, and implements of every description that are intended to be carried in war, but without fuel or reserve boiler feed water on board. The omission of fuel and water was to avoid penalizing the British who had greater global reach and required higher fuel loads.

### Light displacement

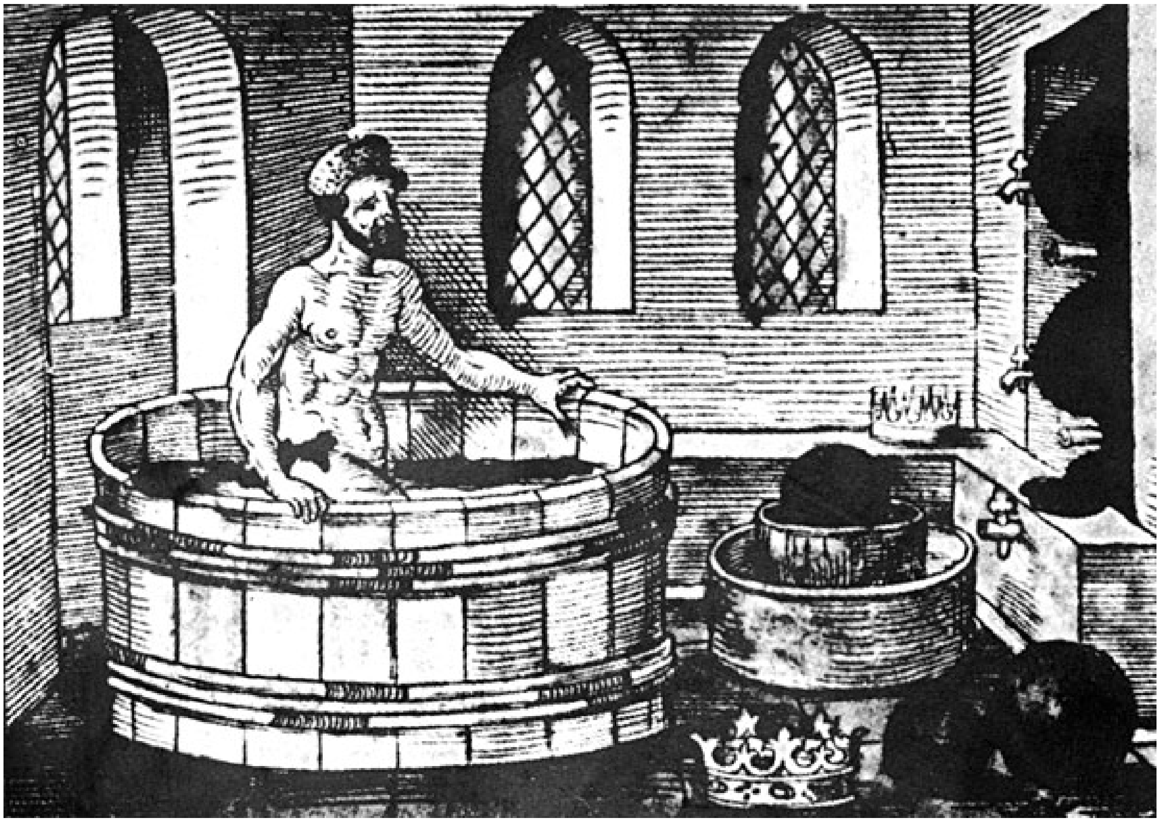
Light displacement is defined as the mass of the ship excluding cargo, fuel, ballast, stores, passengers, crew, but with water in boilers to steaming level.

### Normal displacement

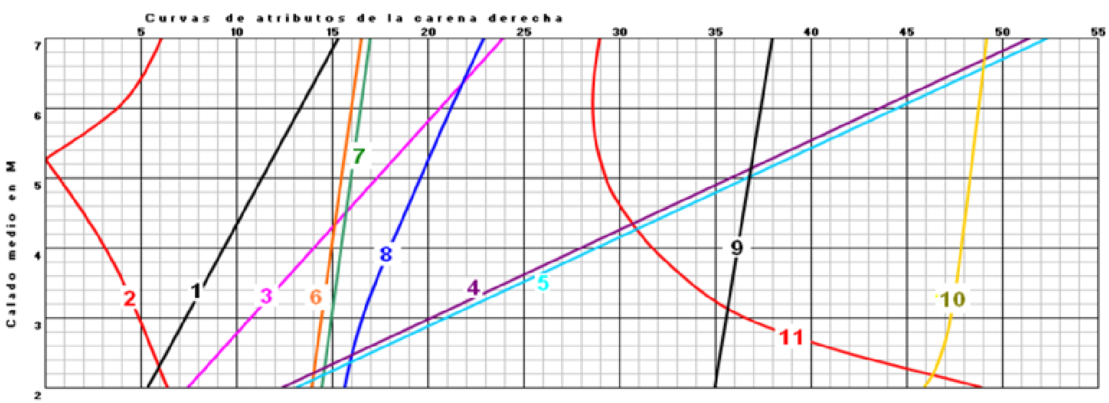
This rare term has been used to mean the ship's displacement "with all outfit, and two-thirds supply of stores, ammunition, etc., on board."




A floating ship's displacement $F_p$ and buoyancy $F_a$ must be equal.



Greek philosopher Archimedes having his famous bath




| | | | |
|---|---|---|---|
| 1 | Altura del centro de carena sobre la LC ( 1cm=0,25 mt) | 6 | Área de flotación (1cm = 100 m2) |
| 2 | Corrección al desplazamiento para 1 cm de asiento (1cm = 0,05 ton) | 7 | Toneladas por centímetro de inmersión (1cm = 1 ton/cm) |
| | | 8 | Momento de asiento unitario (1cm = 5tons/cm) |
| 3 | Área sumergida sección maestra (1cm=5m2) | 9 | Coeficiente prismático (1cm = 0,02) |
| 4 | Desplazamiento en agua dulce (1cm=200 tons) | 10 | Coeficiente de sección maestra (1cm = 0,02) |
| 5 | Desplazamiento en agua salada (1cm=200 tons) | 11 | Altura del metacentro trasversal sobre LC (1cm = 0,25 mt) |

A ship's hydrostatic curves. Lines 4 and 5 are used to convert from mean draft in meters to displacement in tonnes.

**Chapter 7**

# Shipyard

Small shipyard in Klaksvík (Faroe Islands), repairing fishing vessels

Fish ladder and shipyard in Grave, Netherlands

Gdynia Shipyard

Kawasaki Shipbuilding Kobe Shipyard & Machinery Works, Kobe, Japan

Zürichsee-Schifffahrtsgesellschaft in Zürich-Wollishofen, Switzerland

**Shipyards** and **dockyards** are places which repair and build ships. These can be yachts, military vessels, cruise liners or other cargo or passenger ships. Dockyards are sometimes more associated with maintenance and basing activities than shipyards, which are sometimes associated more with initial construction. The terms are routinely used interchangeably, in part because the evolution of dockyards and shipyards has often caused them to change or merge roles.

Countries with large shipbuilding industries include South Korea, Australia, Japan, China, Germany, Turkey, Poland and Croatia. The shipbuilding industry tends to be more fragmented in Europe than in Asia. In European countries there are more smaller companies, compared to the fewer, larger companies in the shipbuilding countries of Asia.

Most shipbuilders in the United States are privately owned, the largest being Northrop Grumman, a multi-billion dollar defense contractor. The publicly owned shipyards in the US are Naval facilities providing basing, support and repair.

Shipyards are constructed by the sea or by tidal rivers to allow easy access for their ships. In the United Kingdom, for example, shipyards were established on the River Thames (King Henry VIII founded yards at Woolwich and Deptford in 1512 and 1513 respectively), River Mersey, River Tees, River Tyne, River Wear and River Clyde - the latter growing to be the World's pre-eminent shipbuilding centre.

Sir Alfred Yarrow established his yard by the Thames in London's Docklands in the late 19th century before moving it northwards to the banks of the Clyde at Scotstoun (1906–08). Other famous UK shipyards include the Harland and Wolff yard in Belfast, Northern Ireland, where the *Titanic* was built, and the naval dockyard at Chatham, England on the Medway in north Kent.

The site of a large shipyard will contain many specialised cranes, dry docks, slipways, dust-free warehouses, painting facilities and extremely large areas for fabrication of the ships.

After a ship's useful life is over, it makes its final voyage to a shipbreaking yard, often on a beach in South Asia. Historically shipbreaking was carried on in drydock in developed countries, but high wages and environmental regulations have resulted in movement of the industry to developing regions.

## *History*

The world's earliest known dockyards were built in the Harappan port city of Lothal circa 2400 BC in Gujarat, India. Lothal's dockyards connected to an ancient course of the Sabarmati river on the trade route between Harappan cities in Sindh and the peninsula of Saurashtra when the surrounding Kutch desert was a part of the Arabian Sea.

Lothal engineers accorded high priority to the creation of a dockyard and a warehouse to serve the purposes of naval trade. The dock was built on the eastern flank of the town, and is regarded by archaeologists as an engineering feat of the highest order. It was located away from the main current of the river to avoid silting, but provided access to ships in high tide as well.

The name of the ancient Greek city of Naupactus means "shipyeard" (combination of the Greek words ναύς *naus* ship, boat and πήγνυμι *pêgnumi*, *pegnymi* builder, fixer). Naupactus' reputation in this field extends to the time of legend, where it is depicted as the place where the Heraclidae built a fleet to invade the Peloponnesus.

In the Spanish city of Barcelona, the Drassanes shipyards were active from at least the mid-13th century until the 18th century, although it as times served as barracks for troops as well as an arsenal. During its time of operation it was continuously changed, rebuilt and modified, but two original towers and part of the original eight construction naves remain today. It is currently a maritime museum.

Ships were the first items to be manufactured in a factory, several hundred years before the Industrial Revolution, in the Venice Arsenal, Venice, Italy. The Arsenal apparently mass produced nearly one ship every day using pre-manufactured parts, and assembly lines and, at its height, employed 16,000 people.

## *Historic shipyards*

Ancient Shipyard of the Seljuks in Alanya, Turkey. The shipyard, consisting of five docks and constructed in 1226 by the Sultan Alaaddin Keykubat, is 56 metres long and 44 metres deep and is the only remaining shipyard from the Seljuks.

- Lothal in Gujarat, India circa 2400 BC to 1900 BC
- Naupactus
- Roman shipyard of Stifone (Narni)
- Blackwall Yard 1614 to 1987
- Shipyard Kraljevica established on 28 April 1729 and still operating yard
- Scotts Shipbuilding & Engineering Co Ltd, Greenock, Scotland, 1711–1984
- Thames Ironworks and Shipbuilding Co. Ltd 1837 to 1912
- John Brown & Company 1851 to 1972
- Gdańsk Shipyard the birthplace of Solidarity Movement - (still a working yard)
- Swan Hunter - (closed in April 2006 and sold to Bharati Shipyards, India's second largest private sector shipbuilder)
- Harland and Wolff - (still a working yard)
- Cammell Laird - (still a working repair yard)
- Blohm + Voss, where the Bismarck was constructed (still a major yard)
- Royal Naval Dockyards in the UK (including Woolwich, Deptford, Chatham, Portsmouth and Devonport), Gibraltar, Bombay, Bermuda, Hong Kong and elsewhere worldwide
- Bethlehem Steel Corporation had 15 shipyards during World War II
    - Staten Island Shipyard 1895
- Charlestown Navy Yard, later Boston Navy Yard, Boston, Massachusetts 1800 to 1974
- Ulstein Verft, Norway, established in 1917 (still a working yard under the Ulstein Group)
- Navy Island, Ontario, Canada - French in the 18th century, then British 1763 to War of 1812
- Mare Island Naval Shipyard, Mare Island, California, 1854 to 1996
- New York Naval Shipyard (NYNSY), also known as the Brooklyn Navy Yard, the New York Navy Yard, and United States Navy Yard, New York 1801 to 1966
- Philadelphia Naval Shipyard 1799 to 1995, at two locations
- San Francisco Naval Shipyard, later Hunters Point Naval Shipyard, then Treasure Island Naval Station Hunters Point Annex, 1941 to 1994
- Potrero Point, San Francisco, California, 1880s - still a working yard
- Long Beach Naval Shipyard, 1943 to 1997
- Golden Horn Shipyard, (Haliç Tersaneleri), Turkey, established in 1455 - still a working yard
- Portsmouth Naval Shipyard, located on Maine-New Hampshire border; Operational: 1800 to present, making it the oldest continuously-operating shipyard of the US Navy.
- Chantiers de l'Atlantique(Aker Yard France) - established in 1861 (still a working yard)
- 3. Maj - One of the largest shipyard in Mediterranean, established in 1892 in Rijeka (still a working yard)

## *Prominent dockyards and shipyards*

- **North America**

- Northrop Grumman Newport News, (formerly Newport News Shipbuilding & Drydock Company) is the largest private ship builder in the US and the one best known for its unique capacity to build the *Nimitz*-class aircraft carriers.
    - Ingalls Shipbuilding, part of Northrop Grumman Ship Systems, located in Pascagoula, Mississippi repaired the USS *Cole* and builds offshore drilling rigs, cruise ships and naval vessels.
    - National Steel and Shipbuilding Company (NASSCO) shipyard in San Diego, California, part of General Dynamics; is the primary shipbuilding location on the west coast of the United States.
- Norfolk Naval Shipyard in Portsmouth, Virginia, is one of the largest shipyards in the world; specializing in repairing, overhauling and modernizing naval ships and submarines. It's the oldest and largest industrial facility that belongs to the United States Navy
- Electric Boat Division (EBDiv) of General Dynamics in Groton, Connecticut with an accessory facility in Quonset Point, Rhode Island, builder of many Naval submarines over the past 100 years, with some types built only here.
- Bath Iron Works (BIW), subsidiary of General Dynamics, is a major American shipyard located on the Kennebec River in Bath, Maine.
- Puget Sound Naval Shipyard in Bremerton, Washington, is also owned by the U.S. Navy. It services ships and submarines from the West Coast.
- The Portland, Oregon shipyard, operated by Cascade General Ship Repair is the largest such facility on the United States West Coast.
- The Louisiana Port is along the Mississippi river. It involves the Bollinger company in St. Rose.

Aerial view of Norfolk Naval Shipyard

- **South America**

(Venezuela) in the city of Puerto Cabello it can be found one of the biggest shipyards of Venezuela, where different diversity of ships are constructed. Also, there are services of reparation and maintenance for ships of different flags.

Brasfels Shipyard - Rio de Janeiro

-
    - SCRA (Construction Refurbishment and Armament Service) with two dry docks, ready for naval and general vessel works.
        - Punta de Lobos (Wolves Point) in west Montevideo, established in 1874.
        - Punta Maua (Maua Point) in east Montevideo, established in 1872.
    - Tsakos Industrias Navales S.A.

- **Europe**

Abdela & Mitchell Shipyards, Brimscombe, Gloucestershire, UK: ‘Contractors To The Admiralty, War Office, India Office And Allied Governments’ 1900-1925. According to research in 2009 the legendary riverboat which starred in the 1951 John Huston movie *The African Queen* was built at the Abdela & Mitchell Brimscombe (Stroud) works around 1912. The yards were owned by Marine architect Isaac J. Abdela. Larger boats built at the Abdela Brimscombe yards were two-deck, galvanised steel, light draught passenger and cargo steamers for South America, including the Islandia of 1903, Humaytha, San Juan and Santa Rosa. The Abdela river-boats were highly-regarded for their elegance and beauty.

Girvan shipyard, Ayrshire, Scotland

- 
    - BAE Systems Surface Ships operates three shipbuilding yards in the United Kingdom; Portsmouth, England and Scotstoun and Govan on the River Clyde in Glasgow, Scotland. Major projects include the Type 45 destroyer and the *Queen Elizabeth* class aircraft carriers.
    - BAE Systems Submarine Solutions operates a major shipyard at Barrow-in-Furness in Cumbria, England. It is one of the few yards in the world capable of building nuclear submarines such as the Royal Navy's *Vanguard* class. This division has built surface ships in the past and will manufacture blocks of the *Queen Elizabeth* class.
    - Devonport Dockyard , located in the city of Plymouth, England in the county of Devon is the largest naval base in Western Europe. It has 15 dry docks, four miles (6 km) of waterfront, 25 tidal berths, five basins and covers 650 acres (2.6 km²). It is the main refitting base for Royal Navy nuclear submarines and also handles work on frigates. It is the base for seven of the Trafalgar class nuclear powered hunter-killer submarines and many frigates, exploiting its convenient access to the Atlantic Ocean. It supports the Vanguard class Trident missile nuclear ballistic missile submarines in a custom-built refitting dock. It houses the HMS *Courageous*, a nuclear powered submarine used in the Falklands War and open to the general public . Facilities in the local area also include a major naval training establishment and a base for the Royal Marines.
    - SOBRENA located in the city of Brest, FRANCE, on the western entrance to the English Channel operates 3 drydocks (up to 420 x 80 m)

- **East Asia**

- Hyundai Heavy Industries Ulsan Shipyard, in South Korea, is currently the largest in the world and has the capability to build a variety of vessels including Commercial Cargo, Offshore and Naval vessels.
- Yantai Raffles Shipyard is the largest offshore builder in China located in Yantai. Its predominant feature is the 20,000 ton crane Taisun, holder of the Heavy Lift World Record. Yantai Raffles' portfolio includes offshore platforms, pipe lay and other specialized vessels.

- **South Asia**
    - Northstar Shipyard is one of the leading shipyard in India for small & Mid size ships, barges, oil tankers, tugs, etc.
    - [**Sulkha Shipyard**, is 500 year Old Ship builder who are specialized in build cargo vessels, Pleasure Yachts, Supply boats, Tugs, Patrol boats and Fishing trawlers, ferry boats, *in steel, Fiberglass and Wood*]

    -
    - Cochin Shipyard is the largest shipyard in India. Currently an aircraft carrier, the Indigenous aircraft carrier (IAC) is under construction at Cochin shipyard.
    - Garden Reach Shipbuilders and Engineers is located in India. It is owned by the Government of India and is constructing the Shardul class Large landing ship tank for the Indian Navy.
    - Karachi Shipyard is the only shipbuilding company in Pakistan located in Karachi. It has built numerous cargo ships, tugboats and support vessels, Naval vessels, submarines and Frigates.
    - Mazagaon Dockyard, operated by state-owned Mazagaon Dock Limited, is one of India's largest shipyards. It constructs a variety of ships both for the defence and civilian sector. The dockyard is known for constructing Britain's HMS *Trincomalee*. Currently the shipyard is building three Shivalik class frigates and three Kolkata class destroyers for the Indian Navy.
    - The beach at Alang in the Indian state of Gujarat is the site of a large complex of shipbreaking yards which processes 50% of the ships that are salvaged.

## Chapter 8

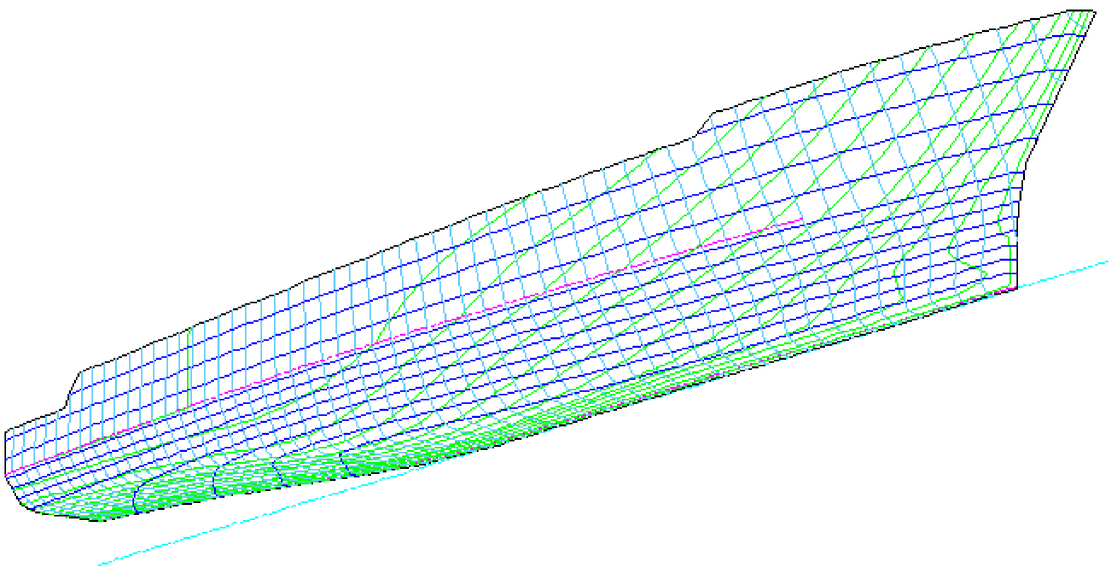
# Hull (Watercraft)

Half-hull of the 46-gun ship of the line *Tigre*, build from 1724 in Toulon after plans by Blaise Coulomb

A **hull** is the watertight body of a ship or boat. Above the hull is the superstructure and/or deckhouse, where present. The line where the hull meets the water surface is called the waterline.

The structure of the hull varies depending on the vessel type. In a typical modern steel ship, the structure consists of watertight and non-tight decks, major transverse and longitudinal members called watertight (and also sometimes non-tight) bulkheads, intermediate members such as girders, stringers and webs, and minor members called ordinary transverse frames, frames, or longitudinals, depending on the structural arrangement. The uppermost continuous deck may be called the "upper deck," "weather deck," "spar deck," "main deck" or simply "deck." The particular name given depends on the context--the type of ship or boat, the arrangement, or even the area where it sails. Not all hulls are decked (for instance a dinghy).

In a typical wooden sailboat, the hull is constructed of wooden planking, supported by transverse frames (often referred to as ribs) and bulkheads, which are further tied together by longitudinal stringers or ceiling. Often but not always there is a centerline longitudinal member called a keel. In fiberglass or composite hulls, the structure may resemble wooden or steel vessels to some extent, or be of a monocoque arrangement. In many cases, composite hulls are built by sandwiching thin fiber-reinforced skins over a lightweight but reasonably rigid core of foam, balsa wood, impregnated paper honeycomb or other material.



*"Hull Form"*

### General features

The shape of the hull is entirely dependent upon the needs of the design. Shapes range from a nearly perfect box in the case of scow barges, to a needle-sharp surface of revolution in the case of a racing multihull sailboat. The shape is chosen to strike a balance between cost, hydrostatic considerations (accommodation, load carrying and stability) and hydrodynamics (speed, power requirements, and motion and behavior in a seaway).

### Hull shapes

Hulls come in many varieties and can have composite shape, (e.g., a fine entry forward and inverted bell shape aft), but are grouped primarily as follows:

- Moulded, round bilged or soft-chined. Examples are the round bilge, semi-round bilge and s-bottom hull.

*defined as smooth curves*

- Chined and Hard-chined. Examples are the flat-bottom (chined), v-bottom and multi-bottom hull (hard chined).

## Categorisation

After this they can be categorized as:

- Displacement

*the hull is supported exclusively or predominantly by buoyancy. They travel through the water at a limited rate which is defined by the waterline length. They are often heavier than planing types, though not always.*

- Semi-displacement, or semi-planing

*the hull form is capable of developing a moderate amount of dynamic lift, however, most of the vessel's weight is still supported through buoyancy*

- Planing

Royal Navy World War II MTB planing at speed on calm water showing its Hard chine hull - note how most of the forepart of the boat is out of the water
*the planing hull form is configured to develop positive dynamic pressure so that its draft decreases with increasing speed. The dynamic lift reduces the wetted surface and therefore also the drag. They are sometimes flat-bottomed, sometimes V-bottomed and sometimes round-bilged. The most common form is to have at least one chine, which makes for more efficient planing and can throw spray down. Planing hulls are more efficient at higher speeds, although they still require more energy to achieve these speeds.* (see: Planing (sailing), Hull speed).

## Most used hull forms

At present, the most widely used form is the round bilge hull.

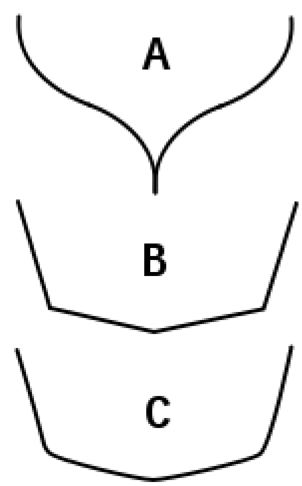
The inverted bell shape of the hull, with smaller payload the waterline cross-section is less, hence the resistance is less and the speed is higher. With higher payload the outward bend provides smoother performance in waves. As such, the inverted bell shape is a popular form used with planing hulls.

## Hull forms

**Smooth curve hulls**

Smooth curve hulls are hulls which use, just like the curved hulls, a sword or an attached keel.

Semi round bilge hulls are somewhat less round. The advantage of the semi-round is that it is a nice middle between the S-bottom and chined hull. Typical examples of a semi-round bilge hull can be found in the Centaur and Laser cruising dinghies.




(A) S-bottom hull compared to a
(B) hard and
(C) soft chine hull

S-bottom hulls are hulls shaped like an s. In the s-bottom, the hull runs smooth to the keel. As there are no sharp corners in the fuselage. Boats with this hull have a fixed keel, or a *kielmidzwaard*. This is a short keel which still sticks a sword. Examples of cruising dinghies that use this s-shape are the yngling and Randmeer.

**Chined and hard-chined hulls**

A chined hull consists of straight plates, which are set at an angle to each other. The chined hull is the most simple hull shape because it works with only straight planks. These boards are often bent lengthwise. Most home-made constructed boats are chined hull boats. Benefits of this type of boating activity is the low production cost and the (usually) fairly flat bottom, making the boat faster at planing. Chined hulls can also make use of a daggerboard or attached keel.

Chined hulls can be divided up into 3 shapes:

- V-bottom chined hulls
- Flat-bottom chined hulls
- Multi-chined hulls.

## *Appendages*

- A protrusion below the waterline forward is called a bulbous bow and is fitted on some hulls to reduce the wave making resistance drag and thus increase fuel efficiency. Bulbs fitted at the stern are less common but accomplish a similar task.

- A keel may be fitted on a hull to increase the transverse stability, directional stability or to create lift.

- Control devices such as a rudder, trim tabs or stabilizing fins may be fitted.

## *Terms*

**Bow** is the frontmost part of the hull

**Stern** is the rear-most part of the hull

**Port** is the left side of the boat when facing the Bow

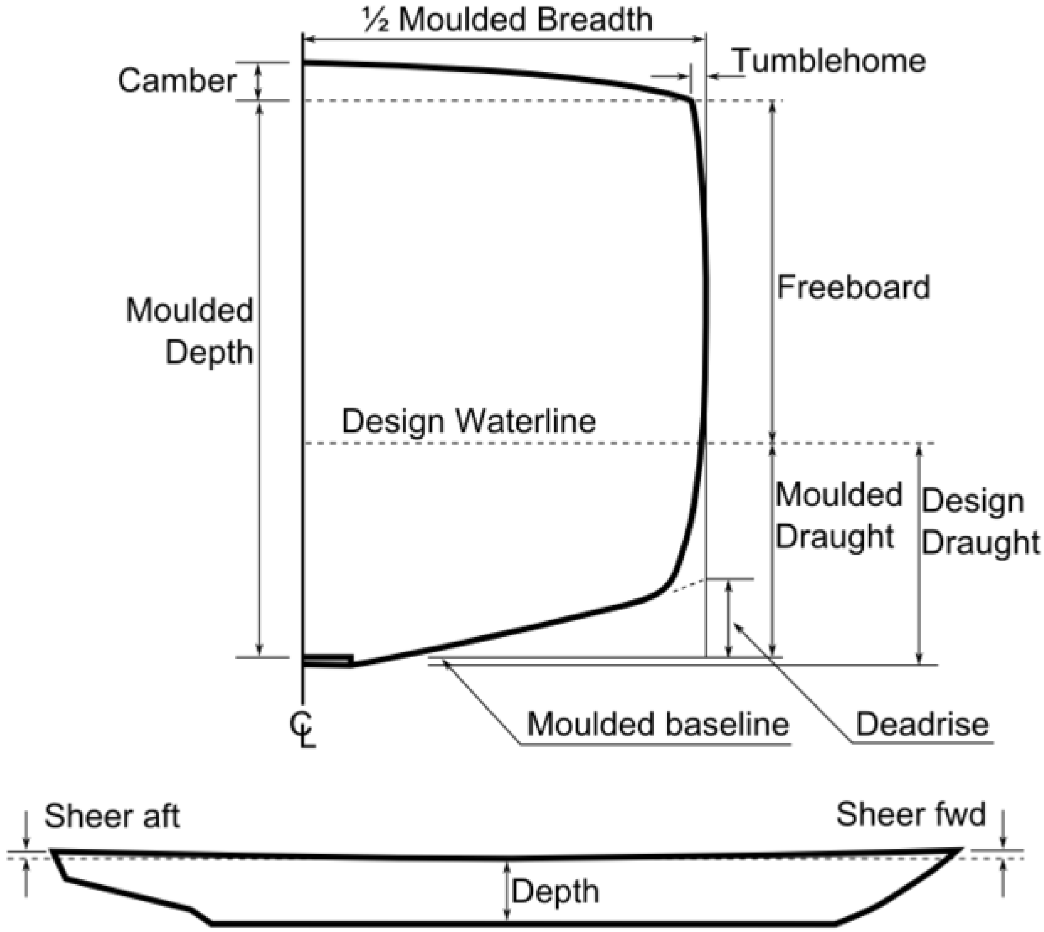
**Starboard** is the right side of the boat when facing the Bow

**Waterline** is an imaginary line circumscribing the hull that matches the surface of the water when the hull is not moving.

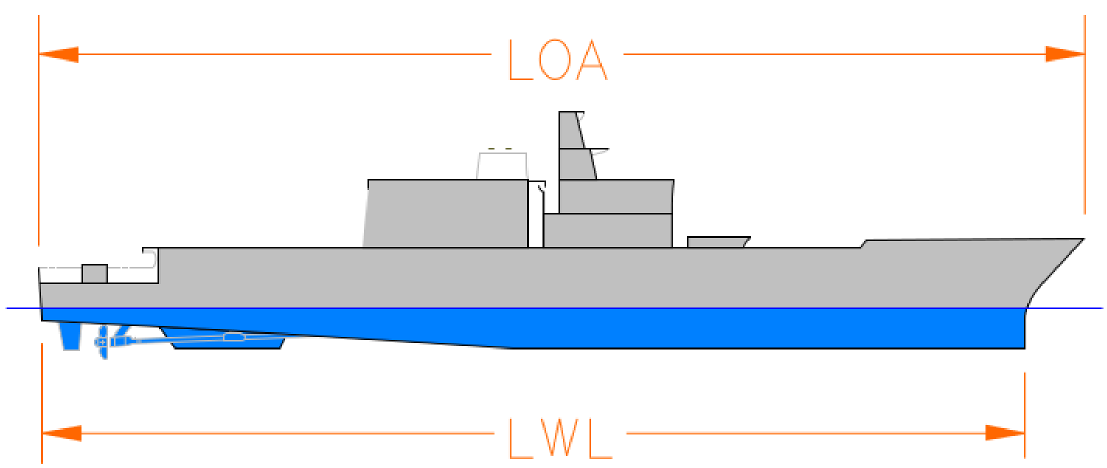
**Midships** is the midpoint of the LWL. It is half-way from the forwardmost point on the waterline to the rear-most point on the waterline.

**Baseline** an imaginary reference line used to measure vertical distances from. It is usually located at the bottom of the hull.

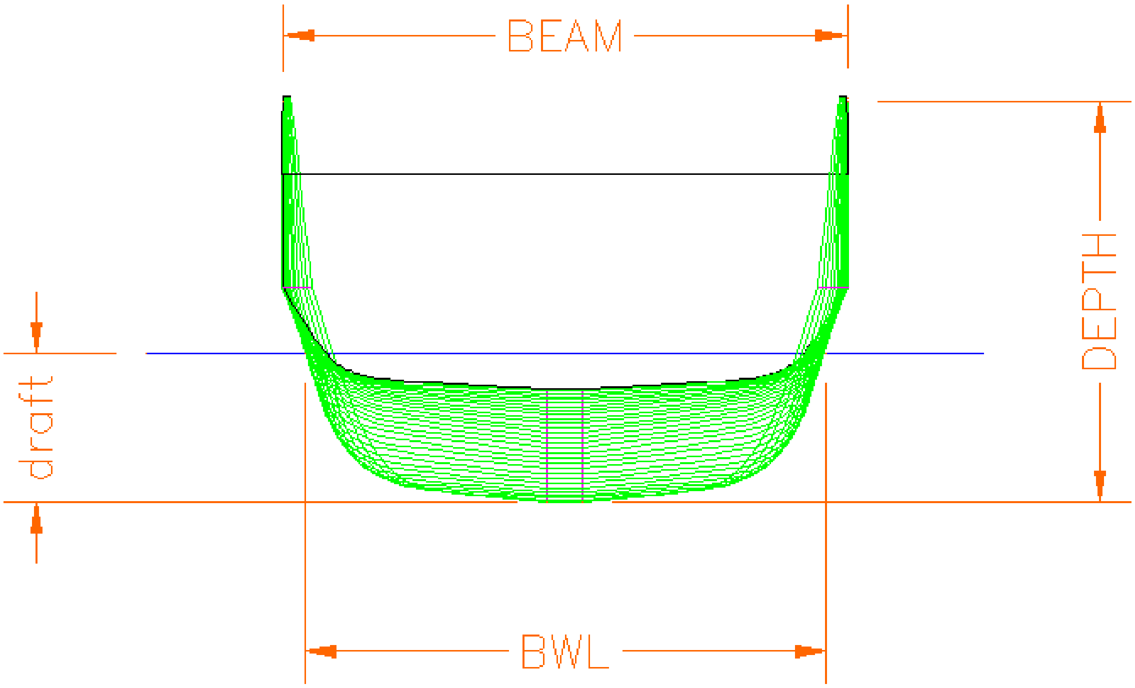
### ***Metrics***




Principal hull measurements




*"LWL & LOA"*




*"Beam, draft & Depth"*

Hull forms are defined as follows:

- **Block Measures** that define the principal dimensions. They are:

- Length overall (**LOA**) is the extreme length from one end to the other.
- Length at the waterline (**LWL**) is the length from the forwardmost point of the waterline measured in profile to the stern-most point of the waterline.
- Length Between Perpendiculars (**LBP** or **LPP**) is the length of the summer load waterline from the stern post to the point where it crosses the stem.
- Beam or breadth (**B**) is the width of the hull. (ex: BWL is the maximum beam at the waterline)
- Depth or moulded depth (**D**) is the vertical distance measured from the top of the keel to the underside of the upper deck at side.
- Draft (**d**) or (**T**) is the vertical distance from the bottom of the hull to the waterline.
- Freeboard (**FB**) is the difference between **Depth** and **draft**.

- **Form Derivatives** that are calculated from the shape and the Block Measures. They are:

- Volume (**V** or $\nabla$) is the volume of water displaced by the hull.
- Displacement (**Δ**) is the weight of water equivalent to the immersed volume of the hull.
- Longitudinal Centre of Buoyancy (**LCB**) is the longitudinal distance from a point of reference (often Midships) to the centre of the displaced volume of water when the hull is not moving. Note that the Longitudinal Centre of Gravity or centre of the weight of the vessel must align with the LCB when the hull is in equilibrium.
- Vertical Centre of Buoyancy (**VCB**) is the vertical distance from a point of reference (often the Baseline) to the centre of the displaced volume of water when the hull is not moving.
- Longitudinal Centre of Floatation (**LCF**) is the longitudinal distance from a point of reference (often Midships) to the centre of the area of waterplane when the hull is not moving. This can be visualized as being the area defined by the water's surface and the hull.

- **Coefficients** help compare hull forms as well:

1) Block Coefficient (**$C_b$**) is the volume (V) divided by the LWL x BWL x T. If you draw a box around the submerged part of the ship, it is the ratio of the box volume occupied by the ship. It gives a sense of how much of the block defined by the $L_{pp}$, beam (B) & draft (T) is filled by the hull. Full forms such as oil tankers will have a high $C_b$ where fine shapes such as sailboats will have a low $C_b$.

$$C_b = \frac{V}{L_{pp} \cdot B \cdot T}$$

2) Midship Coefficient (**$C_m$** or **$C_x$**) is the cross-sectional area ($A_x$) of the slice at Midships (or at the largest section for $C_x$) divided by beam x draft. It displays the ratio of the largest underwater section of the hull to a rectangle of the same overall width and depth as the underwater section of the hull. This defines the fullness of the underbody. A low Cm indicates a cut-away mid-section and a high Cm indicates a boxy section shape. Sailboats have a cut-away mid-section with low $C_x$ whereas cargo vessels have a boxy section with high $C_x$ to help increase the $C_b$.

$$C_m = \frac{A_m}{B \cdot T}$$

3) Prismatic Coefficient (**$C_p$**) is the volume (V) divided by $L_{pp}$ x $A_x$. It displays the ratio of the underwater volume of the hull to a rectangular block of the same overall length as the underbody and with cross-sectional area equal to the largest underwater section of the hull. This is used to evaluate the distribution of the volume of the underbody. A low Cp indicates a full mid-section and fine ends, a high Cp indicates a boat with fuller ends. Planing hulls and other highspeed hulls tend towards a higher $C_p$. Efficient displacement hulls travelling at a low Froude number will tend to have a low $C_p$.

$$C_p = \frac{V}{L_{pp} \cdot A_m}$$

4) Waterplane Coefficient (**$C_w$**) is the waterplane area divided by $L_{pp}$ x B. The waterplane coefficient expresses the fullness of the waterplane, or the ratio of the waterplane area to a rectangle of the same length and width. A low $C_w$ figure indicates fine ends and a high $C_w$ figure indicates fuller ends. High $C_w$ improves stability as well as handling behavior in rough conditions.

$$C_w = \frac{A_w}{L_{pp} \cdot B}$$

**Note:**

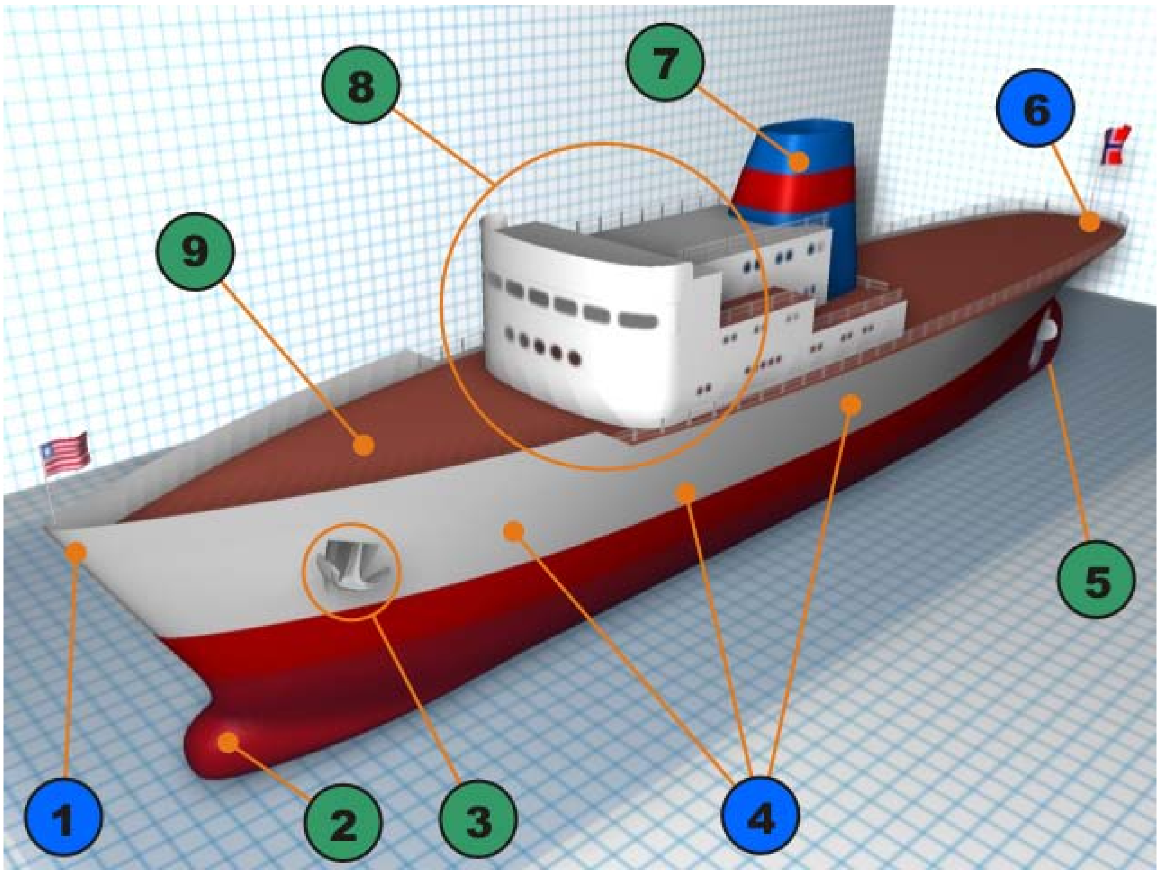
$$C_b = C_p \cdot C_m$$

## *History*

Rafts have a hull of sorts, however, hulls of the earliest design are thought to have each consisted of a hollowed out tree bole: in effect the first canoes. Hull form then proceeded to the Coracle shape and on to more sophisticated forms as the science of Naval architecture advanced.

Chapter 9

# Net Tonnage




Net tonnage is calculated by measuring a ship's internal volume and applying mathematical formulae.

**Net tonnage** (often abbreviated as **NT**, **N.T.** or **nt**) is a calculated representation of a the internal volume of a ship's cargo holds. It is expressed in "tons", which are units of volume defined as 100 cubic feet (~2.83 m³). The "ton" as a unit of volume should not be confused with the far more common "ton" as a unit of weight or mass. Net tonnage is not a measure of the ship's weight or displacement and should not be confused with terms such as deadweight tonnage, net register tonnage, or displacement.

Net tonnage, along with gross tonnage, was defined by *The International Convention on Tonnage Measurement of Ships, 1969*, adopted by the International Maritime Organization in 1969, and came into force on July 18, 1982. These two measurements replaced gross register tons (grt) and net register tons (nrt). Net tonnage is calculated based on "of the moulded volume of all cargo spaces of the ship" and is used to determine things such as a ship's port dues.

## History

The International Convention on Tonnage Measurement of Ships, 1969 was adopted by IMO in 1969. The Convention mandated a transition from the former measurements of net register tons (nrt) and gross register tons (grt) to net tons (NT) and gross tons (GT) . It was the first successful attempt to introduce a universal tonnage measurement system.

Various methods were previously used to calculate merchant ship tonnage, but they differed significantly and one single international system was needed. All previous methods traced back to George Moorsom of Great Britain's Board of Trade who devised one such method in 1854.

The rules apply to all ships built on or after July 18, 1982. Ships built before that date were given 12 years to migrate from their existing tonnage to use of NT and NGT. The phase-in period was provided to allow ships time to adjust economically, since tonnage is the basis for satisfying manning regulations and safety rules. Tonnage is also the basis for calculating registration fees and port dues. One of the Convention's goals was to ensure that the new units "did not differ too greatly" from the traditional GRT and NRT units.

Both NT and GT are obtained by measuring ship's volume and then applying a mathematical formula. Net tonnage is based on "the moulded volume of all cargo spaces of the ship where gross tonnage is based on "the moulded volume of all enclosed spaces of the ship"." In addition, a ship's net tonnage is constrained to be no less than 30% of her gross tonnage.

## Calculation

### Choice of draft value

The net tonnage calculation is based on a number of factors, one of which is the moulded draft $d$. The choice of the value to use for $d$ can be complicated. For ships subject to the International Convention on Load Lines, the Summer Load Line draft is used, with the exception of cases where that is a timber load line. For passenger ships, the draft used is the deepest subdivision load line assigned in accordance with the International Convention for the Safety of Life at Sea. Otherwise, if a ship has been assigned a load line by its national government, the draft for that summer load line is used. If the ship has no load line, instead, a maximum draft assigned by its national government, that value is used, if it has been assigned a maximum. Finally, for a ship to which none of the above applies, the value of $d$ is taken as 75 per cent of the moulded depth amidships.

## 12 or fewer passengers

The Net tonnage calculation is defined in Regulation 4 of Annex 1 of *The International Convention on Tonnage Measurement of Ships, 1969*. It is based on two main variables:

- $V_c$, the total volume of the ship's cargo spaces in cubic meters ($m^3$), and
- $d$, the ship's moulded draft amidships in meters,

The first step in calculating NT is to find the value known as $K_2$, a multiplier based on $V_c$. It is obtained by using the following formula:

$$K_2 = 0.2 + 0.02 \times \log_{10}(V_c)$$

And then these three values are used to calculate NT using this formula:

$$NT = V_c \times K_2 \times 4d^2$$

Where the factor $4d^2$ will not exceed 1, the term $V_c \times K_2 \times 4d^2$ will not be less than 0.25 GT, and the final value of NT shall not be taken as less than 0.30 GT.

## 13 or more passengers

When calculating NT for ships certified to carry 13 or more passengers, an additional term is used in the NT formula. It is based on three additional variables:

- $GT$, the ship's gross tonnage,
- $N_1$, number of passengers in cabins with not more than 8 berths, and
- $N_2$, number of other passengers,

First, a multiplier $K_3$, based on the ship's gross tonnage is found,

$$K_3 = \frac{1.25 \times (GT + 10000)}{10000}$$

Then the net tonnage is calculated:

$$NT = V_c \times K_2 \times 4d^2 + K_3 \times (N_1 + N_2)$$

Where the factor $4d^2$ will not exceed 1, the term $V_c \times K_2 \times 4d^2$ will not be less than 0.25 GT, and the final value of NT shall not be taken as less than 0.30 GT.

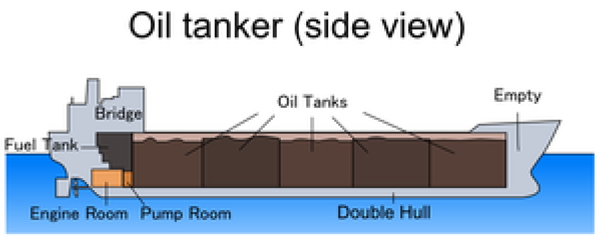
The difference between the cases of 12 of fewer passengers and 13 or more passengers is due to a restriction given in the net tonnage definition that states "...when $N_1 + N_2$ is less than 13, $N_1$ and $N_2$ shall be taken as zero."

## Chapter 10

# Oil Tanker

The commercial oil tanker *AbQaiq*, in ballast

| Class overview | |
|---|---|
| Name: | Oil tanker |
| Subclasses: | Handysize, Panamax, Aframax, Suezmax, Very Large Crude Carrier (VLCC), Ultra Large Crude Carrier (ULCC) |
| Built: | *c.* 1863–present |
| In service: | 4,024 (above 10,000 long tons deadweight (DWT)). |
| **General characteristics** | |
| Class and type: | Tank ship |
| Capacity: | up to 550,000 DWT |
| Notes: | Rear house, full hull, midships pipeline |




An **oil tanker**, also known as a **petroleum tanker**, is a ship designed for the bulk transport of oil. There are two basic types of oil tankers: the **crude tanker** and the **product tanker**. Crude tankers move large quantities of unrefined crude oil from its point of extraction to refineries. Product tankers, generally much smaller, are designed to move petrochemicals from refineries to points near consuming markets.

Oil tankers are often classified by their size as well as their occupation. The size classes range from inland or coastal tankers of a few thousand metric tons of deadweight (DWT) to the mammoth **ultra large crude carriers** (**ULCCs**) of 550,000 DWT. Tankers move approximately 2,000,000,000 metric tons ($2.2\times10^9$ short tons) of oil every year. Second only to pipelines in terms of efficiency, the average cost of oil transport by tanker amounts to only two or three United States cents per 1 US gallon (3.8 L).

Some specialized types of oil tankers have evolved. One of these is the naval replenishment oiler, a tanker which can fuel a moving vessel. Combination ore-bulk-oil carriers and permanently moored floating storage units are two other variations on the standard oil tanker design. Oil tankers have been involved in a number of damaging and high-profile oil spills. As a result, they are subject to stringent design and operational regulations.

## *History*

The *Falls of Clyde* is the oldest surviving American tanker and the world's only surviving sail-driven oil tanker.

The technology of oil transportation has evolved alongside the oil industry. Although man's use of oil reaches to prehistory, the first modern commercial exploitation dates back to James Young's manufacture of parafin in 1850. In these early days, oil from Upper Burma was moved in earthenware vessels to the river bank where it was then poured into boat holds.

In the 1850s, the Pennsylvania oil fields became a major supplier of oil, and a center of innovation after Edwin Drake had struck oil near Titusville, Pennsylvania. The first oil well in the United States was dug here in 1859, initially yielding around ten barrels per day. Within two years, the Titusville field was providing 3,000 barrels per day. By this time, petroleum oil had already begun to supplant fish, whale, and vegetable oils for applications such as indoor and outdoor lighting, and transatlantic export had already begun.

Break-bulk boats and barges were originally used to transport Pennsylvania oil in 40-US-gallon (150 l) wooden barrels. But transport by barrel had several problems. The first problem was weight: the standard empty barrel weighed 64 pounds (29 kg), representing 20% of the total weight of a full barrel. Other problems with barrels were their expense, their tendency to leak, and the fact that they were generally used only once. The expense was significant, for example, in the early years of the Russian oil industry, barrels accounted for half the cost of petroleum production.

The movement of oil in bulk was attempted in many places and in many ways. Modern oil pipelines have existed since 1860. In 1863, two sail-driven tankers were built on England's River Tyne. These were followed in 1873 by the first oil-tank steamer, the *Vaderland*, which was built by Palmers Shipbuilding and Iron Company for Belgian owners. The vessel's use was curtailed by U.S. and Belgian authorities citing safety concerns. By 1871, the Pennsylvania oil fields were making limited use of oil tank barges and cylindrical railroad tank-cars similar to those in use today.

## The Nobel Brothers

In 1876, Ludvig and Robert Nobel, brothers of Alfred Nobel, founded Branobel (short for Brothers Nobel) in Baku, Azerbaijan. It was, during the late 19th century, one of the largest oil companies in the world.

Ludvig was a pioneer in the development of early oil tankers. He first experimented with carrying oil in bulk on single-hulled barges. Turning his attention to self-propelled tankships, he faced a number of challenges. A primary concern was to keep the cargo and fumes well away from the engine room to avoid fires. Other challenges included allowing for the cargo to expand and contract due to temperature changes, and providing a method to ventilate the tanks.

The world's first successful oil tanker was Nobel's *Zoroaster*. He designed this ship in Gothenburg, Sweden, with Sven Almqvist. The contract to build it was signed in January 1878, and it made its first run later that year from Baku to Astrakhan. The *Zoroaster* design was widely studied and copied, with Nobel refusing to patent any part of it. In October 1878, he ordered two more tankers of the same design: the *Buddha* and the *Nordenskjöld*.

*Zoroaster* carried its 242 long tons of kerosene cargo in two iron tanks joined by pipes. One tank was forward of the midships engine room and the other was aft. The ship also featured a set of 21 vertical watertight compartments for extra buoyancy. The ship had a length overall of 184 feet (56 m), a beam of 27 feet (8.2 m), and a draft of 9 feet (2.7 m). Unlike later Nobel tankers, the *Zoroaster* design was built small enough to sail from Sweden to the Caspian by way of the Baltic Sea, Lake Ladoga, Lake Onega, the Rybinsk and Mariinsk Canals and the Volga River.

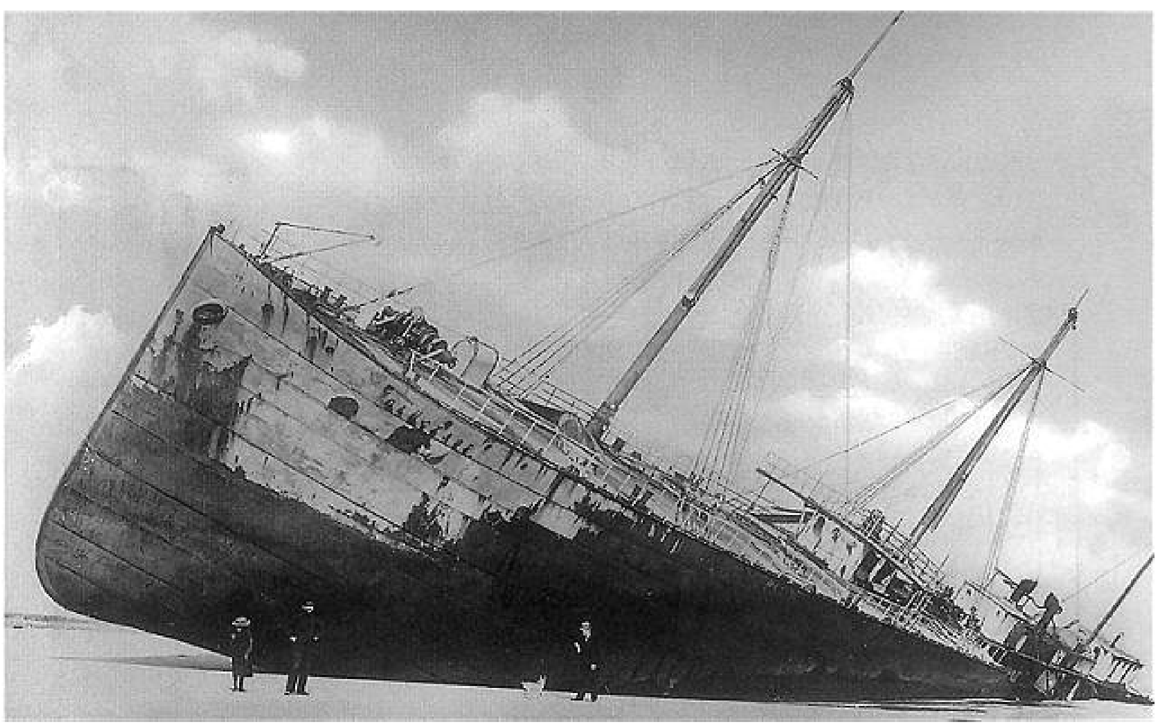
Nobel then began to adopt a single-hull design, where the ship's hull forms part of its tank structure. In November 1880, he ordered his first single-hulled tanker, the *Moses*. Within a year, he ordered seven more single-hulled tankers: the *Mohammed*, *Tatarin*, *Bramah*, *Spinoza*, *Socrates*, *Darwin*, *Koran*, *Talmud*, and *Calmuck*.

Branobel experienced one of the first oil tanker disasters. In 1881, the *Zoroaster's* sister-ship, the *Nordenskjöld* exploded in Baku while taking on kerosene. The pipe carrying the cargo was jerked away from the hold when the ship was hit by a gust of wind. Kerosene then spilled onto the deck and down into the engine room, where mechanics were working in the light of kerosene lanterns. The ship then exploded, killing half the crew.

Nobel responded to the disaster by creating a flexible, leak proof loading pipe which was much more resistant to spills.

In 1883, oil tanker design took a large step forward. Working for the Nobel company, Colonel Henry F. Swan designed a set of three Nobel tankers. Instead of one or two large holds, Swan's design used several holds which spanned the width, or beam, of the ship. These holds were further subdivided into port and starboard sections by a longitudinal bulkhead. Earlier designs suffered from stability problems caused by the free surface effect, where oil sloshing from side to side could cause a ship to capsize. But this approach of dividing the ship's storage space into smaller tanks virtually eliminated free-surface problems. This approach, almost universal today, was first used by Swan in the Nobel tankers *Blesk*, *Lumen*, and *Lux*.

In 1903, the Nobel brothers built two oil tankers which ran on internal combustion engines, as opposed to the older steam engines. The *Vandal*, the first diesel-electric ship, was capable of carrying 750 long tons of refined oil was powered by three 120 horsepower (89 kW) diesel motors. The larger *Sarmat* employed four 180 h.p. engines. The first seagoing diesel-powered tanker, 4,500 ton *Mysl*, was built by Nobel's competitors in Kolomna. Nobel responded with *Emanuel Nobel* and *Karl Hagelin*, 4,600 long ton kerosene tankers with 1,200 horsepower (890 kW) engines.



23/24-3-1893 The *Glückauf* grounded in heavy fog at Blue Point Beach on Fire Island.

The *Glückauf* represented a large step forward in tanker design. Another design of Colonel Swan, the ship has been called the "true progenitor of all subsequent tanker tonnage." Its features included cargo valves operable from the deck, cargo main piping, a vapor line, cofferdams for added safety, and the ability to fill a ballast tank with seawater when empty of cargo. Wilhelm Anton Riedemann, an agent for the Standard Oil Company purchased *Glückauf* and several of her sister ships. After the *Glückauf* was lost in 1893, Standard Oil purchased the sister ships.

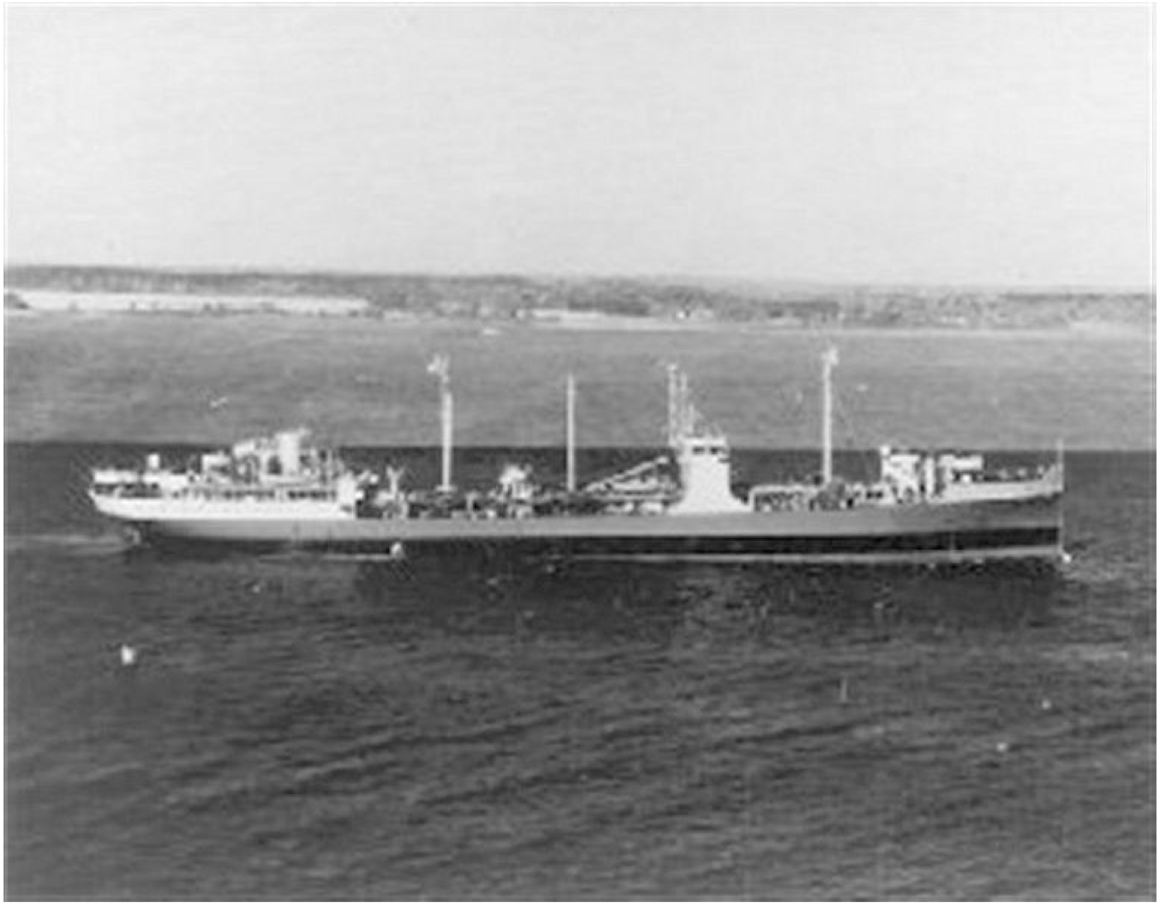
## Breaking the Standard Oil monopoly

The 1880s also saw the beginnings of the Asian oil trade. The idea that led to moving Russian oil to the Far East via the Suez Canal was the brainchild of two men: importer Marcus Samuel and shipowner/broker Fred Lane. Prior bids to move oil through the canal had been rejected by the Suez Canal Company as being too risky. Samuel approached the problem a different way: asking the company for the specifications of a tanker it would allow through the canal.

Armed with the canal company's specifications, Samuel ordered three tankers from William Gray in northern England. Named the *Murex*, the *Conch* and the *Clam*, each had a capacity of 5,010 long tons of deadweight. These three ships were the first tankers of the Tank Syndicate, forerunner of today's Royal Dutch Shell company.

With facilities prepared in Jakarta, Singapore, Bangkok, Saigon, Hong Kong, Shanghai, and Kobe, the fledgling Shell company was ready to become Standard Oil's first challenger in the Asian market. On August 24, 1892, the *Murex* became the first tanker to pass through the Suez Canal. By the time Shell merged with Royal Dutch Petroleum in 1907, the company had 34 steam-driven oil tankers, compared to Standard Oil's four case-oil steamers and 16 sailing tankers.

## World War I



Underway replenishment was pioneered aboard the USS *Maumee*

The fleet oiler USS *Maumee*, launched on April 17, 1915, pioneered the technique of underway replenishment. A large ship at the time, with a capacity of 14,500 long tons of deadweight, *Maumee* began refuelling destroyers *en route* to Britain at the outset of World War I. This technique enabled the Navy to keep its fleets at sea for extended periods, with a far greater range independent of the availability of a friendly port. This independence proved crucial to victory in World War II by the ships commanded by Fleet Admiral Nimitz who, as *Maumee*'s executive officer, had played a key role in developing underway replenishment.

Underway replenishment was quickly adopted by other navies. One example of this is the Australian fleet oiler HMAS *Kurumba* which provided underway replenishment services in the United Kingdom's Royal Navy from 1917 to 1919.

During World War I, unrestricted submarine warfare caused a shortage of tankers. The United States ambassador to the United Kingdom, Walter Hines Page, wrote:

The submarines are sinking freight ships faster than freight ships are being built by the whole world. In this way, too, then, the Germans are succeeding. Now if this goes on long enough, the Allies' game is up. For instance, they have lately sunk so many fuel oil ships, that this country may very soon be in a perilous condition—even the Grand Fleet may not have enough fuel.

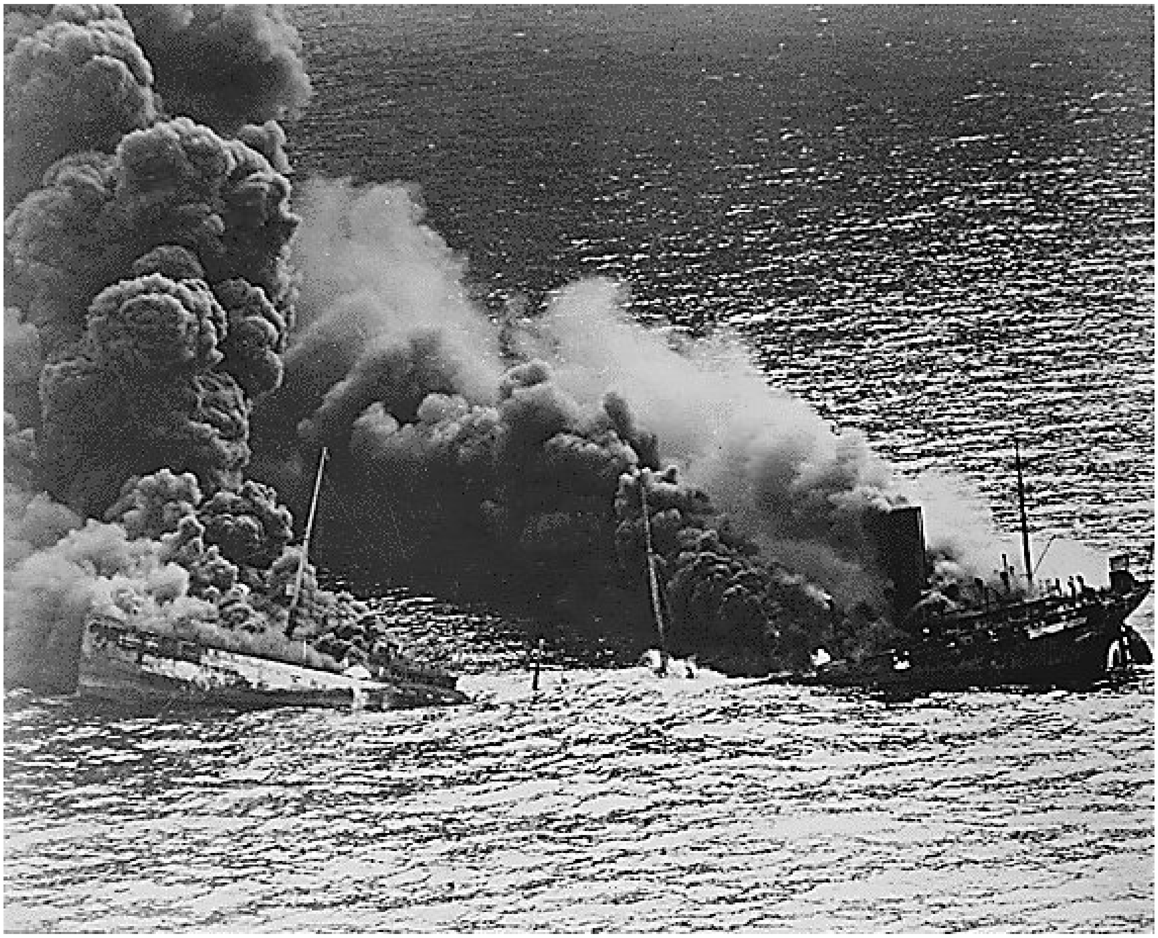
Georges Clemenceau wrote to US president Wilson

Gasoline is as vital as blood in the coming battles…a failure in the supply of gasoline would cause the immediate paralysis of our armies.

Wilson reacted strongly. The War Shipping Board commandeered all ships in the United States and also took over all yards. An unprecedented budget of $US1.3 billion was used for this end. At Hog Island, the largest shipyard in the world was built, known for the Hog Islander.

Between 1916 and 1921, 316 tankers were built with a total capacity of 3.2 million long tons of deadweight, where the entire world fleet before World War I was just above 2 million tons. In 1923, about 800,000 long tons were laid up, which gave enormous opportunities for speculators, such as Daniel Keith Ludwig. In 1925 he had bought the freighter *Phoenix* and put tanks in the holds. These riveted tanks leaked, which resulted in a explosive mixture. The resulting explosion killed two crew members and badly injured Ludwig. After this, he was a strong believer in welding.

## World War II



Allied oil tankers were often targeted by U-Boats in World War II

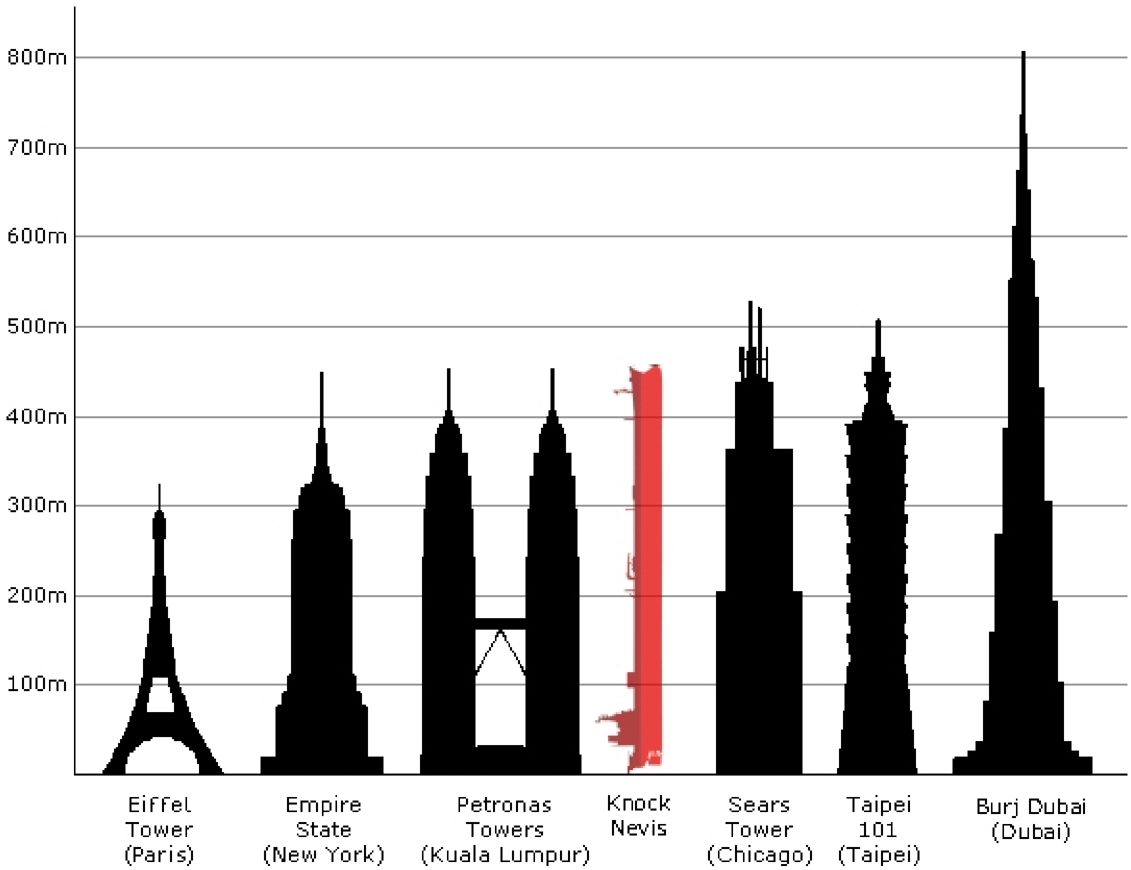
Oil tankers, particularly the T2 tanker, played an important part in World War II. The T2-SE-A1 with a capacity of 16,613 long tons of deadweight, was the most popular variant with nearly 500 built during the war. After the war, these tankers were used commercially for decades, and many were sold on the international market.

Until 1956, tankers were designed to be able to navigate the Suez Canal. This size restriction became much less of a priority after the closing of the canal during the Suez Crisis of 1956. Forced to move oil around the Cape of Good Hope, shipowners realized that bigger tankers were the key to more efficient transport.

## The supertanker era

Tankers have grown significantly in size since World War II. A typical T2 tanker of the World War II era was 532 feet (162 m) long and had a capacity of 16,500 DWT. A modern ultra-large crude carrier (ULCC) can be 1,300 feet (400 m) long and have a capacity of 500,000 DWT. Several factors encouraged this growth. Hostilities in the Middle East which interrupted traffic through the Suez Canal contributed, as did nationalization of Middle East oil refineries. Fierce competition among shipowners also played a part. But apart from these considerations is a simple economic advantage: the larger an oil tanker is, the more cheaply it can move crude oil, and the better it can help meet growing demands for oil.

In 1958, United States shipping magnate Daniel K. Ludwig broke the barrier of 100,000 long tons of heavy displacement. His *Universe Apollo* displaced 104,500 long tons, a 23% increase from the previous record-holder, *Universe Leader* which also belonged to Ludwig.




The *Knock Nevis, ex Seawise Giant* rivaled some of the world's largest buildings in size

The world's largest supertanker ever was built in 1979 at the Oppama shipyard by Sumitomo Heavy Industries, Ltd. as the *Seawise Giant*. This ship was built with a capacity of 564,763 DWT, a length overall of 458.45 metres (1,504.1 ft) and a draft of 24.611 metres (80.74 ft). She had 46 tanks, 31,541 square metres (339,500 sq ft) of deck, and was too large to pass through the English Channel.

*Seawise Giant* was renamed *Happy Giant* in 1989 and *Jahre Viking* in 1991. From 1979 to 2004, she was owned by Loki Stream, at which point she was bought by First Olsen Tankers, renamed *Knock Nevis*, and converted into a permanently moored storage tanker.

In 2009, she was sold to an Indian Breaker Company, and renamed *Mont*. She was subsequently beached and scrapped.

As of 2008, the world's four largest working supertankers are the TI class supertankers, currently known as the *TI Asia*, *TI Europe*, *TI Oceania*, and *TI Africa*. These ships were built in 2002 and 2003 as the *Hellespont Alhambra*, *Hellespont Metropolis*, *Hellespont Tara* and *Fairfax* for the Greek Hellespont Steamship Corporation. Hellespont sold these ships to Overseas Shipholding Group and Euronav in 2004.

Each of the four sister ships has a capacity of over 441,500 DWT, a length overall of 380.0 metres (1,246.7 ft) and a cargo capacity of 3,166,353 barrels (503,409,900 l). The first ULCC tankers to be built for some 25 years, they were also the first ULCCs to be double-hulled. To differentiate them from smaller ULCCs, these ships are sometimes given the *V-Plus* size designation. In February 2008, their owners announced plans to convert *TI Africa* and the *TI Asia* into stationary floating storage and offloading units to be placed in the Al Shaheen oilfield near Qatar in late 2009.

With the exception of the pipeline, the tanker is the most cost-effective way to move oil today. Worldwide, tankers carry some 2 billion barrels ($3.2\times10^{11}$ l) annually, and the cost of transportation by tanker amounts to only US$0.02 per gallon at the pump.

## *Size categories*

Oil tanker size categories

<table>
<tr><th colspan="2">AFRA Scale</th><th colspan="4">Flexible market scale</th></tr>
<tr><th>Class</th><th>Size in DWT</th><th>Class</th><th>Size in DWT</th><th>New price</th><th>Used price</th></tr>
<tr><td>General Purpose tanker</td><td>10,000–24,999</td><td>Product tanker</td><td>10,000–60,000</td><td rowspan="2">$43M</td><td rowspan="2">$42.5M</td></tr>
<tr><td>Medium Range tanker</td><td>25,000–44,999</td><td>Panamax</td><td>60,000–80,000</td></tr>
<tr><td>LR1 (Large Range 1)</td><td>45,000–79,999</td><td>Aframax</td><td>80,000–120,000</td><td rowspan="2">$58M</td><td rowspan="2">$60.7M</td></tr>
<tr><td>LR2 (Large Range 2)</td><td>80,000–159,999</td><td>Suezmax</td><td>120,000–200,000</td></tr>
<tr><td>VLCC (Very Large Crude Carrier)</td><td>160,000–319,999</td><td>VLCC</td><td>200,000–320,000</td><td rowspan="2">$120M</td><td rowspan="2">$116M</td></tr>
<tr><td>ULCC (Ultra Large Crude Carrier)</td><td>320,000–549,999</td><td>Ultra Large Crude Carrier</td><td>320,000–550,000</td></tr>
</table>


*Hellespont Alhambra* (now *TI Asia*), a ULCC TI class supertanker, which are the largest ocean-going ships in the world

In 1954 Shell Oil developed the average freight rate assessment (AFRA) system which classifies tankers of different sizes. To make it an independent instrument, Shell consulted the *London Tanker Brokers' Panel (LTBP)*. At first, they divided the groups as *General Purpose* for tankers under 25,000 tons deadweight (DWT); *Medium Range* for ships between 25,000 and 45,000 DWT and *Large Range* for the then-enormous ships that were larger than 45,000 DWT. The ships became larger during the 1970s, which prompted rescaling.

The system was developed for tax reasons as the tax authorities wanted evidence that the internal billing records were correct. Before the New York Mercantile Exchange started trading crude oil futures in 1983, it was difficult to determine the exact price of oil, which could change with every contract. Shell and BP, the first companies to use the system, abandoned the AFRA system in 1983, later followed by the US oil companies. However, the system is still used today. Besides that, there is the flexible market scale, which takes typical routes and lots of 500,000 barrels.

Merchant oil tankers carry a wide range of hydrocarbon liquids ranging from crude oil to refined petroleum products. Their size is measured in deadweight metric tons (DWT). Crude carriers are among the largest, ranging from 55,000 DWT Panamax-sized vessels to ultra-large crude carriers (ULCCs) of over 440,000 DWT.

"Supertanker" is an informal term used to describe the largest tankers. Today it is applied to very-large crude carriers (VLCC) and ULCCs with capacity over 250,000 DWT. These ships can transport 2,000,000 barrels of oil/318 000 metrioc tons. By way of comparison, the combined oil consumption of Spain and the United Kingdom in 2005 was about 3.4 million barrels (540,000 $m^3$) of oil a day.

Because of their great size, supertankers often can not enter port fully loaded. These ships can take on their cargo at off-shore platforms and single-point moorings. On the other end of the journey, they often pump their cargo off to smaller tankers at designated lightering points off-coast. A supertanker's routes are generally long, requiring it to stay at sea for extended periods, up to and beyond seventy days at a time.

Smaller tankers, ranging from well under 10,000 DWT to 80,000 DWT Panamax vessels, generally carry refined petroleum products, and are known as product tankers. The smallest tankers, with capacities under 10,000 DWT generally work near-coastal and inland waterways. Although they were in the past, ships of the smaller Aframax and Suezmax classes are no longer regarded as supertankers.

### *Chartering*

Oil tanker at Guanabara Bay, in Rio de Janeiro, Brazil.

The act of hiring a ship to carry cargo is called chartering. Tankers are hired by four types of charter agreements: the voyage charter, the time charter, the bareboat charter, and contract of affreightment. In a voyage charter, the charterer rents the vessel from the loading port to the discharge port. In a time charter, the vessel is hired for a set period of time, to perform voyages as the charterer directs. In a bareboat charter, the charterer acts as the ship's operator and manager, taking on responsibilities such as providing the crew and maintaining the vessel. Finally, in a contract of affreightment, or COA, the charterer specifies a total volume of cargo to be carried in a specific time period and in specific sizes, for example a COA could be specified as "one million barrels of JP-5 in a year's time in 25,000 barrel shipments." A completed chartering contract is known as a charter party.

One of the key aspects of any charter party is the freight rate, or the price specified for carriage of cargo. The freight rate of a tanker charter party is specified in one of four ways: by a lump sum rate, by rate per ton, by a time charter equivalent rate, or by Worldscale rate. In a lump sum rate arrangement, a fixed price is negotiated for the delivery of a specified cargo, and the ship's owner/operator is responsible to pay for all port costs and other voyage expenses. Rate per ton arrangements are used mostly in chemical tanker chartering, and differ from lump sum rates in that port costs and voyage expenses are generally paid by the charterer. Time charter arrangements specify a daily rate, and port costs and voyage expenses are also generally paid by the charterer.

The Worldwide Tanker Normal Freight Scale, often referred to as Worldscale, is established and governed jointly by the Worldscale Associations of London and New York. Worldscale establishes a baseline price for carrying a metric ton of product between any two ports in the world. In Worldscale negotiations, operators and charterers will determine a price based on a percentage of the Worldscale rate. The baseline rate is expressed as WS 100. If a given charter party settled on 85% of the Worldscale rate, it would be expressed as WS 85. Similarly, a charter party set at 125% of the Worldscale rate would be expressed as WS 125.

## Recent markets

| Recent time charter equivalent rates | | | | | |
|---|---|---|---|---|---|
| **Ship size** | **Cargo** | **Route** | **2004** | **2005** | **2006** |
| VLCC | Crude | Persian Gulf–Japan | $95,250 | $59,070 | $51,550 |
| Suezmax | Crude | West Africa – Caribbean or East Coast of North America | $64,800 | $47,500 | $46,000 |
| Aframax | Crude | Cross-Mediterranean | $43,915 | $39,000 | $31,750 |
| All product carriers | | Caribbean – East Coast of North America or Gulf of Mexico | $24,550 | $25,240 | $21,400 |

As of 2007, the chartering market is persistently volatile across all tanker sectors. The market is affected by a wide variety of variables such as the supply and demand of oil as well as the supply and demand of oil tankers. Some particular variables include winter temperatures, excess tanker tonnage, supply fluctuations in the Persian Gulf, and interruptions in refinery services.

In 2006, the sustained rise in oil prices had only a limited impact on demand. It was a good year across all segments of the tanker market segments, but not as good as 2004 and 2005. Amidst high oil prices, geopolitical tension, and fears of disruptions to the oil supply, growing demand was the main driving force in the tanker shipping market for the year. As demand grew moderately in the United States and Western Europe, expanding economies such as China fueled exponential growth in demand. Despite these strengths, each of the five tanker freight indices dropped during 2006. Product tanker demand increased in 2006 due to economic expansion in Asia, especially China and India, however, average time charter equivalent earnings for these ships decreased compared with the two prior years.

In 2006, time-charters tended towards long term. Of the time charters executed in that year, 58% were for a period of 24 or more years, 14% were for periods of 12 to 24 years, 4% were from 6 to 12 years, and 24% were for periods of less than 6 years. The average one-year time charter rate for a 5-year-old tanker of 280,000 metric tons of deadweight varied from $56,500 per day in December 2005 to $53,000 per day in September 2007 with a high of $64,500 per day in September 2006.

The first half of 2007 was relatively strong, but in the second half rates dropped significantly. A sudden rise in oil production, longer transport routes, and slow steaming because of high bunker prices led to a shortage in tonnage towards the end of the year. Overnight, VLCC rates climbed from $20,000 per day to $200–$300,000 per day, and even higher numbers were recorded.

Since 2003, the demand for new ships has started to grow, in 2007 resulting in a record breaking order backlog for shipyards, exceeding their capacity with rising newbuilding prices as a result.

Owners of large oil tanker fleets include Teekay Corporation, A P Moller Maersk, DS Torm, Frontline, MOL Tankship Management, Overseas Shipholding Group, and Euronav.

## *Fleet characteristics*

In 2005, oil tankers made up 36.9% of the world's fleet in terms of deadweight tonnage. The world's total oil tankers deadweight tonnage has increased from 326.1 million DWT in 1970 to 960.0 million DWT in 2005. The combined deadweight tonnage of oil tankers and bulk carriers, represents 72.9% of the world's fleet.

### Cargo movement

In 2005, 2.42 billion metric tons of oil were shipped by tanker. 76.7% of this was crude oil, and the rest consisted of refined petroleum products. This amounted to 34.1% of all seaborne trade for the year. Combining the amount carried with the distance it was carried, oil tankers moved 11,705 billion metric-ton-miles of oil in 2005.

By comparison, in 1970 1.44 billion metric tons of oil were shipped by tanker. This amounted to 34.1% of all seaborne trade for that year. In terms of amount carried and distance carried, oil tankers moved 6,487 billion metric-ton-miles of oil in 1970.

The United Nations also keeps statistics about oil tanker productivity, stated in terms of metric tons carried per metric ton of deadweight as well as metric-ton-miles of carriage per metric ton of deadweight. In 2005, for each 1 DWT of oil tankers, 6.7 metric tons of cargo was carried. Similarly, each 1 DWT of oil tankers was responsible for 32,400 metric-ton miles of carriage.

The main loading ports in 2005 were located in Western Asia, Western Africa, North Africa, and the Caribbean, with 196.3, 196.3, 130.2 and 246.6 million metric tons of cargo loaded in these regions. The main discharge ports were located in North America, Europe, and Japan with 537.7, 438.4, and 215.0 million metric tons of cargo discharged in these regions.

## Flag states

International law requires that every merchant ship be registered in a country, called its flag state. A ship's flag state exercises regulatory control over the vessel and is required to inspect it regularly, certify the ship's equipment and crew, and issue safety and pollution prevention documents. As of 2007, the United States Central Intelligence Agency statistics count 4,295 oil tankers of 1,000 long tons deadweight (DWT) or greater worldwide. Panama was the world's largest flag state for oil tankers, with 528 of the vessels in its registry. Six other flag states had more than 200 registered oil tankers: Liberia (464), Singapore (355), China (252), Russia (250), the Marshall Islands (234) and the Bahamas (209). The Panamanian, Liberian, Marshallese and Bahamian flags are open registries and considered by the International Transport Workers' Federation to be flags of convenience. By way of comparison, the United States and the United Kingdom only had 59 and 27 registered oil tankers, respectively.

## Vessel life cycle

Tankers may carry unusual cargoes such as grain on their final trip to the scrapyard.

In 2005, the average age of oil tankers worldwide was 10 years. Of these, 31.6% were under 4 years old and 14.3% were over 20 years old. In 2005, 475 new oil tankers were built, accounting for 30.7 million DWT. The average size for these new tankers was 64,632 DWT. Nineteen of these were VLCC size, 19 were suezmax, 51 were aframax, and the rest were smaller designs. By way of comparison, 8.0 million DWT, 8.7 million DWT, and 20.8 million DWT worth of oil tanker capacity was built in 1980, 1990, and 2000 respectively.

Ships are generally removed from the fleet through a process known as scrapping. Ship-owners and buyers negotiate scrap prices based on factors such as the ship's empty weight (called light ton displacement or LDT) and prices in the scrap metal market. In 1998, almost 700 ships went through the scrapping process at shipbreakers in places like Alang, India and Chittagong, Bangladesh. In 2004 and 2005, 7.8 million DWT and 5.7 million DWT respectively of oil tankers were scrapped. Between 2000 and 2005, the capacity of oil tankers scrapped each year has ranged between 5.6 million DWT and 18.4 million DWT. In this same timeframe, tankers have accounted for between 56.5 and 90.5 of the world's total scrapped tonnage. During this period, the average age of scrapped oil tankers has ranged from 26.9 to 31.5 years.

### Vessel pricing

| Size | 1985 | 2005 |
|---|---|---|
| 32,000–45,000 DWT | US$18M | $43M |
| 80,000–105,000 DWT | $22M | $58M |
| 250,000–280,000 DWT | $47M | $120M |

In 2005, the price for new oil tankers in the 32,000–45,000 DWT, 80,000–105,000 DWT, and 250,000–280,000 DWT ranges were US$43 million, $58 million, and $120 million respectively. In 1985, these vessels would have cost $18 million, $22 million, and $47 million respectively.

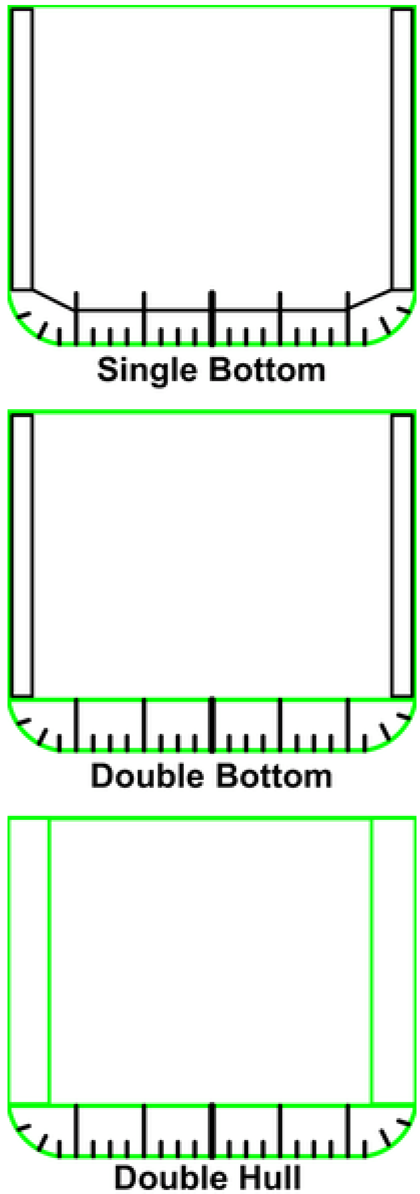
Oil tankers are often sold second-hand. In 2005, 27.3 million DWT worth of oil tankers were sold used. Some representative prices for that year include $42.5M for a 40,000 DWT tanker, $60.7 million for a 80,000–95,000 DWT, $73 million for a 130,000–150,000 DWT, and $116 million for 250,000–280,000 DWT tanker. For a concrete example, in 2006, Bonheur subsidiary First Olsen paid US$76.5 million for *Knock Sheen*, a 159,899 DWT tanker.

## *Current structural design*

Oil tankers generally have from 8 to 12 tanks. Each tank is split into two or three independent compartments by fore-and-aft bulkheads. The tanks are numbered with tank one being the forwardmost. Individual compartments are referred to by the tank number and the athwartships position, such as "one port", "three starboard", or "six center."

A cofferdam is a small space left open between two bulkheads, to give protection from heat, fire, or collision. Tankers generally have cofferdams forward and aft of the cargo tanks, and sometimes between individual tanks. A pumproom houses all the pumps connected to a tanker's cargo lines. Some larger tankers have two pumprooms. A pumproom generally spans the total breadth of the ship.

## Hull designs




Single hull, Double bottom, and Double hull ship cross sections. Green lines are watertight; black structure is not watertight

A major component of tanker architecture is the design of the hull or outer structure. A tanker with a single outer shell between the product and the ocean is said to be *single-hulled.* Most newer tankers are *double-hulled*, with an extra space between the hull and the storage tanks. Hybrid designs such as *double-bottom* and *double-sided* combine aspects of single and double-hull designs. All single-hulled tankers around the world will be phased out by 2026, in accordance with the International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL). The United Nations has decided to phase out single hull oil tankers by 2010.

In 1998, the Marine Board of the National Academy of Science conducted a survey of industry experts regarding the pros and cons of double-hull design. Some of the advantages of the double-hull design that were mentioned include ease of ballasting in emergency situations, reduced practice of saltwater ballasting in cargo tanks decreases corrosion, increased environmental protection, cargo discharge is quicker, more complete and easier, tank washing is more efficient, and better protection in low-impact collisions and grounding.

The same report lists the following as some drawbacks to the double-hull design, including higher build costs, greater operating expenses (e.g. higher canal and port tariffs), difficulties in ballast tank ventilation, the fact that ballast tanks need continuous monitoring and maintenance, increased transverse free surface, the greater number of surfaces to maintain, the risk of explosions in double-hull spaces if a vapor detection system not fitted, and that cleaning ballast tanks is more difficult for double hull ships.

In all, double-hull tankers are said to be safer than a single-hull in a grounding incident, especially when the shore is not very rocky. The safety benefits are less clear on larger vessels and in cases of high speed impact.

Although double-hull design is superior in low energy casualties and prevents spillage in small casualties, in high energy casualties where both hulls are breached, oil can spill through the double-hull and into the sea and spills from a double-hull tanker can be significantly higher than designs like the Mid-Deck Tanker, the Coulombi Egg Tanker and even a pre-MARPOL tanker, as the last one has a lower oil column and reaches hydrostatic balance sooner.

## Inert gas system

An oil tanker's inert gas system is one of the most important parts of its design. Fuel oil itself is very difficult to ignite, but its hydrocarbon vapors are explosive when mixed with air in certain concentrations. The purpose of the system is to create an atmosphere inside tanks in which the hydrocarbon oil vapors cannot burn.

As inert gas is introduced into a mixture of hydrocarbon vapors and air, it increases the lower flammable limit or lowest concentration at which the vapors can be ignited. At the same time it decreases the upper flammable limit or highest concentration at which the vapors can be ignited. When the total concentration of oxygen in the tank reaches about 11%, the upper and lower flammable limits converge and the flammable range disappears.

Inert gas systems deliver air with an oxygen concentration of less than 5% by volume. As a tank is pumped out, it's filled with inert gas and kept in this safe state until the next cargo is loaded. The exception is in cases when the tank must be entered. Safely gas-freeing a tank is accomplished by purging hydrocarbon vapors with inert gas until the hydrocarbon concentration inside the tank is under about 1%. Thus, as air replaces the inert gas, the concentration cannot rise to the lower flammable limit and is safe.

### *Cargo operations*

Cargo flows between a tanker and a shore station by way of marine loading arms attached at the tanker's cargo manifold.

Operations aboard oil tankers are governed by an established body of best practices and a large body of international law. Cargo can be moved on or off of an oil tanker in several ways. One method is for the ship to moor alongside a pier, connect with cargo hoses or marine loading arms. Another method involves mooring to offshore buoys, such as a single point mooring, and making a cargo connection via underwater cargo hoses. A third method is by ship-to-ship transfer, also known as lightering. In this method, two ships come alongside in open sea and oil is transferred manifold to manifold via flexible hoses. Lightering is sometimes used where a loaded tanker is too large to enter a specific port.

### Pre-transfer preparation

Prior to any transfer of cargo, the chief officer must develop a transfer plan detailing specifics of the operation such as how much cargo will be moved, which tanks will be cleaned, and how the ship's ballasting will change. The next step before a transfer is the pretransfer conference. The pretransfer conference covers issues such as what products will be moved, the order of movement, names and titles of key people, particulars of shipboard and shore equipment, critical states of the transfer, regulations in effect, emergency and spill-containment procedures, watch and shift arrangements, and shutdown procedures.

After the conference is complete, the person in charge on the ship and the person in charge of the shore installation go over a final inspection checklist. In the United States, the checklist is called a Declaration of Inspection or DOI. Outside of the U.S., the document is called the "Ship/Shore Safety Checklist." Items on the checklist include proper signals and signs are displayed, secure mooring of the vessel, choice of language for communication, securing of all connections, that emergency equipment is in place, and that no repair work is taking place.

### Loading cargo

Oil is pumped on and off the ship by way of connections made at the cargo manifold.

Loading an oil tanker consists primarily of pumping cargo into the ship's tanks. As oil enters the tank, the vapors inside the tank must be somehow expelled. Depending on local regulations, the vapors can be expelled into the atmosphere or discharged back to the pumping station by way of a vapor recovery line. It is also common for the ship to move water ballast during the loading of cargo to maintain proper trim.

Loading starts slowly at a low pressure to ensure that equipment is working correctly and that connections are secure. Then a steady pressure is achieved and held until the "topping-off" phase when the tanks are nearly full. Topping off is a very dangerous time in handling oil, and the procedure is handled particularly carefully. Tank-gauging equipment is used to tell the person in charge how much space is left in the tank, and all tankers have at least two independent methods for tank-gauging. As the tanker becomes full, crew members open and close valves to direct the flow of product and maintain close communication with the pumping facility to decrease and finally stop the flow of liquid.

### Unloading cargo

This cargo pump aboard a VLCC can move 5,000 cubic meters of product per hour.

The process of moving oil off of a tanker is similar to loading, but has some key differences. The first step in the operation is following the same pretransfer procedures as used in loading. When the transfer begins, it is the ship's cargo pumps that are used to move the product ashore. As in loading, the transfer starts at low pressure to ensure that equipment is working correctly and that connections are secure. Then a steady pressure is achieved and held during the operation. While pumping, tank levels are carefully watched and key locations, such as the connection at the cargo manifold and the ship's pumproom are constantly monitored. Under the direction of the person in charge, crew members open and close valves to direct the flow of product and maintain close communication with the receiving facility to decrease and finally stop the flow of liquid.

### Tank cleaning

The nozzle of an automated tank cleaning machine

Tanks must be cleaned from time to time for various reasons. One reason is to change the type of product carried inside a tank. Also, when tanks are to be inspected or maintenance must be performed within a tank, it must be not only cleaned, but made "gas-free."

On most crude-oil tankers, a special crude oil washing (COW) system is part of the cleaning process. The COW system circulates part of the cargo through the fixed tank-cleaning system to remove wax and asphaltic deposits. Tanks that carry less viscous cargoes are washed with water. Fixed and portable automated tank cleaning machines, which clean tanks with high-pressure water jets, are widely used. Some systems use rotating high-pressure water jets to spray hot water on all the internal surfaces of the tank. As the spraying takes place, the liquid is pumped out of the tank.

After a tank is cleaned, provided that it is going to be prepared for entry, it will be "purged". Purging is accomplished by pumping inert gas into the tank until hydrocarbons have been sufficiently expelled. Next the tank is "gas freed" which is usually accomplished by blowing fresh air into the space with portable air powered or water powered air blowers. "Gas freeing" brings the oxygen content of the tank up to 20.8% $O_2$. This process ensures the tank never has an atmosphere capable of ignition. Specially trained personnel monitor the tank's atmosphere, often using hand-held gas indicators which measure the percentage of hydrocarbons present. After a tank is gas-free, it may be further hand-cleaned in a manual process known as mucking. Mucking requires protocols for entry into confined spaces, protective clothing, designated safety observers, and possibly the use of airline respirators.

## *Special-use oil tankers*

Some sub-types of oil tankers have evolved to meet specific military and economic needs. These sub-types include naval replenishment ships, oil-bulk-ore combination carriers, floating storage and offloading units (FSOs) and floating production storage and offloading units (FPSOs).

## Replenishment ships

HMAS *Success* refuels the USS *Kitty Hawk* and the USS *Cowpens*.

Replenishment ships, known as oilers in the United States and fleet tankers in Commonwealth countries, are ships that can provide oil products to naval vessels while on the move. This process, known as underway replenishment, extends the length of time a naval vessel can stay at sea, as well as her effective range. Prior to underway replenishment, naval vessels had to enter a port or anchor to take on fuel. In addition to fuel, replenishment ships may also deliver water, ammunition, rations, stores and personnel.

## Ore-bulk-oil carriers

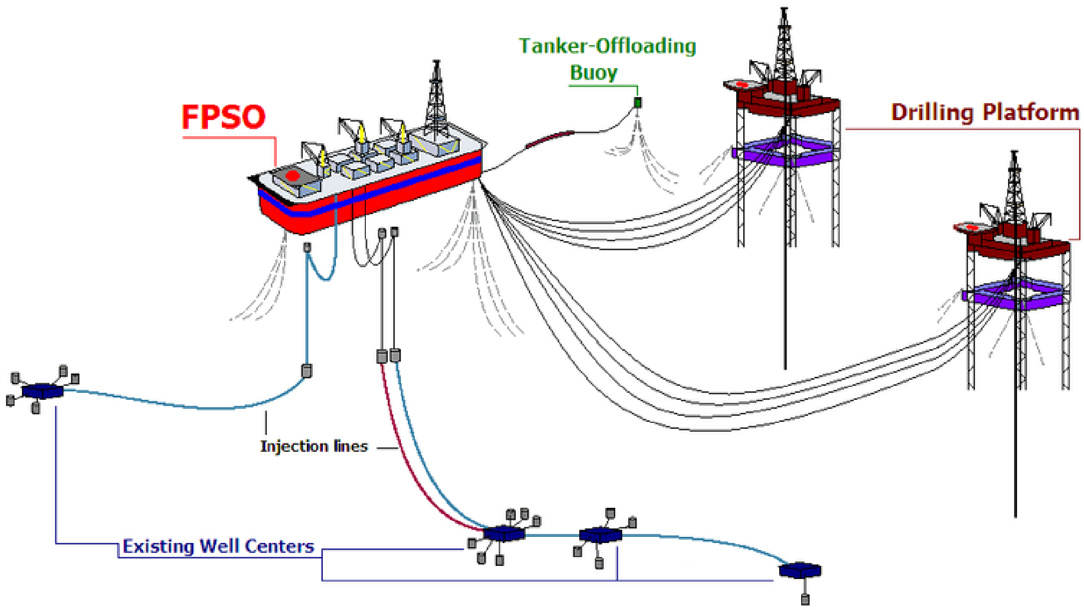
The OBO-carrier *Maya*. The picture is showing both the cargo hold hatches used for bulk and the pipes used for oil

An ore-bulk-oil carrier, also known as combination carrier or OBO, is a ship designed to be capable of carrying wet or dry bulk cargoes. This design was intended to provide flexibility in two ways. Firstly, an OBO would be able to shift between the dry and wet bulk trades based on market conditions. Secondly, an OBO could carry oil on one leg of a voyage and return carrying dry bulk, reducing the number of unprofitable ballast voyages it would have to make.

In practice, the flexibility which the OBO design allows has gone largely unused, as these ships tend to specialize in either the liquid or dry bulk trade. Also, these ships have endemic maintenance problems. On one hand, due to a less specialized design, an OBO suffers more from wear and tear during dry cargo onload than a bulker. On the other hand, components of the liquid cargo system, from pumps to valves to piping, tend to develop problems when subjected to periods of disuse. These factors have contributed to a steady reduction in the number of OBO ships worldwide since the 1970s.

One of the more famous OBOs was the MV *Derbyshire* of 180,000 DWT which in September 1980 became the largest British ship ever lost at sea. It sank in a Pacific typhoon while carrying a cargo of iron ore from Canada to Japan.

## Floating storage units




Floating storage units, often former oil tankers, accumulate oil for tankers to retrieve.

Floating storage and offloading units (FSO) are used worldwide by the offshore oil industry to receive oil from nearby platforms and store it until it can be offloaded onto oil tankers. A similar system, the floating production storage and offloading unit (FPSO), has the ability to process the product while it is onboard. These floating units reduce oil production costs and offer mobility, large storage capacity, and production versatility.

FPSO and FSOs are often created out of old, stripped-down oil tankers, but can be made from new-built hulls Shell España first used a tanker as an FPSO was in August 1977. An example of a FSO that used to be an oil tanker is the *Knock Nevis*. These units are usually moored to the seabed through a spread mooring system. A turret-style mooring system can be used in areas prone to severe weather. This turret system lets the unit rotate to minimize the effects of sea-swell and wind.

### *Pollution*

The *Exxon Valdez* spilled 10.8 million gallons of oil into Alaska's Prince William Sound.

Oil spills have devastating effects on the environment. Crude oil contains polycyclic aromatic hydrocarbons (PAHs) which are very difficult to clean up, and last for years in the sediment and marine environment. Marine species constantly exposed to PAHs can exhibit developmental problems, susceptibility to disease, and abnormal reproductive cycles.

By the sheer amount of oil carried, modern oil tankers must be considered a threat to the environment. As discussed above, a VLCC tanker can carry 2 million barrels (320,000 $m^3$) of crude oil, or 84,000,000 gallons. This is about eight times the amount spilled in the widely known *Exxon Valdez* incident. In this spill, the ship ran aground and dumped 10,800,000 US gallons (41,000 $m^3$) of oil into the ocean in March 1989. Despite efforts of scientists, managers, and volunteers over 400,000 seabirds, about 1,000 sea otters, and immense numbers of fish were killed. Considering the volume of oil carried by sea, however, tanker owners' organisations often argue that the industry's safety record is excellent, with only a tiny fraction of a percentage of oil cargoes carried ever being spilled. The International Association of Independent Tanker Owners has observed that "accidental oil spills this decade have been at record low levels—one third of the previous decade and one tenth of the 1970s—at a time when oil transported has more than doubled since the mid 1980s."

Oil tankers are only one source of oil spills. According to the United States Coast Guard, 35.7% of the volume of oil spilled in the United States from 1991 to 2004 came from tank vessels (ships/barges), 27.6% from facilities and other non-vessels, 19.9% from non-tank vessels, and 9.3% from pipelines; 7.4% from mystery spills. On the other hand, only 5% of the actual spills came from oil tankers, while 51.8% came from other kinds of vessels. The detailed statistics for 2004 shown in the table below show tank vessels responsible for somewhat less than 5% of the number of total spills but more than 60% of the volume. In summary, spills are much more rare but much more serious on tank vessels than on non-tank vessels.

The International Tanker Owners Pollution Federation has tracked 9,351 accidental spills that have occurred since 1974. According to this study, most spills result from routine operations such as loading cargo, discharging cargo, and taking on fuel oil. 91% of the operational oil spills are small, resulting in less than 7 metric tons per spill. On the other hand, spills resulting from accidents like collisions, groundings, hull failures, and explosions are much larger, with 84% of these involving losses of over 700 metric tons.

Following the *Exxon Valdez* spill, the United States passed the Oil Pollution Act of 1990 (OPA-90), which included a stipulation that all tankers entering its waters be double-hulled by 2015. Following the sinkings of the *Erika* (1999) and *Prestige* (2002), the European Union passed its own stringent anti-pollution packages (known as Erika I, II, and III), which also require all tankers entering its waters to be double-hulled by 2010. The Erika packages are controversial because they introduced the new legal concept of "serious negligence".

## Air pollution


A 1990 fire, lasting 3 days, destroyed the laker *Jupiter*, a gasoline tanker.

Air pollution from normal tanker engines operation and from cargo fires is another serious concern. Large ships are often run on low quality fuel oils, such as bunker oil which are highly polluting and have been shown to be a health risk. Ship fires may not only result in the loss of the ship due to lack of specialized firefighting gear and techniques but the fires sometimes burn for days and require evacuations of nearby residents due to the dangerous smoke.