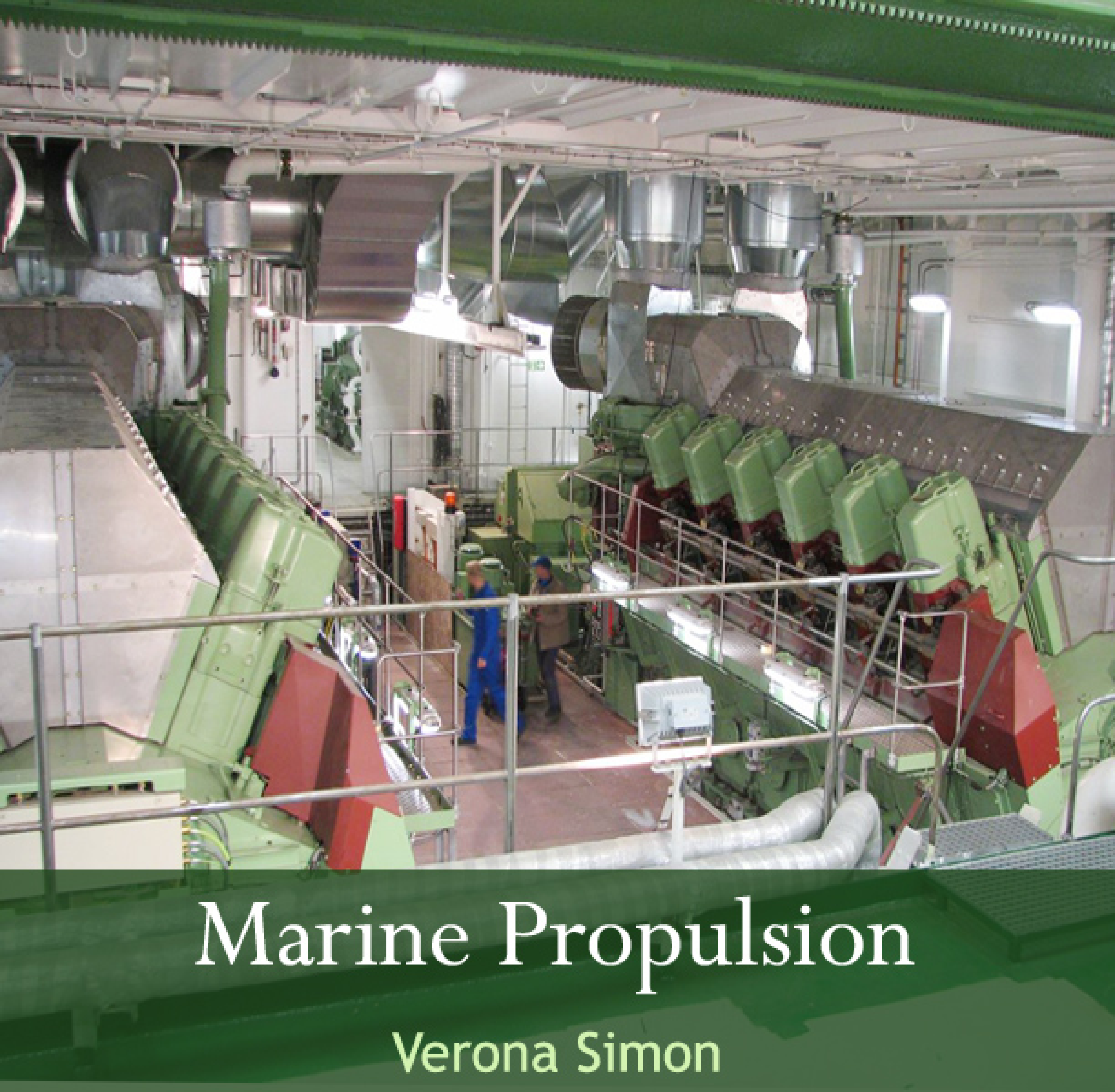

Marine Propulsion

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Chapter- 1

Marine Propulsion

A view of a ship's engine room

Marine propulsion is the mechanism or system used to move a ship or boat across water. While paddles and sails are still used on some smaller boats, most modern ships are propelled by mechanical systems consisting a motor or engine turning a propeller, or less frequently, in jet drives, an impeller. Marine engineering is the discipline concerned with the design of marine propulsion systems.

Steam engines were the first mechanical engines used in marine propulsion, but have mostly been replaced by two-stroke or four-stroke diesel engines, outboard motors, and gas turbine engines on faster ships. Nuclear reactors producing steam are used to propel warships and icebreakers, and there have been attempts to utilize them to power commercial vessels. Electric motors have been used on submarines and electric boats and have been proposed for energy-efficient propulsion.

Power sources

Pre-mechanisation

A wind propelled fishing boat in Mozambique

Until the application of the steam engine to ships in the early 19th century, oars propelled galleys, or the wind propelled sailing ships. Before mechanisation, merchant ships always used sail, but as long as naval warfare depended on ships closing to ram or to fight hand-to-hand, galleys dominated in marine conflicts because of their maneuverability and speed. The Greek navies that fought in the Peloponnesian War used triremes, as did the Romans at the Battle of Actium. The use of large numbers of cannon from the 16th century meant that maneuverability took second place to broadside weight; this led to the dominance of the sail-powered warship.

In modern times, human propulsion is found mainly on small boats or as auxiliary propulsion on sailboats. Human propulsion includes the pole, still widely used in marshy areas, rowing which was used even on large galleys, and the pedals.

Propulsion by sail generally consists of a sail hoisted on an erect mast, supported by stays and spars and controlled by ropes. Sail systems were the dominant form of propulsion until the nineteenth century. They are now generally used for recreation and racing, although experimental sail systems, such as the kites/royals, turbosails, rotorsails, wingsails, windmills and SkySails's own kite buoy-system have been used on larger modern vessels for fuel savings.

Reciprocating steam engines

SS *Ukkopekka* uses a triple expansion steam engine

The development of piston-engined steamships was a complex process. Early steamships were fueled by wood, later ones by coal or fuel oil. Early ships used stern or side paddle wheels, while later ones used screw propellers.

The first commercial success accrued to Robert Fulton's *North River Steamboat* (often called *Clermont*) in the US in 1807, followed in Europe by the 45-foot *Comet* of 1812. Steam propulsion progressed considerably over the rest of the 19th century. Notable developments included the steam surface condenser, which eliminated the use of sea water in the ship's boilers. This permitted higher steam pressures, and thus the use of higher efficiency multiple expansion (compound) engines. As the means of transmitting the engine's power, paddle wheels gave way to more efficient screw propellers.

Steam turbines

The NS *Savannah* was the first nuclear-powered cargo-passenger ship

Steam turbines were fueled by coal or, later, fuel oil or nuclear power. The marine steam turbine developed by Sir Charles Algernon Parsons raised the power to weight ratio. He achieved publicity by demonstrating it unofficially in the 100-foot *Turbinia* at the Spithead Naval Review in 1897. This facilitated a generation of high-speed liners in the first half of the 20th century, and rendered the reciprocating steam engine obsolete; first in warships, and later in merchant vessels.

In the early 20th century, heavy fuel oil came into more general use and began to replace coal as the fuel of choice in steamships. Its great advantages were convenience, reduced manpower by removal of the need for trimmers and stokers, and reduced space needed for fuel bunkers.

In the second half of the 20th century, rising fuel costs almost led to the demise of the steam turbine. Most new ships since around 1960 have been built with diesel engines. The last major passenger ship built with steam turbines was the *Fairsky*, launched in 1984. Similarly, many steam ships were re-engined to improve fuel efficiency. One high profile example was the 1968 built *Queen Elizabeth 2* which had her steam turbines replaced with a diesel-electric propulsion plant in 1986.

Most new-build ships with steam turbines are specialist vessels such as nuclear-powered vessels, and certain merchant vessels (notably Liquefied Natural Gas (LNG) and coal carriers) where the cargo can be used as bunker fuel.

LNG carriers

New LNG carriers (a high growth area of shipping) continue to be built with steam turbines. The natural gas is stored in a liquid state in cryogenic vessels aboard these ships, and a small amount of 'boil off' gas is needed to maintain the pressure and temperature inside the vessels within operating limits. The 'boil off' gas provides the fuel for the ship's boilers, which provide steam for the turbines, the simplest way to deal with the gas. Technology to operate internal combustion engines (modified marine two-stroke diesel engines) on this gas has improved, however, so such engines are starting to appear in LNG carriers; with their greater thermal efficiency, less gas is burnt. Developments have also been made in the process of re-liquefying 'boil off' gas, letting it be returned to the cryogenic tanks. The financial returns on LNG are potentially greater than the cost of the marine-grade fuel oil burnt in conventional diesel engines, so the re-liquefaction process is starting to be used on diesel engine propelled LNG carriers. Another factor driving the change from turbines to diesel engines for LNG carriers is the shortage of steam turbine qualified seagoing engineers. With the lack of turbine powered ships in other shipping sectors, and the rapid rise in size of the worldwide LNG fleet, not enough have been trained to meet the demand. It may be that the days are numbered for marine steam turbine propulsion systems, even though all but sixteen of the orders for new LNG carriers at the end of 2004 were for steam turbine propelled ships.

Nuclear-powered steam turbines

In these vessels, the nuclear reactor heats water to create steam to drive the turbines. Due to low prices of diesel oil, nuclear propulsion is rare except in some Navy and specialist vessels such as icebreakers. In large aircraft carriers, the space formerly used for ship's bunkerage could be used instead to bunker aviation fuel. In submarines, the ability to run submerged at high speed and in relative quiet for long periods holds obvious advantages. A few cruisers have also employed nuclear power; as of 2006, the only ones remaining in service are the Russian *Kirov* class. An example of a non-military ship with nuclear marine propulsion is the *Arktika* class icebreaker with 75,000 shaft horsepower (55,930 kW). Commercial experiments such as the NS *Savannah* have so far proved uneconomical compared with conventional propulsion.

In recent times, there is some renewed interest in commercial nuclear shipping. Nuclear powered cargo ships could lower costs associated with carbon dioxide emissions and travel at higher cruise speeds than conventional diesel powered vessels.

Reciprocating diesel engines

A modern diesel engine aboard a cargo ship

About 99% of modern ships use diesel reciprocating engines. The rotating crankshaft can power the propeller directly for slow speed engines, via a gearbox for medium and high speed engines, or via an alternator and electric motor in diesel-electric vessels.

The reciprocating marine diesel engine first came into use in 1903 when the diesel electric rivertanker *Vandal* was put in service by Branobel. Diesel engines soon offered greater efficiency than the steam turbine, but for many years had an inferior power-to-space ratio.

Diesel engines today are broadly classified according to

- Their operating cycle: two-stroke engine or four-stroke engine
- Their construction: crosshead, trunk, or opposed piston
- Their speed
    - Slow speed: any engine with a maximum operating speed up to 300 revolutions per minute (rpm), although most large two-stroke slow speed diesel engines operate below 120 rpm. Some very long stroke engines have a maximum speed of around 80 rpm. The largest, most

powerful engines in the world are slow speed, two stroke, crosshead diesels.
  - Medium speed: any engine with a maximum operating speed in the range 300-900 rpm. Many modern four-stroke medium speed diesel engines have a maximum operating speed of around 500 rpm.
  - High speed: any engine with a maximum operating speed above 900 rpm.

Most modern larger merchant ships use either slow speed, two stroke, crosshead engines, or medium speed, four stroke, trunk engines. Some smaller vessels may use high speed diesel engines.

The size of the different types of engines is an important factor in selecting what will be installed in a new ship. Slow speed two-stroke engines are much taller, but the area needed, length and width, is smaller than that needed for four-stroke medium speed diesel engines. As space higher up in passenger ships and ferries is at a premium, these ships tend to use multiple medium speed engines resulting in a longer, lower engine room than that needed for two-stroke diesel engines. Multiple engine installations also give redundancy in the event of mechanical failure of one or more engines, and greater efficiency over a wider range of operating conditions.

As modern ships' propellers are at their most efficient at the operating speed of most slow speed diesel engines, ships with these engines do not generally need gearboxes. Usually such propulsion systems consist of either one or two propeller shafts each with its own direct drive engine. Ships propelled by medium or high speed diesel engines may have one or two (sometimes more) propellers, commonly with one or more engines driving each propeller shaft through a gearbox. Where more than one engine is geared to a single shaft, each engine will most likely drive through a clutch, allowing engines not being used to be disconnected from the gearbox while others keep running. This arrangement lets maintenance be carried out while under way, even far from port.

Gas turbines

Many warships built since the 1960s have used gas turbines for propulsion, as have a few passenger ships, like the jetfoil. Gas turbines are commonly used in combination with other types of engine. Most recently, the *Queen Mary 2* has had gas turbines installed in addition to diesel engines. Because of their poor thermal efficiency at low power (cruising) output, it is common for ships using them to have diesel engines for cruising, with gas turbines reserved for when higher speeds are needed however, in the case of passenger ships the main reason for installing gas turbines has been to allow a reduction of emissions in sensitive environmental areas or while in port. Some warships, and a few modern cruise ships have also used the steam turbines to improve the efficiency of their gas turbines in a combined cycle, where wasted heat from a gas turbine exhaust is utilized to boil water and create steam for driving a steam turbine. In such combined cycles, thermal efficiency can be the same or slightly greater than that of diesel engines alone; however, the grade of fuel needed for these gas turbines is far more costly than that needed for the diesel engines, so the running costs are still higher.

Screws

The technical term for what is often described as a "propeller" on a ship is a screw. The differentiation is necessary as the two systems, although similar in appearance, have very different physical properties. There are many variations of marine screw systems, including twin, contra-rotating, controllable-pitch, and nozzle-style screws. Smaller vessels tend to have a single screw. Some modern aircraft carriers use four propellers, supplemented with bow- and stern-thrusters. Power is transmitted from the engine to the screw by way of a propeller shaft, which may or may not be connected to a gearbox.

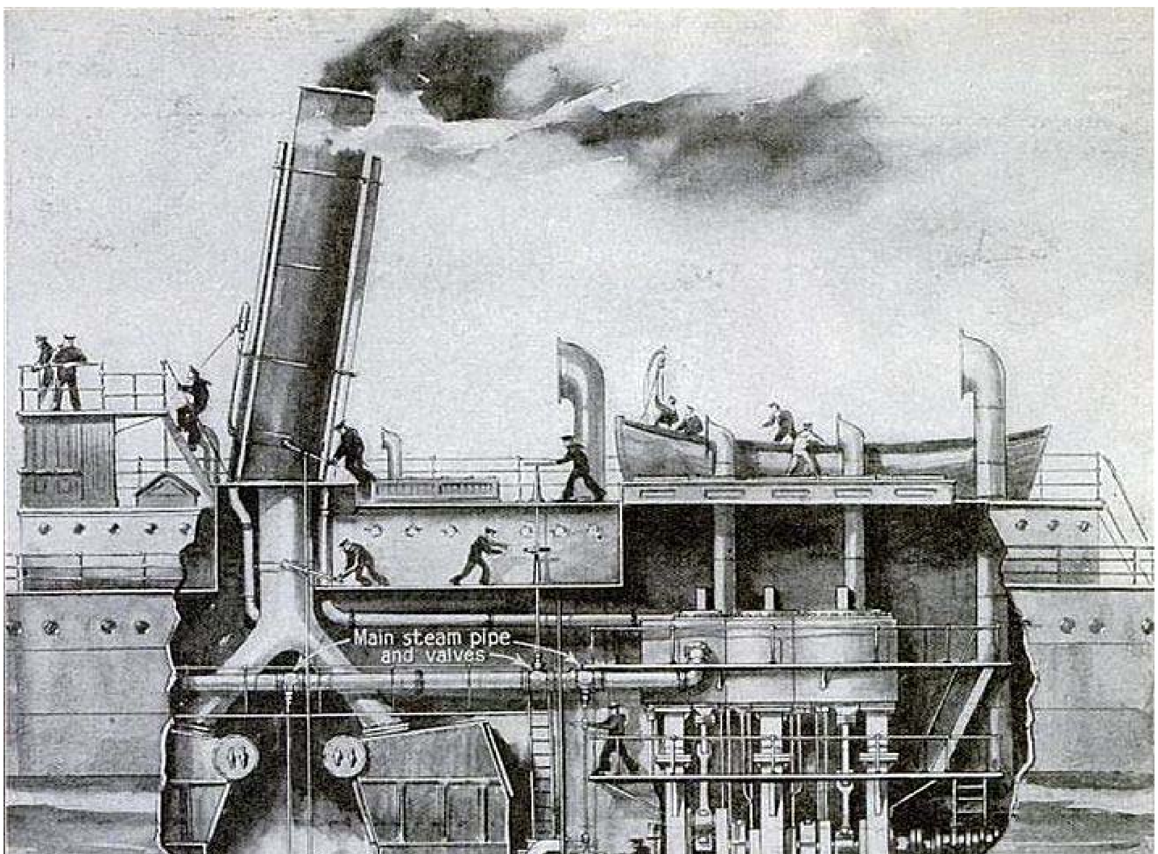
Paddle wheels

Left: original paddle wheel from a paddle steamer.
Right: detail of a paddle steamer.

The paddle wheel is a large wheel, generally built of a steel framework, upon the outer edge of which are fitted numerous paddle blades (called *floats* or *buckets*). The bottom quarter or so of the wheel travels underwater. Rotation of the paddle wheel produces thrust, forward or backward as required. More advanced paddle wheel designs have featured *feathering* methods that keep each paddle blade oriented closer to vertical while it is in the water; this increases efficiency. The upper part of a paddle wheel is normally enclosed in a paddlebox to minimise splashing.

Chapter- 2

Marine Steam Engine



Period cut away diagram of a triple expansion steam engine installation, circa 1918

A **marine steam engine** is a reciprocating steam engine that is used to power a ship or boat. Steam turbines and diesel engines largely replaced reciprocating steam engines in marine applications during the 20th century, so this chapter describes the more common types of marine steam engine in use from their inception in the early 19th century to their last years of large-scale manufacture during World War II.

History

The first commercially successful steam engine was developed by Thomas Newcomen in 1712. However, successful adaptation of the steam engine to marine applications would have to wait until almost a century later, when Scottish engineer William Symington built the world's "first practical steamboat", the *Charlotte Dundas*, in 1802. In 1807, the American Robert Fulton built the world's first commercially successful steamboat, simply known as the *North River Steamboat*.

Following Fulton's success, steamboat technology developed rapidly on both sides of the Atlantic. Steamboats initially had a short range and were not particularly seaworthy due to their weight, lack of horsepower, and tendency to break down, but they were employed successfully along rivers and canals, and for short journeys along the coast. The first successful transatlantic crossing by a steamship occurred in 1819 when *Savannah* sailed from Savannah, Georgia to Liverpool, England. The first steamship to make regular transatlantic crossings was the sidewheel steamer *Great Western* in 1838.

As the 19th century progressed, marine steam engine and steamship technology developed alongside it. Paddle propulsion gradually gave way to the screw propeller, and the introduction of iron and later steel hulls to replace the traditional wooden hull allowed ships to grow ever larger, necessitating steam power plants that were increasingly complex and powerful.

Types of marine steam engine

A wide variety of reciprocating marine steam engines was developed over the course of the 19th century. The two main methods of classifying such engines are by *connection mechanism* and *cylinder technology*.

Most early marine engines had the same cylinder technology but a number of different methods of supplying power to the crankshaft (i.e. connection mechanism) were in use. Thus, early marine engines are classified mostly according to their connection mechanism. Some common connection mechanisms were side-lever, steeple, walking beam and direct-acting.

However, steam engines can also be classified according to their cylinder technology (simple expansion, compound, annular etc.). One can therefore sometimes find examples of engines which were classified under both methods, such as the compound walking beam (*compound* being the cylinder technology and *walking beam* being the connection method). Over time, as most engines became direct-acting but cylinder technologies were growing more complex, engines began to be classified solely according to their cylinder technology instead.

Some of the more commonly encountered types of marine steam engine are listed in the following sections. Note that not all of these terms may have been used exclusively in relation to marine applications.

Engines classified by connection mechanism

Side-lever

The side-lever engine was the first type of steam engine to be widely adopted for marine use in Europe. In the early years of steam navigation, the side-lever was the most common type of marine engine for inland waterway and coastal service in Europe, and it remained for many years the preferred engine for oceangoing service on both sides of the Atlantic.

The side-lever was an adaptation of the earliest form of steam engine, the beam engine. Each cylinder of a side-lever engine operated a pair of heavy horizontal iron beams, known as side levers, located on each side of the cylinder near the cylinder base. The side levers were each secured by a pin in the centre which acted as a fulcrum. The far end of each lever was attached to a connecting rod which rotated the crankshaft as the levers rocked up and down around the central pin.

The main disadvantages of the side-lever engine were that it was large and heavy, and for inland waterway and coastal service, it was soon replaced by lighter and more efficient designs. It remained the dominant engine type for oceangoing service through much of the first half of the 19th century however, due to its relatively low centre of gravity which gave ships more stability in heavy seas. It was also a common early engine type for warships, since its relatively low height made it less susceptible to battle damage.

The side-lever engine was a paddlewheel engine and was not suitable for driving screw propellers. The last ship built for transatlantic service to be fitted with a side-lever engine was the Cunard Line's paddle steamer RMS *Scotia*, considered an anachronism when it entered service in 1862.

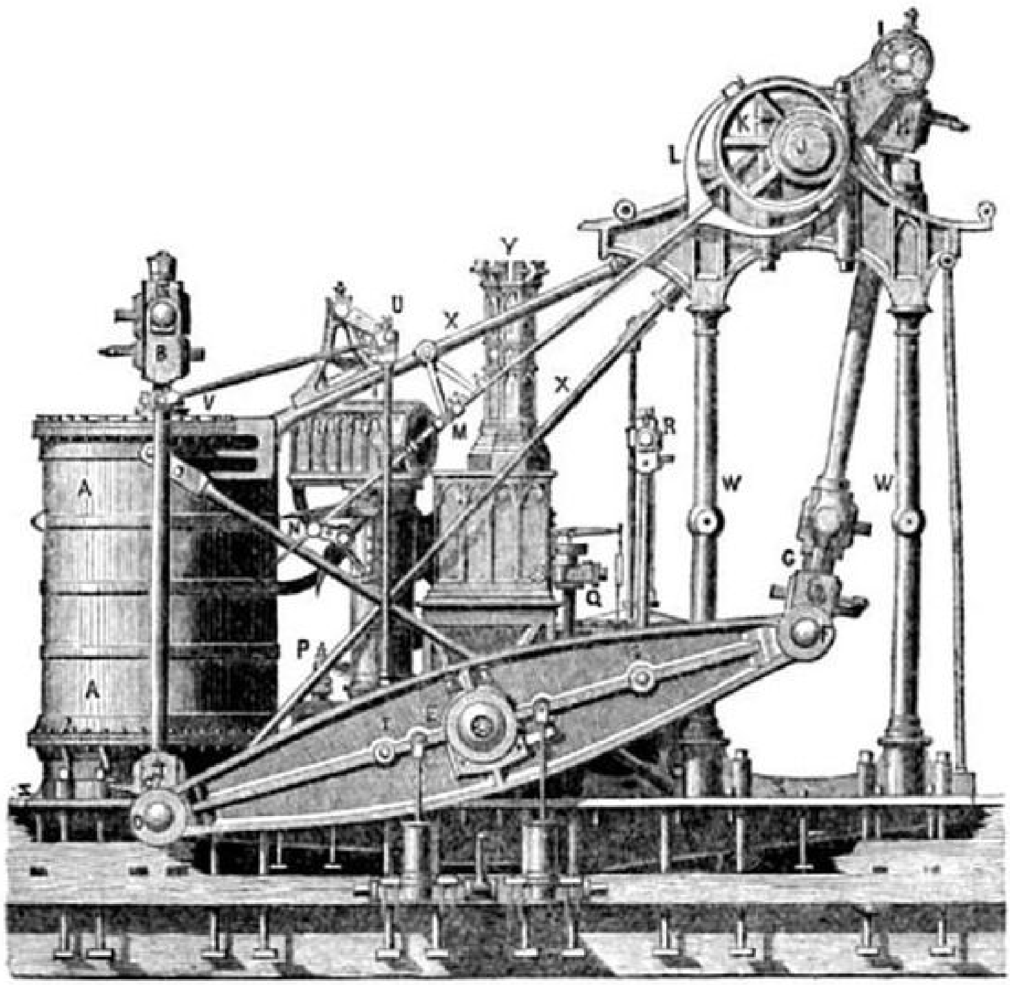
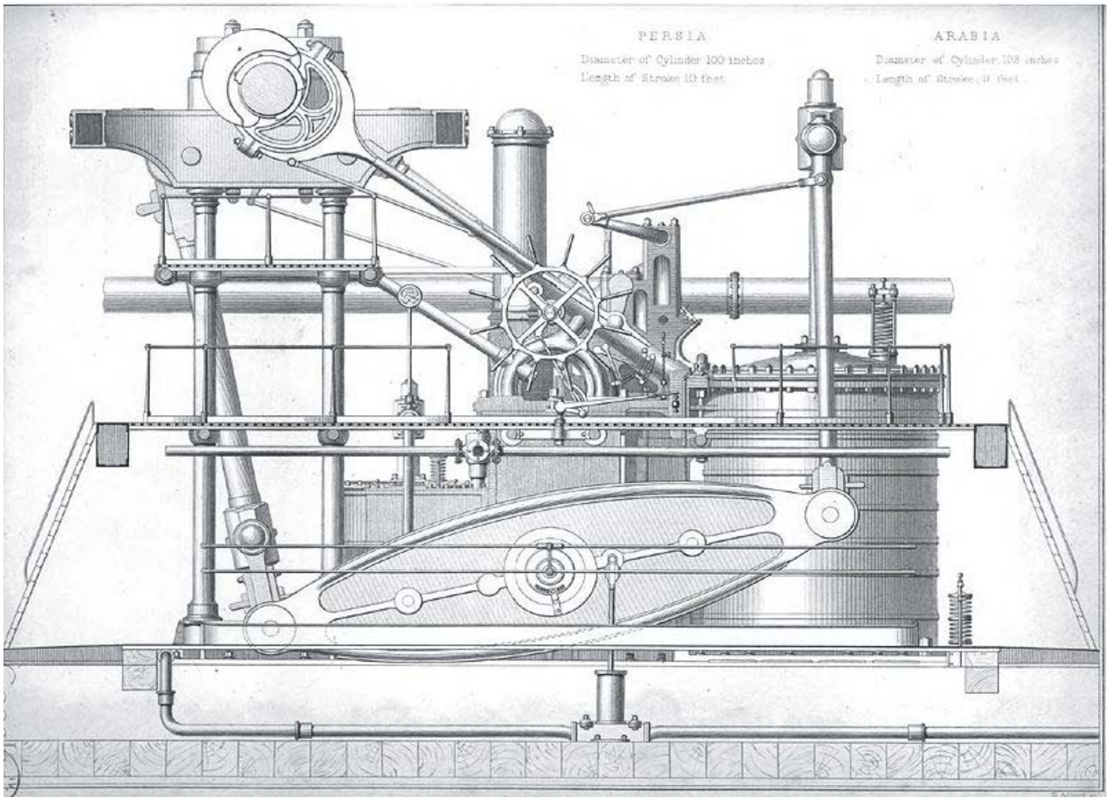


FIG. 92.—The Side-Lever Engine, 1849.

Side-lever engine of SS *Pacific* (1849)



Side-lever engine of RMS *Persia* (1855)

Early Napier side-lever engine from PS *Leven*, on display at Dumbarton, Scotland

Grasshopper

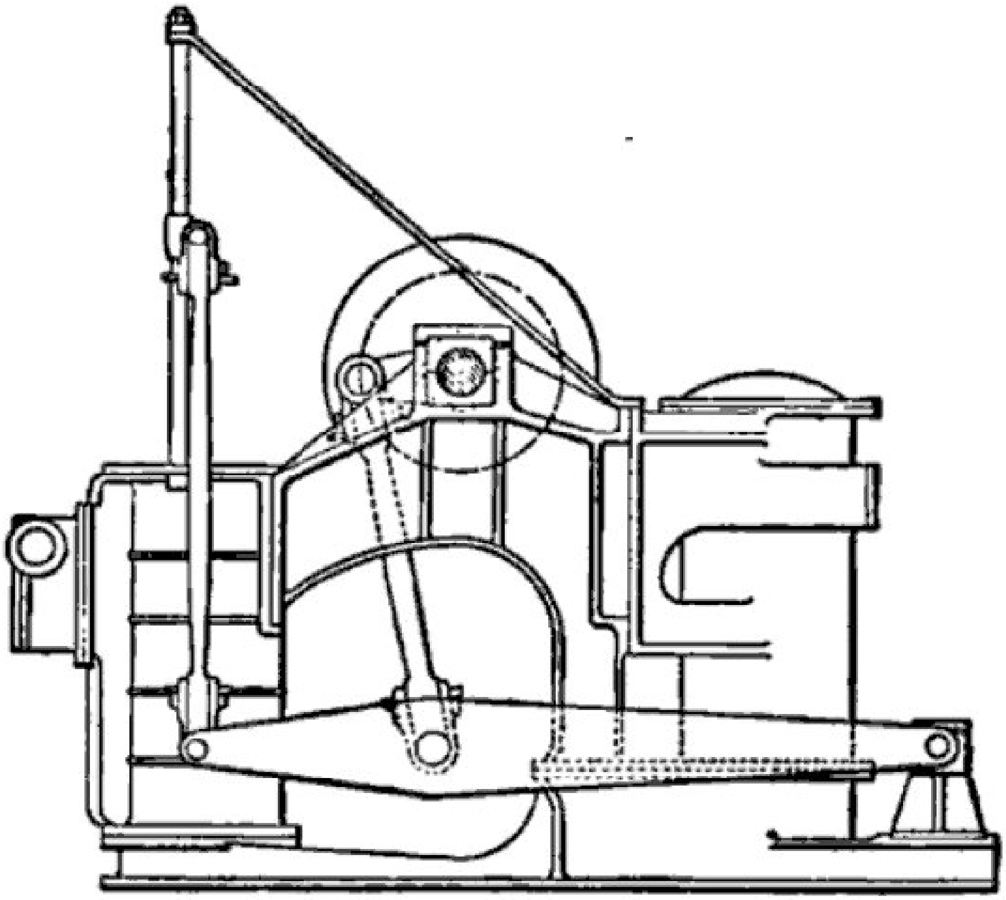


Fig. 3.—"Grasshopper" Engine.

Diagram of a grasshopper engine

The **grasshopper** engine was a variant of the side-lever engine. The grasshopper engine differs from the conventional side-lever in that the location of the lever fulcrum and connecting rod are more or less reversed, with the fulcrum located at one end of the lever instead of the centre, while the connecting rod is attached to the lever between the cylinder at one end and the fulcrum at the other.

Chief advantages of the grasshopper engine were cheapness of construction and robustness, with the type said to require less maintenance than any other type of marine steam engine. Another advantage is that the engine could be easily started from any crank position. Like the conventional side-lever engine however, grasshopper engines were disadvantaged by their weight and size. They were mainly used in small watercraft such as riverboats and tugs.

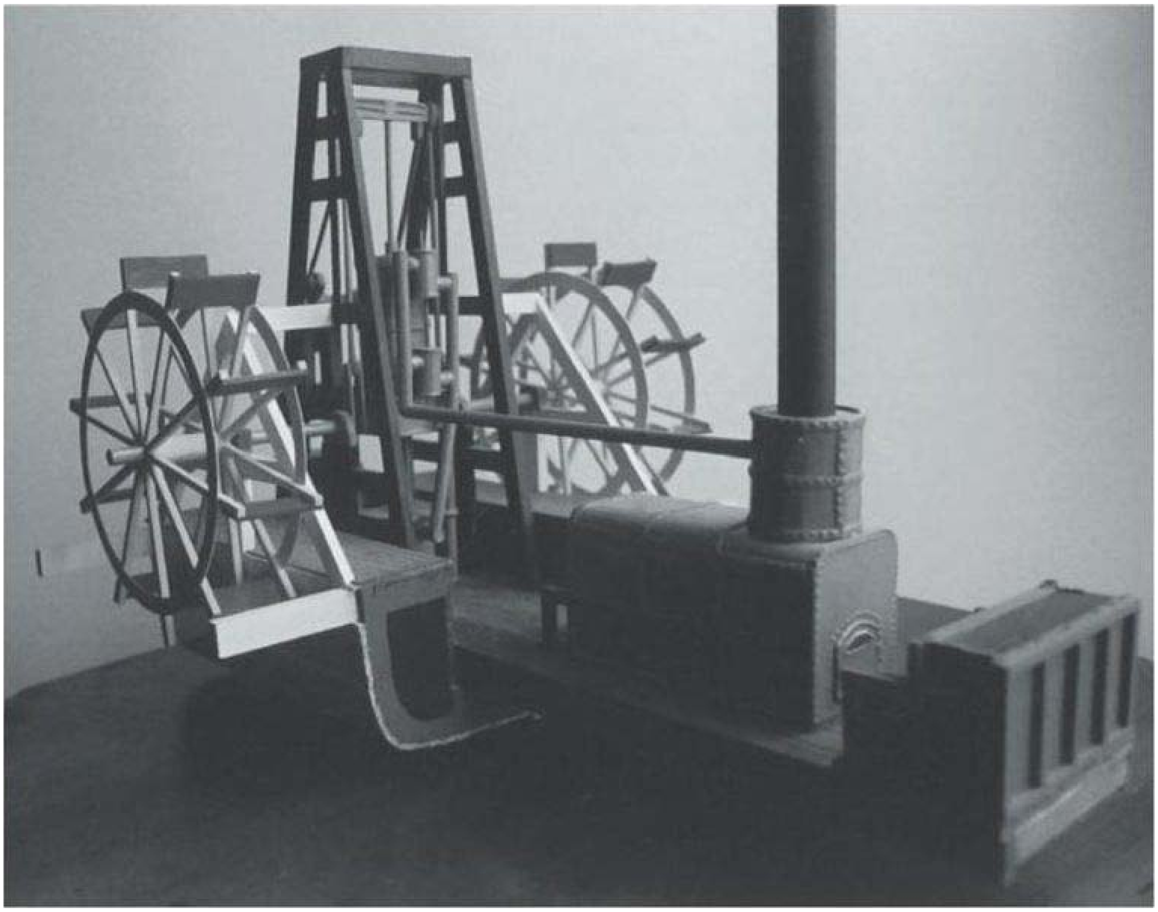
Crosshead (square)

The crosshead engine, also known as a **square**, **sawmill** or **A-frame** engine, was a type of paddlewheel engine used in the United States. It was the most common type of engine in the early years of American steam navigation.

The crosshead engine is described as having a vertical cylinder above the crankshaft, with the piston rod secured to a horizontal crosshead, from each end of which, on opposite sides of the cylinder, extended a connecting rod which rotated its own separate crankshaft. The crosshead operated within vertical guides that enabled the assembly to maintain the correct path as it moved. The engine's alternative name "A-frame" presumably derived from the shape of the frames supporting these guides. Some crosshead engines had more than one cylinder, in which case the piston rods were usually all connected to the same crosshead. An unusual feature of early examples of this type of engine was the installation of flywheels—geared to the crankshafts—which were thought necessary to ensure smooth operation. These gears could apparently be very noisy in operation.

Because the cylinder was placed above the crankshaft in this type of engine, it had a high center of gravity and was therefore deemed unsuitable for oceangoing service, so that its use was largely confined to vessels plying inland waterways. As marine engines grew steadily larger and heavier through the course of the century, the high center of gravity of square crosshead engines became increasingly impractical, leading to their abandonment by the 1840s in favor of the walking beam engine.

The name of this engine can sometimes lead to confusion as "crosshead" is also an alternative name for the steeple engine. Many sources thus prefer to refer to it by its informal name of "square" engine to avoid confusion. Additionally, the marine crosshead or square engine described here should not be confused with the term "square engine" as applied to combustion engines, which in the latter case refers to an engine whose bore is equal to its stroke.



Model of a crosshead or "square" engine, showing location of engine cylinder above the crankshaft; also piston rod, crosshead, connecting rods and paddlewheels

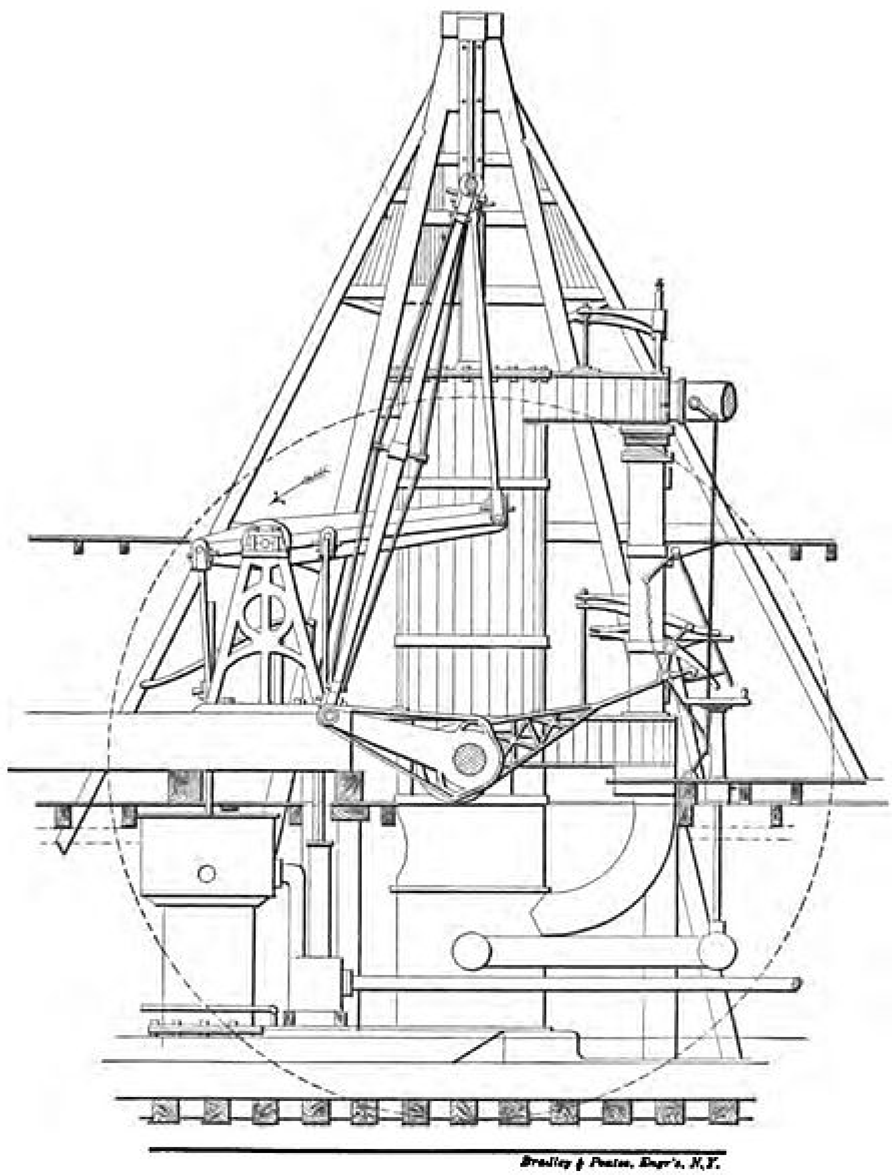
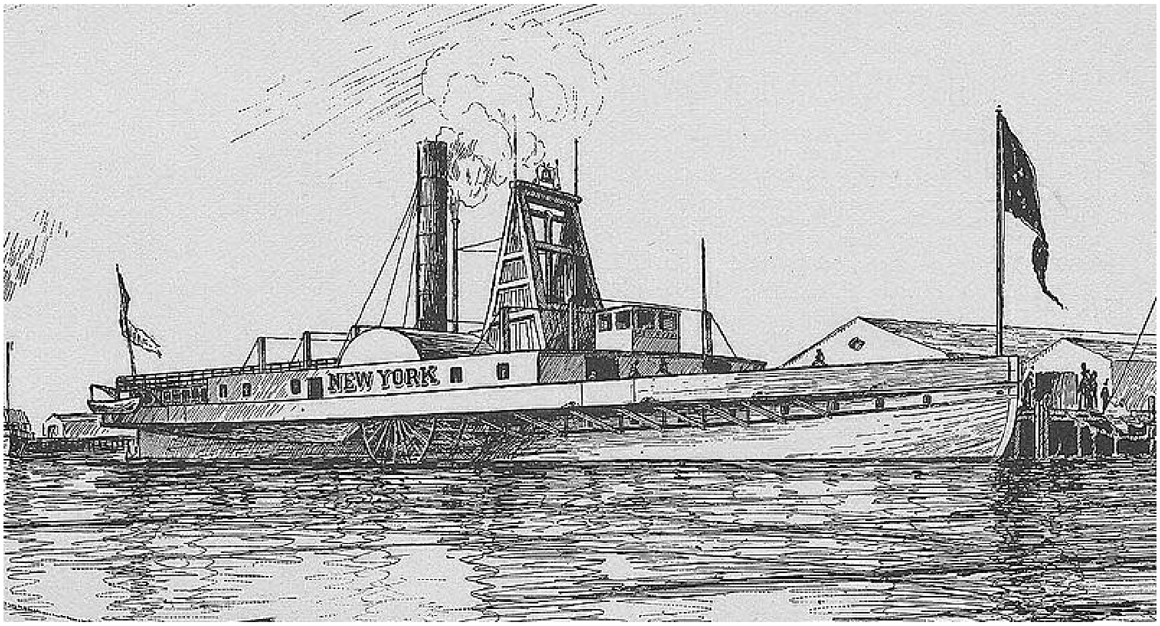


Diagram of a typical Hudson River steamboat crosshead engine (side view)



The 1836 paddle steamer *New York*. Between the paddlewheels is the tall square or "A-frame" engine, within which can be seen the long piston rod, near the top of its stroke, making a "T" with the horizontal crosshead

Walking beam

The walking beam, also known as a "vertical beam", "overhead beam", or simply "beam", was another early adaptation of the beam engine, but its use was confined almost entirely to the United States. After its introduction, the walking beam quickly became the most popular engine type in America for inland waterway and coastal service, and the type proved to have remarkable longevity, with walking beam engines still being occasionally manufactured as late as the 1940s. In marine applications, the beam itself was generally reinforced with iron struts that gave it a characteristic diamond shape, although the supports on which the beam rested were often built of wood. The adjective "walking" was applied because the beam, which rose high above the ship's deck, could be seen operating, and its rocking motion was (somewhat fancifully) likened to a walking motion.

Walking beam engines were a type of paddlewheel engine and were rarely used for powering propellers. They were used primarily for ships and boats working in rivers, lakes and along the coastline, but were a less popular choice for seagoing vessels because the great height of the engine made the vessel less stable in heavy seas. They were also unsuitable for military use, because the engine was exposed to enemy fire and could thus be easily disabled. Their popularity in the United States was due primarily to the fact that the walking beam engine was well suited for the shallow-draft boats which operated in America's shallow coastal and inland waterways.

Walking beam engines remained popular with American shipping lines right to the end of the 19th century. The Philadelphian shipbuilder Charles H. Cramp blamed America's general lack of competitiveness with the British shipbuilding industry in the mid-to-late

19th century upon the conservatism of American domestic shipbuilders and shipping line owners, who doggedly clung to outdated technologies like the walking beam and its associated paddlewheel long after they had been abandoned in other parts of the world.

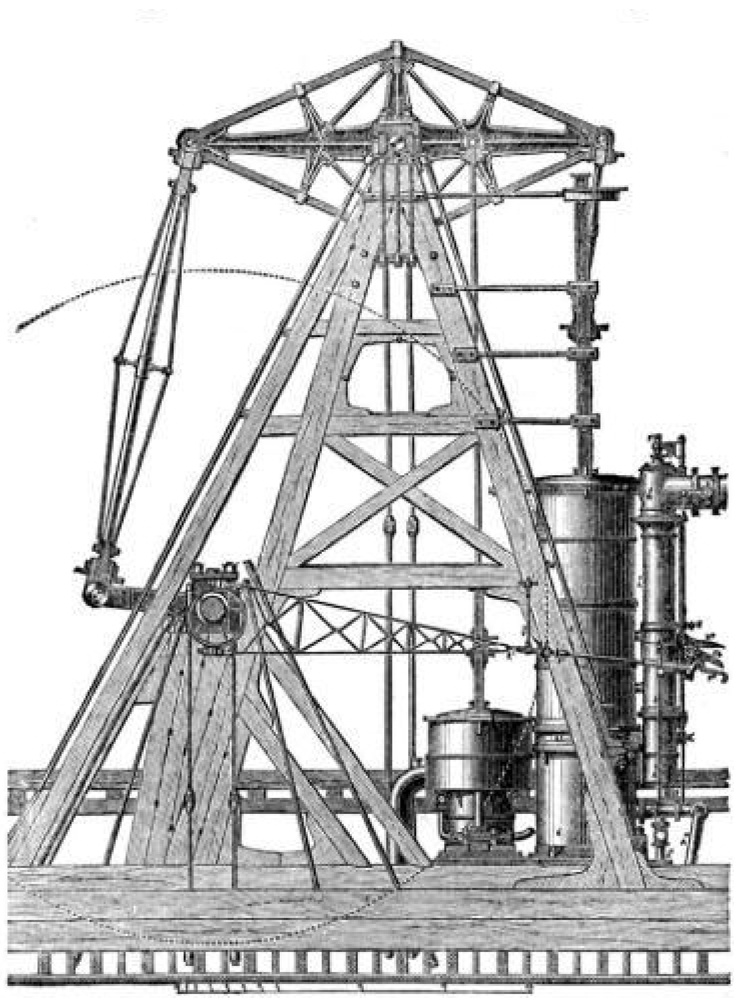
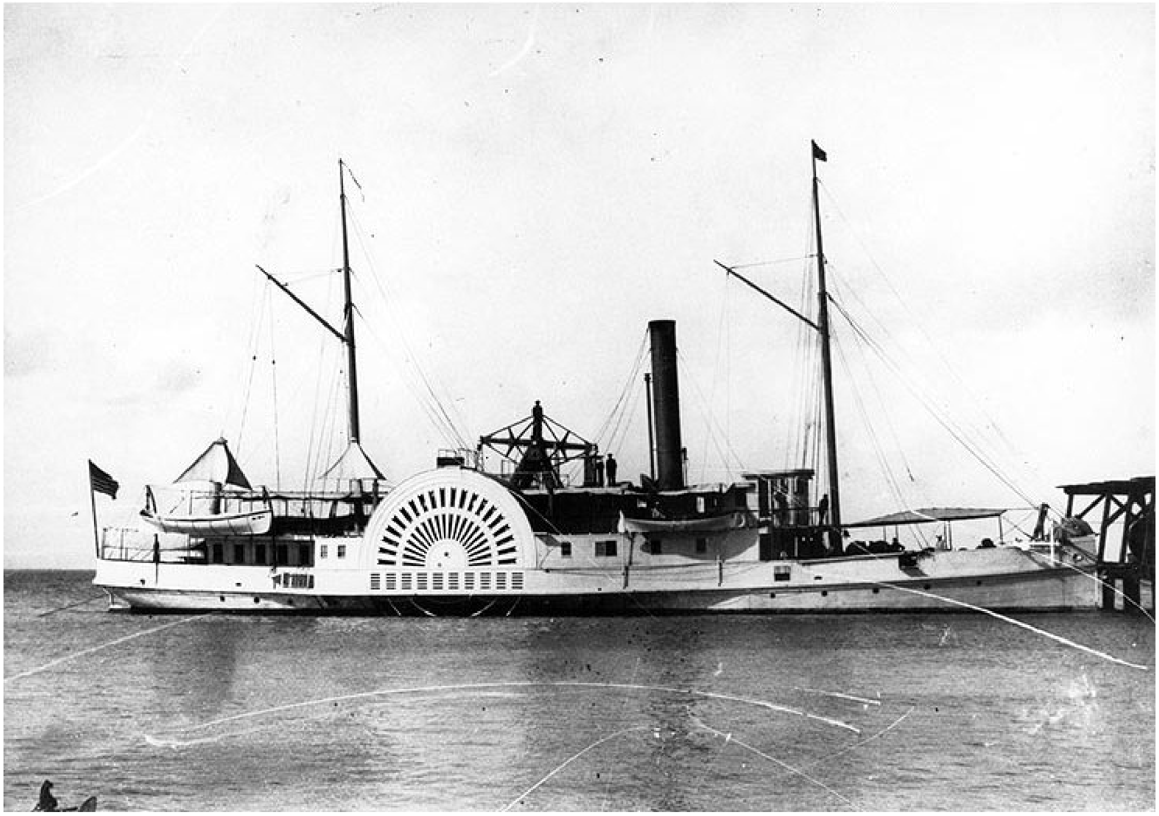


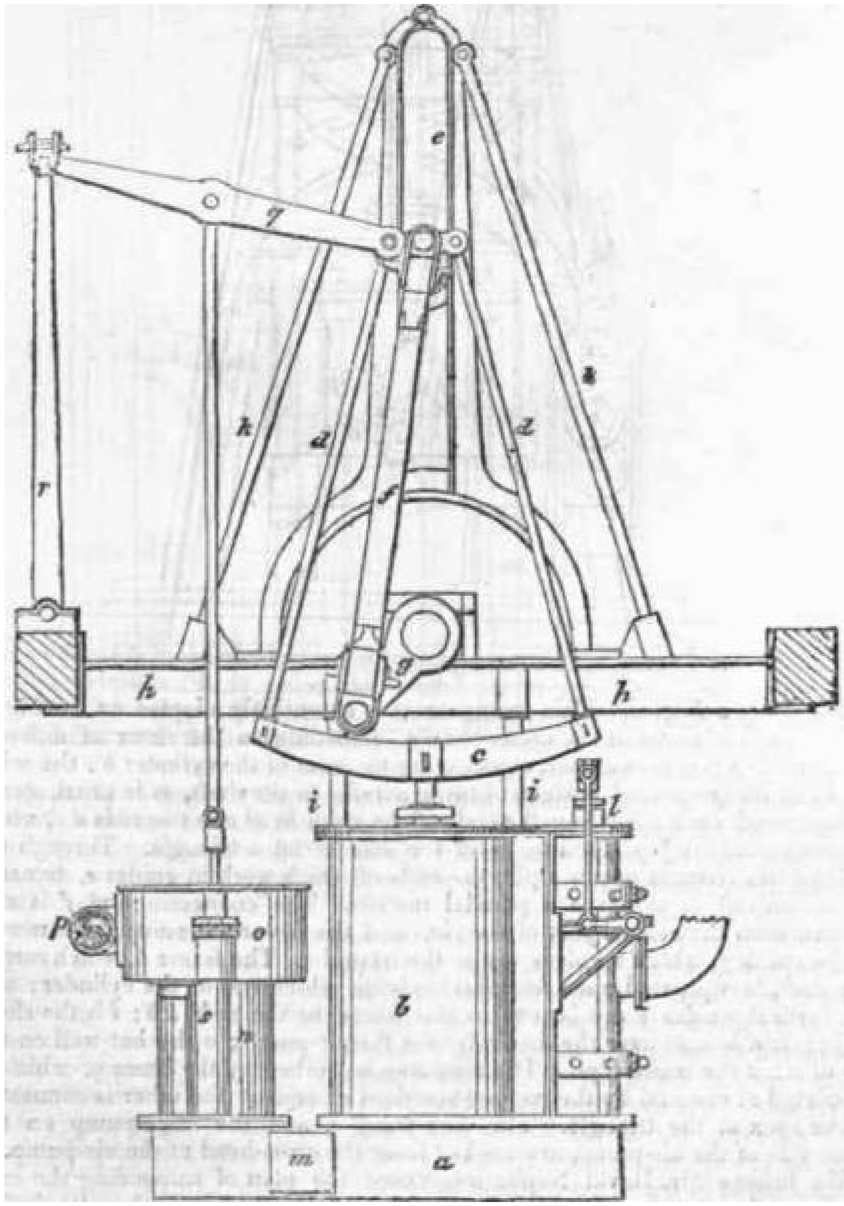
Fig. 180.—Beam-Engine.

Basic diagram of a walking beam engine



USS *Delaware* (1861). The vessel's diamond shaped "walking beam" can clearly be seen amidships

Steeple



Steeple engine

The steeple engine, sometimes referred to as a "crosshead" engine, was an early attempt to break away from the beam concept common to both the walking beam and side-lever types, and come up with a smaller, lighter, more efficient design. In a steeple engine, the vertical oscillation of the piston is not converted to a horizontal rocking motion as in a beam engine, but is instead used to move an assembly, composed of a crosshead and two rods, through a vertical guide at the top of the engine which in turn rotates the crankshaft connecting rod below. In early examples of the type, the crosshead assembly was rectangular in shape, but over time it was refined into an elongated triangle. The triangular assembly above the engine cylinder gives the engine its characteristic "steeple" shape, hence the name.

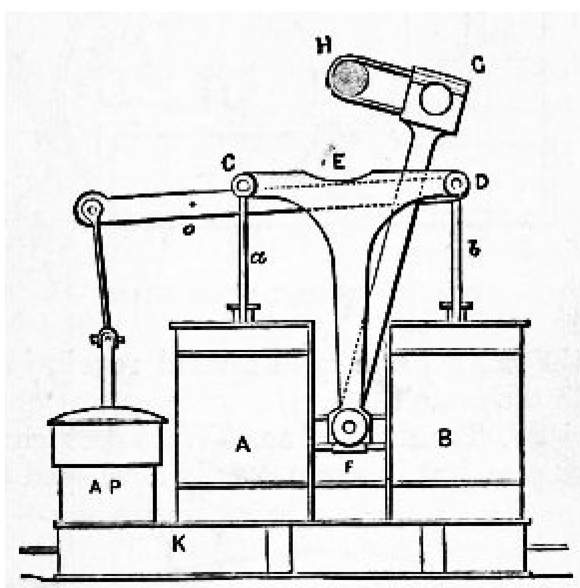
Steeple engines were tall, though not as tall as walking beams, but much narrower laterally, saving both space and weight. Because of their height and high centre of gravity, they were, like walking beams, considered to be less appropriate for oceangoing service, but they remained highly popular for several decades, especially in Europe, for inland waterway and coastal vessels.

Steeple engines began to appear in steamships in the 1830s and the type was perfected in the early 1840s by the British shipbuilder David Napier. The steeple engine was gradually superseded by the various types of direct-acting engine.

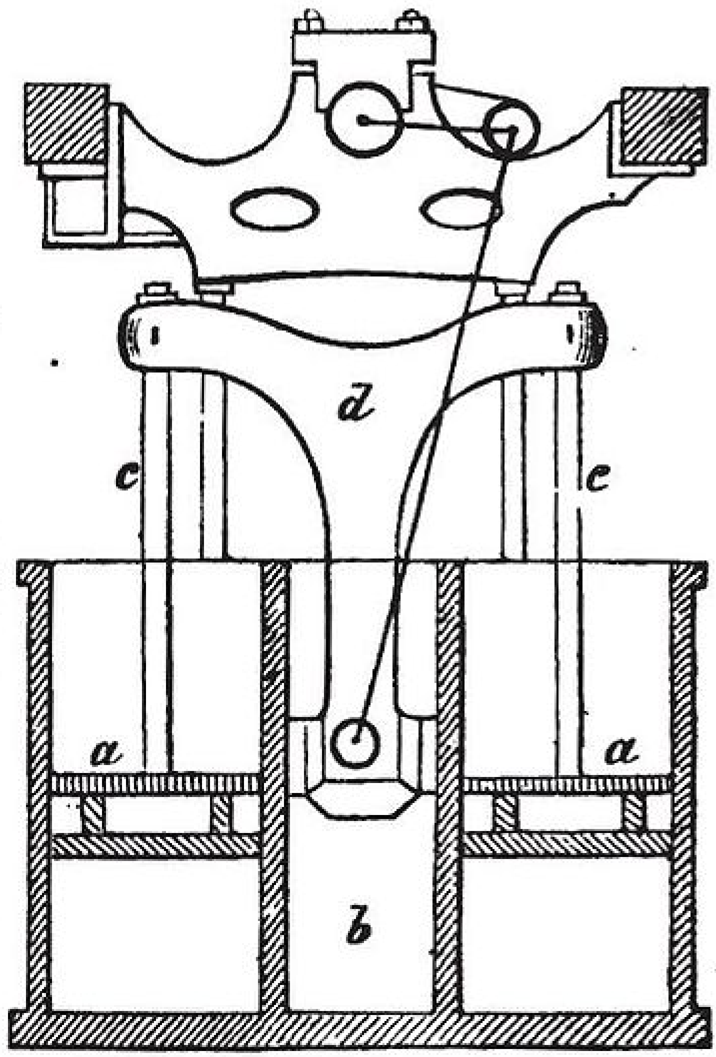
Siamese

The Siamese engine, also referred to as the "double cylinder" or "twin cylinder" engine, was another early alternative to the beam or side-lever engine. This type of engine had two identical, vertical engine cylinders arranged side-by-side, whose piston rods were attached to a common, T-shaped crosshead. The vertical arm of the crosshead extended down between the two cylinders and was attached at the bottom to both the crankshaft connecting rod and to a guide block that slid between the vertical sides of the cylinders, enabling the assembly to maintain the correct path as it moved.

The Siamese engine was invented by British engineer Joseph Maudslay (son of Henry), but although he invented it after his oscillating engine, it failed to achieve the same widespread acceptance, as it was only marginally smaller and lighter than the side-lever engines it was designed to replace. It was however used on a number of mid-century warships, including the first warship fitted with a screw propeller, HMS *Rattler*.

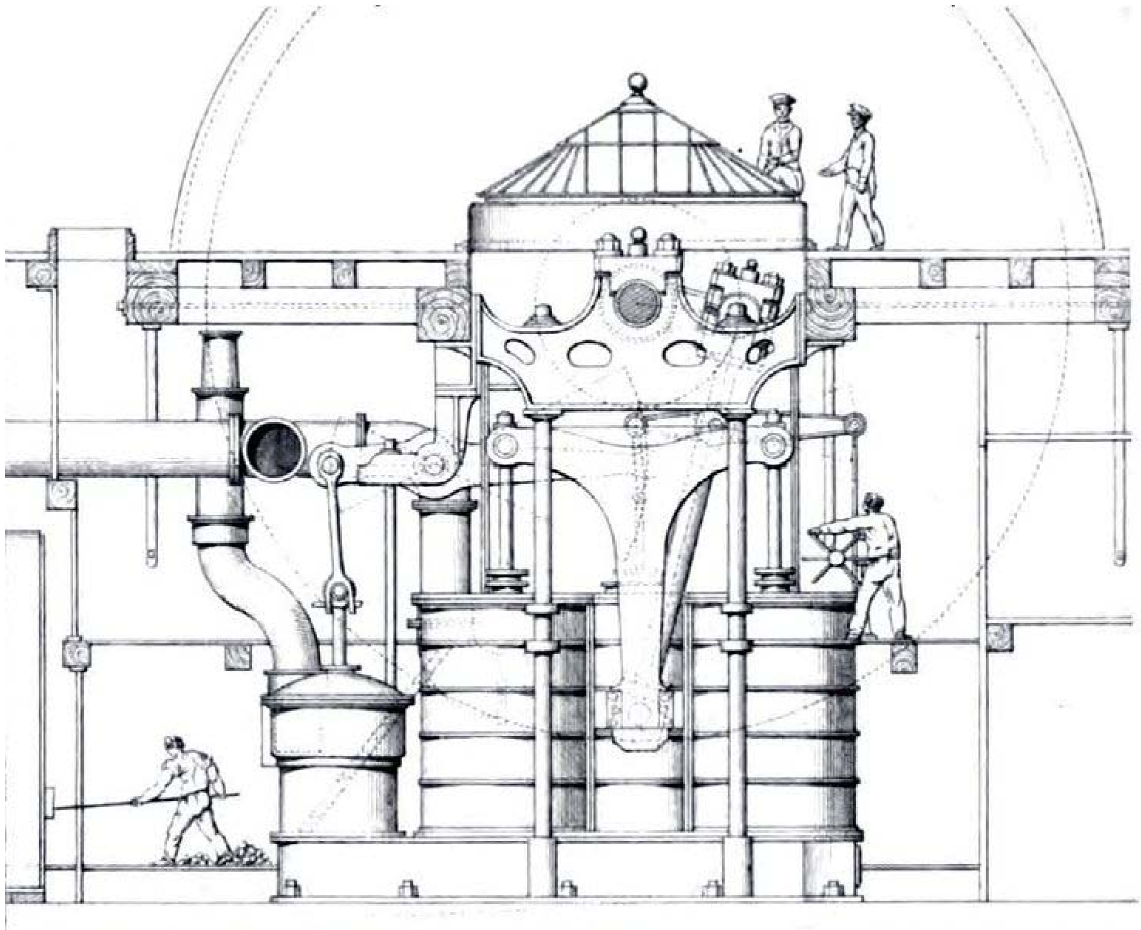


Basic diagram of a Siamese engine



Annular Engine.

Diagram of an annular engine with Siamese connection mechanism



Siamese engine of HMS *Retribution* (1844)

Direct acting

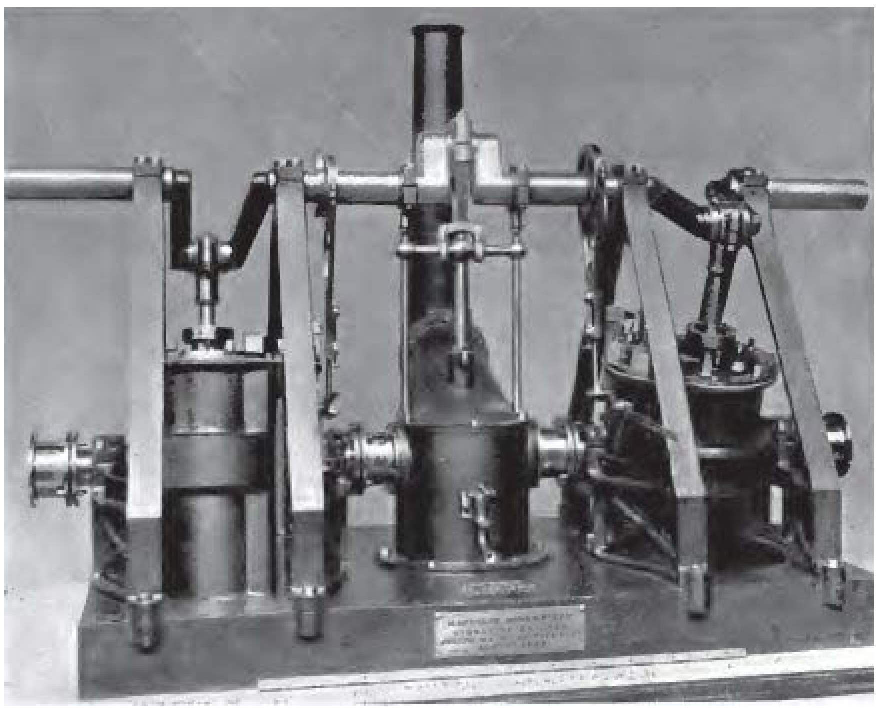
There are two definitions of a direct-acting engine encountered in 19th-century literature. The earlier definition applies the term "direct-acting" to any type of engine other than a beam (i.e. walking beam, side-lever or grasshopper) engine. The later definition only uses the term for engines which apply their power directly to the crankshaft via the piston rod and/or connecting rod.

Unlike the side-lever or beam engine, a direct-acting engine could be readily adapted to power either paddlewheels or a propeller. As well as offering a lower profile, direct-acting engines had the advantage of being smaller and weighing considerably less than beam or side-lever engines. The Royal Navy found that on average a direct-acting engine (early definition) weighed 40% less and required an engine room only two thirds the size of that for a side-lever of equivalent power. One disadvantage of such engines is that they were more prone to wear and tear and thus required more maintenance.

Oscillating

An oscillating engine was a type of direct-acting engine that was designed to achieve further reductions in engine size and weight. Oscillating engines had the piston rods connected directly to the crankshaft, dispensing with the need for connecting rods. In order to achieve this aim, the engine cylinders were not immobile as in most engines, but secured in the middle by trunnions which allowed the cylinders themselves to pivot back and forth as the crankshaft rotated, hence the term *oscillating*. Steam was supplied and exhausted through the trunnions.

The first patented oscillating engine was built by Joseph Maudslay in 1827, but the type is considered to have been perfected by John Penn. Oscillating engines remained a popular type of marine engine for much of the 19th century.



Model of a Maudslay oscillating engine

Oscillating engine built in 1853 by J. & A. Blyth of London for the Austrian paddle steamer *Orsova*

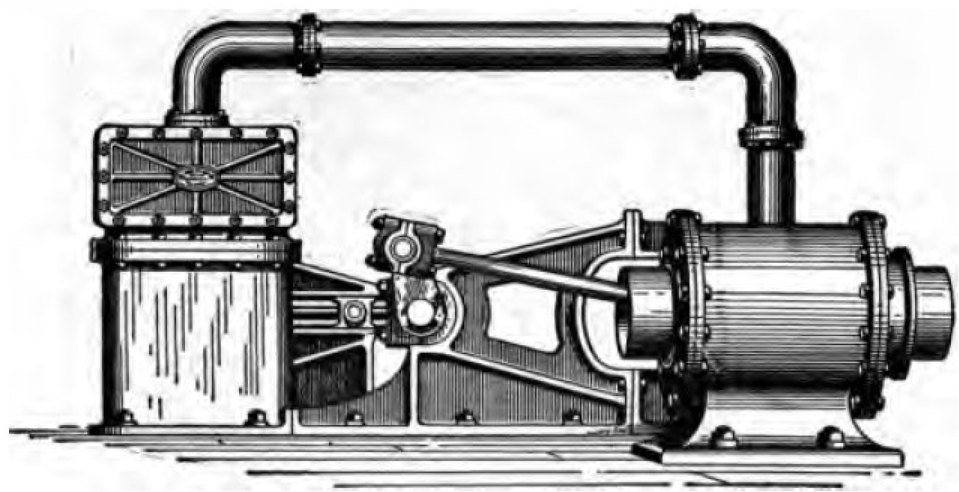
Trunk

The trunk engine, another type of direct-acting engine, was originally developed as a means of reducing an engine's height while retaining a long stroke. Early examples of such engines had vertical cylinders; however, it was quickly realized that the type was compact enough to be laid horizontally across the keel. In this configuration, it was very useful to navies, as it had a profile low enough to fit entirely below a ship's waterline, where it would be as safe as possible from enemy fire. The type was generally produced for military service by John Penn.

This type of engine had a horizontal cylinder, through the centre of which passed a cylindrical "trunk" or passage containing the connecting rod. The walls of the trunk were either bolted to the piston or cast as one piece with it, and moved back and forth with it. The working portion of the cylinder was annular or ring-shaped, with the trunk passing through the centre of the cylinder itself.

Trunk engines were quite common on mid-19th century warships, and were also to be found in commercial vessels, where though valued for their compact size and low centre of gravity, they proved expensive to operate. Trunk engines however proved poorly adapted to the higher boiler pressures that became prevalent in the latter half of the 19th century, and were abandoned in favour of other solutions.

Normally large engines, a small mass-produced, high-revolution, high-pressure version was produced for the Crimean War. In being quite effective, the type persisted in later gunboats. An original trunk engine of the gunboat type exists in the Western Australian Museum in Fremantle. After sinking in 1872, it was raised in 1985 from the SS *Xantho* and can now be turned over by hand. The Trunk Engine's mode of operation, illustrating its compact nature can be viewed on the *Xantho* project's website.



Trunk Engine

Trunk engine illustration

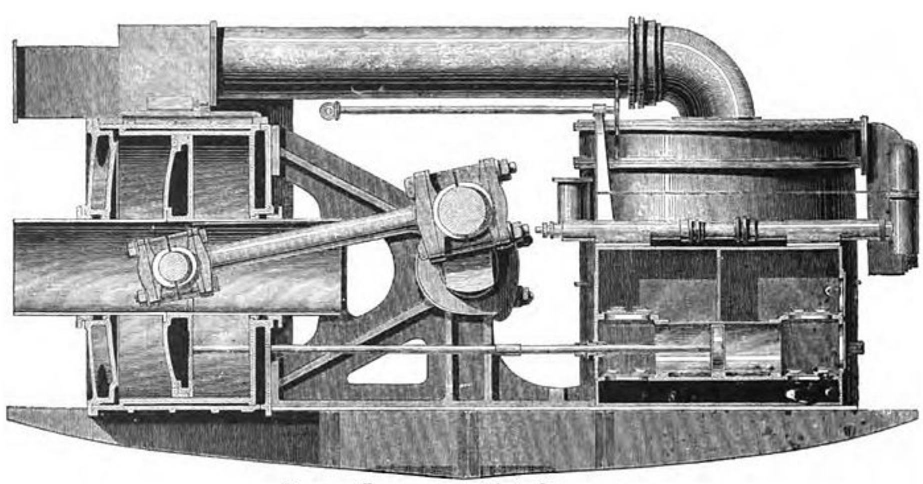
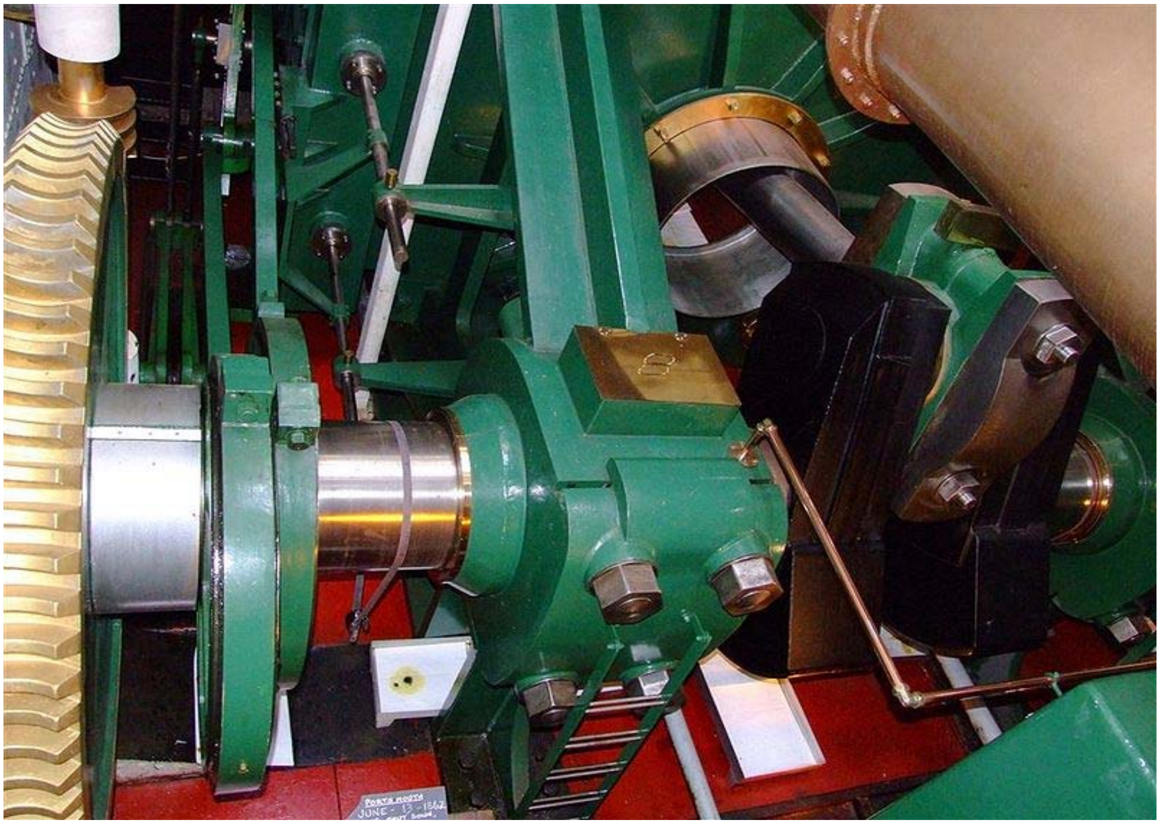


FIG. 10.—ENGINE OF H. M. S. BELLEROPHON.

Cutaway view of trunk engine of HMS *Bellerophon*, showing (on the left) engine cylinder, annular piston and trunk assembly, and connecting rod inside trunk



Looking down at the trunk engine of HMS *Warrior* (1860). The connecting rod can be seen emerging from the trunk at right.

Vibrating lever

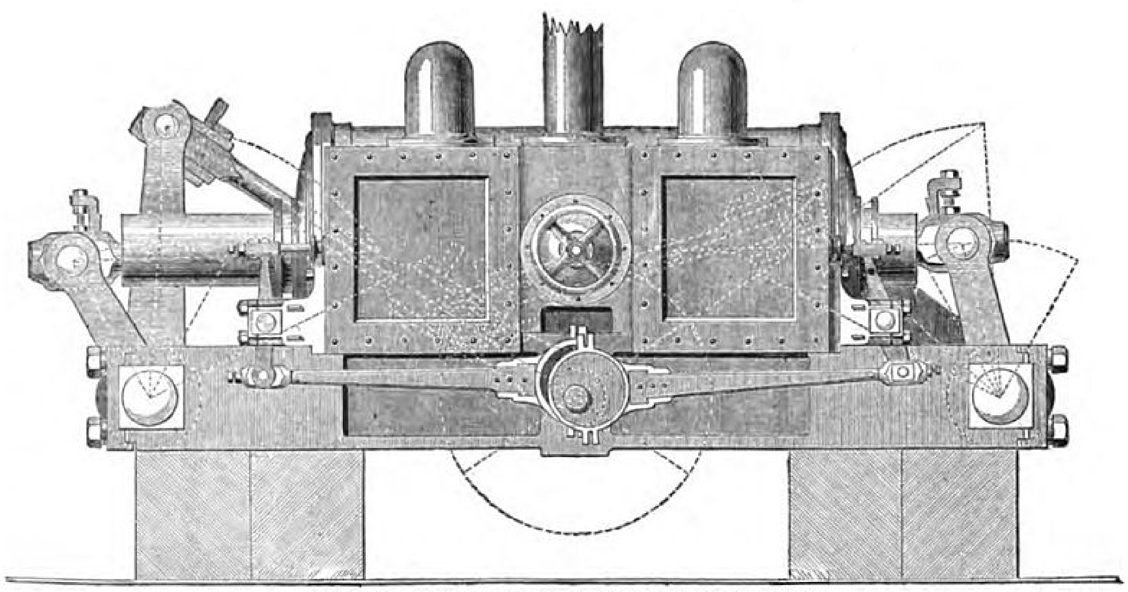


FIG. 38.—ENGINE OF U. S. MONITOR MONADNOCK.

Vibrating-lever engine of USS *Monadnock* (1863) - front view

The vibrating lever, or **half-trunk** engine, was a development of the conventional trunk engine conceived by Swedish-American engineer John Ericsson. Ericsson needed a small, low-profile engine like the trunk engine to power the U.S. Federal government's monitors, a type of warship developed during the American Civil War that had very little space for a conventional powerplant. The trunk engine itself was however unsuitable for this purpose because the preponderance of weight was on the side of the engine containing the cylinder and trunk, a problem which could not be compensated for on the small monitor warships.

Ericsson resolved this problem by placing two horizontal cylinders back-to-back in the middle of the engine, working two "vibrating levers", one on each side, which by means of shafts and additional levers rotated a centrally located crankshaft. Vibrating lever engines were later used in some other warships and merchant vessels, but their use was confined to ships built in the United States and in Ericsson's native country of Sweden, and as they had few advantages over more conventional engines, were soon supplanted by other types.

Back acting

The back-acting engine, also known as the **return connecting rod engine**, was another engine designed to have a very low profile. A back-acting engine can be thought of as something like a steeple engine, but laid horizontally across the keel of a ship rather than standing vertically above it. Instead of the triangular crosshead assembly found in a typical steeple engine however, the back-acting engine generally utilized a set of two or more elongated, parallel piston rods terminating in a crosshead to perform the same function. The term "back-acting" or "return connecting rod" derives from the fact that the connecting rod "returns" or comes back from the side of the engine opposite the engine cylinder to rotate a centrally located crankshaft.

Back-acting engines were another type of engine popular in both warships and commercial vessels in the mid-19th century, but like many other engine types in this era of rapidly changing technology, they were eventually abandoned for other solutions. There is only one back-acting engine known to be still in existence—that of the TV *Emery Rice* (formerly USS *Ranger*), now the centerpiece of a display at the American Merchant Marine Museum.

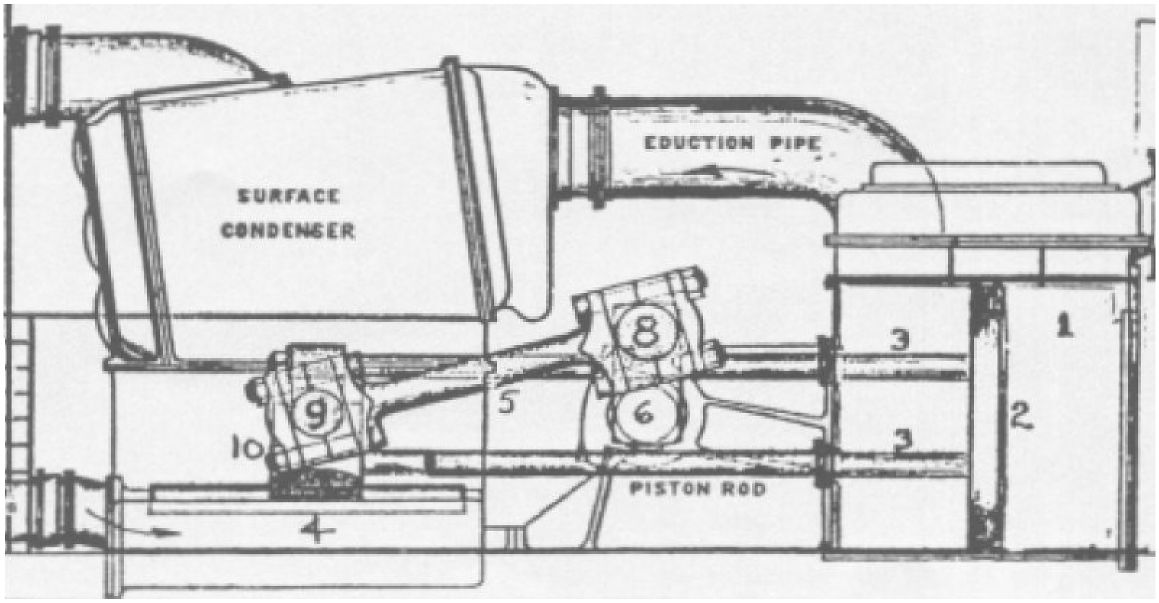


Diagram of back-acting engine of USS *Ranger*

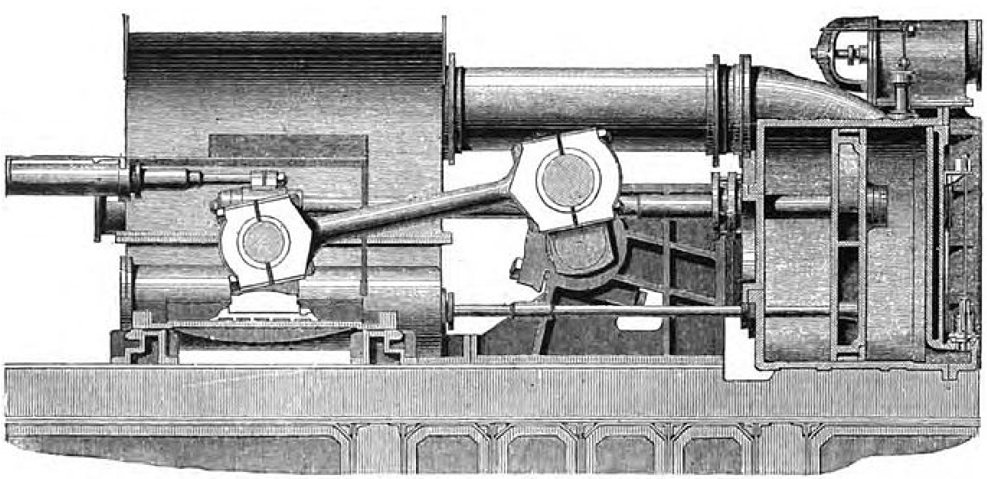


FIG. 12.—ENGINE OF H. M. S. AGINCOURT.

Return connecting rod engine of HMS *Agincourt* (1865)

Vertical

As steamships grew steadily in size and tonnage through the course of the 19th century, the need for low profile, low centre-of-gravity engines correspondingly declined. Freed increasingly from these design constraints, engineers were able to revert to simpler, more efficient and more easily maintained designs. The result was the growing dominance of the so-called "vertical" engine (more correctly known as the **vertical inverted direct acting** engine).

In this type of engine, the cylinders are located directly above the crankshaft, with the piston rod/connecting rod assemblies forming a more or less straight line between the two. The configuration is similar to that of a modern internal combustion engine (one notable difference being that the steam engine is double acting, whereas an internal combustion engine generates power only in the downward stroke). Vertical engines are sometimes referred to as "hammer", "forge hammer" or "steam hammer" engines, due to their roughly similar appearance to another common 19th-century steam technology, the steam hammer.

Vertical engines came to supersede almost every other type of marine steam engine toward the close of the 19th century. Because they became so common, vertical engines are not usually referred to as such, but are instead referred to based upon their cylinder technology, i.e. as compound, triple expansion, quadruple expansion etc. It should be noted that the term "vertical" for this type of engine is imprecise, since technically any type of steam engine is "vertical" if the cylinder is vertically orientated. An engine described as "vertical" should therefore not be assumed to be of the vertical inverted direct-acting type unless the term "vertical" is unqualified.

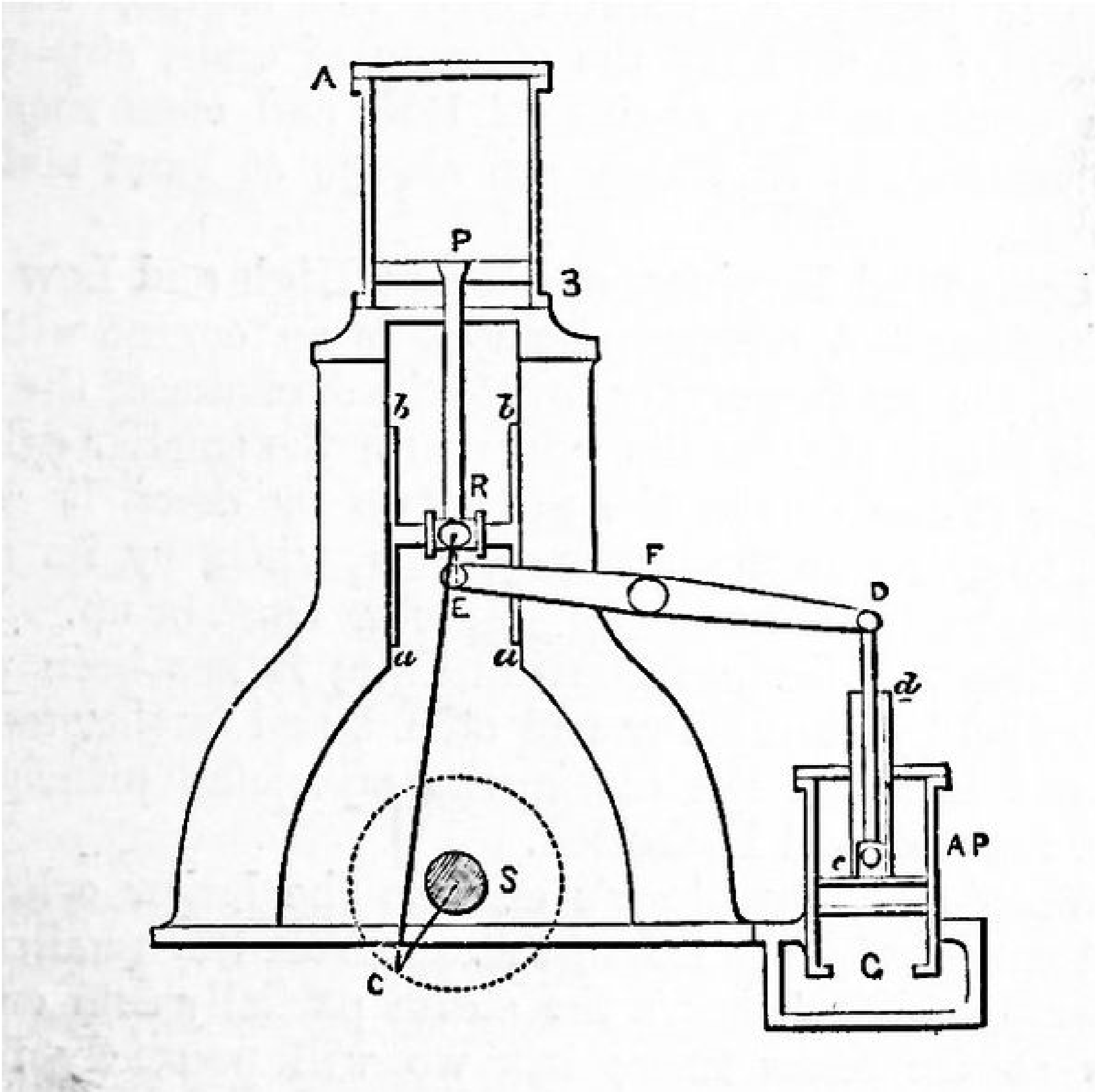
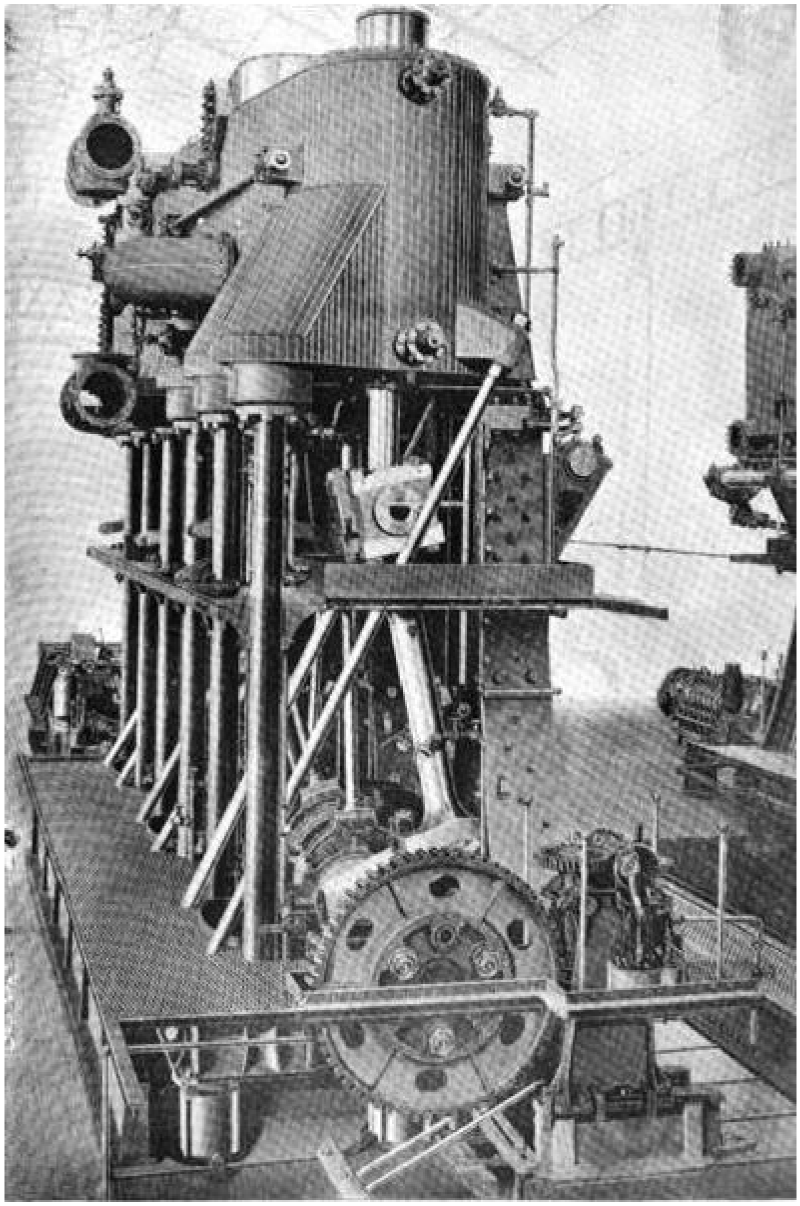


Diagram of a simple "hammer" engine



Vertical triple expansion engine of USS *Wisconsin* (BB-9). The typical vertical engine arrangement of cylinder, piston rod, connecting rod and crankshaft can clearly be seen in this photo.

Engines classified by cylinder technology

Simple expansion

A simple expansion engine is a steam engine that expands the steam through only one stage, which is to say, all its cylinders are operated at the same pressure. Since this was by far the most common type of engine in the early period of marine engine development, the term "simple expansion" is rarely encountered; rather, an engine is assumed to be simple expansion unless otherwise stated.

Compound

A compound engine is a steam engine which operates cylinders through more than one stage, i.e., at different pressure levels. Compound engines were a method of improving efficiency. Up until the development of compound engines, steam engines used the steam only once before being recycled back to the boiler, but a compound engine recycles the steam into one or more larger, lower pressure second cylinders first, in order to utilize more of its heat energy. Compound engines could be configured to either increase a ship's economy or its speed. Although broadly speaking a compound engine can refer to a steam engine with any number of different-pressure cylinders, the term usually refers to engines which expand steam through only two stages, i.e. those which operate cylinders at only two different pressures (or "double expansion" engines).

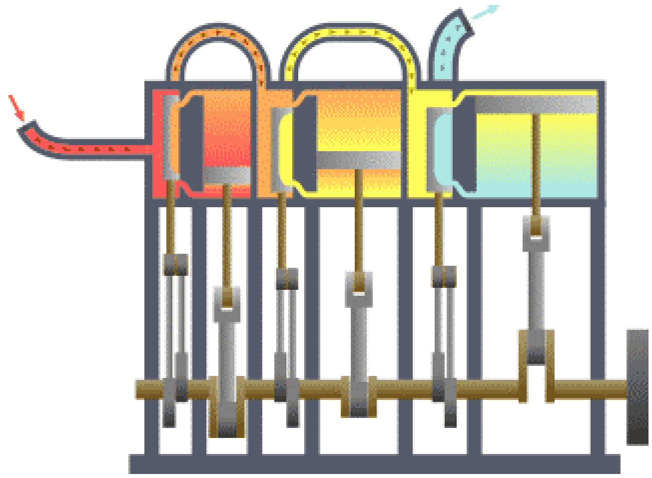
Note that a compound engine can have more than one *set* of variable-pressure cylinders. For example, an engine might have two cylinders operating at pressure x and two operating at pressure y, or one cylinder operating at pressure x and three operating at pressure y. What makes it compound (or double expansion) as opposed to multiple expansion is that there are only two *pressures*, x and y.

The first compound engine believed to have been installed in a ship was that fitted to *Henry Eckford* by the American engineer James P. Allaire in 1824. However, many sources attribute the "invention" of the marine compound engine to Glasgow's John Elder in the 1850s. Elder made improvements to the compound engine that made it safe and economical for transcontinental voyages for the first time.

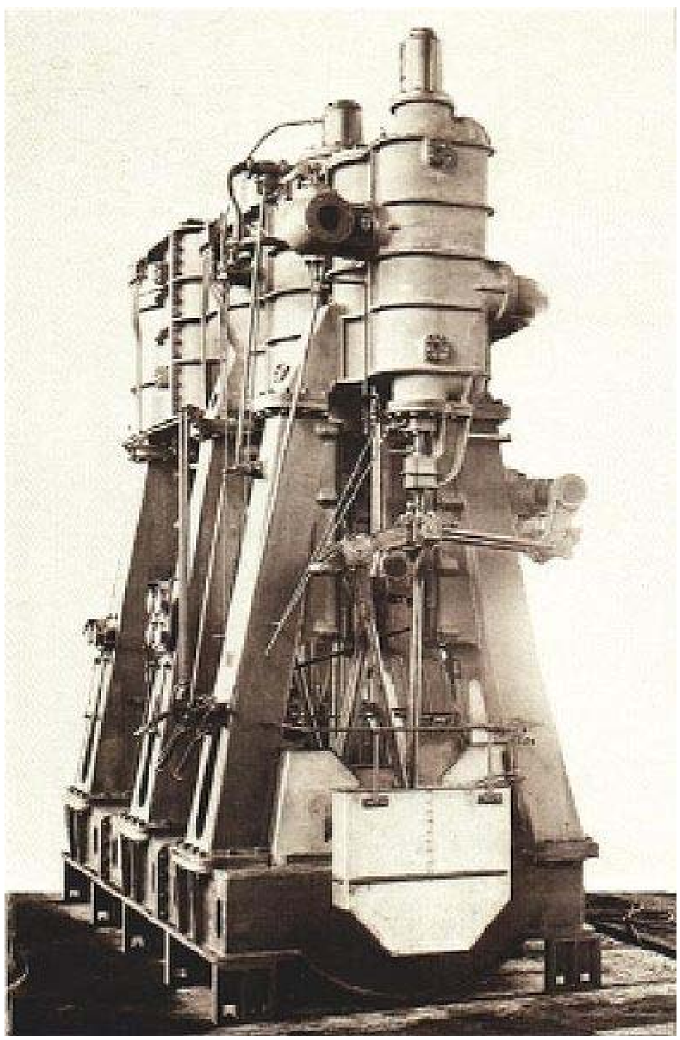
Triple or multiple expansion

A triple expansion engine is a compound engine that expands the steam in three stages, i.e. an engine which has cylinders operating at three different pressures. A quadruple expansion engine expands the steam in four stages, and so on.

Multiple expansion engines survived well into the 20th century. All 2,700 Liberty ships built by the United States during World War II were powered by triple-expansion engines, because the capacity of the US to manufacture steam turbines was still limited. The biggest manufacturer of triple expansion engines during the war was the Joshua Hendy Iron Works. Toward the end of the war, turbine-powered Victory ships were manufactured in increasing numbers.



A typical vertical triple-expansion engine



A Joshua Hendy triple expansion engine

A triple expansion engine on the Lydia Eva (steam drifter)

Annular

An annular engine is an unusual type of engine that has an annular (ring-shaped) cylinder. Some of American pioneering engineer James P. Allaire's early compound engines were of the annular type, with a smaller, high pressure cylinder placed in the centre of a larger, ring-shaped low-pressure cylinder. Trunk engines were another type of annular engine. A third type of annular marine engine which was sometimes produced utilized the Siamese engine connecting mechanism, but instead of two separate cylinders, had a single annular-shaped cylinder wrapped around the vertical arm of the crosshead.

Other terms

Some other terms are encountered in marine engine literature of the period. These terms, listed below, are usually used in conjunction with one or more of the basic engine classification terms listed above.

Simple

A simple engine is an engine with only one cylinder. Up until about the mid-19th century, most ships had engines with only one cylinder (although some vessels had more than one engine). Simple engines are always also simple expansion engines by necessity.

Double acting

A double acting engine is an engine where steam is applied to both the up and down stroke of the piston. Earlier steam engines applied steam in only one direction, allowing momentum or gravity to return the piston to its starting place, but a double acting engine uses steam to force the piston in both directions, thus increasing RPM and power. Like the term "simple expansion", the term "double acting" is infrequently encountered in the literature since almost all marine engines were of the double acting type.

Vertical, horizontal, inclined, inverted

These terms refer to the orientation of the engine cylinder. A vertical cylinder stands vertically with its piston rod operating above it. An inverted cylinder (or "vertical inverted" cylinder) can be thought of as a vertical cylinder positioned upside down. With an inclined or horizontal type, the cylinder and piston are positioned at an incline or horizontally. An inclined inverted cylinder is an inverted cylinder operating at an incline. These terms are all generally used in conjunction with the engine types above. Thus, one may have a horizontal direct-acting engine, or an inverted walking beam, and so on.

Inclined and horizontal cylinders could be very useful in naval vessels as their orientation kept the engine profile as low as possible and thus less susceptible to damage. They could also be used in a low profile ship or to keep a ship's centre of gravity lower. In addition, inclined or horizontal cylinders had the advantage of reducing the amount of vibration by comparison with a vertical cylinder.

Geared

A geared engine or "geared screw" turns the propeller at a different rate to the engine's RPM. Early marine propeller engines were geared upward, which is to say the propeller was geared to run at a higher RPM than the engine itself. As engines became faster and more powerful through the latter part of the 19th century, gearing was often dispensed with and the propeller ran at the same RPM as the engine.

Chapter- 3

Air-Independent Propulsion

Air-independent propulsion (AIP) is a term that encompasses technologies which allow a submarine to operate without the need to surface or use a snorkel to access atmospheric oxygen. The term usually excludes the use of nuclear power, and describes augmenting or replacing the diesel-electric propulsion system of non-nuclear vessels. The United States Navy uses the hull classification symbol "SSP" to designate boats powered by AIP, while retaining "SS" for classic diesel-electric attack submarines.

AIP is usually implemented as an auxiliary source. Most such systems generate electricity which in turn drives an electric motor for propulsion or recharging the boat's batteries. The submarine's electrical system is also used for providing "hotel services"—ventilation, lighting, heating etc.—although this consumes a small amount of power compared to that required for propulsion.

A benefit of this approach is it can be retrofitted into existing submarine hulls by inserting an additional hull section. AIP does not normally provide the endurance or power to replace the atmospheric dependent propulsion, but allows it to remain submerged longer than a more conventionally propelled submarine. A typical conventional power plant will provide 3 megawatts maximum, and an AIP source around 10% of that. A nuclear submarine's propulsion plant is usually much greater than 20 megawatts.

Internal oxygen supply

History

In 1867 Narcís Monturiol i Estarriol successfully developed an anaerobic air independent propulsion system powered by a chemical reaction. In 1908 the Imperial Russian Navy launched the Pochtovy submarine which used a gasoline engine fed with compressed air and exhausted under water.

During World War II the German firm Walter experimented with submarines that used concentrated hydrogen peroxide as their source of oxygen underwater. These used steam turbines, employing steam heated by burning diesel fuel in the steam/oxygen atmosphere created by the decomposition of hydrogen peroxide by a potassium permanganate catalyst.

Several experimental boats were produced, and one, U-1407, which had been scuttled at the end of the war, was salvaged and recommissioned into the Royal Navy as HMS *Meteorite*. The British built two improved models in the late 1950s, HMS *Explorer*, and HMS *Excalibur*.

The Soviet Union also experimented with the technology and one experimental boat was built. Hydrogen peroxide was eventually abandoned since it is highly reactive when in contact with various metals, is volatile, and submarines had a high rate of consumption. Both the British and the Soviets, the only countries known to be experimenting with it, abandoned it when the United States developed a nuclear reactor small enough for submarine propulsion.

It was retained for propelling torpedoes by the British and the Soviet Union, although hastily abandoned by the former following the HMS *Sidon* tragedy. Both this and the loss of the Russian Submarine *Kursk* were due to accidents involving hydrogen peroxide propelled torpedoes.

Closed cycle diesel engines

This technology uses a submarine diesel engine which can be operated conventionally on the surface, but which can also be provided with oxidant, usually stored as liquid oxygen, when submerged. Since the metal of an engine will burn in pure oxygen, the oxygen is usually diluted with recycled exhaust gas. As there is no exhaust gas upon starting, argon is used.

During World War II the Kriegsmarine experimented with such a system as an alternative to the Walter peroxide system, including a variant of the Type XXVIIB *Seehund* midget submarine, the "Klein U-boot". It was powered by a 95 hp Diesel engine of a type commonly used by the Kriegmarine and which was available in large numbers, supplied with oxygen from a tank in the boat's keel holding 1,250 litres at 4 atm (410 kPa). It was thought likely that the boat would have a maximum submerged speed of 12 kn (22 km/h; 14 mph) and a range of 70 mi (110 km), or 150 mi (240 km) at 7 kn (13 km/h; 8.1 mph).

The German work was subsequently expanded upon by the Soviet Union who invested heavily in this technology, developing the small 650 ton *Quebec*-class submarine of which thirty were built between 1953 and 1956. These had three diesel engines—two were conventional and one was closed cycle using liquid oxygen.

In the Soviet system, called a "single propulsion system", oxygen was added after the exhaust gases had been filtered through a lime-based chemical absorbent. The submarine could also run its diesel using a snorkel. The *Quebec* had three engines: a 32D 900 bhp diesel on the centre shaft and two M-50P 700 bhp diesels on the outer shafts. In addition a 100 hp "creep" motor was coupled to the centre shaft. The boat could be run at slow speed using the centreline diesel only.

Because liquid oxygen cannot be stored for any great length of time these boats could not operate far from a base. It was also a dangerous system; at least seven submarines suffered explosions, and one of these, *M-256*, sank following an explosion and fire. They were sometimes nicknamed *cigarette lighters*. The last was scrapped in the early 1970s.

The German Navy's former Type 205 submarine U1 was fitted with an experimental 3000 horsepower (2.2 MW) unit.

Closed cycle steam turbines

The French MESMA (Module d'Energie Sous-Marine Autonome) system is being offered by the French shipyard DCNS. MESMA is available for the Agosta 90B and Scorpène class submarines. It is essentially a modified version of their nuclear propulsion system with heat being generated by ethanol and oxygen. Specifically, a conventional steam turbine power plant is powered by steam generated from the combustion of ethanol (grain alcohol) and stored oxygen at a pressure of 60 atmospheres. This pressure-firing allows exhaust carbon dioxide to be expelled overboard at any depth without an exhaust compressor.

Each MESMA system costs around $50–60 million. As installed on the Scorpène, it requires adding a new 8.3 meter (27 foot), 305 tonne hull section to the submarine, and results in a submarine able to operate for greater than 21 days underwater, depending on variables like speed, etc.

An article in Undersea Warfare Magazine notes that: “although MESMA can provide higher output power than the other alternatives, its inherent efficiency is the lowest of the four AIP candidates, and its rate of oxygen consumption is correspondingly higher.”

Stirling cycle engines

The Swedish shipbuilder Kockums has constructed three Gotland class submarines for the Swedish Navy which are fitted with an auxiliary Stirling engine which uses liquid oxygen and diesel fuel to drive 75 kilowatt generators for either propulsion or charging batteries. The AIP endurance of the 1,500 tonne boats is around 14 days at five knots (9 km/h).

Kockums has also delivered Stirling engines to Japan. The new Japanese submarines will all be equipped with Stirling engines. The first submarine, *Sōryū*, in the class was launched on 5 December 2007 and were delivered to the navy in March 2009.

Fuel cells

Type 212 submarine with fuel cell propulsion of the German Navy in dock

Siemens has developed a 30-50 kilowatt fuel cell unit. Nine of these units are incorporated into Howaldtswerke Deutsche Werft AG's 1,830t submarine *U31*, lead ship for the Type 212A class of the German Navy. The other boats of this class and HDW's AIP equipped export submarines (Type 209 mod and Type 214) use two 120 kW modules, also from Siemens.

After the success of Howaldtswerke Deutsche Werft AG's in its export activities, several builders have developed their own fuel-cell auxiliary units for submarines but as of 2008 no other shipyard has a contract for a submarine so equipped.

Nuclear power

Nuclear reactors have been used for 50 years to power submarines, the first being USS *Nautilus*. The United States, France, the United Kingdom, Russia, and the People's Republic of China are the only countries currently operating nuclear powered submarines. India is developing Arihant class nuclear submarines, the first submarine, INS Arihant (s-73), is undergoing sea trials and induction is expected in 2011. India in the past has leased a Charlie class nuclear powered submarine from Russia and plans to acquire two used Akula class submarines which would be used for training purposes. Many other developing countries have also attempted to research nuclear propulsion for submarine use in the past, but with disappointing results. However, Air Independent Propulsion is a term normally used in the context of improving the performance of conventionally propelled submarines.

There have nevertheless been suggestions for a reactor as an auxiliary power supply, which does fall into the normal definition of AIP. For example, there has been a proposal to use a small 200 kilowatt reactor for auxiliary power (styled a "nuclear battery") to improve the under-ice capability of Canadian submarines.

Production non-nuclear AIP submarines

As of 2009, some nations have non-nuclear AIP submarines:

- the French-Spanish *Scorpène*-class submarine (1,700 tonnes) (MESMA)
- the Spanish S-80 class (2,400 tonnes) of the Spanish Navy
- the German Type 209-1400mod (1,810 tonnes) (Fuel cell)
- the German Type 212 submarine (1,830 tonnes) (Fuel cell) of the German Navy and Italian Navy
- the German Type 214 (1,980 tonnes) (Fuel cell)
- the Russian Project 677 Лада (Lada)
- the Russian Project 1650 *Амур* (Amur)
- the Japanese Asashio (2,750 tonnes) (Stirling AIP) of the Japan Maritime Self-Defense Force
- the Japanese Sōryū class submarine (4,200 tonnes) (Stirling AIP) of the Japan Maritime Self-Defense Force
- the Swedish Gotland class submarine (1,450 tonnes) (Stirling AIP) of the Swedish navy
- the Swedish Södermanland class submarine (1,500 tonnes) (Stirling AIP) of the Swedish navy
- the Singaporean Archer class submarine. Its two submarines are originally Swedish Västergötland class submarines. They are upgraded to Södermanland class submarine standards.
- the Chinese Type 041 Yuan class submarine (Stirling AIP) of the PLAN

Also several shipbuilders offer AIP upgrades for existing submarines:

- German Nordseewerke (Closed-cycle diesel)
- Sweden Kockums (Stirling), owned by German company ThyssenKrupp
- Pakistan Agosta 90B class submarine Made with cooperation with France
- French Scorpene made by French Company DCNS

Chapter- 4

Electric Boat

Passenger solar boat Solifleur, Switzerland 1995

While most boats on the water today are powered by diesel engines, and sail power and gasoline engines are also popular, it is perfectly feasible to power boats by electricity too. **Electric boats** were very popular from the 1880s until the 1920s, when the internal combustion engine took dominance. Since the energy crises of the 1970s, interest in this quiet and potentially renewable marine energy source has been increasing steadily again, especially as solar cells became available, for the first time making possible motorboats with an infinite range like sailboats. The first practical **solar boat** was probably constructed in 1975 in England.

History

Possibly the first electric boat was developed by Moritz von Jacobi in 1839 in St Petersburg, Russia - a 24-foot (7.3 m) boat which carried 14 passengers at 3 mph. But it took more than 30 years of battery and motor development before they began to be deployed in any numbers. In 1886 an electric boat crossed the English Channel both ways in 8 hours. By 1889 the first 6 electric charter boats were working on the Thames and in the 1893 Chicago World Fair 55 carried more than a million passengers.

Electric boats had an early period of popularity between around 1890 and 1910, before the emergence of the internal combustion engine drove them out. For example, an 1893 pleasure map of the Thames shows 8 "charging stations for electric launches" between Kew (Strand-on-the-Green) and Reading (Caversham). Most of these were small passenger boats on non-tidal waters at a time when the only power alternative was steam. One of the largest in Britain, and the only surviving example, is the Mary Gordon which was built on the Thames for Leeds City Council for use on the Roundhay Park Lake. It was 52 feet (16 m) long and could take 75 passengers, and is now being restored.

In the US, the Electric Boat Company was founded in 1899 and built the first submarine purchased by the U.S. Navy in 1900. Since then, electric power has been used almost exclusively for powering submarines underwater, although diesel was used for powering them on the surface until the development of diesel-electric transmission by the US Navy in 1928. The Electric Boat Company eventually became General Dynamics Corporation in 1952.

The use of combined fuel and electric propulsion has gradually been extended over the years to the extent that some modern liners such as the Queen Mary 2 use only electric motors, powered by diesel and gas turbine engines. The advantages include being able to run the fuel engines at an optimal speed at all times and being able to mount the electric motor in a pod which may be rotated by 360° for increased manoeuvrability.

The use of electricity alone to power boats stagnated apart from their outboard use as trolling motors until the Californian firm of Duffy started producing small electric craft in 1968. It wasn't until the 1980s that the *Electric Boat Association* was formed and solar powered boats started to emerge.

Components

The main components of the drive system of any electrically powered boat are similar in all cases, and similar to the options available for any electric vehicle.

Charger

Electric energy has to be obtained for the battery bank from some source.

Solar panels deployed on a small yacht at sea

- **Mains charger** allows the boat to be charged from shore-side power when available. Shore-based power stations are subject to much stricter environmental controls than the average marine diesel or outboard motor. By purchasing green electricity it is possible to operate electric boats using sustainable or renewable energy.

- **Solar panels** can be built into the boat in reasonable areas in the deck, cabin roof or as awnings. Some solar panels, or photovoltaic arrays, can be flexible enough to fit to slightly curved surfaces and can be ordered in unusual shapes and sizes. Nonetheless, the heavier, rigid mono-crystalline types are more efficient in terms of energy output per square meter. The efficiency of solar panels rapidly decreases when they are not pointed directly at the sun, so some way of tilting the arrays while under way is very advantageous.

- **Towed generators** are common on long-distance cruising yachts and can generate a lot of power when travelling under sail. If an electric boat has sails as well, and will be used in deep water (deeper than about 15 m or 50 ft), then a towed generator can help build up battery charge while sailing (there is no point in trailing such a generator while under electric propulsion as the extra drag from the generator would waste more electricity than it generates). Some electric power systems use the free-wheeling drive propeller to generate charge through the drive motor when sailing, but this system, including the design of the propeller and any gearing, cannot be optimised for both functions. It may be better locked off or feathered while the towed generator's more efficient turbine gathers energy.

- **Wind turbines** are common on cruising yachts and can be very well suited to electric boats. There are safety considerations regarding the spinning blades, especially in a strong wind. It is important that the boat is big enough that the turbine can be mounted out of the way of all passengers and crew under all circumstances, including when alongside and when coming alongside a dock, a bank or a pier. It is also important that the boat is big enough and stable enough that the *top hamper* created by the turbine on its pole or mast does not compromise its stability in a strong wind or gale. Large enough wind generators could produce a completely wind-powered electric boat. No such boats are yet known although a few *mechanical* wind turbine powered boats exist.

- If the boat has an **internal combustion engine** anyway, then its alternator will provide significant charge when it is running. Two schemes are in use: the combustion engine and the electric motor both coupled to the drive, or a separate generator with the combustion engine only charging the storage batteries.

In all cases, a **charge regulator** is needed. This ensures that the batteries are charged at the maximum rate that they safely can stand when the power is available. It also ensures that they are not overcharged when nearing full charge and not overheated when a large charge current becomes available.

Battery bank

There have been significant technical advances in battery technology in recent years, and more are to be expected in the future.

Example of a modern production electric boat

- **Lead-acid batteries** may still be the most viable option at the moment (2008). Deep-cycle, 'traction' batteries are the obvious choice. They are heavy and bulky, but not much more so than the diesel engine, tanks and fittings that they may replace. They need to be securely mounted, low down and centrally situated in the boat. It is essential that they *cannot* move around under *any* circumstances. Care must be taken that there is no risk of spilled, strong acid in the event of a capsize as this could be very dangerous. Venting of explosive hydrogen and oxygen gases is also necessary. Typical lead-acid batteries must be kept topped-up with distilled water.

- **Valve-regulated lead-acid (VRLA) batteries**, usually known as sealed lead-acid, Gel, or AGM batteries, minimize the risk of spillage, and gases are only vented when the batteries are overcharged. These batteries require minimal maintenance, as they cannot and usually do not need to be refilled with water.

- **Nickel metal hydride**, **lithium-ion** and other solid-state batteries are becoming available, but are still expensive. These are the kind of batteries currently common in rechargeable hand tools like drills and screwdrivers, but they are relatively new to this environment. They require different charge controllers to those that suit lead-acid types.

- **Fuel cells** may provide significant advantages in years to come. Today (2010) however they are still expensive and require specialist equipment and knowledge.

The size of the battery bank determines the *range* of the boat under electric power alone. The speed that the boat is motored at also affects this - a lower speed can make a big difference to the energy required to move a hull. Other factors that affect range include sea-state, windage and any charge that can be reclaimed while under way, for example by solar panels in full sun. A wind tubine in a good following wind will help, and motor-sailing in any wind could do so even more.

SB Collinda, the first solar powered boat to cross the English Channel, seen here in Bristol Harbour

Speed controller

To make the boat usable and maneuverable, a simple-to-operate forward/stop/backwards speed controller is needed. This must be efficient—i.e. it must not get hot and waste energy at any speed—and it must be able to stand the full current that could conceivably flow under any full-load condition. One of the most common types of speed controllers uses Pulse-width modulation (PWM). PWM controllers send high frequency pulses of power to the motor(s). As more power is needed the pulses become longer in duration.

Electric motor

A wide variety of electric motor technologies are in use. Traditional field-wound DC motors were and still are used. Today many boats use lightweight permanent magnet DC motors. The advantage of both types is that while the speed can be controlled electronically, this is not a requirement. Some boats use AC motors or permanent magnet brushless motors. The advantages of these are the lack of commutators which can wear out or fail and the often lower currents allowing thinner cables; the disadvantages are the total reliance on the required electronic controllers and the usually high voltages which require a high standard of insulation.

Drive train

Traditional boats use an inboard motor powering a propeller though a propeller shaft complete with bearings and seals. Often a gear reduction is incorporated in order to be able to use a larger more efficient propeller. This can be a traditional gear box, coaxial planetary gears or a transmission with belts or chains. Because of the inevitable loss associated with gearing, many drives eliminate it by using slow high-torque motors. The electric motor can be encapsulated into a pod with the propeller and fixed outside the hull (saildrive) or on an outboard fixture (outboard motor).

Types

There are as many types of electric boat as there are boats with any other method of propulsion, but some types are significant for various reasons.

RA66 Helio is a solar-powered 20m-catamaran cruising on the *Untersee*, a part of Lake Constance. It is based in Radolfzell, Germany.

- **Historical and restored** electric boats exist and are often important projects for those involved.

- **Canal, river and lake** boats. Electric boats, with their limited range and performance, have tended to be used mostly on inland waterways, where their complete lack of local pollution is a significant advantage. Electric drives are also available as auxiliary propulsion for sailing yachts on inland waters.

- **Electric outboards** and trolling motors have been available for some years at prices from about $100 (US) up to several thousand. These require external batteries in the bottom of the boat, but are otherwise practical one-piece items. Most available electric outboards are not as efficient as custom drives, but are optimised for their intended use, e.g. for inland waterway fishermen. They are quiet and they do not pollute the water or the air, so they do not scare away or harm fish, birds and other wildlife. Combined with modern waterproof battery packs, electric outboards are also ideal for yacht tenders and other inshore pleasure boats.

- **Cruising yachts** usually have an auxiliary engine, and there are two main uses for it: One is to power ahead or motor-sail at sea when the wind is light or from the wrong direction. The other is to provide the last 10 minutes or so of propulsion when the boat is in port and needs to be manoeuvred into a tight berth in a crowded and confined marina or harbour. Electric propulsion is not suitable for prolonged cruising at full power although the power required to motor slowly in light airs and calm seas is small. Regarding the second case, electric drives are ideally suited as they can be finely controlled and can provide substantial power for short periods of time. However, several cruising yachts have sailed across the Atlantic on solar power alone and one is in the process of crossing the Pacific Ocean on solar power alone.

- **Diesel-electric**. There is a third potential use for a diesel auxiliary and that is to charge the batteries, when they suddenly start to wane far from shore in the middle of the night, or at anchor after some days of living aboard. In this case, where this kind of use is to be expected, perhaps on a larger cruising yacht, then a combined diesel-electric solution may be designed from the start. The diesel engine is installed with the prime purpose of charging the battery banks, and the electric motor with that of propulsion. There is some reduction in efficiency if motoring for long distances as the diesel's power is converted first to electricity and then to motion, but there is a balancing saving every time the wind-, sail- and solar-charged batteries are used for manoeuvring and for short journeys without starting the diesel. There is the flexibility of being able to start the diesel as a pure generator whenever required. The main losses are in weight and installation cost, but on the bigger cruising boats that may sit at anchor running large diesels for hours every day, these are not too big an issue, compared to the savings that can be made at other times.

- **Solar powered**. A boat propelled by direct solar energy is a marine solar vehicle. The available sunlight is almost always converted to electricity by solar cells, temporarily stored in accumulator batteries, and used to drive a propeller through an electric motor. Power levels are usually on the order of a few hundred watts to a few kilowatts. Solar powered boats started to become known around 1985 and in 1995 the first commercial solar passenger boats appeared. Solar powered boats have been used successfully at sea. The first crossing of the Atlantic Ocean was achieved in the winter of 2006/2007 by the solar catamaran Sun21.

Pollution and embodied energy

All the component parts of any boat have to be manufactured and will eventually have to be disposed of. Some pollution and use of other energy sources are inevitable during these stages of the boat's life and electric boats are no exception. The benefits to the global environment that are achieved by the use of electric propulsion are manifested during the working life of the boat, which can be many years. These benefits are also most directly felt in the sensitive and very beautiful environments in which such a boat is used.

The May 2010 edition of *Classic Boat* magazine carried a pro and con article entitled *Electric debate*. Jamie Campbell argued against electric boating on four main counts, which were rebuffed by Kevin Desmond and Jamie Campbell, Vice Chairman, Electric Boat Association. He asserted that electric propulsion can no more be justified afloat than a *Seagull* outboard motor, proposing wooden sailing boats and rowing dinghies as "by far the most environmentally sensitive and renewable options for recreational boating".

Electricity production

Campbell asserts that the lack of pollution from an electric boat "reeks of nimbyism" as "the discharge is all in someone else's back yard" and that the provision of re-charging points may involve digging up miles of habitat. Desmond responds that while there is no doubt that rechargeable batteries derive their energy from power stations (when not charged on board by solar and wind generation), noisier internal-combustion-engined boats obtain their fuel from even further away and that, once installed a power cable is less environmentally disruptive than a petrol station. Rutter notes that electric boats tend to recharge overnight, using 'base load'.

Efficiency

While there are losses in the charge/discharge cycle and in the conversion of electricity to motive power, Rutter points out that most electric boats need only about 1.5 kW or 2 hp to cruise at 5 mph, a common maximum river speed and that a 30 hp petrol or diesel engine producing only 2 hp is considerably more inefficient. While Campbell refers to heavy batteries requiring a "load-bearing hull" and "cranky, even unseaworthy vessels", Desmond points out that electric boaters tend to prefer efficient, low-wash hull forms that are more friendly to river banks.

Pollution

Campbell discusses the pollution that "traditional" batteries put into the water when a boat sinks, but Desmond says that electric boats are no more liable to sinking than other types and lists the leakage of fuel, engine oil and coolant additives as inevitable when an internal-combustion-engined boat sinks. Rutter points to the "very nasty cocktail of pollutants" that come out of a diesel wet exhaust in normal use.

Battery manufacture

Campbell mentions "all manner of noxious chemicals ... involved in battery manufacture", but Rutter describes them as being "lead and sulphuric acid with a few extra trace metals in a modest plastic box" with a potential lifetime of 10–12 years. Desmond says that the US has a 98% recycling rate for lead acid batteries and that the battery and lead-smelting industries observe some of the tightest pollution control standards in the world.

Mentions 25% and 30% discounts being offered to electric boaters by the UK Environment Agency and the Broads Authority and that battery powered vehicles have $\frac{3}{5}$ the carbon footprint of their petrol equivalents. It is claimed that a typical recharge after a day's cruising costs £1.50, without the use of solar or wind power.

Solar ships

Tûranor PlanetSolar, the world's largest solar-powered boat

Japan's biggest shipping line Nippon Yusen KK and Nippon Oil Corporation said solar panels capable of generating 40 kilowatts of electricity would be placed on top of a 60,000 tonne car carrier ship to be used by Toyota Motor Corporation.

In 2010, the Tûranor PlanetSolar, a 30 metre long, 15.2 metre wide catamaran yacht powered by 470 square metres of solar panels, was unveiled. It is set to circumnavigate the Earth and is so far the largest solar-powered boat ever built.

The Monaco yacht company Wally has announced a "gigayacht" designed for billionaires torn between buying a mansion and a superyacht. The *Why 58 x 38* is designed to have an autonomous cruising range of 12,000 miles at 12 knots by means of $900m^2$ of solar panels which generate 150 kW to assist the diesel-electric motors and optional Skysails.

Chapter- 5

Inboard Motor and Internal Drive Propulsion

Inboard motor

The MAN B&W 5S50MC 5-cylinder, 2-stroke, low-speed marine diesel engine. This particular engine is found aboard a 29000 tonne chemical carrier.

An **inboard motor** is a marine propulsion system for boats. As opposed to an outboard motor where an engine is mounted outside of the hull of the craft, an *inboard motor* is an engine enclosed within the hull of the boat, usually connected to a propulsion screw by a driveshaft.

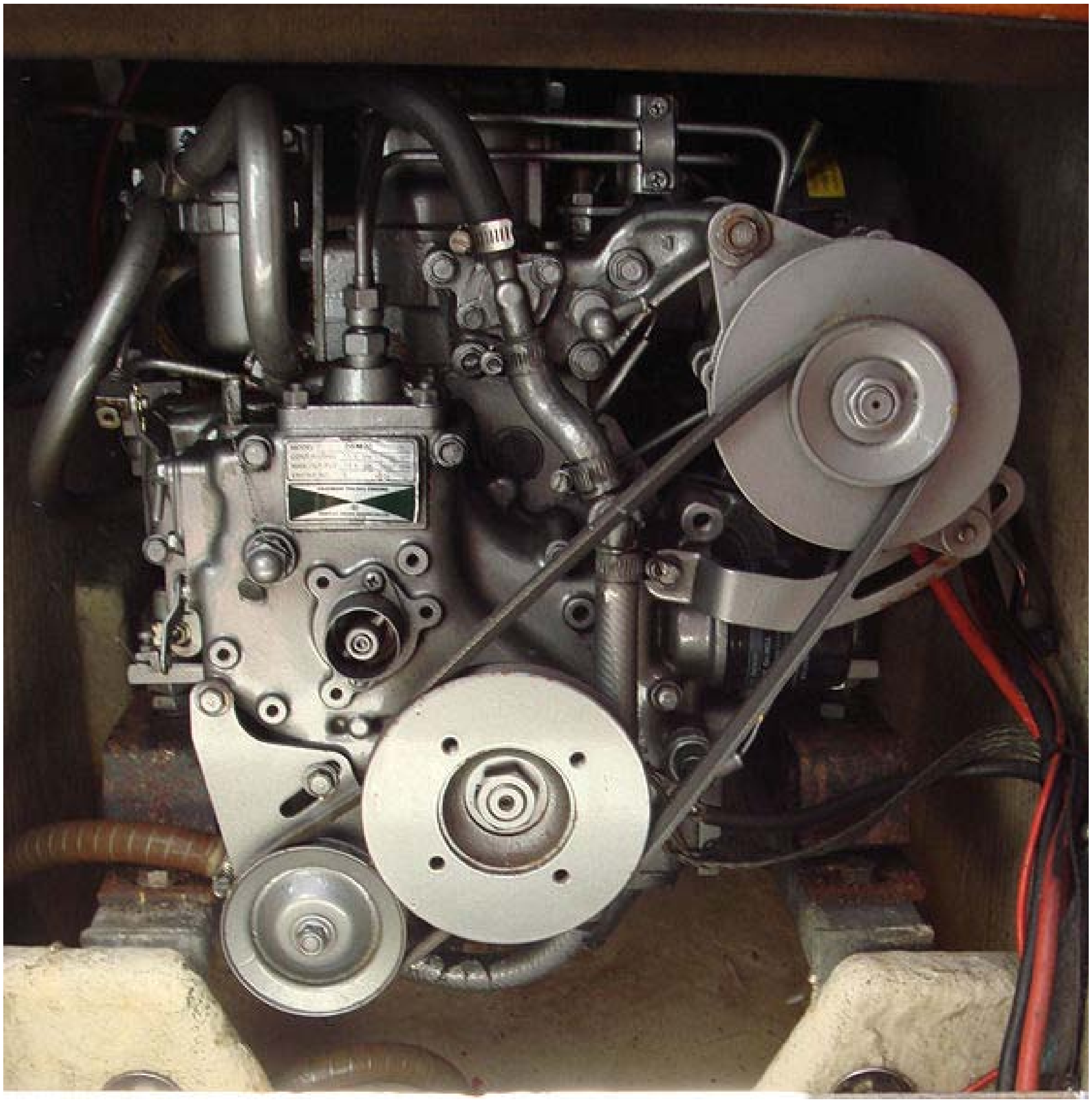
History

Cat diesels in rescueboat of Eire

The first inboard were steam engines going back to 1805 and the Clermont and the Charlotte Dundas. Harbour tugs, and small steam launches had inboard steam engines. In the 1880s the naphtha engine made its appearance and a few boat engines appeared. They were dangerous and difficult to run.

The gas engine pioneer Gottlieb Daimler and Maybach built a four-cycle boat engine and tested it in 1887 on the Neckar River. Sintz in America built several commercially available engines from 1893. About 1895 the inboard oil engine emerged for small boats. From this hundreds of small boat engine manufactures set up shop: Bolinder, Gray Marine Engine, Kermath, Union Iron Works, Caille, Palmer, Red Wing, St. Lawrence, and Buda; Sulzer, B and W, Gardner, and Ailsa Craig to mention a few. Two cycle engines were popular for many years, however, the parallel development of the auto engine, with their many cylinders, became a natural transposition. Chrysler, Ford, Packard, and Hudson also made marine engines.

Sizes



A Yanmar 2GM20 inboard marine diesel engine, installed in a sailboat.

Inboard motors may be of several types, suitable for the size of craft they are fitted to. Boats can use one cylinder to v12 engines, depending if they are used for racing or trolling.

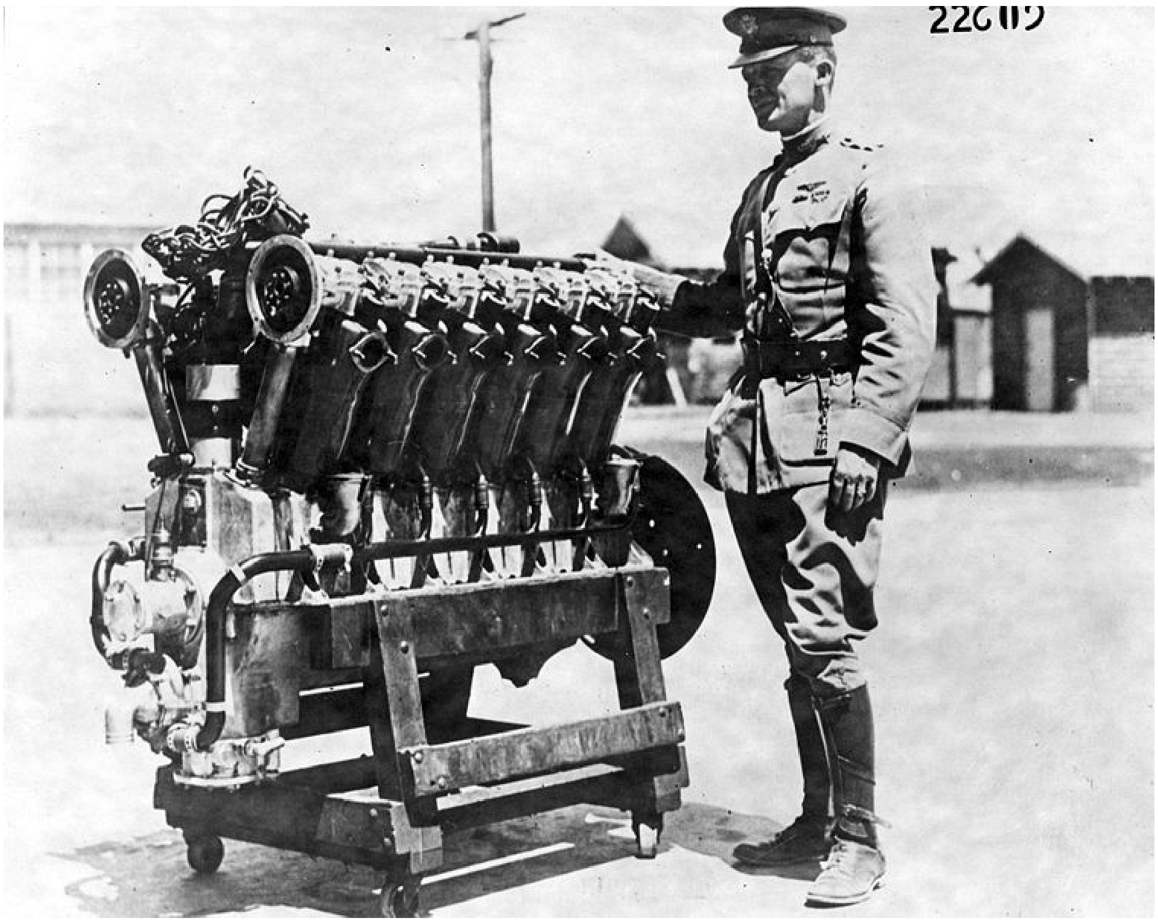
Small craft

For pleasure craft, such as sailboats and speedboats, both diesel and gasoline engines are used. Many inboard motors are derivatives of automobile engines, known as marine automobile engines. The advent of the stern drive propulsion leg improved design so that auto engines could easily power boats.

Large craft

For larger craft, including ships (where outboard propulsion would in any case not be suitable) the propulsion system may include many types, such as diesel, gas turbine, or even fossil-fuel or nuclear-generated steam. Some early models used coal for steam-driven ships.

Cooling



Major Henry H. Arnold with the first Liberty engine. Aircraft engines were later used in boats. Hap Arnold went on to command all US Airforces in WWII.

Some inboard motors are freshwater cooled, while others have a raw water cooling system where water from the lake, river or sea is pumped by the engine to cool it.

However, as seawater is corrosive, and can damage engine blocks and cylinder heads, some seagoing craft have engines which are indirectly cooled via a heat exchanger. Other engines, notably small single and twin cylinder diesels specifically designed for marine use, use raw seawater for cooling and zinc sacrificial anodes are employed protect the internal metal castings.

Internal drive propulsion

Internal drive propulsion is a form of marine propulsion commonly used in recreational boating. Like other forms of motorized boating, internal drive propulsion employs a motor that turns a propeller to move the boat forward. The primary difference between internal drive boats and stern drive boats is that the propeller is enclosed inside the hull of an internal drive boat where as the propeller is exposed outside the hull of a stern drive boat.

A conventional screw propeller accelerates a large volume of water by a small amount, similar to the way an airplane propeller accelerates a large volume of air by a small amount. An aircraft's jet engine, by contrast, accelerates a small volume of air by a large amount. Both methods yield thrust due to Newton's third law — every force gives rise to an equal and opposite force.

In an internal drive boat, pumping a small volume of water and accelerating it by a large amount delivers the thrust. The acceleration of the water is achieved by using multiple impeller stages. Steering is accomplished by small vanes that direct the water jet.

Internal drive propulsion was originally designed by Sir William Hamilton (who invented the waterjet in 1954) for operation in the fast-flowing and shallow rivers of New Zealand, specifically to overcome the problem of propellers striking rocks in such waters.

Primary benefits:

- Water skiers, wakeboarders, swimmers, divers, etc. are not exposed to external propellers.
- Less potential for damage to internal drive boats from floating debris.
- Less potential for major drive damage from running aground as with exposed propellers.
- Better maneuverability and acceleration compared to stern-drive counterparts.

Leading manufacturer of internal drive boats in the US:

- Yamaha Motor Corporation

Chapter- 6

Jetboat

A rider on a Yamaha Waverunner XL performing a high-speed turn

A **jetboat** is a boat propelled by a jet of water ejected from the back of the craft. Unlike a powerboat or motorboat that uses a propeller in the water below or behind the boat, a jetboat draws the water from under the boat into a pump inside the boat, then expels it through a nozzle at the stern.

Jetboats were originally designed by Sir William Hamilton (who developed a waterjet in 1954) for operation in the fast-flowing and shallow rivers of New Zealand, specifically to overcome the problem of propellers striking rocks in such waters.

Previous attempts at waterjet propulsion had very short lifetimes, generally due to the inefficient design of the units and the fact that they offered few advantages over conventional propellers. Unlike these previous waterjet developments, such as Campini's and the Hanley Hydrojet, Hamilton had a specific need for a propulsion system to operate in very shallow water, and the waterjet proved to be the ideal solution. From this the popularity of the jet unit and jetboat increased rapidly, and through further developments it was found the waterjet offered several other advantages over propellers for a wide range of vessel types, and as such waterjets are used widely today for many high speed vessels including passenger ferries, rescue craft, patrol boats and offshore supply vessels.

Jet boats are highly maneuverable, and many can, from full speed, be reversed and brought to a stop within little more than their own length, in a maneuver known as a "crash stop". The well known *Hamilton turn* or "jet spin" is a high speed manoevre where the boat's engine throttle is cut, the steering is turned sharply and the throttle opened again causing the boat to spin quickly around with a large spray of water.

There is no engineering limit to the size of jet boats, though the validity of their use depends a lot on the type of application. Classic prop-drives are generally more efficient and economical at low speeds (up to about 20 knots) but as boat speed increases beyond this the extra hull resistance generated by struts, rudders, shafts, etc., means waterjets are more efficient in the 20-50 knot range. Also, in situations with very large propellers turning at slow speeds (such as tug boats), the equivalent size waterjet would be too big to be practical. For these reasons the vast majority of waterjet units are installed in high-speed vessels and in particular situations where shallow draught, maneuverability, and load flexibility are main concerns.

The biggest jet-driven vessels are found in military use or the high speed passenger/car ferry industry. South Africa's Valour class frigates (approximately 120m long) are the biggest jet-propelled vessels so far. Even these German-built vessels are capable of performing "crash stops".

Function

Jetboat on the Rogue River by Grants Pass, Oregon.

A conventional screw propeller works within the body of water below a boat hull, effectively "screwing" through the water to drive a vessel forward by generating a difference in pressure between the forward and rear surfaces of the propeller blades and by accelerating a mass of water rearward. By contrast a waterjet unit delivers a high pressure "push" out the stern of a vessel by accelerating a volume of water as it passes through a specialised pump mounted above the waterline inside the boat hull. Both methods yield thrust due to Newton's third law — every action has an equal and opposite reaction.

In a jetboat, the waterjet draws water from beneath the hull where it passes through a series of impellers and stators - known as stages - which increase the velocity of the waterflow. Most modern jets are single stage while older waterjets may have as many as three stages. The tail section of the waterjet unit extends out through the transom of the hull above the waterline. This jetstream exits the unit through a small nozzle at high velocity to push the boat forward. Steering is accomplished by moving this nozzle to either side, or less commonly, by small gates on either side that direct the jetstream. Because the jet boat relies on the flow of water through the nozzle for control, it is not possible to steer a conventional jet boat without the engine running.

A jetboat on Shotover Canyon in New Zealand, the country for which jetboats were originally invented.

Unlike conventional propeller systems where the rotation of the propeller is reversed to provide astern movement, a waterjet will continue to pump normally while a deflector is lowered into the jetstream after it leaves the outlet nozzle. This deflector redirects thrust forces forward to provide reverse thrust. Most highly developed reverse deflectors redirect the jetstream down and to each side to prevent recirculation of the water through the jet again - which may cause aeration problems - and increase reverse thrust. Steering is still available with the reverse deflector lowered so the vessel will have full maneuverability. With the deflector lowered about halfway into the jetstream, forward and reverse thrust are equal so the boat maintains a fixed position, but steering is still available to allow the vessel to turn on the spot - something which is impossible with a conventional single propeller.

Unlike hydrofoils, which use underwater wings or struts to lift the vessel clear of the water, standard jetboats use a conventional planing hull to ride across the water surface, with only the rear portion of the hull displacing any water. With the majority of the hull clear of the water, there is reduced drag, greatly enhancing speed and maneuverability, so jetboats are normally operated at planing speed. At slower speeds with less water pumping through the jet unit, the jetboat will lose some steering control and maneuverability and will quickly slow down as the hull comes off its planing state and hull resistance is increased. However, loss of steering control at low speeds can be negated by lowering the reverse deflector slightly and increasing throttle - so you increase thrust and thus control without increasing boat speed itself. A conventional river-going jet boat will have a shallow-angled (but not flat-bottomed) hull to improve its high speed cornering control and stability while also allowing it to traverse very shallow water. At speed, jetboats can be safely operated in less than 3 inches (7.5 cm) of water.

One of the most significant breakthroughs in the development of the waterjet was to change the design so it expelled the jetstream *above* the water line, contrary to many people's intuition. Hamilton discovered early on that this greatly improved performance, compared to expelling below the waterline, while also providing a "clean" hull bottom (i.e.: nothing protruding below the hull line) to allow the boat to skim through very shallow water. It makes no difference to the amount of thrust generated whether the outlet is above or below the waterline, but being above the waterline reduces hull resistance and draught. Hamilton's first waterjet design had the outlet below the hull and actually in front of the inlet. This probably meant that disturbed water was entering the jet unit and reducing its performance, and the main reason why the change to above the waterline made such a difference.

Queenstown, New Zealand, where jetboats are used extensively for adventure tourism, claims to be the jetboat capital of the world, and jetboats are very common for many coastal and riverine tourism activities in the country, such as the Excitor in the Bay of Islands.

Applications

USMC Expeditionary Fighting Vehicle. Note the bow, which is extended into hydroplaning position.

Applications for jetboats include most activities where conventional propellers are also used, but in particular passenger ferry services, coastguard and police patrol, navy and military, adventure tourism (which is becoming increasingly popular around the globe), pilot boat operations, surf rescue, farming, fishing, exploration, pleasure boating, and other water activities where motor boats are used. Jetboats can also be raced for sport, both on rivers and on specially designed racecourses. Recently there has been increasing use of jetboats in the form of rigid-hulled inflatable boats and as luxury yacht tenders. Many jetboats are small enough to be carried on a trailer and towed by car. Jetboating Australia is a group of people with jetboats, most of which can be towed on a trailer.

One very important feature of the jetboat is the fact that it has no external rotating parts; it is thus safer for swimmers and marine life, though these can still be struck by the hull. The safety benefit itself can sometimes be reason enough to use this type of propulsion.

In 1977 Sir Edmund Hillary led a jetboat expedition, titled "Ocean to Sky", from the mouth of the Ganges River to its source. One of the jetboats was sunk by a friend of Hillary.

Drawbacks

The fuel efficiency and performance of a jet boat can be affected by anything that effects the smooth flow of water through the jet unit. For example a plastic bag sucked onto the jetunit's intake grill can have quite an adverse effect.

Another disadvantage of jetboats appears to be that they are more sensitive to engine / jetunit mismatch compared to engine / propeller mismatch in propeller driven craft. If the jetpropulsion unit is not well matched to the engine performance, inefficient fuel consumption and poor performance can result.

However, a jet propulsion unit that is well matched to the engine is more fuel efficient that a propeller because it does not waste power by throwing water radially. Normally, the engine in a jetboat is directly coupled to the pump shaft eliminating the need for a gearbox and therefore eliminating any gearbox losses. Most propeller driven vessels have gearboxes in which power is lost resulting in increased fuel consumption and/or reduced performance. In my experience, a jet boat will normally use about half the fuel that a boat of the same size does which is propelled by an outboard motor at the same speed. The main reason commercial ferries use jets is to reduce fuel consumption.

Chapter- 7

Marine Automobile Engine and Rotor Ship

Marine automobile engine

Volkswagen Marine 3.0 litre V6 TDI 265-6 marine engine. This is a marine-modified version of Volkswagen Groups 3.0 V6 24v TDI CR automobile engine.

Marine automobile engines are types of automobile petrol- or diesel engines that have been specifically modified for use in the marine environment. The differences include changes made for the operating in a marine environment, safety, performance, and for regulatory requirements. The act of modifying is called 'marinisation'.

All of the "Big 3" American auto companies have had engines marinised at some point. Chrysler is notable, because the company marinised engines in-house through Chrysler Marine, as well as selling engines to third parties such as Indmar or Pleasurecraft Marine.

General Motors marine automobile engines are based on a gasoline truck engine. That means four-bolt main bearing caps instead of just two; sometimes the crankshaft is forged steel and the pistons an upgraded aluminum alloy. Most importantly the camshaft profile is different with the overlap ground to 112 degrees instead of 110. Expansion plugs are bronze to better fight corrosion. The head gasket's metal O-ring is also more corrosion resistant.

Safety modifications

Electrical systems

- Marine starter motor — it has an internal screen to minimize the egression of spark movements.
- Marine alternator differs from an automobile alternator — it has an internal screen to minimize the egression of spark movements.

Fuel systems (petrol/gasoline engines)

- Fuel pump vented — if the fuel pump diaphragm ruptures, then the excess fuel will be directed into the carburettor. This kind of fuel pump is referred to as a marine fuel pump.
- Marine carburettor does not allow the overflow into the boat engine compartment.
- Spark arrestor on the air intake (carburettor or electronic fuel injection) — a wire mesh screen on the spark arrestor cools any internal flame or spark created by back-fire, thereby preventing it from igniting fuel vapours inside the engine compartment.

Cooling systems

- Marine automobile engines are water cooled; drawing raw water in from a pickup underneath the boat. In an open cooling configuration, the raw water is circulated directly through the engine and exits after passing through jackets around the exhaust manifolds. In a closed cooling configuration anti-freeze circulates through the engine and raw water is pumped into a heat exchanger. In both cases hot water is released into the exhaust system and blown out with the engine exhaust gasses.
- The transmission oil cooler is cooled by raw water.

Performance modifications

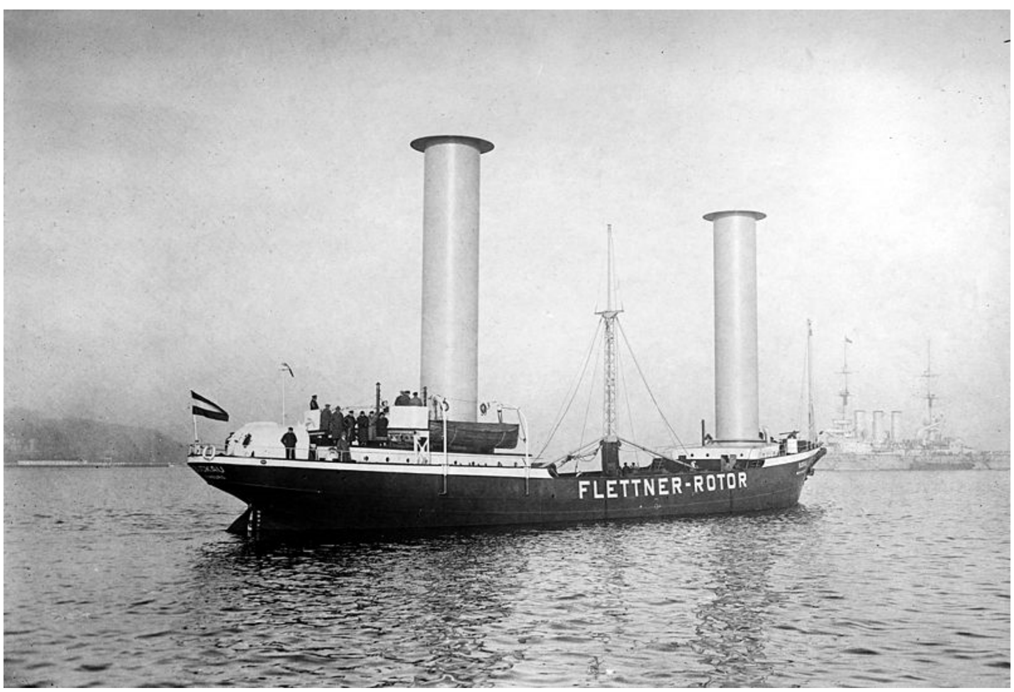
- The marine distributor does not have a vacuum advance. Vacuum advance is normally actuated at high engine revolutions per minute (rpm) in low load situations - and this situation generally does not occur in the marine environment. Under normal operation, high rpm generally means high engine load.

Engine rotation

- Many marine engine crankshafts rotate in the opposite direction when compared to an automobile engine; RH rotation instead of LH rotation. This difference requires, depending on the engine design, a different camshaft, a different distributor gear, a different oil pump and different crankshaft seals.

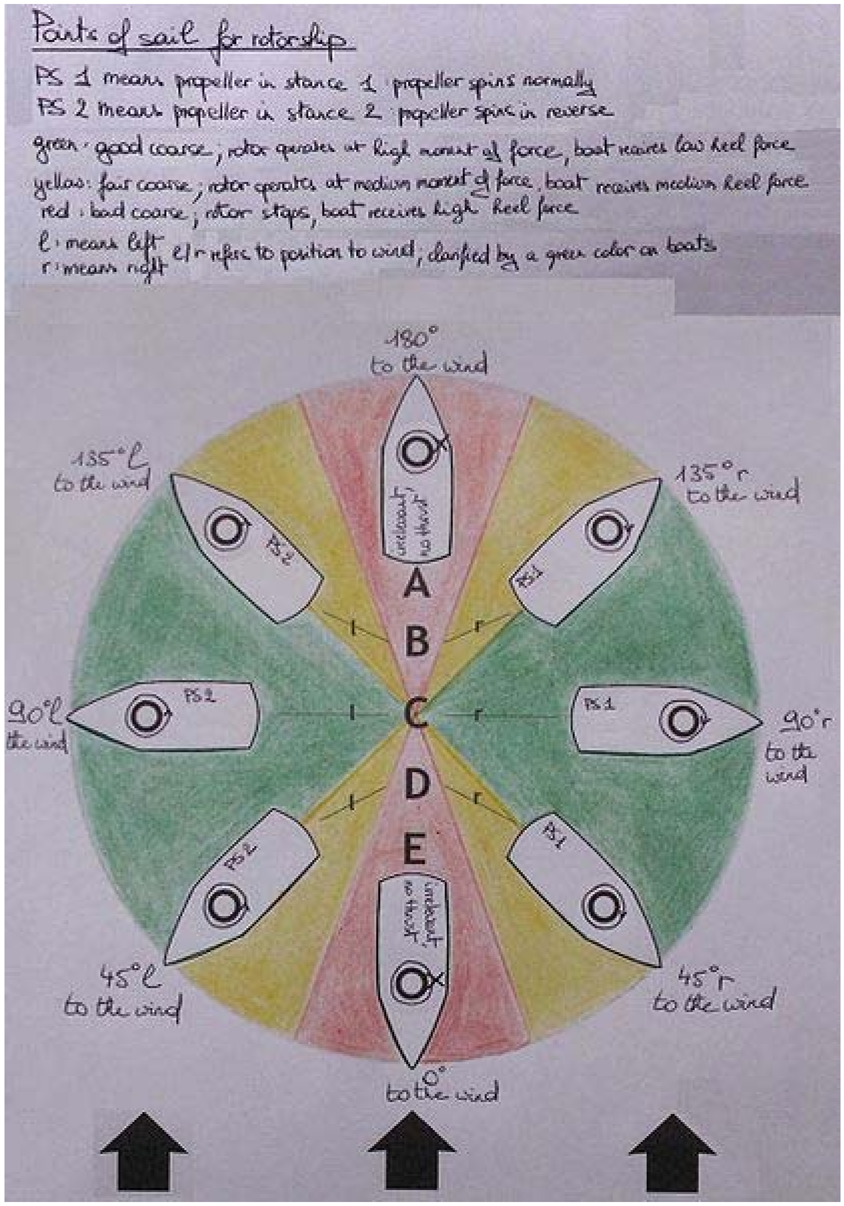
However, since the introduction of electronic fuel injection, and electronic engine management systems to marine engines this is not nearly as common. Engines equipped with a suite of electronics are LH rotation. The rotation is reversed for the propeller in the transmission.

Rotor ship



Rotor ship *Buckau*

Two Flettner rotors of the E-Ship 1



The points of sail for a rotorship

Flensburg catamaran at the Kiel Week 2007

A **rotor ship**, or **Flettner ship**, is a ship designed to use the Magnus effect for propulsion. To take advantage of this effect, it uses rotorsails which are powered by an engine. The Magnus effect is a force acting on a spinning body in a moving airstream, which acts perpendicularly to the direction of the airstream. German engineer Anton Flettner was the first to build a ship which attempted to tap this force for propulsion.

Invention

Flettner's spinning bodies were vertical cylinders; the basic idea was to use the Magnus effect. The idea worked, but the propulsion force generated was less than the motor would have generated if it had been connected to a standard marine propeller. These types of propulsion cylinders are now commonly called Flettner rotors.

His first idea was to produce the propulsion force by using a belt running round two cylinders. Later Flettner decided that the cylinders would be better rotated by individual motors. Flettner applied for a German patent for the rotor ship on 16 September 1922.

Assisted by Albert Betz, Jacob Ackeret and Ludwig Prandtl, Flettner constructed an experimental rotor vessel, and in October 1924 the Germaniawerft finished construction of a large two-rotor ship named *Buckau*. The vessel was a refitted schooner which carried two cylinders (or rotors) about 15 metres (50 ft) high, and 3 metres (10 ft) in diameter, driven by an electric propulsion system of 50 hp (37 kW) power.

Voyages

Following completion of its trials, the *Buckau* set out on her first voyage in February 1925, from Danzig to Scotland across the North Sea. The rotors did not give the slightest cause for concern in even the stormiest weather, and the rotor ship could tack (sail into the wind) at 20-30 degrees, while the vessel with its original sail rig could not tack closer than 45 degrees to the wind.

On 31 March 1926, the *Buckau*, now renamed *Baden Baden* after the German spa town, sailed to New York via South America, arriving in New York harbor on 9 May.

However, it was found that the rotor system was less efficient than conventional engines. Flettner turned his attention to other projects and the rotors were dismantled. *Baden Baden* was destroyed in a Caribbean storm in 1931.

Types

Several types of rotor ships can be distinguished, similar to sailing ships. Both rotor sail-assist (hybrid) ships exist, as well as rotor sail only ships. Wind Ship Development Corporation has also worked out two types of sail assist setups, for use with different ships sizes.

Most rotor ships have a system with an electric engine which allows the stopping or initial starting of the rotor by the sailor. This allows the sailor to control the rotor's RPM and direction of spin.

Uses today

The University of Flensburg is developing the *Flensburg catamaran* or *Uni-cat Flensburg*, a rotor-driven catamaran.

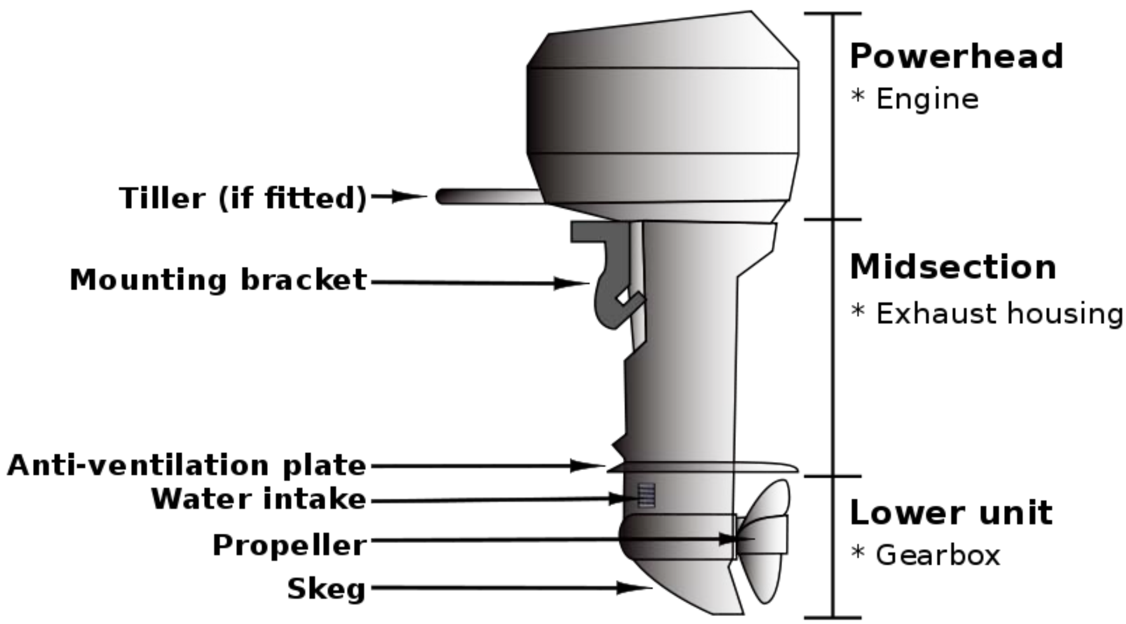
The German wind-turbine manufacturer Enercon launched and christened its new rotor-ship E-Ship 1 on the 2nd of August 2008. The ship will be used to transport turbines and other equipment to locations around the world. The maiden delivery of turbines for Castledockrell Windfarm arrived in Dublin Port on 11th Aug 2010.

In 2009 the Finland-based maritime engineering company Wärtsilä unveiled a concept for a cruiseferry that would utilise flettner rotors as means of reducing fuel consumption. This concept has been linked with the Finnish ferry operator Viking Line, who have stated they will make a decision on whether or not they'll order new ships during 2010.

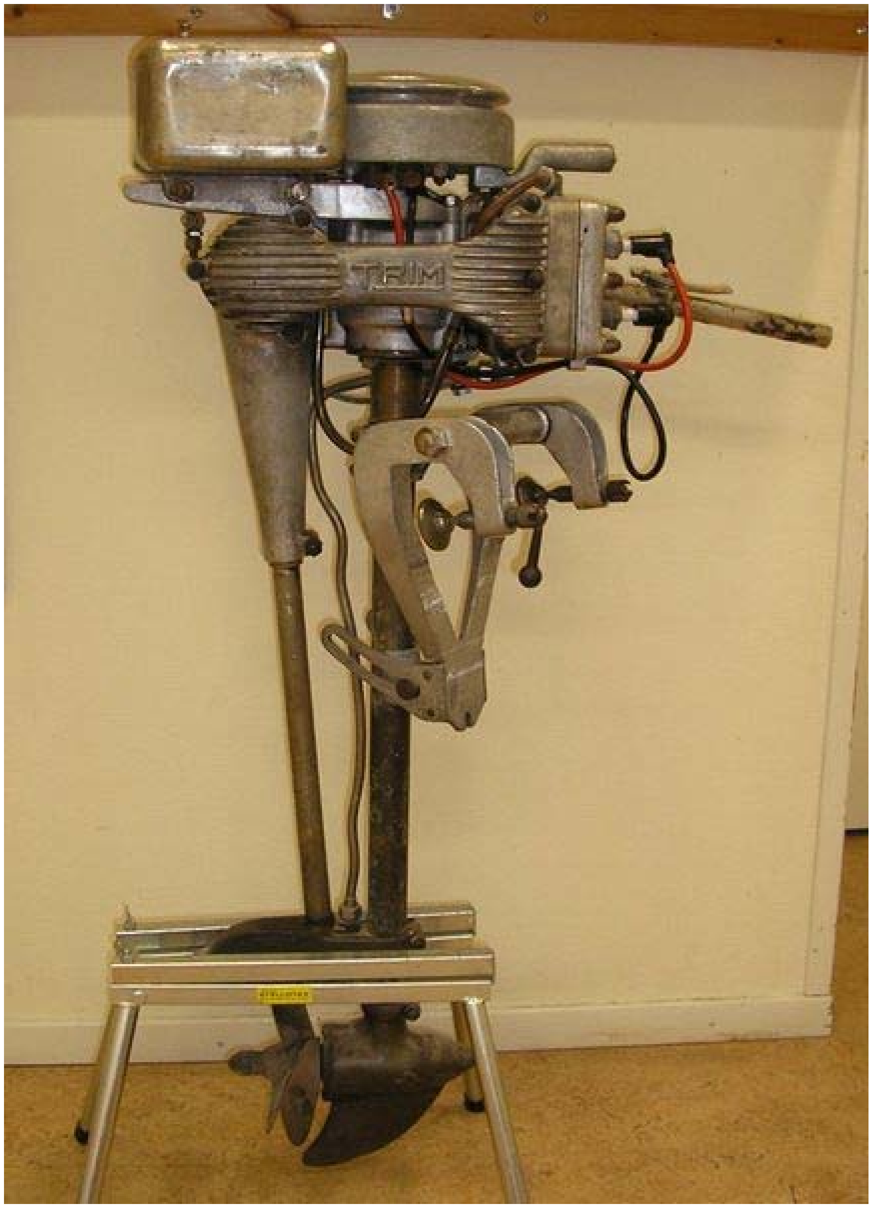
Stephen H. Salter and John Latham recently proposed the building of 1,500 robotic rotor-ships to mitigate global warming. The ships would spray seawater into the air to enhance cloud reflectivity. A prototype rotor ship was tested on Discovery Project Earth. The rotors were made of carbon fibre and were attached to a retrofitted trimaran and successfully propelled the vessel stably through the water at a speed of six knots. The focus of the experiment was based on the ability for the boat to move emissions free for a specialized purpose leaving it unclear whether or not the efficiency of the rotors was on parity or superior to conventionally propelled vessels.

Chapter- 8

Outboard Motor



Basic parts of an outboard motor



Bolinder's two cylinder *Trim* outboard engine.

A Mercury Marine 50 HP outboard engine, circa 1970's

1979 Evinrude 70 HP outboard, cowling and air silencer removed, exposing its shift/throttle/spark advance linkages, flywheel, and three carburetors

Rotor of the impeller pump (cooling system) of an outboard motor

A motorboat with an outboard motor attached to it

An **outboard motor** is a propulsion system for boats, consisting of a self-contained unit that includes engine, gearbox and propeller or jet drive, designed to be affixed to the outside of the transom and are the most common motorized method of propelling small watercraft. As well as providing propulsion, outboards provide steering control, as they are designed to pivot over their mountings and thus control the direction of thrust. The skeg also acts as a rudder when the engine is not running. Compared to inboard motors, outboard motors can be easily removed for storage or repairs.

When boats are out of service or being drawn through shallow waters, outboard motors can be tilted up (tilt forward over the transom mounts) to elevate the propeller and lower unit out of the water to avoid accumulation of seaweed, underwater hazards such as rocks, and to clear road hazards while trailering.

General uses

Portable

Small outboard motors, up to 15 horsepower or so are easily portable. They are affixed to the boat via clamps, and thus easily moved from boat to boat. These motors typically use a manual pull start system, with throttle and gearshift controls mounted on the body of the motor, and a tiller for steering. The smallest of these weigh as little as 12 kilograms

(26 lb), have integral fuel tanks, and provide sufficient power to move a small dinghy at around 8 knots (15 km/h; 9.2 mph) This type of motor is typically used:

- to power small craft such as jon boats, dinghies, canoes, etc.
- to provide auxiliary power for sailboats,
- for trolling aboard larger craft, as small outboards are typically more efficient at trolling speeds. In this application, the motor is frequently installed on the transom alongside and connected to the primary outboard to enable helm steering.

Large Outboards

Large outboards are usually bolted to the transom (or to a bracket bolted to the transom), and are linked to controls at the helm. These range from 2- 3- and 4-cylinder models generating 15 to 135 horsepower suitable for hulls up to 17 feet (5.2 m) in length, to powerful V-6 and V-8 cylinder blocks rated up to 350 hp (260 kW)., with sufficient power to be used on boats of 18 feet (5.5 m) or longer.

Electric-Powered

Commonly referred to as "trolling motors" or "electric outboard motors" , electric outboards are used

- on very small craft or on small lakes where gasoline motors are prohibited,
- as a secondary means of propulsion on larger craft, and
- as repositioning thrusters while fishing for bass and other freshwater species,

and any other application where their quietness, and ease of operation and zero emissions outweigh the speed and range deficiencies.

Diesel

Diesel outboards are also available but their weight and cost make them rare.

Pump-jet

Pump-jet propulsion is available as an option on most outboard motors. Although less efficient than an open propeller, they are particularly useful in applications where the ability to operate in very shallow water is important. They also eliminate the laceration dangers of an open propeller.

History and developments

The outboard motor, as a portable propulsion system for boats that would otherwise be powered manually by oars, was made possible by the experimentations of Cameron Waterman, a young Yale Engineering student. The Waterman outboard engine appears to be the first real gasoline-powered outboard offered for sale. It was four stroke. Between

1903 and his patent in 1905 he successfully created the outboard. Starting with two dozen built in 1907, the company went on to make thousands of the units in the next 5 years. The inboard boat motor firm of Caille Motor Company of Detroit were instrumental in making the cylinder and engines. Kiekhaefer eventually bought out Cameron Waterman and used magazine ads with references to the Waterman.

The creation of the first practical and marketable outboard motor is often miscredited to Norwegian-American inventor Ole Evinrude in 1909. Between 1909 and 1912 Evinrude made thousands of his outboards and the three horse units were sold around the world. His Evinrude Outboard Co. was spun off to other owners, and he went onto success with ELTO. The 1920s were the first highwater mark for the outboard with Evinrude, Johnson, ELTO, Atwater Lockwood and dozens of other makers in the field.

Historically, a majority of outboards have been two-stroke powerheads fitted with a carburetor due to the design's inherent simplicity, reliability, low cost and light weight. Drawbacks include increased pollution, due to the high volume of unburned gasoline in their exhaust, and louder noise.

In the 1990s US and European exhaust emissions regulations led to the proliferation of four-stroke outboards. Though fewer in number, four-stroke outboards have always been available. For example Honda Marine has been marketing small four-stroke outboards since the early 70s. Other brands have been produced for over a 100 years, but again in fewer numbers.

Mercury Marine, Mercury Racing, Tohatsu Outboards, Nissan Marine, Honda Marine, Suzuki Marine, and Yamaha Marine, China Oshen-Hyfong marine have all developed new four-stroke engines. Some are carbureted, usually the smaller engines. The balance are electronically fuel-injected. Some models benefit from variable camshaft timing, and multiple valves per cylinder. Mercury Verado four-strokes are unique in that they are supercharged.

Mercury Marine, Mercury Racing, Tohatsu, Yamaha Marine, Nissan and Evinrude each developed computer-controlled Direct-Injected two-stroke engines. Each brand boasts a different method of DI.

Fuel economy on both direct injected and four-stroke outboards measures from a 10 percent to 80 percent improvement, compared with conventional two-strokes. Depending on rpm and load at cruising speeds figure on about a 30 percent mileage improvement.

Outboard motors benefit from the use of a submerged pump to draw water for cooling, obviating the need for radiators and cooling fans, thereby simplifying the design and lowering component weight, however constant usage in seawater is liable to cause corrosion.

For boats which are moored rather than trailered, bronze propellers are unsuitable owing to galvanic effects. It is a surprising fact that quite often sacrificial anodes are found which have been painted over. One can only assume that owners notice that these parts were corroding and thought that the factory forgot to paint them. Severe damage is usually the result.

Outboard motor selection

It is important to select a motor that is a good match for the hull in terms of power and shaft length.

Power requirements

Overpowering is a dangerous condition and underpowering often results in a boat that is incapable of performing in the role for which it was acquired. Boats built in the U.S. have a *Coast Guard Rating Plate* which specifies the maximum recommended horsepower for the hull. A motor with less than 75% of the maximum will most likely result in unsatisfactory performance.

Shaft length

Outboard motor shaft lengths are standardized to fit 15-inch, 20-inch and 25-inch transoms. If the shaft is too long it will extend farther into the water than necessary creating drag, which will impair performance and fuel economy. If the shaft is too short, the motor will be prone to ventilation. Even worse, if the water intake ports on the lower unit are not sufficiently submerged, engine overheating is likely, which can result in severe damages.

Operational issues

Motor mounting height

Motor height on the transom is an important factor in achieving optimal performance. The motor should be as high as possible without ventilating or loss of water pressure. This minimizes the effect of hydrodynamic drag while underway, allowing for greater speed. Generally, the antiventilation plate should be about the same height as, or up to two inches higher than, the keel, with the motor in neutral trim.

Trim

Trim is the angle of the motor in relation to the hull, as illustrated below. The ideal trim angle is the one in which the boat rides level, with most of the hull on the surface instead of plowing through the water.

If the motor is trimmed out too far, the bow will ride too high in the water. With too little trim, the bow rides too low. The optimal trim setting will vary depending on many factors including speed, hull design, weight and balance, and conditions on the water (wind and waves). Many large outboards are equipped with *power trim*, an electric motor on the mounting bracket, with a switch at the helm that enables the operator to adjust the trim angle on the fly. In this case, the motor should be trimmed fully in to start, and trimmed out (with an eye on the tachometer) as the boat gains momentum, until it reaches the point just before ventilation begins or further trim adjustment results in an RPM increase with no increase in speed. Motors not equipped with power trim are manually adjustable using a pin called a topper tilt lock.

Ventilation

Ventilation is a phenomenon that occurs when surface air or exhaust gas (in the case of motors equipped with through-hub exhaust) is drawn into the spinning propeller blades. With the propeller pushing mostly air instead of water, the load on the engine is greatly reduced, causing the engine to race and the prop to spin fast enough to result in cavitation, at which point little thrust is generated at all. The condition continues until the prop slows enough for the air bubbles to rise to the surface. The primary causes of ventilation are: motor mounted too high, motor trimmed out excessively, damage to the antiventilation plate, damage to propeller, foreign object lodged in the diffuser ring.

Cavitation

Cavitation as it relates to outboard motors is often the result of a foreign object such as marine vegetation caught on the lower unit interrupting the flow of water into the propeller blades.

Preventive Maintenance

- Lower unit gear lubricant—change annually.
  - Inspect the old oil for metal fragments and if found, disassemble gearbox for inspection and repair.
  - Inspect old oil for evidence of water intrusion and if found, replace seals at propshaft, drive shaft and shift rod.

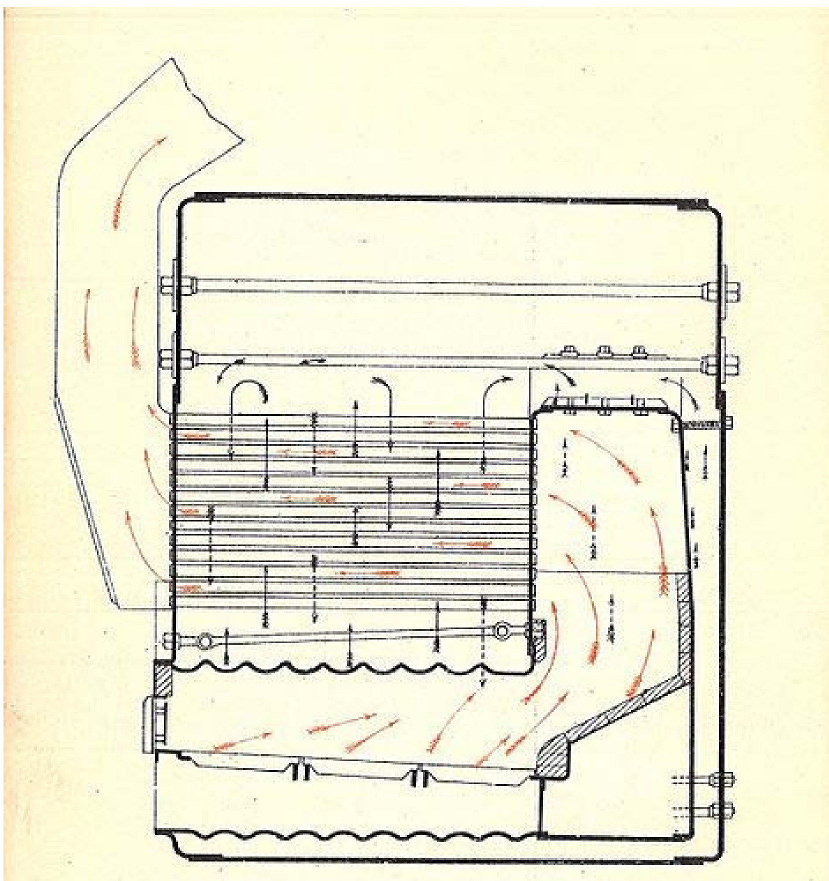
- Water pump impeller -- replace every two years (annually in a salt water environment).
    - Inspect pump housing, and replace if scored or damaged.
    - Inspect old impeller for missing pieces and if found, remove thermostat housing and water jacket cover if necessary, to recover the liberated material.
- Powerhead—annual inspection
    - Inspect engine wiring for corrosion, burned/chafed/missing insulation. Check all connections for tightness.
    - Inspect fuel lines for signs of aging.
    - Inspect spark plugs and replace when necessary.
    - Check all fasteners for tightness, torque to manufacturer specification if necessary.
    - Clean and inspect throttle, shift, spark advance linkages, lubricate according to manufacturer recommendations.
    - Starter motor (if equipped) -- apply two drops of light oil to the bendix gear threads.
    - Test overtemp warning horn or light (if equipped).

Manufacturers

- British Anzani
- Aquawatt Electric Outboard Motor
- British Seagull
- Briggs & Stratton
- China Parsun Marine
- Evinrude/Johnson, a division of Bombardier Recreational Products
- Hidea
- Honda
- Honda Marine
- Mercury/Mariner
- McCulloch
- Nissan Marine
- Oshen-Hyfong Marine
- Parsun Marine
- Selva Marine
- Suzuki
- Tohatsu
- Ul'yanovsk Motor Plant
- West Bend
- Yamaha Motor Corporation
- Yanmar Diesel Power

Chapter- 9

Scotch Marine Boiler



Sectional diagram of a "wet back" boiler

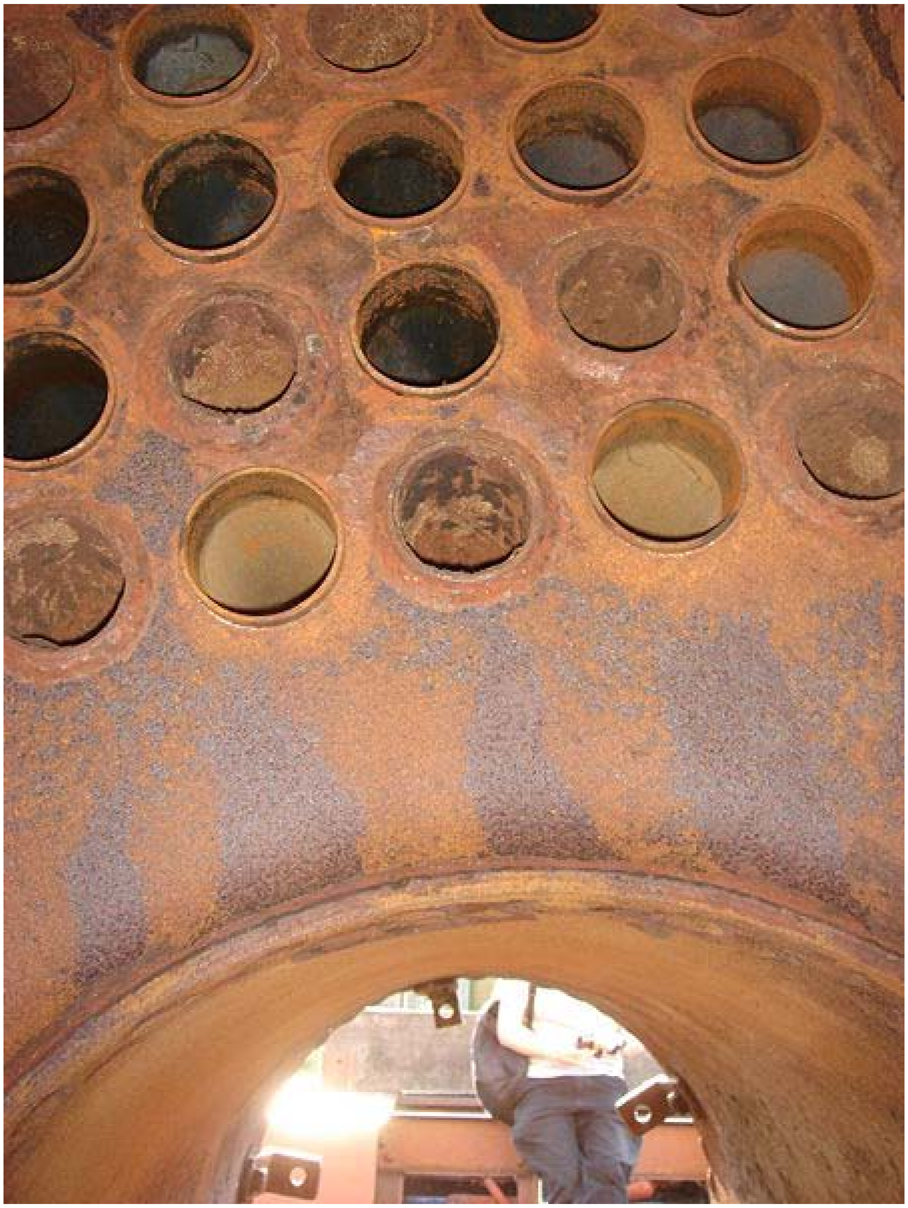
Rear face of the boiler, showing the stays supporting the combustion chambers

A **"Scotch" marine boiler** (or simply **Scotch boiler**) is a design of steam boiler used mostly on ships.

The general layout is that of a squat horizontal cylinder. One or more large cylindrical furnaces are in the lower part of the boiler shell. Above this is a large number of small-diameter firetubes. Gases and smoke from the furnace pass to the back of the boiler, then return through the small tubes and up and out of the chimney. The ends of these multiple tubes are capped by a smokebox, outside the boiler shell.

The Scotch boiler is a fire-tube boiler, in that hot flue gases pass through tubes set within a tank of water. As such, it is a descendant of the earlier Lancashire boiler and like the Lancashire it uses multiple separate furnaces to give greater heating area for a given furnace capacity. It differs from the Lancashire in two aspects: the notion of smaller diameter tubes to increase the ratio of heating area to cross-section is taken even further to use a great many small return tubes (typically 3 or 4 inches diameter each). Secondly the overall length of the boiler is halved by folding the gas path back on itself.

Combustion chamber



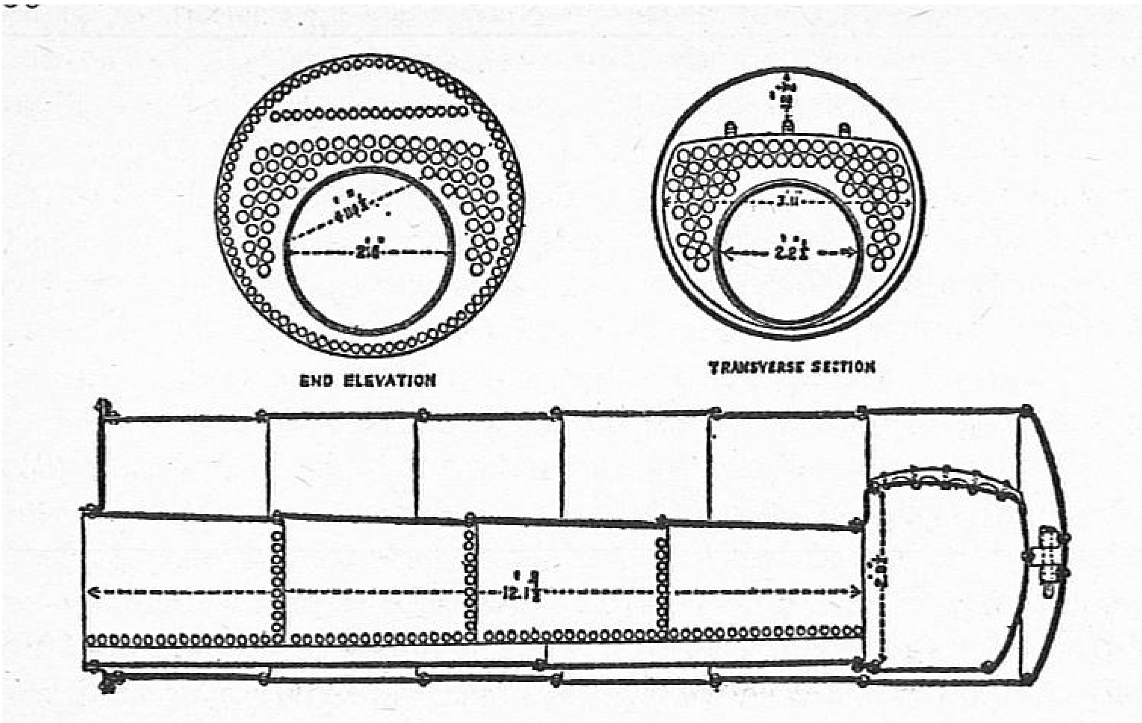
Inside the combustion chamber, looking up at the tubeplate

The far end of the furnace is an enclosed box called the *combustion chamber* which extends upwards to link up with the firetubes.

The front wall of the combustion chamber is supported against steam pressure by the tubes themselves. The rear face is stayed by rod stays through the rear shell of the boiler. Above the combustion chamber and tubes is an open steam collecting space. Larger long rod stays run the length of the boiler through this space, supporting the ends of the boiler shell.

With multiple furnaces, there is a separate combustion chamber for each furnace. A few small boilers did connect them into one chamber, but this design is weaker. A more serious problem is the risk of reversing the draught, where exhaust from one furnace could blow back and out of the adjacent one, injuring the stokers working in front of it.

Origins



'Wilberforce' boiler in section

The first recorded boiler of comparable form was used in a railway locomotive, Hackworth's *'Wilberforce'* class of 1830. This had a long cylindrical boiler shell similar to his earlier return-flued *'Royal George'* , but with the return flue replaced by a number of small firetubes, as had been demonstrated so effectively by Stephenson with his *'Rocket'* a year earlier. The novel feature of an entirely internal combustion chamber was used. Unlike the later Scotch boiler though, this was self-supported by its own stays, rather than using stays through the walls of the boiler shell. This allowed the entire assembly of outer tubeplate, furnace tube, combustion chamber and firetubes to all be removed from the boiler shell as one unit, simplifying manufacture and maintenance. Although a valuable feature, this became impractical for larger diameter chambers that would require the support of the shell.

Variants

Number of furnaces

Typical practice for ships was to have two furnaces. Smaller boilers might only have one, larger boilers commonly had three. The limitation in boiler size was the amount of work each stoker could do, firing one furnace per man. Larger ships (meaning anything above the smallest) would have many boilers.

As with the Lancashire boiler, the furnace was often corrugated for strength. Various makers had their own particular ways of making these corrugations, leading to their classification for maintenance purposes under the broad titles of, Leeds, Morrison, Fox, Purves or Brown.

Wet back and dry back

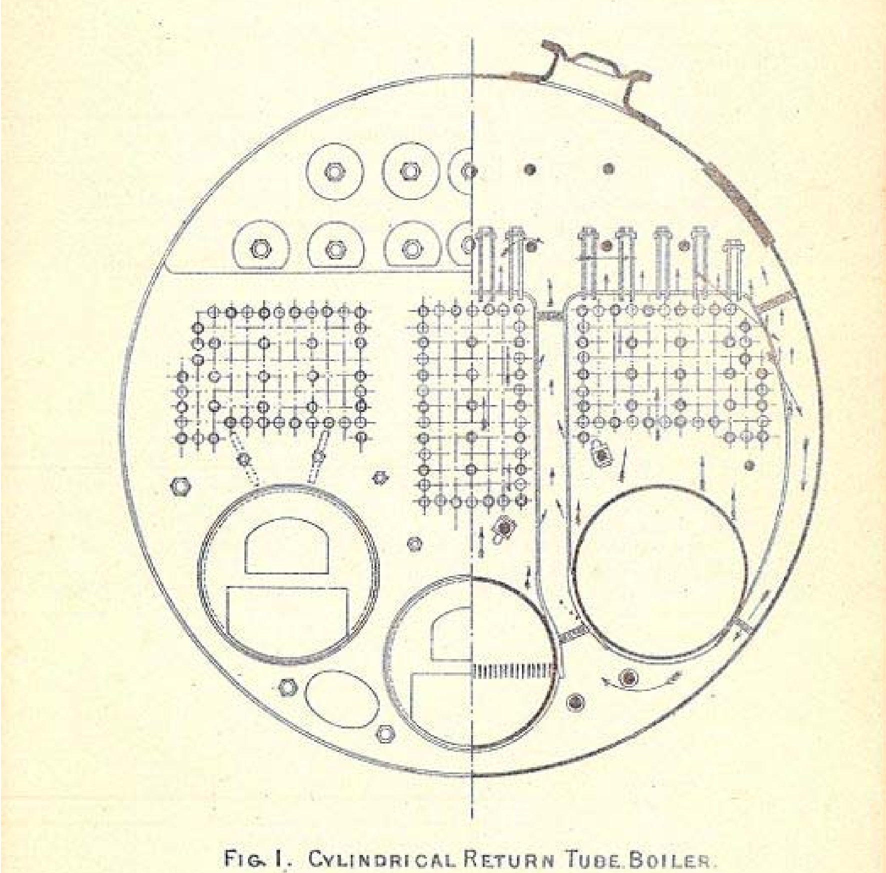


FIG. I. CYLINDRICAL RETURN TUBE BOILER.

Arrows show direction of circulation of water.

End view and half-section of a three-furnace boiler

The typical design is the "wet back", where the rear face of the combustion chamber is water-jacketed as a heating surface.

The "dry back" variation has the rear of the combustion chamber as an open box, backed or surrounded only by a sheetmetal jacket. This simplifies construction, but also loses much efficiency. It is only used for small boilers where capital cost outweighs fuel costs. Although the Scotch boiler is nowadays rarely the primary steam generator on a ship, small dry-back designs such as the Minipac are still encountered, for supporting secondary demands whilst alongside in port with the main boilers cold.

One interesting variant of the dry-back design has been a patent for burning ash-prone fuels. The rear of the combustion chamber is used as an access point for an ash separator, removing the ash before the small-diameter tubes.

Double-ended

The double-ended design places two boilers back-to-back, removing the rear wall of the boiler shell. The combustion chambers and firetubes remain separate. This design saves some structural weight, but it also makes the boiler longer and more difficult to install into a ship. For this reason they were not commonly used, although back-to-back arrangements of multiple single-ended boilers were common.

Inglis

The "Inglis" modification adds an extra combustion chamber where an additional single large flue returns from the rear to the front of the boiler. Flow through the multiple tubes is thus from front to back, and so the exhaust is at the rear. Multiple furnaces would share a single combustion chamber.

The major advantage of the Inglis is the extra heating area it adds, for a comparable shell volume, of perhaps 20%. Surprisingly this is not from the additional combustion chamber, but from lengthening the narrow firetubes. These can now run the full length of the boiler shell, rather than just the rather shorter distance from the inner combustion chamber to the front tubeplate. Despite this advantage, it is rarely used.

Use in ships

The Scotch marine boiler achieved near-universal use throughout the heyday of steam propulsion, particularly for the most highly developed piston engines such as the triple-expansion compounds. It lasted from the end of the low-pressure haystack boilers in the mid-19th century through to the early 20th century and the advent of steam turbines with high-pressure water-tube boilers such as the Yarrow.

Large or fast ships could require a great many boilers. *Titanic* had 29 boilers: 24 double-ended and 5 smaller single-ended. The larger boilers were 15 feet 9 inch diameter and 20 feet long, the smaller were 11 feet 9 inch diameter. All had three corrugated Morrison furnaces of 3 feet 9 inch diameter, 159 furnaces in total, and a working pressure of 215 psi.

Working examples today

Boiler removed from steam tug Mayflower

Numerous scotch boilers are still in use and new boilers can be built to replace life-expired ones. Examples of preserved steam boats employing scotch boilers include:

- Steam tug *Mayflower*, Bristol Industrial Museum

  Mayflower's boiler is currently removed for restoration and may easily be seen in close-up.

- *Baltimore*, of 1906, is the oldest working steam tug in the USA.
- Steamship *Shieldhall* based in Southampton, UK, is fully operational and has two, oil-fired, scotch boilers.

Chapter- 10

Trolling Motor and Turbosail

Trolling motor

A 12 volt electric trolling motor mounted on a 8 foot inflatable boat

A **trolling motor** is a marine propulsion system consisting of a self-contained unit that includes an electric motor, propeller and controls, and is affixed to an angler's boat, either at the bow or stern. A gasoline-powered outboard used in trolling, if it is not the vessel's primary source of propulsion, may also be referred to as a *trolling motor.* Trolling motors are often lifted from the water to reduce drag when the boat's primary engine is in operation.

Uses

- Trolling for game fish; a motor used for this purpose is usually a secondary means of propulsion, and mounted on the transom alongside the primary outboard motor or on a bracket made for the purpose.
- Auxiliary power for precision maneuvering of the boat, to enable the angler to cast his bait to where the fish are located; trolling motors designed for this application are typically mounted in the bow.
- Primary source of propulsion for smaller water craft, such as canoes and kayaks, and on lakes where the use of a gasoline-powered engine is prohibited; usually transom-mounted.

History

Before 1934 - A PORTABLE ELECTRIC PROPELLER FOR BOATS. Article in Scientific American 1895-09-21. "Briefly described, it consists of a movable tube which is hinged at the stern of the boat, much as an oar is used in sculling. The tube contains a flexible shaft formed of three coils of phosphor bronz. This tube extends down and out into the water, where it carries a propeller, and at the inboard end an electric Motor is attached, which is itself driven by batteries." Invented and sold by the Electric Boat company.

The electric trolling motor was invented by O.G.Schmidt in 1934 in Fargo, North Dakota, when he took a starter motor from a Model A Ford, added a flexible shaft, and a propeller. Because his manufacturing company was near the Minnesota/North Dakota border, he decided to call the new company MinnKota. The company still is a major manufacturer of trolling motors.

Several other trolling motor manufacturers have appeared over the last few decades, including Motor Guide and Rhodan Marine Systems. Motor Guide introduced the Pin Point system using sonar to follow bottom countours. Minn Kota and Rhodan Marine Systems recently introduced wireless trolling motors with integrated GPS systems. The Rhodan GPS Anchor has been demonstrated at trade shows to precisely hold a boat's position within a couple feet in wind and current acting as a virtual anchor.

Design

Electric Trolling Motors

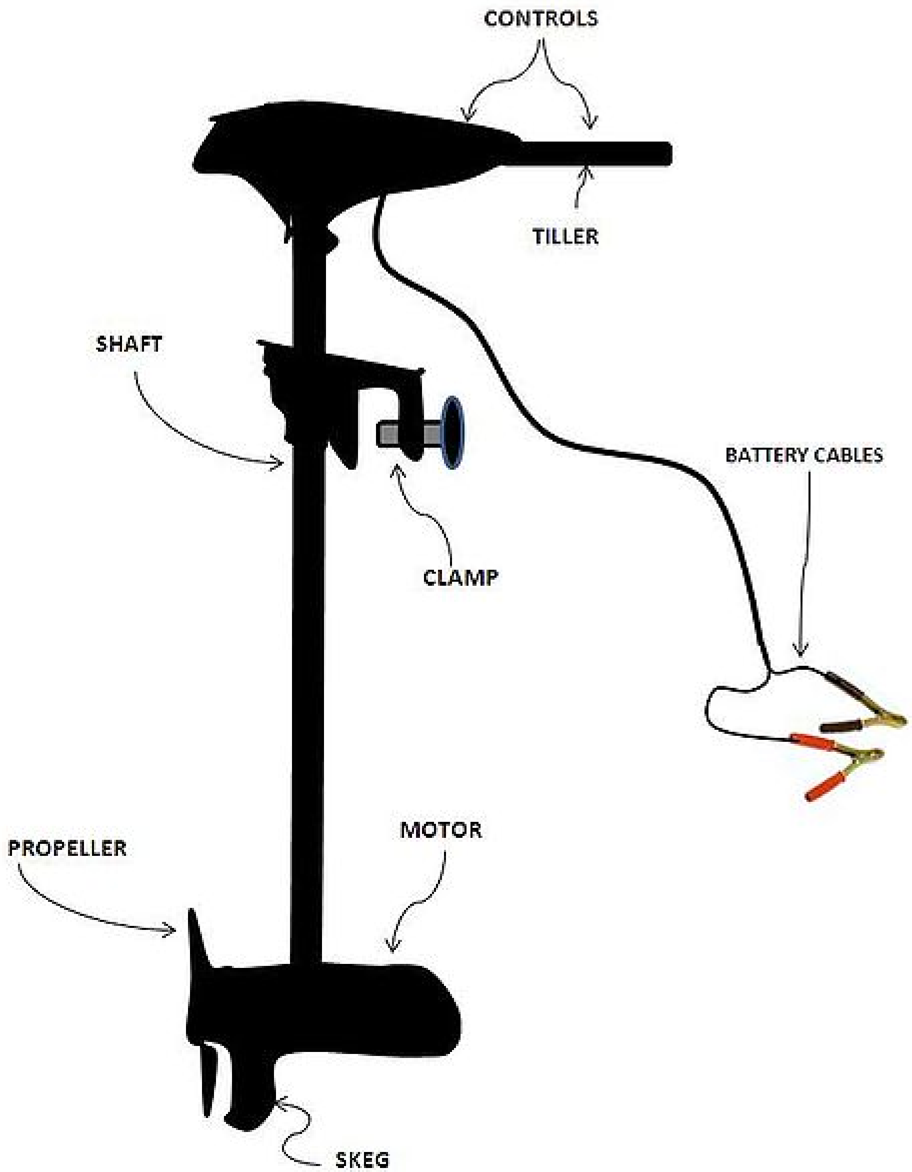


Diagram of a hand-controlled trolling motor.

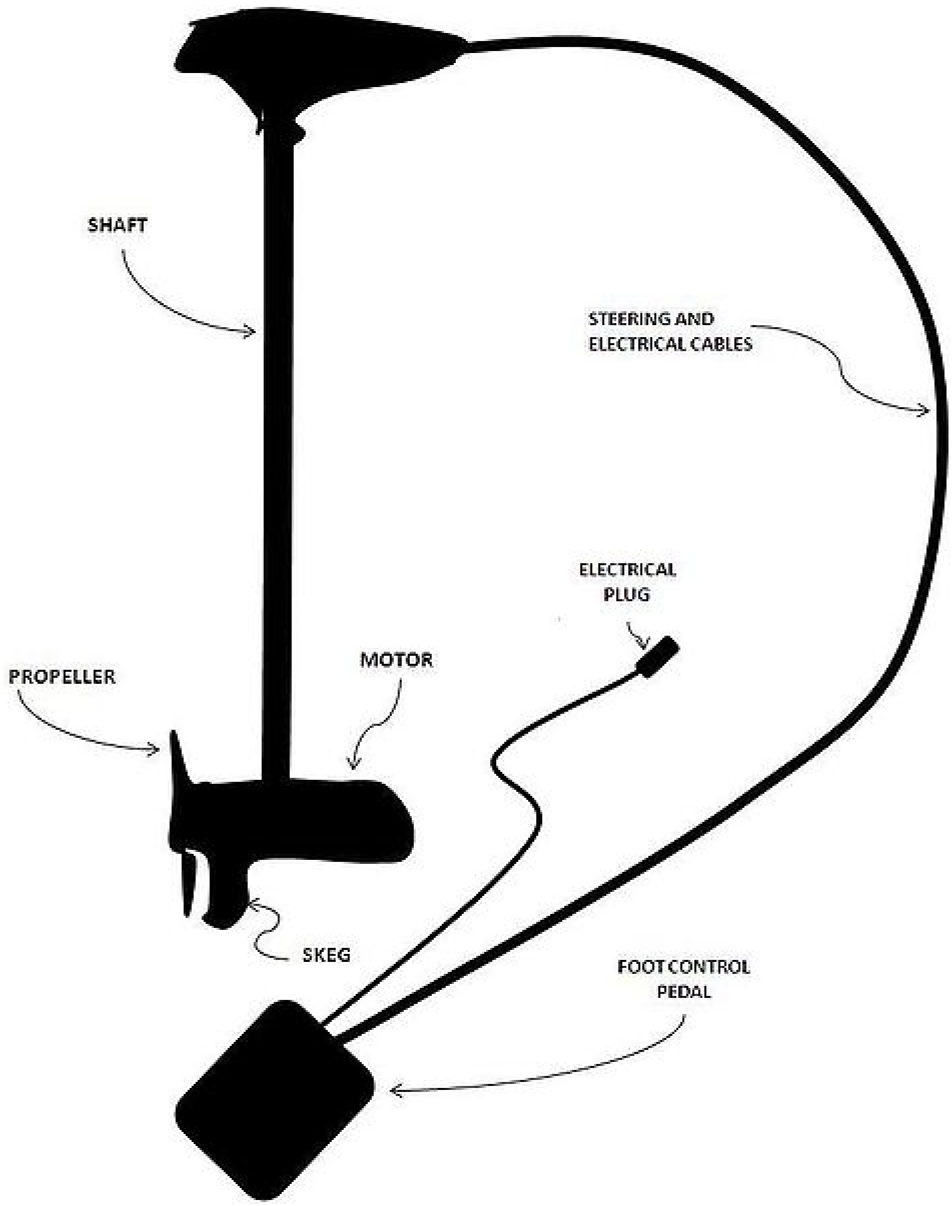


Diagram of a foot-controlled trolling motor.

- Modern electric trolling motors are designed around a 12-volt, 24-volt or 36-volt brushed DC electric motor, to take advantage of the availability of 12-volt deep cycle batteries.
- The motor itself is sealed inside a watertight compartment at the end of the shaft. It is submerged during operation, which prevents overheating.
- The propeller is fitted directly on to the propshaft.
- Hand-control: tiller for steering, with speed control either built in to the tiller or a control knob on top of the unit. Hand controlled trolling motors are attached to the boat with a clamp.
- Foot-control: on/off and speed controls are foot-operated, and built into a pedal that also controls the steering mechanism. Steering may be via electronically

controlled servo motors, or in early-model (and late-model low-end units), a push-pull cable. Foot controlled trolling motors require a specialized mounting bracket that bolts horizontally to the deck.

- Wireless remote: available on high-end late-model trolling motors. Servo-controlled steering and speed control both respond to a wireless device, either in a foot pedal or a key-fob transmitter (similar to an automotive remote keyless system).

Foot controlled trolling motor mount in the deployed position.

Foot controlled trolling motor mount in the stowed position.

Gasoline-powered Trolling Motors

- Small outboard motors are frequently used as trolling motors on boats with much larger engines that do not operate as efficiently or quietly at trolling speeds. These typically are designed with a manual pull start system, throttle and gearshift controls mounted on the body of the motor, and a tiller for steering, but in a trolling application, will be connected to the steering mechanism at the helm.

Turbosail

The *Alcyone*

Technical design

Concept

In 1980, Cousteau dreamed of creating a ship with a modern engine that would be powered, at least in part, by the wind, a clean, free, renewable energy source. The idea of using a hollow, rotating metal cylinder for propulsion, the Flettner rotor, had been tried and discarded decades before Cousteau and a team of engineers decided to revive and improve on it.

Aerodynamics

Cousteau and his associates, Professor Lucien Malavard and Dr. Bertrand Charrier, used a fixed cylinder that looked like a smokestack and functioned like an airplane wing.

It consists of an airfoil, vertical and grossly ovoidal tube, with a mobile flap which improves the separation between the intrados and extrados. An aspiration system pulls air into the tubes, and is used to create an important depression on one side of the sail; propulsion occurs perpendicularly to the pressure. In this way, the "sails" act as wings, with air moving slower on one side, creating drag.

A movable shutter and system of fan-drawn aspiration improved the efficiency of this new sail. Small-scale models tested in a wind tunnel functioned perfectly, and the Turbosail was born.

As a result of this design, the turbosail gains its most unique characteristic: thrust is available for the direction of travel, regardless of wind direction. A ship equipped with turbosails can make headway even into a headwind, gaining energy from differential pressure created by the captive vortex both inside and outside the sail.

Standard engines can then be used in conjunction with the turbosails. These in turn can be coordinated with computers to control the angles, suction power, and rotation of the sails.

Engineering analysis

When compared to the thrust coefficient of the best sails ever built (Marconi or square types, i.e. ships of the American Cup or the Japanese wind propulsion system) that of the Turbosail is 3.5 to 4 times superior and gives the system a unique advantage for the economical propulsion. This figure is the result of research on the *Alcyone*.

The efficiency of the system has however not been subjected to sufficient comparative engineering research. There have been only two turbosail equipped vessels on which active research has been performed. The Cousteau group is the only organisation with a large body of data available on turbosails.

The Alcyone reported a 1/3 fuel savings, and a larger commercial vessel had a 15% increase in fuel efficiency over a three year study.

The system bears similarities with Anton Flettner's *Rotorschiff*, a different design based on the Magnus effect.

Early development 1981-1982 : Moulin à Vent

Cousteau and his research team mounted the invention on a catamaran christened *Moulin à Vent* (Windmill). Cousteau and his colleagues validated the system by sailing from Tangier to New York. The crossing was nearly complete when, not far from the American shore, they ran into winds of more than 50 knots. The soldering that held the Turbosail in place gave way and the prototype fell into the sea.

The system consisted of a single turbosail mast, painted a navy blue. The research program for this vessel was designed to test efficiency of thrust with the propulsive system. While the turbosail did generate thrust and power, they were less than those of the sails and generator set which it replaced. Structural problems on the prototype turbosail resulted in buckling of structure, as well as mechanical sheer fatigue cracks at the base of the sail, reducing the effectiveness of the sail quite dramatically. Having proved the concept, the prototype development was ultimately abandoned in 1982 as Cousteau's group turned their attention to a larger vessel, the *Alcyone*.

The Alcyone

Cousteau's experience was turned to good use in designing a new vessel. Working with naval engineers, he designed an innovative hull of aluminum, both lightweight and strong. The catamaran-like stern gave it stability. The monohull forward was designed to split swells and improve ride in heavy seas. Two Turbosails rose from her deck and two diesel engines provided the necessary suction forces. The ship was named Alcyone, the daughter of the wind.

When the Alcyone was launched in 1985, it benefited from the development of the original turbosail *Moulin a Vent*. With two turbosails of reduced aspect ratio, the stresses placed on the metal of the sail surfaces was much reduced. Both sails also contained axial turbines for power generation, and with decreases in the cost of computers, also featured sensor driven controls to actuate the sails for optimal thrust.

Practical experience with the ship saw the Cousteau group adopting the vessel as flagship and primary research platform in the 1980s. Computers optimized the functioning of Turbosails and engines. To maintain a constant speed, the engines take over automatically when the wind dies down, and they stop completely when the wind is of sufficient strength when blowing in the right direction. A crew of five is required to maintain the ship.

The *Alcyone* thus traveled around the world, gaining data about the turbosail's performance in varying wind and weather conditions - in all cases proving the concept and finding the propulsive potential to be very good.

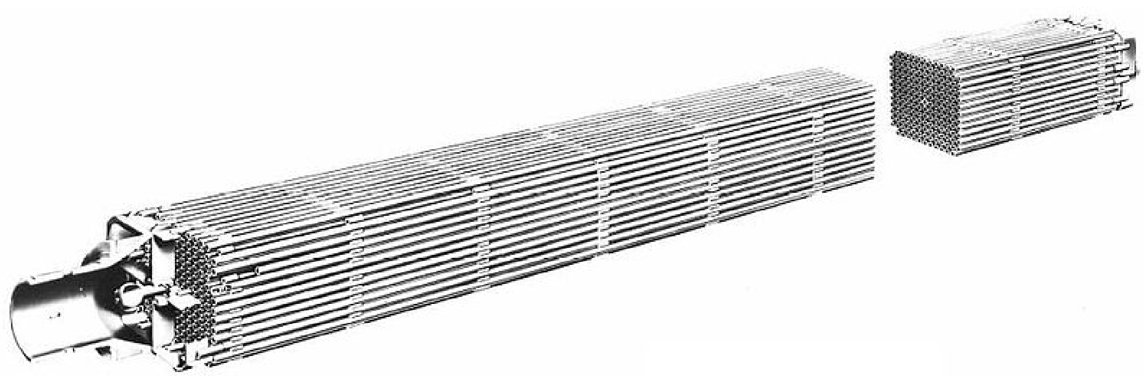
Further development

With an interest in expanding adoption of the turbosail, it was suggested that tankers and other large vessels would soon install turbosails as a mean to decrease fuel consumption. The system was intended to power the *Calypso II*, which has yet to be built.

Chapter- 11

Nuclear Marine Propulsion

Nuclear marine propulsion is propulsion of a registered ship class (cargo, bulk, tanker, container, etc.) by a nuclear reactor. **Naval nuclear propulsion** is propulsion that specifically refers to naval warships. Only a very few experimental civil nuclear ships have been built; the elimination of fossil fuel does not overcome the myriad technical, economic and political problems of this application of nuclear power.



A nuclear fuel element for the cargo ship NS *Savannah*. The element contains four bundles of 41 fuel rods. The uranium oxide is enriched to 4.2 and 4.6 percent of U-235

Power plants

Operation of a civil or naval ship power plant is similar to land-based nuclear power reactors. A sustained nuclear reaction in the reactor produces heat that is used to boil water. The resulting steam spins a turbine. The turbine shaft may be coupled through a gearbox speed reducer to the ship's propeller, or in a turbo-electric drive system may operate a generator that supplies electric power to motors connected to the propellers.

The majority of marine reactors are of the pressurized water type, although the US and Soviet navies have designed and fielded warships powered with liquid metal cooled reactors. Marine-type reactors differ from commercial reactors in that:

- marine reactors are compact but have high power density, i.e. they produce significant power in a small volume, however the total amount of power produced in a marine reactor is small (hundreds of MW_t) compared to a commercial power reactor (thousands of MW_t).
- the fuel used is typically of higher enrichment; some run on low-enriched uranium (requiring frequent refuelings), others run on highly enriched uranium (greater than 20% U-235, varying to over 96% in U.S. submarines (They do not need to be refueled as often and are quieter in operation from smaller core) to between 30–40% in Russian submarines to lower levels in some others),
- the fuel is not a ceramic UO_2 (uranium oxide) but a metal-zirconium alloy (circa 15% U with 93% enrichment, or more U with lower enrichment),
- marine reactors are designed for long core life, enabled by the relatively high enrichment of the uranium and by incorporating a "burnable poison" in the cores which is progressively depleted as fission products and minor actinides accumulate; the two effects cancel each other out. One of the technical difficulties is the creation of a fuel which will tolerate the very large amount of radiation damage. During use, the properties of nuclear fuel change. Fuel elements may crack and fission gas bubbles may form.

- The reactor, as the ship's propulsion system energy (heat) source, is mobile, not stationary, as in a land based nuclear reactor plant. The reactor, and all of its auxiliary support equipment, must be of an exceptionally rugged design, to withstand the forces associated with the movement of a ship.

- Oceanic weather, the wide variations of air and water temperature, plus the corrosive nature of the salt air and water environments, place even greater, unique design demands upon the sea-based nuclear power propulsion plant.

- Finally, the marine reactor propulsion plant must be of cost effective design, construction and operation. It must be highly reliable and self sufficient, so as to be easily reparable and sustainable through repairs, conducted many thousands of miles from its home port.

Long-term integrity of the compact reactor pressure vessel is maintained by providing an internal neutron shield. (This is in contrast to early Soviet civil PWR designs where embrittlement occurs due to neutron bombardment of a very narrow pressure vessel.)

The Russian, U.S. and British navies rely on steam turbine propulsion, while the French and Chinese use the turbine to generate electricity for propulsion (turbo-electric propulsion). Most Russian submarines as well as most American aircraft carriers are powered by two reactors, an exception being the first nuclear powered aircraft carrier the USS *Enterprise* with eight. The majority of U.S., British, French and Chinese submarines are powered by one, with the notable exception of the USS *Triton*, the first submarine to circumnavigate the world submerged, with two reactors.

Decommissioning nuclear-powered submarines has become a major task for US and Russian navies. After defuelling, U.S. practice is to cut the reactor section from the vessel for disposal in shallow land burial as low-level waste. In Russia, whole vessels, or sealed reactor sections, typically remain stored afloat, although a new facility near Sayda Bay is to provide storage in a concrete-floored facility on land for some submarines in the far north.

Russia is well advanced with plans to build a floating nuclear power plant for their far eastern territories. The design has two 35 MWe units based on the KLT-40 reactor used in icebreakers (with refueling every four years). Some Russian naval vessels have been used to supply electricity for domestic and industrial use in remote far eastern and Siberian towns.

Lloyd's Register is investigating the possibility of civilian nuclear marine propulsion and rewriting draft rules.

History

Military

Under the direction of Admiral Hyman G. Rickover, the design, development and production of nuclear marine propulsion plants started in the USA in the 1940s, with the first test reactor being started up in 1953. The first nuclear-powered submarine, USS *Nautilus*, put to sea in 1955. Much of the early development work on naval reactors was done at the Naval Reactor Facility on the campus of the Idaho National Laboratory.

The Soviets were also involved in the production of a nuclear submarine. They produced the November class, the first of which, K-3 "Leninskiy Komsomol", was underway under nuclear power on July 4, 1958.

The large amounts of power produced by an air-independent nuclear reactor marked the transition of submarines from slow vessels required to surface often, to warships capable of sustaining 20-25 knots (37-46 km/h) submerged for many weeks.

Nautilus led to the parallel development of further *Skate*-class submarines, powered by single reactors, and a cruiser, USS *Long Beach*, in 1961, powered by two reactors. The aircraft carrier USS *Enterprise*, commissioned in 1961, is powered by eight reactor units.

By 1962 the United States Navy had 26 nuclear submarines operational and 30 under construction. Nuclear power had revolutionized the Navy. The technology was shared with the United Kingdom, while French, Soviet, Indian and Chinese developments proceeded separately.

After the *Skate*-class vessels, reactor development proceeded and in the USA a single series of standardized designs was built by both Westinghouse and General Electric, one reactor powering each vessel. Rolls-Royce built similar units for Royal Navy submarines and then developed the design further to the PWR-2 (pressurized water reactor).

The largest nuclear submarines ever built are the 26,500 tonne Russian *Typhoon* class.

The most compact nuclear submarines to date ever built are the 2,700 tonne french Rubis class submarine attack submarines.

USA and France have built nuclear aircraft carrier vessels.

Civil

Development of nuclear merchant ships began in the 1950s, but has not been commercially successful. The US-built NS *Savannah* was commissioned in 1962 and decommissioned eight years later. It was a technical success, but not economically viable; it was too expensive to operate and too small to carry commercial cargo. Since the ship had been conceived as s demonstration of peaceful use of nuclear energy, it had a compromised design, neither efficient freighter nor viable passenger liner. The German-built *Otto Hahn* cargo ship and research facility sailed some 650,000 nautical miles (1,200,000 km) on 126 voyages in 10 years without any technical problems. However, it proved too expensive to operate and was converted to diesel. The Japanese *Mutsu* was the third civil vessel. It was dogged by technical and political problems and was an embarrassing failure due to significant radiation leakage on first criticality of its reactor. All three vessels used reactors with low-enriched uranium fuel.

The fourth nuclear merchant ship, *Sevmorput*, operated successfully in the specialised environment of the Northern Sea Route. Recently there has been renewed interest in nuclear propulsion, and some proposals have been drafted. For example, the cargo coaster is a new design for a nuclear cargo ship. Using the new micro nuclear reactors, other existing cargo ships could potentially be converted to nuclear propulsion as well.

When the Arktika class NS *50 Let Pobedy* was put into service in 2007, it became the world's largest icebreaker.

Nuclear propulsion has proven both technically and economically feasible for nuclear powered icebreakers in the Soviet Arctic. The power levels and energy required for icebreaking, coupled with refueling difficulties for other types of vessels, are significant factors. The Soviet icebreaker *Lenin* was the world's first nuclear-powered surface vessel and remained in service for 30 years (new reactors were fitted in 1970). It led to a series of larger icebreakers, the 23,500 ton *Arktika* class, launched from 1975. These vessels have two reactors and are used in deep Arctic waters. NS *Arktika* was the first surface vessel to reach the North Pole.

For use in shallow waters such as estuaries and rivers, shallow-draft *Taymyr* class icebreakers with one reactor are being built in Finland and then fitted with their nuclear steam supply system in Russia. They are built to conform with international safety standards for nuclear vessels.

Naval nuclear accidents

United States

- USS *Thresher* (SSN-593) (1963; *Thresher*/*Permit*-class; sank, 129 killed)

- USS *Scorpion* (SSN-589) (1968; *Skipjack*-class; sank, 99 killed)

  Both sank for reasons unrelated to their reactor plants and still lie on the Atlantic sea floor.

Russian or Soviet

- K-8 (1960; November-class submarine; loss of coolant)
- K-19 (1961; Hotel-class submarine; two loss of coolant accidents, 27 killed due to one accident)
- K-11 (1965; November-class submarine; two refueling criticalities)
- K-159 (1965; November-class submarine; radioactive discharge)
- *Lenin* (1965; *Lenin*-class icebreaker; loss of coolant)
- *Lenin* (1967; *Lenin*-class icebreaker; loss of coolant)
- K-140 (1968; Yankee-class submarine; power excursion)
- K-8 (loss of coolant) (1970; November-class submarine; sank after fire, 52 killed)
- K-320 (1970; Charlie I-class submarine; uncontrolled startup)
- K-116 (1979; Echo II-class submarine; reactor accident)
- K-122 (1980; Echo I-class submarine; fire, 14 killed)
- K-222 (1980; Papa-class submarine; uncontrolled startup)
- K-27 (1982; Modified November-class submarine; scuttled)
- K-123 (1982; Alfa-class submarine; loss of coolant)
- K-429 (1983; Charlie I-class submarine; sank due to improper work at shipyard, 16 killed)
- K-431 (1985; Echo II-class submarine; refueling criticality, 10 killed)
- K-429 (1985; Charlie I-class submarine; sank at moorings)
- K-219 (1986; Yankee I-class submarine; sank after collision, 6 killed)
- K-278 *Komsomolets* (1989; Mike class submarine; sank, 42 killed)
- K-192 (1989; Echo II-class submarine; loss of coolant)
- K-141 *Kursk* (2000; Oscar II-class submarine; sank, 118 killed)
- K-159 (2003; November-class submarine; sank under tow, 9 killed)

  While not all of these were reactor accidents, they have a major impact on nuclear marine propulsion and the global politics because they happened to nuclear vessels. Many of these accidents resulted in the sinking of the boat containing nuclear weapons on board, which remain there to this day.

Chapter- 12

Effort on Sail

Example of wind effort on different sail types. Regattas in Cannes, 2006.

The purpose of sail is to take wind energy and transmit this energy to boat. Effort of wind is on all surface of sail. We need to calculate :

- location of center of pressure
- intensity of **effort on sail**

This calculating is very important for the design of ship (stability). Calculation is very complex and much more complex that a wing . Calculus is part of Fluid mechanics and Aerodynamics.

In the reality the sail is not in-deformable, the wind is not constant, the boat is not in uniform speed, the mast is not infinitely stiff, the air is viscous (losses by friction). The flow of the air varies (turbulent, laminar), the mast perturbs the flow (except when it is profiled). For clarity, these phenomena will not be taken into account .

Center of pressure of sail

The effort on sail could be summarize and could be reduce in on point. This point is named center of pressure. In first approach, the center of pressure is the geometric center of sail. With the wind, the sail have a ball shape and if shape is stable, then the location of center of pressure is stable. On a sail of topsail and by rear wind, the center goes back up(raises) little towards the top according to the tension of the sheep and the tangon. On a sail of genoa and in the speed(look) of near, the center move to the front of the boat from around 10 to 15% .

Chord of sail

The chord of sail is a straight line between leading edge and training edge. This notion is useful for a good approximation of direction of effort on sail. The effort of sail is quasi perpendicular to chord and located quasi at the maximum camber of sail.

Effort on sail

At the microscopic level, in a perpetual motion of air parcels moving continuously. However, macroscopically, the air can not move. If the air does not move, it means that each parcel is more or less in the same place (random motion). The parcel of air moves around an imaginary fixed point in space without too much away from this point. If air moves mean that overall the parcel moving in large numbers in the same direction (directed movement). Of course the resulting motion can be a combination of both. The movement of air parcels have two origins : temperature and mechanical influence of wind.

Role of Atmospheric pressure

Thanks to the energy of the temperature, the parcel are constantly shifting erratically. By moving an air parcel will soon meet one another, and the meeting is a shock. Shock changes the trajectories. The two parcels bounce one on the other. Each off go approximately to its starting point. Again, it meets another parcel for a new shock reducing it back to its point of departure etc. Overall in distance, it gives impression that parcel do not move (random motion).

More air parcel is at high altitude, less gravity is important. It is therefore less strength for the return to Earth, and shocks are less violent and frequent. Thus more parcel is close to sea level, more collisions are frequent and violent.

When the plot is very close to the sail, the shock occurs between sail and parcel. These collisions generate a considerable force on sail, the force at sea level is about 10 tons per square meter on sail. This force is exerted on a surface, therefore force is a pressure. This pressure is atmospheric pressure. If a wing has two sides, air pressure is on both sides. Finally, two pressures are perfectly balanced, sail does not move.

Role of wind

Now a part of the movement of parcels is globally ordered (seen far away), parcels move together in the same direction. From a distance the air moves, so call wind.

Depending on the configuration of the sail, a parcel of air near sail could have different state :

- sail is free, wind have no resistance except thickness of cloth, air parcel passes without being significantly disturbed
- sail is perpendicular to the wind (sail or spinnaker topsail downwind), parcel of air crashes against sail. It is almost stopped. Other parcel behind strongly prevent reversing (rebound). Air parcel send a maximum of energy to sail, quasi all energy of movement ordered.
- In the intermediate cases, the air parcel bounces more or less, they give a portion of its energy. They disrupt orderly movement of those who accompany the collision. These in turn disrupt the orderly movement of other parcel by other collisions, etc., etc.. But rebounding, it will also result, disrupt balance of air pressure, creating an overpressure in wind face of sail and depression under wind face of sail.

There are two phenomena, condition which push sail (wind pressure) and condition which pull sail (depression due to wind).

Direction of effort

The shock of air parcel on sail set back the sail. Shock moves only push very little on the side. Effort is almost perpendicular to the surface of sail.

value of effort

The plots of air strike sail on both sides so:

- On the windward side efforts are atmospheric pressure, wind pressure, and virtually no depression due to wind.

- On the leeward side efforts are atmospheric pressure, a bit of depression and almost no wind pressure.

To simplify the manipulation of these forces, the forces are summed into a single force and that the entire surface of the profile (sailing) in a simple formula (valid for airplane wings like a rudder, a sail, an anti Plan -drift) :

$$F = C \times E$$

with

- E = effort that can give up the wind;

- C = coefficient Aerodynamic

According to the Bernoulli, the maximum stress of wind or density of kinetic energy maximum for the entire surface of the sail:

$$E = e_c \times S = MaxQ \times S = \frac{1}{2} \times \rho \times S \times V^2$$

The full expression of the force is:

$$F = \frac{1}{2} \times \rho \times S \times C \times V^2$$

with

- F = lift, expressed in Newton

- ρ (rho) = density air (ρ varies with the temperature and the pressure) ;

- S = typical surface, for sail, it is the sail area in m^2

- C = coefficient Aerodynamic. Aerodynamic coefficient is unit-less, it is the sum of two percentages: the percentage of recovered energy leeward side + percentage of the recovered energy into the wind. For this reason, the coefficient aerodynamics can be greater than 1. It depends on the angle of upwind sailing.
- V = Speed is the speed of the wind relative to the sail (Apparent wind) in m / s.

The sail is deformed by the wind and takes a form named Airfoil. When the flow of air around the profile is Laminar , the factor against depression in the wind becomes crucial. This effect is then called lift. Studies and theory to draw a sail that:

- Depression on the upper (leeward side) represents two thirds of the lift,

- The pressure on the lower surface (facing the wind) represents one third of the lift.

Lift effect on sail

The study effect of lift can compare cases with and without lift . A typical example is a gaff sail. The sail is rectangular and is approximately vertical. The sail has an area of 10 sqm, with 2.5m of foot by 4m of leech. The apparent wind is 8.3 m / s (about 30 km / h). The boat is supposed to uniform velocity, no wave. It does not heel, does not pitch. The density of air is set at: $\rho = 1.2 kg / m^3$

turbulent flow or downwind

The boat is running downwind. The shape of the sail is approximated by a plane perpendicular to the apparent wind.

The depression effect on the sail is second order, and therefore negligible, it remains:

- On the windward side, efforts are atmospheric pressure and wind pressure
- On the leeward side, there remains only the atmospheric pressure

Efforts to atmospheric pressure cancel out. There remains only pressure generated by the wind.

Roughly speaking, shock of parcel on the sail forward all their energy from wind in 90% of the surface of the sail. This means that the Cz or aerodynamic lift coefficient is equal to 0.9.

$$F = \frac{1}{2} \times 1.2 \times 10 \times 0.9 \times 8.3^2 = 372\ newton$$

laminar flow

The boat is Close hauled. The wind has an angle of about 15 degrees with chord of the sail.

Because the setting of the sail at 15 ° relative to the apparent wind, the camber of the sail creates a lift. In other words, the effect of depression on the leeward side is not neglected. As air pressure forces cancel out, efforts remain are:

- On the windward side, wind pressure,
- On the leeward side, wind depression.

The only unknown is the drag coefficient to be estimated. Curve takes a good adjustment of sail is close to upper shape NACA 0012. A sail less well adjusted or older technology (old rig), will be more hollow, more camber. The coefficient of aerodynamic lift will be higher but the sail will be less efficient (lower finesse). The profiles would be more suitable profiles as NACA 0015, NACA 0018 .

For a given profile, there are tables which giving the lift coefficient of the profile. The lift coefficient (Cz) depends on several variables:

- Incidence (angle: apparent wind / Profile)
- The lift hill of the sail, which depends on its extension,
- The surface roughness and Reynolds number, which affect the flow of fluid (laminar, turbulent).

The coefficient is determined for a fluid stable and uniform, and a profile of infinite extension.

The Reynolds number is: $\mathrm{Re} = \frac{\rho \mathrm{U} L}{\mu} = \frac{\mathrm{U} L}{\nu}$

with

- U - fluid velocity or apparent wind [m / s]
- L- characteristic length or foot of the sail [m]
- ν - kinematic viscosity fluid: $\nu = \eta / \rho$ [m / s]
- ρ - density air [kg / m³]
- μ - dynamic viscosity air [Pa] or Poiseuille [pl]

so for this sail about Re = 10^6

Under an incidence of 15 ° and a Reynolds number to one million, reached a NACA0012 Profile Cz 1.5 instead of 0.9 for 90 ° incidence.

$$F = \frac{1}{2} \times 1.2 \times 10 \times 1.5 \times 8.3^2 = 620\ Newton$$

The lift has increased by 50%. This also corresponds on sheet an increase of 50% effort for the same apparent wind.

influence of effort on sheet on lift performance

Set a sail is the setting of two parameters:

- Addressing the impact, i.e. adjust the angle "apparent wind / sail" is at maximum lift, or a maximum of finesse (ratio lift / drag). This angle varies in height (aerodynamic twist)
- Set the profile (camber) of the sail.

Sailing is a generally flexible. The profile of the sail changes depending on the settings of the sail. At a given incidence, the sail can take different forms. The shapes depends on the stress on clew corner of sail thanks to main sheep. Other stress: at the point of tack, the Cunningham, the backstay. These elements help determine a possible shape of sailing. More exactly they can decide position of maximum camber on sail.

Each profile represents an appropriate value of Cz. The position of the trough along the chord with the most lift is about 40% foot from luff. Leeward side of sail is close to the NACA series 0012 (NACA 0015, NACA 0018, etc. within the possibilities of tunning).

Influence of Aspect ratio

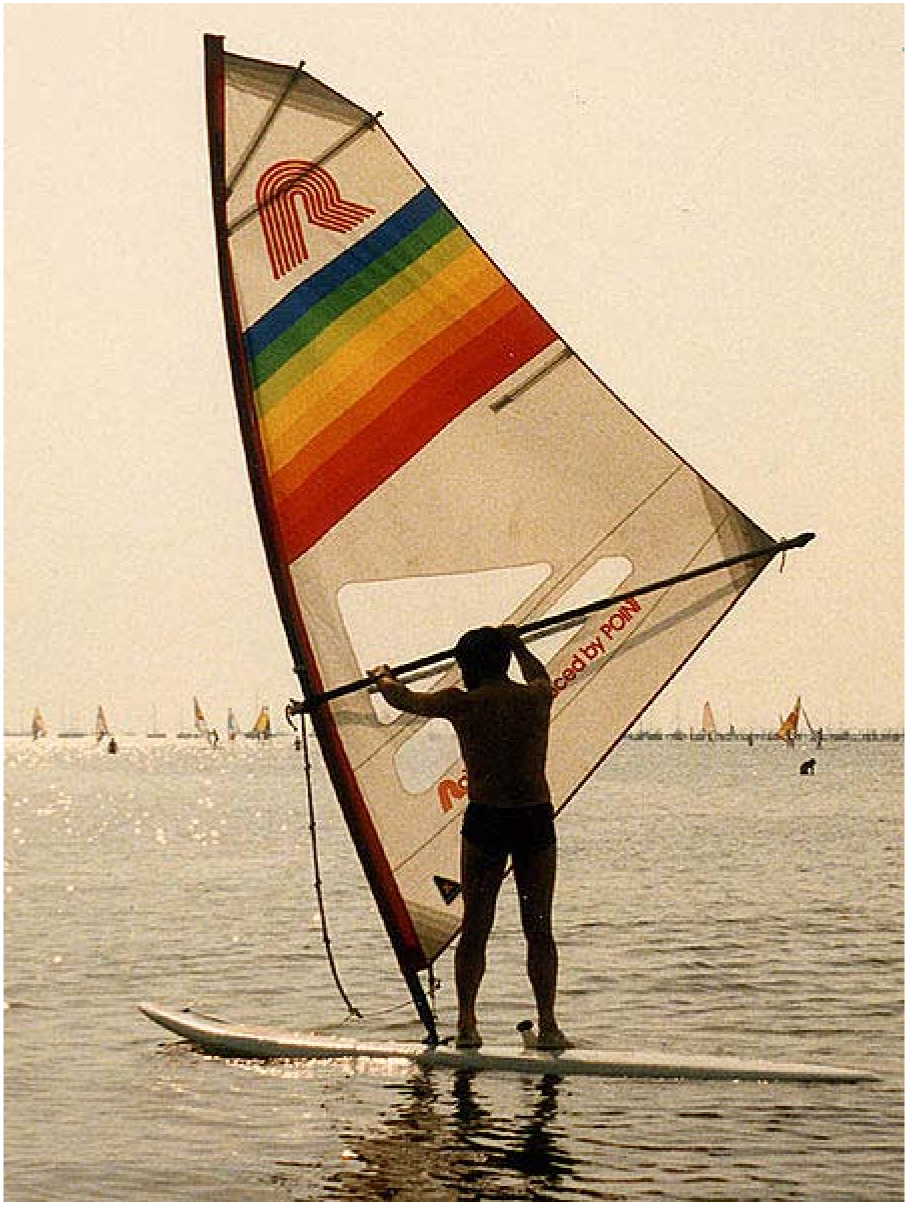
A sail is not infinitely long. So there have ends, in our case of mainsail :

- Boom
- Horn.

When the sail propels the ship, leeward side is depressed, windward side is under pressure. At border of sail, depression is in contact with pressure. Naturally, compressed air molecules (many and frequent shocks) will rush into the area depression (low impact and less frequent). Consequence is that the area was depressed more air molecules than expected so the depression is lower (more pressure than expected). Similarly, the area is under pressure from air molecules than expected so the pressure is less strong. Propulsive effect is less.

The distance between the downwind and upwind ends of the veil is very low , a pressure zone closer to a depression zone, the transfer movement of molecules from one side of the sail to another is very violent. This creates significant turbulence. On a sail Bermuda, foot and leech are two areas where this phenomenon exists. The drag of leech is included in drag "usual lift curves, profile is considered as infinite (ie no border). But foot drag is to be calculated separately. This loss of efficiency of the sail the border is called Lift-induced drag.

Lift-induced drag is directly related to the length of the extremities. More horn is long more induced drag is high. Conversely sail can reefing, i.e. surface of the sail without reducing the length of the horn changes. This means that value of the lift-induced drag will be substantially the same. For a given length of horn, more sail is bigger, lower is ratio lift-induced drag on lift. More sail is stretched, more lift-induced drag alter slightly value of lift coefficient.



Curved shape of the mast and the slats to maintain the curved profile of the leech are clearly visible in this picture of windsurfing sail.

Lift-induced drag depends only on aspect ratio. The extension is defined :

$$\lambda = \frac{b^2}{S}$$

with

- *B* is the length of luff
- *S* on the surface of the sail.

Lift-induced drag is:

$$Ci = \frac{Cz^2}{\pi \times \lambda \times e}$$

with

- Cz : Lift coefficient of airfoil
- π (pi) : 3.1416
- λ : Aspect ratio (wing) (dimensionless)
- e : Oswald efficiency number (less than 1) which depends on the distribution of lift in scale. "e" could be equal to 1 for a distribution of lift "ideal" (elliptical). An elliptical shape of the ends to reduce induced drag better. In practice "e" is the order of 0.75 to 0.85. Only a three-dimensional model and tests to determine the value of "e".

Optimal distribution of maximum reducing lift-induced drag is elliptical in shape . Accordingly, luff will be elliptical, so the mast is not straight as on classic boat, but the mast is design with the closest possible form of ellipse. Elliptical configuration mast is possible with modern materials. It is very pronounced on surfboards. On modern sailboats, mast is curved thanks to Shroud (sailing). Similarly leech will be elliptical. This profile is not natural for a flexible sail, its reason sial uses batten for maintain leech for this curvature.

An ideal lift-induced drag distribution creates an elliptical sail, but current shape of the sails is rather a half-ellipse, as if second half part of ellipse was completely immersed in the sea. It is logical, because as wind speed is nul at the sea level (0 m), sea is equivalent to "mirror" for an aerodynamic point of view. So only half of an ellipse in air is necessary.

Shape of luff of leech, and foot

A sail hauled up have a three-dimensional shape. This form is form chosen by the sailmaker. Now 3D shape is different between hauled up form and empty (no wind, see for example when sail is deployed at sailmaker). We must take this into account when cutting the sail.

The general shape of a sail is a deformed polygon. The polygon is slightly distorted in the case of Bermuda sail, heavily distorted in the case of spinnaker. Shape of edges empty is different from shape of edges once the sail is hauled up. Convex empty can go to straight edge when sail is hauled up.

Edge can be:

- convex
- concave

- right

When the convex shape is not natural (except for a free edge, a spinnaker), sail is equipped with batten to maintain this form when the convex shape is pronounced. Except for the spinnaker with a balloon-shaped, variation of edge empty compared to straight line remains low, a few centimeters.

Once hauled up, sail elliptical would be ideal. But as sail is not rigid:

- You need a mast for reasons of technical feasibility is quite right.
- Flexibility of the sail can bring other problems, it is better to fix at the expense of ideal elliptic shape (convex).

Leech

The oval is the ideal (convex), but a fall concave vacuum improves the twist at the top of the sail and prevents the collapse of "padding" in the gusts, thereby improving its stability. The fall concave make sailing more tolerant and more neutral. A convex shape is also an easy way to increase the sail area (roach).

Luff

Once hauled up, edge must be parallel to forestay or mast. Similarly when the veil is horn. Masts and spars are very often (except surfing) rights, right luff is priori in form to use.

But hollow of the sail is normally closer to luff than foot. So to facilitate the implementation of hollow of sail hauled up, the empty form of luff is convex. Convexity is called the luff luff round. When rigging is complex, shape of the mast is not straight . In this case we must take into account, and the shape of luff empty can be convex at bottom and concave to top.

Foot

Foot form has little importance, particularly on sails with free edge. Its shape is more motivated by aesthetic reasons. Often convex empty to be right once hauled up. When the border is attached to a spar or boom a convex shape is preferred to facilitate formation of hollow of sail. By conception on retractable booms, the chosen of shape of foot edge is more based on technical constraints than aerodynamics consideration.

Contribution of the lift at the progress of the vessel

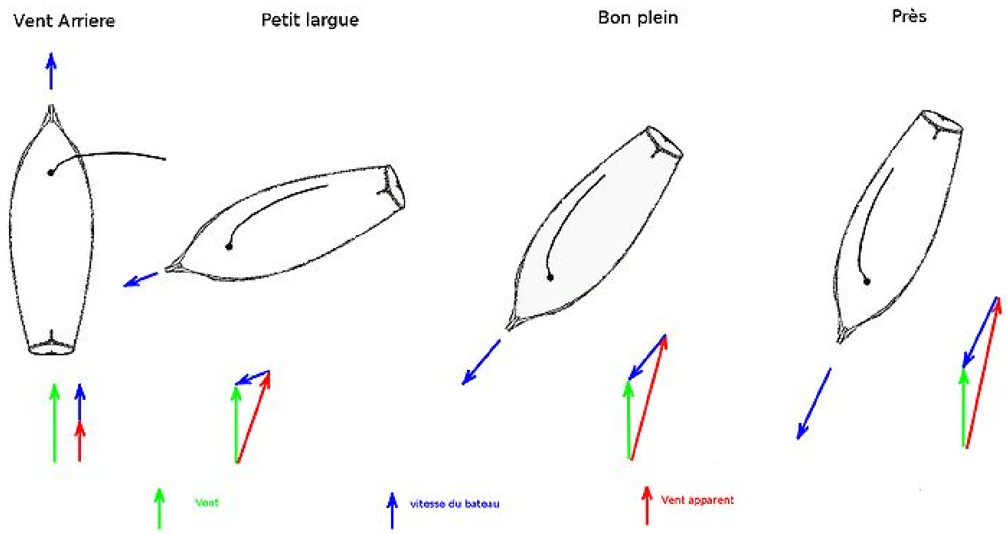


Diagram outlining the velocity vectors boat, wind and apparent wind following ways of boat

In case without lift, apparent wind direction is identical to the wind. If ship direction is identical to wind, all sailing effort contributes to the advancement of ship. Without lift of sail, ship can go faster than the wind, and propulsive force decreases gradually as ship approaches speed wind and effort down to zero.

In case with lift, sail has an impact with apparent wind. Apparent wind also forms an angle with the wind. Similarly, wind creates an angle to the direction taken by ship. Effort of sail does not contribute fully to the advancement of ship. With a ship in close hauled, hypothesis are :

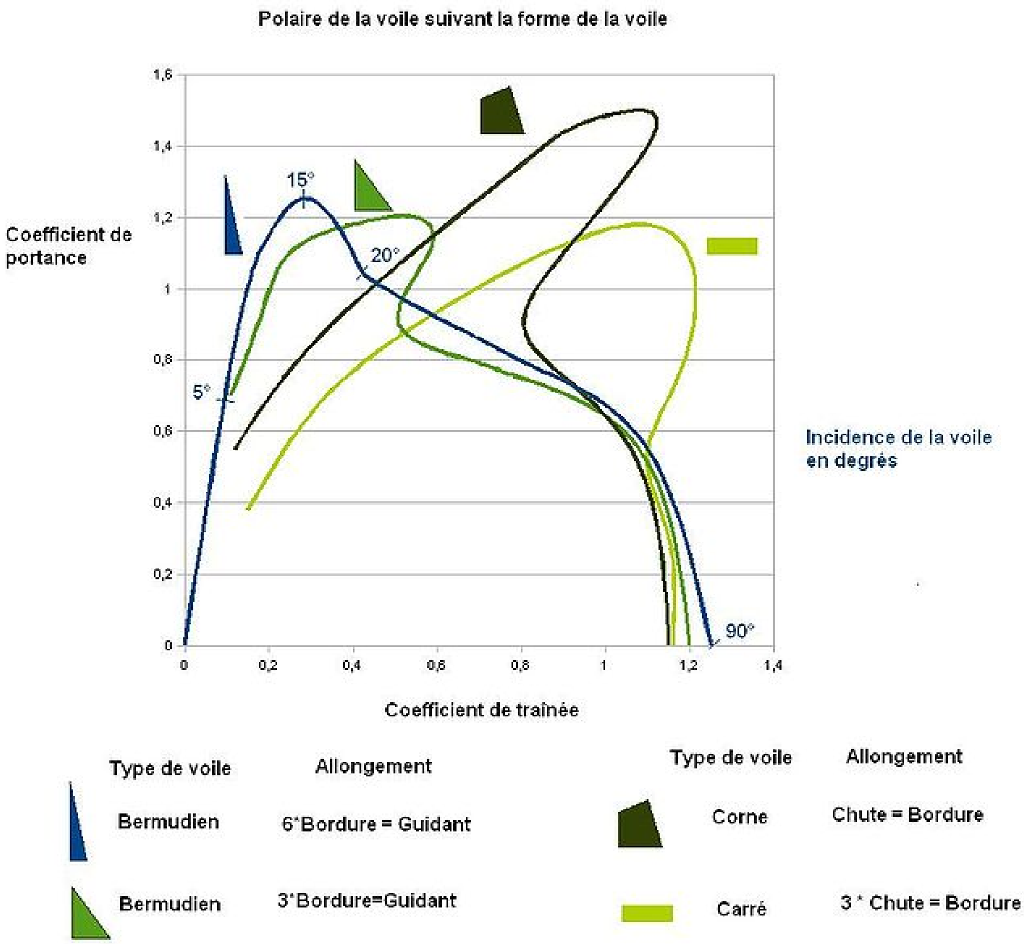
- Apparent wind angle / course of the ship 40° degrees
- Sailing with 20° incidence.

Lift does not participate fully in progress of vessel, it forms an angle of 40° is the propulsive force is more than 76% of its value. The remaining 36% is perpendicular to the vessel, and this effort generates the drift boat.

If the same sail with the same apparent wind speed, lift coefficient is 1.5 close hauled and 1 downwind. Part of effort involved for advancement of vessel remains above 15% cases without lift. Another advantage, more the boat accelerates more apparent wind increases, effort of sail increases. At each speed increase apparent wind direction moves, it must tunning the sail to be the optimum effect (maximum lift). More ship accelerates, more the angle "apparent wind / direction of ship" is closer, so sail thrust is less oriented towards course of ship, forcing a shift to be back in maximum thrust sailing conditions. The ship can go faster than the wind. The angle "ship and wind" can be quite small, consequently the ship may be close hauled to reaching. The ship goes back to the wind.

Another consequence, for same boat apparent wind speed close hauled is much higher than downwind. Consequently the gain of close hauled well over 15% of sailing downwind.

Evolution of lift coefficient following incidence: polar sail



Graph showing the relationship between lift and dragged for a sail. This type of chart is known as "Polar sail.

The lift coefficient of the sail varies with angle of incidence. Coefficient is often divided into two components:

- The component perpendicular to the apparent wind is called lift;
- The component parallel to the apparent wind is called drag.

For each incidence angle matches a single pair of lift-drag. Sailmakers provides an evolution of the drag and lift in a graph called a polar sailing.

Behavior of the sail due to incidence (angle: apparent wind / sail) is:

- The sail is free, equivalent to have no sail, it does lift and drag null;
- Sailing is perpendicular to the wind, the movement is turbulent. This is the case no lift and maximum drag;
- It is the intermediate cases:
    - Sail free to maximum lift: the flow is attached, i.e. the wind glue airfoil. There are no eddies (dead zones) created on the sail. It is noted in case of a good sail (well regulated), maximum lift is greater than maximum drag;
    - Maximum lift to maximum dead zone: the wind does not stick properly to profile of the sail. Flow is less stable it becomes gradually lifted or taken off. This creates an area on leeward side, a dead zone which depress perform of sail. At typical angle, dead zone has invaded the whole face on leeward side.
    - The dead zone to maximum drag: Dead zone has invaded whole face on leeward side, only windward side have an effect. Air in these high incidence, is somewhat deviated from its trajectory, Air parcel are just crashing on all surface of windward side. Effort is almost constant, so the polar sailing describes an arc of a circle.

As the lift is more effective than drag to contribute to the advancement of ship, sail makers trying to increase the zone of lift, i.e. increase effort of lift and angle of incidence. Any knowledge of a sailmaker is to decrease size of dead zone at height incidence, i.e. in the control of the boundary layer.

Sail twist

The yacht *The Bluenose* in 1921. The photography shows the twist on sails properly trimmed, particularly on the mainsail.

The air moves primarily slices parallel to the ground, in our case sea. If air density can be regarded as constant for our calculations of effort, this is not the case of wind speed distribution, it will be different according to altitude. As at the sea surface, the difference of speed between air parcel and plots of water is zero, the speed of wind varies strongly in the first ten meters . This rapid increase of the wind speed with altitude, consequently, will also vary apparent wind. It follows that intensity and speed of wind vary widely when altitude is between 0 and 20 meters. In the case of using sails with lift, sail must be twisted to have a good incidence with apparent wind along the leading edge (luff) .

KW Ruggles gives a generally accepted formula for the evolution of the wind speed with altitude:

$$U = \frac{\mu'}{k} \, ln(\frac{z + z0}{z0})$$

With data collected by Rod Carr the parameters are:

- k = 0.42,
- z altitude in meters;
- z0 is an altitude that reflects the state of the sea, i.e. the wave height and speed:
    - 0.01 for 0-1 Beaufort;
    - 0.5 2-3 Beaufort
    - 5.0 to 4 Beaufort;
    - 20 5-6 Beaufort;
- μ'= 0335 related to viscosity of air;
- U m / s.

In practice, the twist must be adjusted to optimize the performance of the sail. The primary means of control is the boom for a sail Bermuda. More boom will be pulled down, less twist will be important.

Several sails: multidimensional problem resolution

A boat is rarely rigged with one sail. Previous method for estimating the thrust of each sail is no longer valid but it remains a good approximation.

Sails are often close to each other. They influence each other . In the case of a sloop-rigged sailboat, sail of bow (Genoa) changes air flow entering on mainsail. The genoa could blanket mainsail, as mainsail can prevent flow of air from Genoa to "get out".

Condition of a stable fluid constant and uniform, necessary for tables which gives lift coefficient is no longer respected.

Cumulative effect of several sails on a boat can be positive or negative. It is well known that the same total surface sail, two sails are properly set more effective than a single set correctly. Two sails can increase the thrust sailing 20%. Only a two-dimensional model explains the phenomenon.

Chapter- 13

Diesel-Electric Transmission

Diesel-electric transmission or **diesel-electric powertrain** is used by a number of vehicle and ship types for providing locomotion.

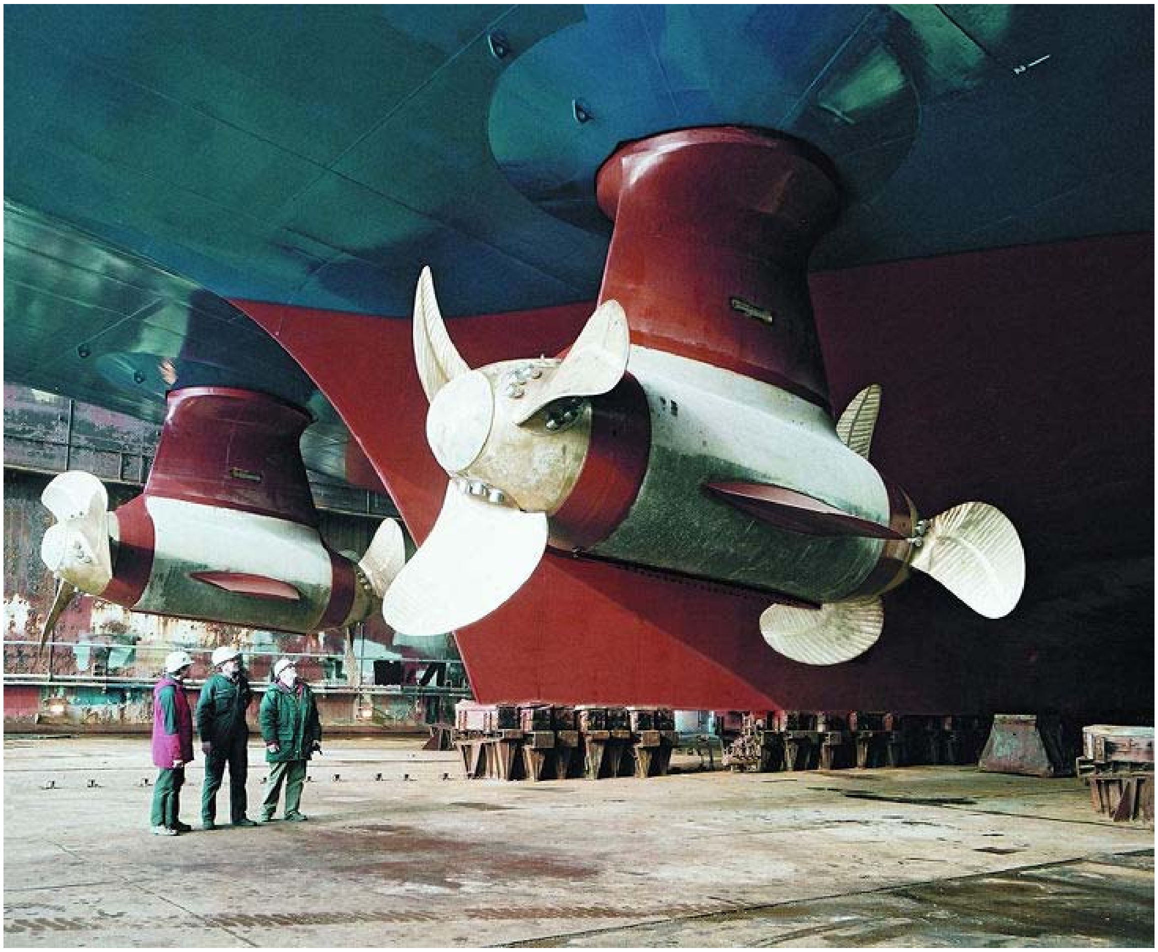
A diesel-electric transmission system includes a diesel engine connected to an electrical generator, creating electricity that powers electric traction motors. No clutch is required.

Before diesel engines came into widespread use, a similar system, using a petrol (gasoline) engine and called petrol-electric or gas-electric, was sometimes used.

This kind of power transmission is used on railways by diesel electric locomotives and diesel electric multiple units as only electric motors are able to supply full torque at 0 RPM. Diesel-electric systems are also used in submarines and surface ships and some land vehicles.

In some high-efficiency applications, electrical energy may be stored in rechargeable batteries, in which case these vehicles can be considered as a class of hybrid electric vehicle.

Ships



Siemens Schottel azimuth thrusters

The first diesel motorship was also the first diesel-electric ship, the Russian tanker *Vandal* from Branobel, which was launched in 1903. Steam turbine-electric propulsion has been in use since the 1920s (Tennessee class battleships), using diesel-electric powerplants in surface ships has increased lately. The Finnish coastal defence ship *Ilmarinen*, laid down in 1929, was among the first surface ships to use diesel-electric transmission. Later, the technology was used in diesel powered icebreakers.

Some modern ships, including cruise ships and icebreakers, use electric motors in pods called azimuth thrusters underneath to allow for 360° rotation, making the ships far more manoeuvrable.

Gas turbines are also used for electrical power generation and some ships use a combination: the *Queen Mary 2* has a set of diesel engines in the bottom of the ship plus two gas turbines mounted near the main funnel; all are used for generating electrical power, including that used to drive the propellers.

Submarines

Early submarines used a direct mechanical connection between the engine and propeller, switching between diesel engines for surface running, and electric motors for submerged propulsion.

True diesel-electric transmissions for submarines were first proposed by the United States Navy's Bureau of Engineering in 1928; instead of driving the propeller directly while running on the surface, the submarine's diesel would instead drive a generator which could either charge the submarine's batteries or drive the electric motor. This meant that motor speed was independent of the diesel engine's speed, and the diesel could run at an optimum and non-critical speed, while one or more of the diesel engines could be shut down for maintenance while the submarine continued to run using battery power. The concept was pioneered in 1929 in the S-class submarines *S-3*, *S-6*, and *S-7* to test the concept. No other navy adopted the system before 1945, though some submarines of the Imperial Japanese Navy used separate diesel generators for low speed running.

In a diesel-electric direct drive arrangement, the (usually single) propeller is driven directly by an electric motor, while two or more diesel-generators provide electric energy for charging the batteries and/or driving the electric motor. This mechanically isolates the noisy engine compartment from the outer pressure hull and reduces the acoustic signature of the submarine. Additionally some nuclear submarines also decouple their reactor room this way, having turbo-electric propulsion driven by reactor steam. Many submarines with diesel and electrical propulsion are mistakenly referred to as "diesel-electric" when they in fact have separately coupled diesel and electric engines.

Railways

In the 1920s, diesel-electric technology first saw limited use in switchers (or *shunters*), locomotives used for moving trains around in railroad yards and assembling and disassembling them. One of the first companies to offer "Oil-Electric" locomotives was the American Locomotive Company (ALCO). The ALCO HH series of diesel-electric switcher entered series production in 1931. In the 1930s, the system was adapted for streamliners, the fastest trains of their day. Diesel-electric powerplants became popular because they greatly simplified the way motive power was transmitted to the wheels and because they were both more efficient and had greatly reduced maintenance requirements. Direct-drive transmissions can become very complex, considering that a typical locomotive has four or more axles. Additionally, a direct-drive diesel locomotive would require an impractical number of gears to keep the engine within its powerband; coupling the diesel to a generator eliminates this problem. An alternative is to use a torque converter or fluid coupling in a direct drive system to replace the gearbox. Hydraulic transmissions are claimed to be somewhat more efficient than diesel-electric technology.

Road and other land vehicles

Trucks

Examples include:

- Large mining machines, such as the Liebherr T 282B dump truck or LeTourneau L-2350 wheel loader.
- NASA's huge Crawler-Transporters.
- Mitsubishi Fuso Canter Eco Hybrid commercial truck.
- International DuraStar Hybrid diesel-electric truck.
- Dodge is conducting fleet tests of a diesel-electric version of the Dodge Sprinter.

Cars

In the automobile industry, diesel engines in combination with electric transmissions and battery power are being proposed for vehicle drive systems - with some models in production. Examples include

- Citroën C-Cactus
- Zytek.
- Chevrolet Volt/Opel Flextreme
- The "Third-Millennium Cruiser" was an attempt to commercialize a diesel-electric automobile in the very early 1980s
- Ford Reflex is a diesel hybrid concept car.

Other land vehicles

Diesel-electric propulsion was tried on some military vehicles, such as tanks. Ferdinand Porsche was the main developer of such drive-trains for military vehicles in World War II Nazi Germany, and created the Elefant tank destroyer and the prototypes of the never-produced, 200-ton class Maus super-heavy tank.

Buses

Diesel electric based buses have also been produced, including hybrid systems able to run on and store electrical power in batteries. The two main providers of hybrid systems for diesel-electric transit buses include Allison Transmission and BAE Systems. New Flyer Industries, Gillig Corporation, and North American Bus Industries are major customers for the Allison EP hybrid systems, while Orion Bus Industries is a major customer for the BAE HybriDrive system. Mercedes-Benz makes their own diesel-electric drive system, which is used in their Citaro.