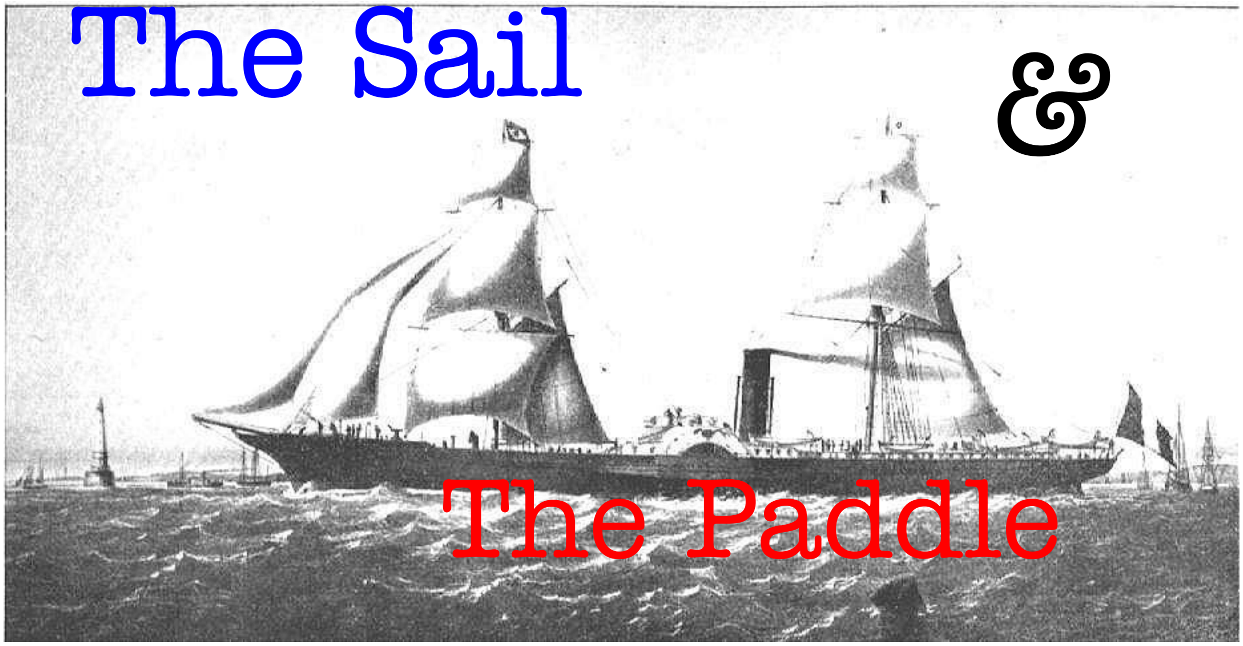
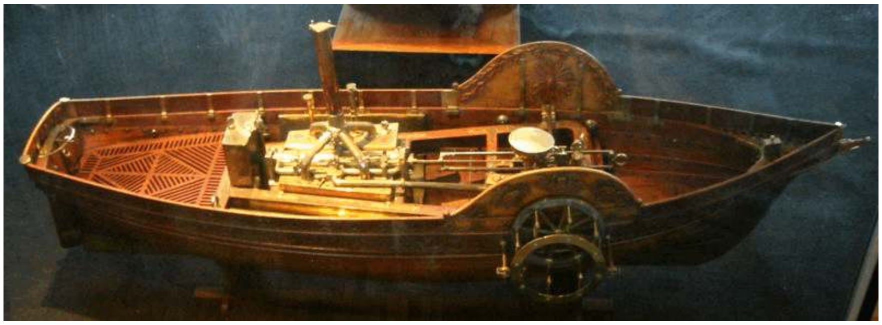


THE MECHANICAL REVOLUTION

The desire for some means of mechanical propulsion for ships is nearly as old as the use of sails for propulsion. The sail, particularly in the days before man had learned to brace the yards to the wind when it was ahead, always placed a limitation on the course that a vessel could steer. She could only sail a course which the wind direction allowed, which was not necessarily the most direct, and to reach her destination if the wind headed her might mean sailing three, or even four, times as far as the straight course. And if her course took her across the equator she might lie motionless for days in the doldrums, without a breath of wind to fill her sails.

The Romans are said to have invented a form of paddlewheel, operated manually by means of a crank, but they discovered, not surprisingly, that rowers with oars were more efficient. During the Middle Ages the Chinese are supposed to have built a junk with paddlewheels attached to the keel and driven by slaves on a treadmill, but this, too, appears to have been a failure, since the invention was not followed up. What was needed - and the innovators soon recognised it - was some means of turning the paddlewheel other than by manpower. In 1685 a French inventor put forward the theory that air pressure would force a piston down a cylinder if a vacuum could be created below it, and that the resultant power could be used to turn a paddlewheel. The vacuum was to be formed by condensing steam injected beneath the piston. Twenty-seven years later, in 1712, this idea was, in fact, to be the basis of the first working steam engine, built by Thomas Newcomen, but even this had no application to ships because it proved impossible to generate enough power to drive a paddlewheel.

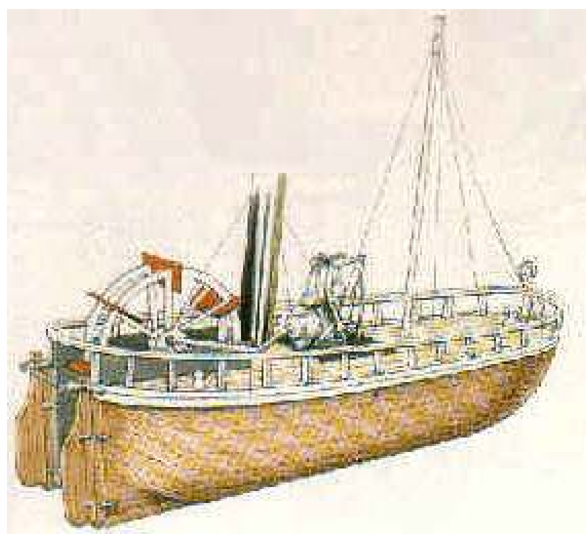
The first breakthrough came in 1765 when James Watt, in an attempt to eradicate the chronic inefficiencies of Newcomen's engine, invented the condenser and made the cylinder double-acting, by admitting steam both above and below the cylinder. Here, at last, was a steam engine which developed reasonable power and , with the further invention of a centrifugal governor, power at a constant speed. This was what was needed if mechanical power was to replace the sail. In 1768 Watt went into partnership with Matthew Boulton, who had an engineering workshop in Birmingham, and it was Boulton and Watt engines which powered most of the world's first steamships.

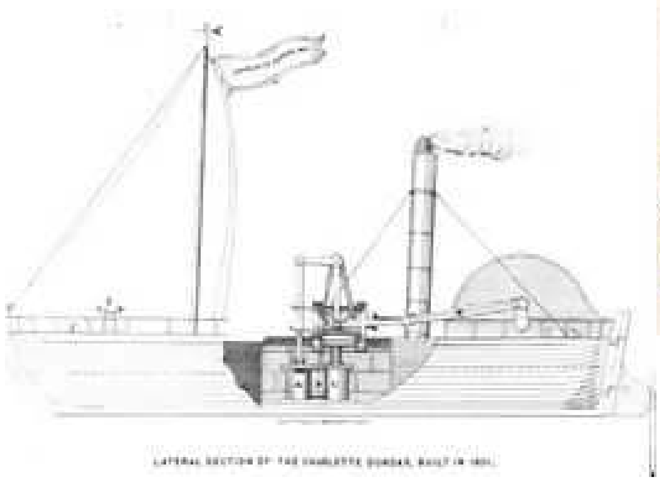


Pyroscaphe

Strictly speaking, the worlds first steam vessel was the *Pyroscaphe*, a large clinker-built boat with an engine which turned a pair of small paddlewheels. It was invented by the Marquis Claude de Jouffroy d'Addans, and in 1783 was tried out on the River Saone in France. The engine worked for 15 minutes before breaking down, and during that time the *Pyroscaphe* moved forward through the water under power. It would be equally correct to say that the second steam vessel in the world was the John Fitch, a small barge-like hull with an engine which operated, through linking beams, six vertical oars on each side. This vessel, named after its inventor, made a short trip on the River Delaware in the United States in 1786. However, since neither of these two was reliable enough to prove that steam was a viable method of propulsion for ships, it was left to a later vessel to demonstrate the steamship's potential.

The vessel which really inaugurated the era of the steamship was the *Charlotte Dundas,* which made her first voyage in March 1802. She was built on the River Clyde in Scotland to the order of Lord Dundas, a governor of the Forth and Clyde Canal, and he named her after his daughter.





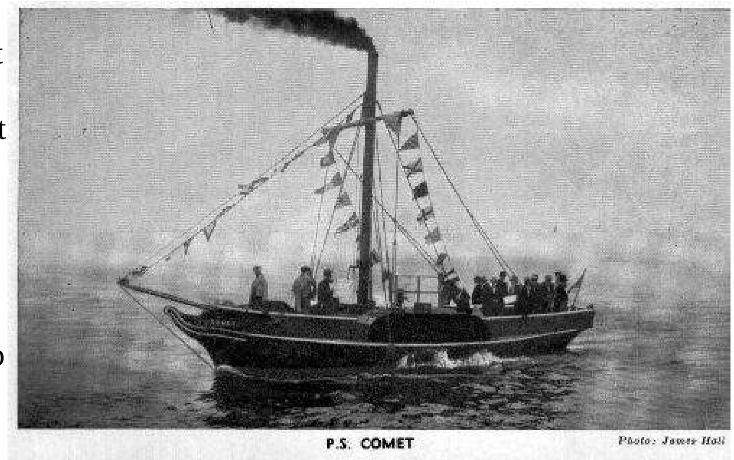
She was a wooden vessel 58 ft. long, with a beam of 18 ft. and a draught of 8 ft., with a single tall funnel amidships. Lord Dundas wanted her to replace the horses which towed the barges un and down the canal, and he gave the order for her to William Symington, an engineer with a workshop on the Clyde. She had a single paddlewheel at the stern, driven by a single-cylinder steam engine which developed about 12 horsepower. On her first voyage she towed two 70-ton barges up the canal for a distance of 20 miles at a speed of over 3 knots, which would have been higher but for a strong headwind. She ran steadily up and down the canal towing barges for three or four weeks, but was then taken out of service as it was feared that the wash from her paddlewheel would cause the banks to fall in.

With the *Charlotte Dundas* proving that a steam-driven ship was a commercial proposition, the race for steam propulsion was on. Robert Fulton, an American inventor who had lived in Paris, and who was involved in the birth of the submarines, was the next on board the *Charlotte Dundas* during one of her canal trips, and decided to attempt a similar feat on the River Seine in Paris. His first attempts were a failure, as the wooden hull which he constructed was not strong enough to take the weight of the engine and boiler. It broke in two and sank. Undeterred, Fulton built a stronger hull, recovered his engine from the bottom of the Seine, and in August 1803 gave a demonstration by towing two boats upriver for an hour and a half.

Convinced that the steamship had a commercial future, Fulton returned to the United States and , in co-operation with a financier named Robert Livingston, who lived at Clermont, built a wooden hull, with a length of 133 ft. and a displacement of 100 tons, on the East Hudson River. As there were no engineers in the United States with sufficient experience of building steam engines he sent over to Britain, to Boulton and Watt, for an engine to be shipped across the Atlantic. The engine had a single vertical cylinder, 24 in. in diameter, with a stroke of 48 in. and, through bell cranks and spur gearing, drove two 15-ft. paddlewheels, one on each side of the hull. She was named *Clermont*, after Livingston's home town, and on her maiden voyage in 1807 she covered approximately 240 miles by steaming to Albany and back in 62 hours, as an average speed over the whole distance of 3.9 knots, though her best speed was 4.7 knots. She continued in commercial service on the East Hudson River for two seasons, eventually proving too small for the crowds that thronged the landing stages to take a passage in her. She was so successful commercially that Fulton built a second steam vessel, which he named the *Phoenix* to operated similarly on the Delaware River. Since she was built at Hoboken and had to steam down the coast of New Jersey to reach the Delaware, she can claim to be the first steamship to make a voyage in the open sea, though she hugged the coastline the whole way.

The "Clermont" New York Sept. 25, 1909

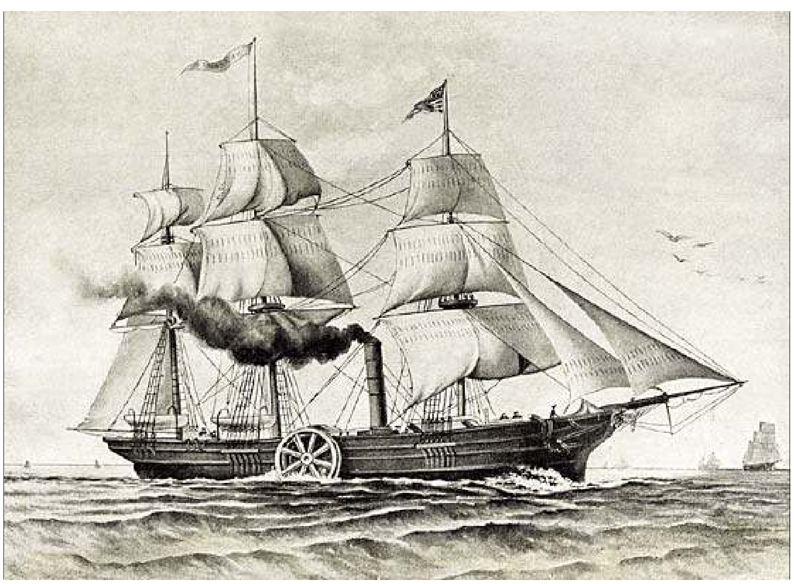
The financial success of the river steamers in the United States inspired a Scottish engineer, Henry Bell, to enter the steamship business. He built the *Comet* at Glasgow in 1812 for a ferry service on the Clyde between Glasgow, Greenock, and Helensburgh, which proved so successful that he extended it up the west coast of Scotland to Oban and Fort William, 200 miles away. The *Comet* was smaller than Fulton's *Clermont*, but her engine produced a better average speed of 6.7 knots. Two years later Henry Bell had five similar ferries running services on the River Thames from London as far down as Margate. The biggest ferry of this early steamship period was the *James Watt*, operating a coastal service between London and Leth. She had an overall length of 141 ft. 10 in. and a maximum beam over her paddle-boxes of 47 ft. Each paddlewheel was 18 ft. in diameter.



Henry Bell's 'Comet'

By 1816 a steamship passenger service was in operation across the English Channel between Brighton and Le Havre, and in 1820 a service between London and Paris was opened with the *Aaron Manby*. She had an engine designed by Henry Bell which gave her an average speed of between eight and nine knots. After a few regular passenger trips she was purchased by a syndicate of French shipowners and used for pleasure trips up and down the River Seine.

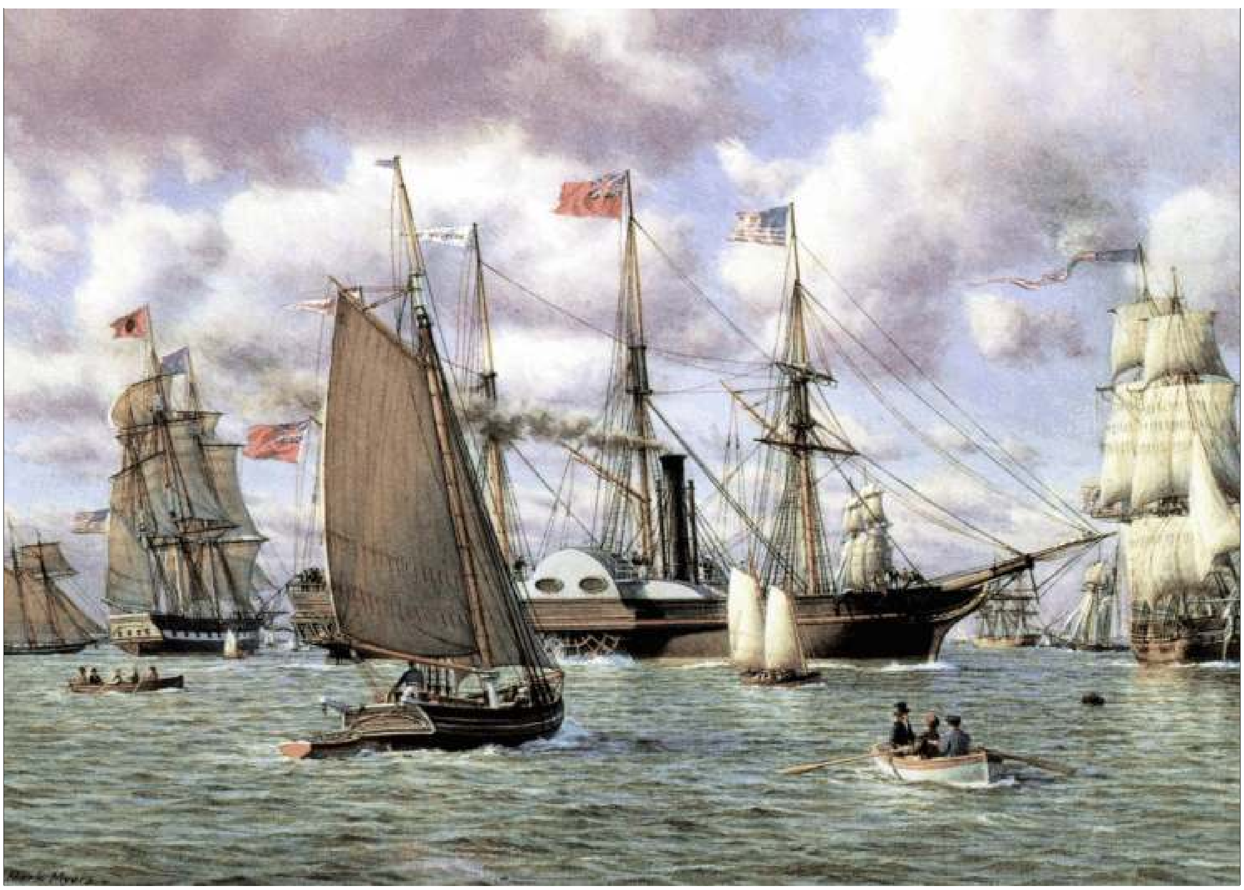
All these vessels were, of course, relatively small; all had paddlewheels driven by single cylinder engines (occasionally, as in the *James Watt*, with one cylinder to each paddlewheel); and all were used only for river or coastal passages. But they opened the way to more ambitious steamship operations, across the oceans, with bigger ships and greater horsepower. In fact, by the year in which the *Aaron Manby* made her passage from London to Paris, the Atlantic had already been crossed by a ship with a steam engine, though she did not really rank as a steamship. This was the American *Savannah*, a full-rigged ship with an auxiliary engine and detachable paddlewheels. She crossed the Atlantic in 1819 from Savannah to Liverpool in 21 days, but used her engine for only 8 hours during the passage. A similar voyage, and much more noteworthy because steam propulsion was used to a significant extent, was made in 1825 by the Enterprise, a ship of 470 tons, which made a passage of 11, 450 miles in 103 days from London to Calcutta. She was still primarily a sailing ship, but used her engine on sixty-four days of the 103.


The "Savannah" first steamship to cross the Atlantic.

The great problem still facing marine engineers and designers was the accommodation of sufficient coal on board to feed the boiler throughout a long ocean passage. By the 1830's the steam engine itself, still a single-cylinder reciprocation engine, was reliable enough to be used for ocean passages, but in general, the ships themselves were still too small to accommodate the amount of coal required and still to provide sufficient space for passengers or cargo to make the ship commercially viable.

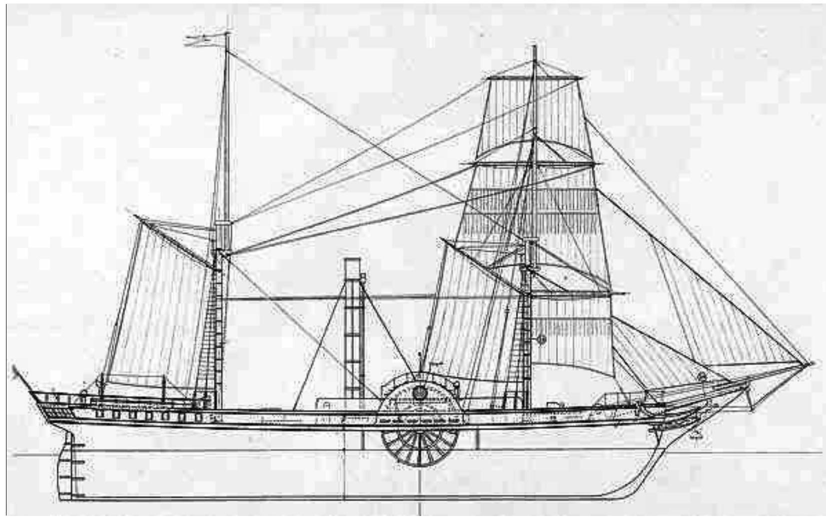
The answer to this particular problem was, of course, one of ship design, and it was finally solved in a somewhat dramatic fashion. The directors of the Great Western Railway Company in Britain decided in 1837 to extend their railway line to Bristol and called in for consultation their company engineer, Isambard Kingdom Brunel. At the meeting one of the directors complained that the line, when extended to Bristol, would be too long, whereupon Brunel said he thought it would be far too short and ought to be extended to New York by building a passenger steamship. The idea was discussed, approved, and as a result Brunel was told to go ahead and build an Atlantic liner, to be named the *Great Western*.

There was at the time a steamship company in existence called the British and American Steam Navigation Company, and as soon as it was learned that the Great Western Railway were building a steamship specially for an Atlantic crossing, they decided that they would beat them to it. It was known that the *Great Western* was to be a ship of 1,340 tons with an engine developing 750 horsepower, and the British and American company placed an order for a larger ship, to be called the *British Queen*.



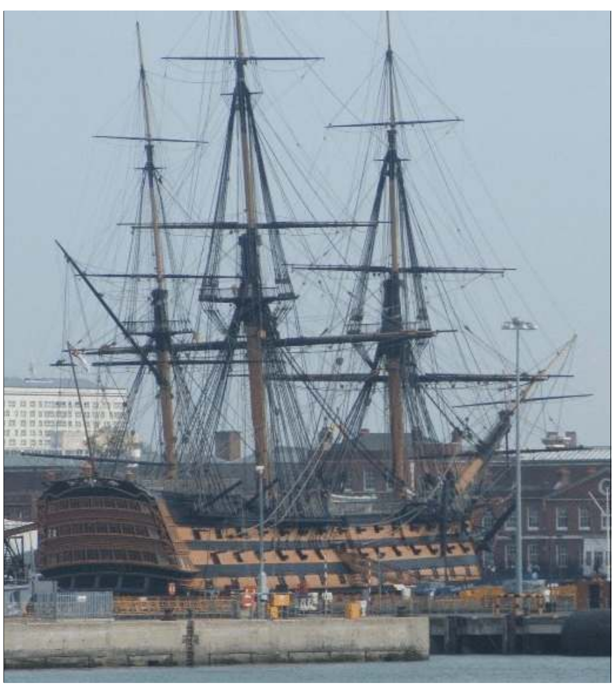
The “Great Western”

There were many delays in her building, and before long it became apparent that the *British Queen* would not be ready before the *Great Western*. British and American, therefore, looked round for a ship to charter, and chose the *Sirius*, built for passenger and cargo service between London and Cork. She was a ship of 700 tons with an engine developing 320 horsepower, and in the race across the Atlantic she was the first away, leaving Cork on 4 April 1838 with 40 passengers on board. Every available space below decks was packed with coal, and she carried two large heaps of it on the upper deck as well. Out in the Atlantic she ran into a severe storm which slowed her up and entailed the use of more coal than had been planned. As a result she ran out of coal before she could complete her crossing, but, by feeding the furnace with all the cabin furniture, the wooden doors throughout the ship, all her spare yards and one of her masts, she reached New York. She was greeted by an immense throng of cheering people eager to greet the first ship in the world to make an ocean crossing entirely under steam power. She had taken 18 days, 10 hours and her average speed for the whole voyage was 6.7 knots.



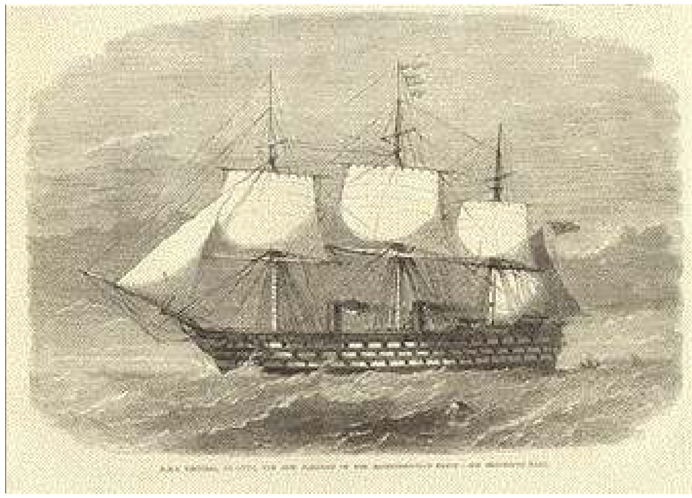
The “Sirius”

She was followed into New York a few hours later by the *Great Western*. The latter had left Bristol four days later than the *Sirius*, carrying only seven passengers, and her time across the Atlantic was 15 days, 5 hours, giving her an average speed of 8.8 knots. What was far more important, however, was the fact that when she arrived in New York she still had 200 tons of coal in her bunkers - proof that, with a proper allowance of bunker space in their design, trans-ocean passages were will within the capability of the new steamships.



HMS Victory

By the middle of the nineteenth century the wooden ship had reached her maximum size, with tonnage approaching 7,000 on waterline lengths of about 340 ft. these huge wooden ships, built only as warships, drew so much water that they could not be used inshore for the classic naval operations of close blockage and bombardment, required immense crews to man them, and were popular only with commanders-in-chief afloat, who found superb personal accommodation in the immense cabins aft. One such ship was the last three-decker of the British navy, H.M.S. *Victory*, launched in 1859. In her, the wooden hull had been taken to the limit, and there was not enough strength in wood to extend any further, or to support the huge array of masts and yards required to drive so large an object through the water.



HMS Victory with 102 guns.

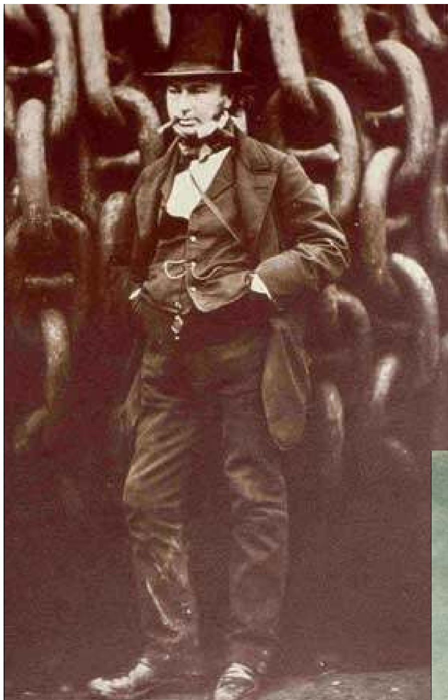
Some other shipbuilding material was obviously necessary, if ships were to develop beyond the limitations imposed by wood, and the only obvious alternative was iron. In the late eighteenth century an iron lighter had been constructed on the Thames, and confounded the sceptics when she did not sink. Nonetheless, there were far more doubters than believers, and resistance to the new material was considerable, even in the face of demonstrable success.

The first true ship to be built with an iron hull was the *Aaron Manby*, the first steamship to operate a service between London and Paris. She was relatively small vessel of 116 tons, and in spite of many gloomy prognostications, she lasted until 1855, when finally she became unsafe through the rusting of her plates. She was followed by a few other iron-hulled vessels, but they were all small and another twenty years were to pass before reluctant shipowners could be convinced that iron had so many advantages over wood that it was worth adopting for large ships as well as small.

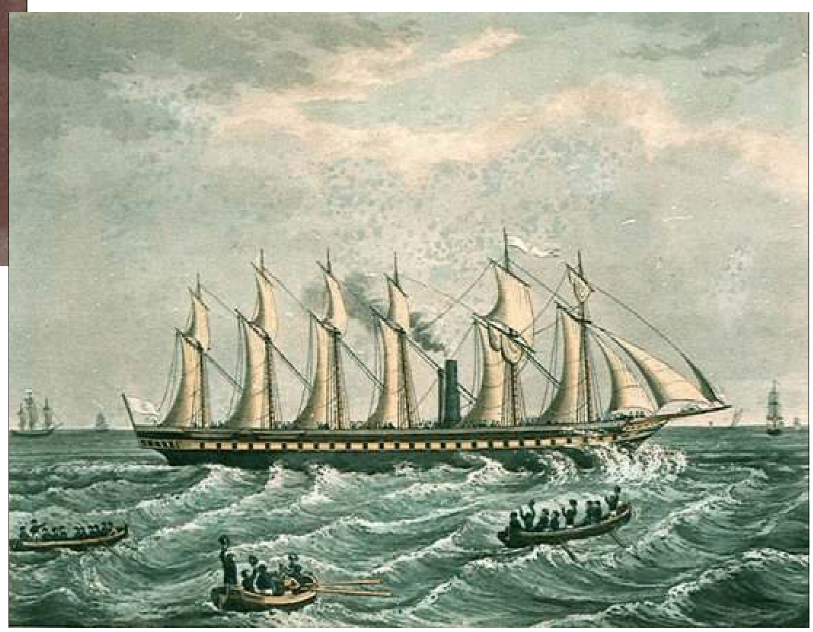
Apart from the obvious fears that iron, because it is heavier than water, was an unsuitable material for shipbuilding, there were other reasons for the delay in its adoption. The science of engineering had yet to perfect a method of bending iron to a desired shape, and the only methods available at the beginning of the nineteenth century were casting in a mould or working when red hot by hammering. These methods frequently led to fractures because of the uneven quality of the iron. There was no knowledge as yet of any means to prevent rusting, which was accelerated by contact with seawater, and it was also quickly discovered that encrustation of the bottom by barnacles and weed occurred considerable faster on an iron hull than on a wooden one. And finally there was the effect of the iron hull on the magnetic compass. So great a mass of magnetic material was certain to throw a compass out, and as yet there was insufficient scientific knowledge of the behavior of compasses to provide an antidote.

Yet the advantages of iron were so obvious that many shipbuilders did not share the conservative views of shipowners, and devised a means of incorporating it in a wooden hull in what was known as ‘composite’ building. One of the great drawbacks of the standard wooden hull was the massive framing needed to provide adequate longitudinal and athwartships strength. This framing was a great source of unnecessary weight in a ship. The composite ship had an inner framework consisting of iron keelson, frames, knees and deck beams to which the outer wooden planking, keel and decks were secured, thus providing not only a considerable saving in weight, but also a big increase in stowage space through the elimination of the thick wooden framing. It was a compromise that lasted only until shipowners at last overcame their reluctance, and went all-out for the iron ship.

The first sign of a decline in the continued dominance of wood for large ships came in 1838, with the building of the 400-ton iron ship *Rainbow* for trade between London, Ramsgate and Antwerp. Her immediate advantage was that she could stow in her holds nearly twice as much cargo as a wooden-hulled ship of the same size, and she proved herself to be a good ship at sea, safe and easy to handle. And with her iron hull she was not subject to the perpetual small leaks endemic in all wooden vessels due to the working of the hull planking. But the final seal of approval was set in the following year, when Isambard Brunel persuaded the directors of the Great Western Railway Company to follow up their successful *Great Western* with an even larger ship, to have an iron hull. This was the *Great Britain*, and he keel was laid at Patterson's shipbuilding yard at Bristol in 1838.



Isambard Brunel

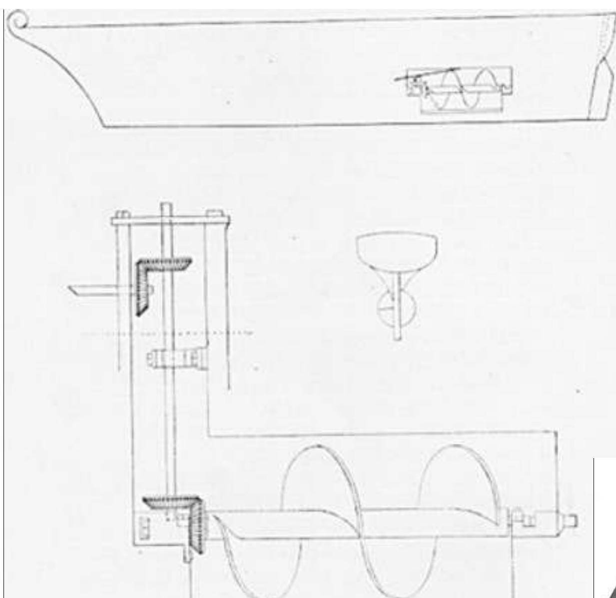


SS Great Britain

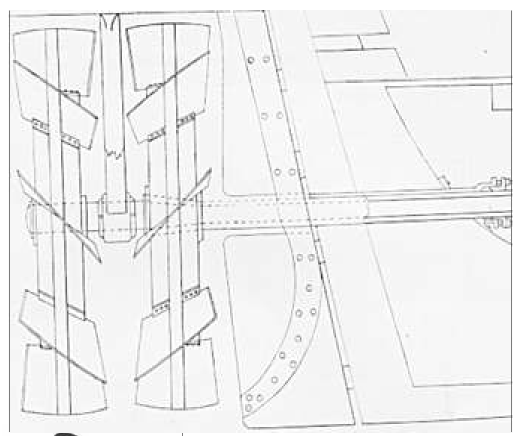
With the *Great Britain*, Brunel showed all the contemporary naval architects how to design their ships in metal and how to use the new material to provide enough hull strength for ships of rapidly increasing size. In the *Great Britain* he stipulated an iron keel of great strength, nearly 1 in. Thick and 21 in wide, and her hull plating varied in thickness between 3/8 in and 3/4 in. The plates were riveted to frames made of angle iron, and longitudinal hull strength was provided by two fore-and-aft bulkheads carried up to the level of the main deck, and athwartships strength of five bulkheads across the whole width of the ship. These athwartships bulkheads were made watertight so that the hull was divided into six watertight compartments, as an additional safety measure.

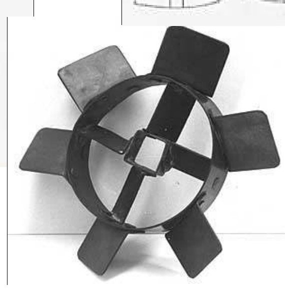
Only in warships was the use of iron delayed, for test carried out at Portsmouth in England had shown that, while a cannon ball fired at short range at iron plating 3/4 in thick had no difficulty in penetrating it, 8in of oak would stop it. And, as the average thickness of a wooden warships hull planking was 18in, the advantages of retaining wood for warships was obvious. Moreover, wrought and cast iron, the only known methods at the time of bending iron to the desired shapes, showed a tendency to crack or shatter under gunfire - a fatal flaw in a warship, forces were at work which would compel navies to make the change, particularly the development of the gun from a short-barrelled weapon discharging a solid ball at a relatively short range to a longer-barrelled piece firing an explosive shell over greater distances. But the day for this transition had not yet arrived, and until it did, the wooden warship remained in many ways just a larger version of the warship of 200 years earlier.

All these early steamships, whether with wooden or iron hulls, were driven through the water by paddlewheels, either a single one at the stern, as in the *Charlotte Dundas*, or by a pair of wheels, one on each side of the ship. There were considerable disadvantages in the use of paddlewheels, the principal one being that when a ship rolled in a seaway, each paddle-wheel (if she had two), would alternately be lifted out of the water, putting a tremendous strain on the engine. And, as they projected outside the hull of the ship, they were easily damaged by careless handling or by other accidents. For warships they were largely useless, since a single hit on a paddlewheel would at once cripple the ship. It was these obvious disadvantages which led several inventors to try to devise a means of ship propulsion which would be permanently submerged, and thus capable of driving the ship without putting a varying strain on the engine or providing an easy target for an enemy gun.



Archimedes screw





Above & left: Ericsson's propeller.

The principle of the Archimedes screw was well known, and it was an adaptation of this principle which finally produced the answer. A very early attempt to produce a marine propeller was John Shorter's invention of 1800, but it suffered from a clumsy form of chain drive and a very long shaft which required a buoy at the end to support it in the water. Four engineers are usually credited with the invention of the ship's propeller, the Englishman Robert Wilson, the Frenchman Frederic Sauvage, the Swede John Ericsson, and another Englishman Francis Pettit Smith. They all took out patents for their inventions between 1833 and 1836. It was Francis Smith's propeller which was at first most widely used by shipowners, though an improved design patented by Ericsson in 1818 was the final winner, when he demonstrated its efficiency in a small steamer aptly named the *Archimedes*.

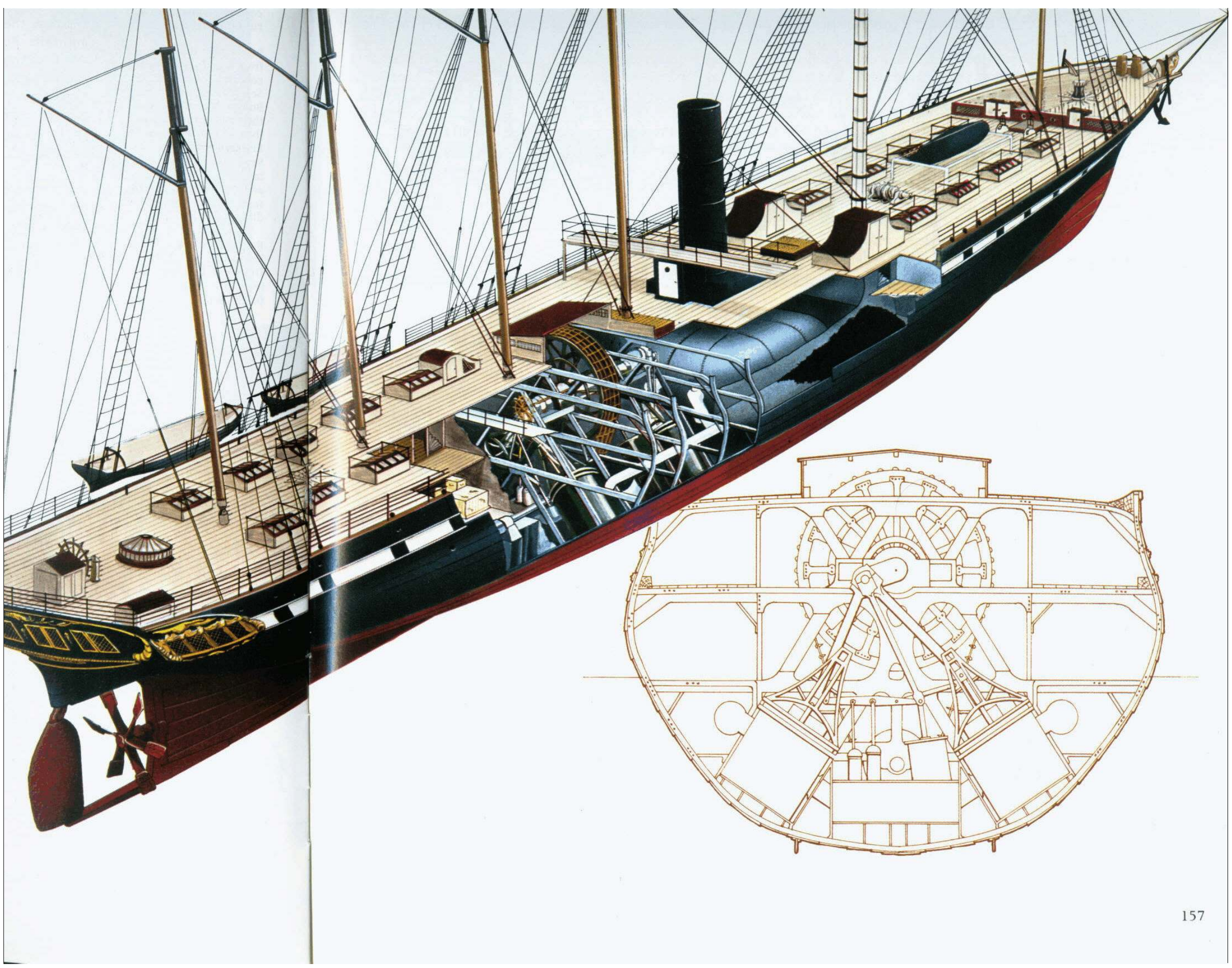
Isambard Brunel, who had laid the keel of his Great Britain in 1839, had designed his ship for propulsion by paddlewheels, but he attended the trials of Ericsson's propeller on the Archimedes and was quickly convinced of its superiority as a means of ship propulsion. The building of the Great Britain was stopped while Brunel prepared new plans and began a series of experiments on various models of propellers to find the one most suited to his ship. The Great Britain was a large ship for her day, displacing 3,620 tons, on an overall length of 322 ft. and a maximum beam of 50 ft. 6 in. As a result of his experiments, Brunel gave her four engines, developing 1,500 horsepower, which drove a six-bladed propeller of 16 ft. diameter at 53 revolutions per minute. Steam from the boilers was fed to the engines at a pressure of 15 lb/sq in.

Like all steamships of her time, except for the smallest, the *Great Britain* was fitted with masts and sails. By 1840's the steam engine had proved itself on thousands of voyages, long and short, but in general most shipowners, and almost all passengers, felt less happy than engineers about trusting their ships and themselves entirely to mechanical propulsion. So sail was carried, mainly as an insurance against breakdown. The *Great Britain* could spread 15,000 square feet of canvas on six masts, but although she crossed and re-crossed the Atlantic many times during her service as a passenger ship, only once did she have to rely on her sails to complete a passage, when her propeller dropped off in mid-ocean.

The "Great Britain" lies on the rocks in Dundrum Bay.

If there were still any who doubted the superiority of iron over wood as a shipbuilding material, the *Great Britain* put their anxieties to rest. In September 1846 she ran aground on the rocky coast of Ireland at Dundrum Bay, due it is said to excessive deviation of her compass caused by the iron in the hull. She went ashore at the top of spring tides, and it was not until six months later that there was another tide high enough to float her off. All through the winter she lay on the rocks, battered by the winter gales, conditions which would have reduced any wooden ship to matchwood. When she was refloated and docked, it was discovered that her hull was hardly strained at all.

To avoid some of the loss caused by having her off the Atlantic service for so long, the Great Western Railway Company sold the *Great Britain*. Her new owners refitted her with smaller and more economical engines, and until 1886 she operated steadily between Liverpool and Australia. During that year she was damaged in a heavy storm off Cape Horn and was towed to the Falkland Islands and grounded in Port Stanley, to act as a coal hulk. Finally, in 1970, enough money was raised in Britain to salvage her and bring her home to Bristol, where she is preserved to this day as a monument to the genius of her brilliant designer.



The "Great Britain" seen here when first built. The cross section and cutaway show two of her 88-in cylinders and the chain drive to the propeller shaft. She had a crew of 130, could carry 600 tons of cargo, Passenger capacity 252.