THE NAVY'S INDUSTRIAL REVOLUTION 1815–1860

BY

D. K. BROWN, M.ENG., C.ENG., F.R.I.N.A., R.C.N.C.

ABSTRACT

During this short span of only 45 years the wooden sailing ship grew dramatically in size and gunpower, and the steam engine made its appearance, at first driving the clumsy paddle wheel and later the screw propeller. Iron hulls were tried, found to have real problems and then reappeared, coated with armour. Guns grew in size due to better metallurgy and were able to fire explosive and incendiary shells.

And books still describe 'The Admiralty' of the period as reactionary!

Seppings and Structural Design

The traditional wooden ship would flex considerably in a seaway; Morgan's measurements in 1827 showed that a wooden frigate bent 1½ inches either way as she tacked. As the ship worked, water would get into the seams which would start to rot, further weakening the structure. The longitudinal distribution of weight and buoyancy caused the ends to droop—hogging—even though both bow and stern were far fuller than desirable for good hydrodynamics.

The problem was lack of shear strength in the sides, since the forces between adjacent planks was resisted only by friction in the caulking. The solution came from Robert Seppings, who drew an analogy with a five bar gate without the diagonal.

Seppings[1], born in 1827, the son of a cattle dealer, was apprenticed to Henslow, the Master Shipwright of Plymouth Dock and later Surveyor of the Navy. Seppings rose rapidly, becoming Master Shipwright of Chatham in 1805. Soon afterwards, he persuaded the Board to fit his scheme of diagonal bracing (FIG. 1) during the major refits of two ships.

After the initial success of the scheme in the *Tremendous*, John Barrow, the progressive and influential Second Secretary, called a meeting of eminent scientists to consider Seppings's proposal in November 1811. The Board called in the mathematician, Young (of modulus fame), to review Seppings's proposal which seems a wise precaution for such a novel approach though whether they could understand Young's tortuous mathematics remains open to doubt. News of the meeting reached Napoleon five days later and he brought in his mathematician, Dupin, for another review.

Developments were rapid; by 1813 Seppings was promoted to Surveyor and all new designs were to his style. His full scheme included a number of other improvements to strengthen the hull and to permit the use of shorter pieces of timber as long compass timbers were in short supply. Seppings then

TABLE I—*Increased size of battleships made possible by iron diagonal bracing*

	Victory	*Victoria*
Date of launch	1765	1855
Displacement (tons)	3500	6959
Length (ft)	186	260
Guns	100	121
Weight of a double broadside (lb)	1182	2372

developed a modified scheme for frigates in which the diagonals were of iron. Later designers such as Edye and Lang adopted iron diagonals for battleships which made possible a very great increase in size (see TABLE I).

Seppings's work was a success for the Admiralty system, as in his papers he argued scientifically, identifying the loading and arranging his structural members to accept these loads. His work is too often denigrated by those who confuse mathematics with science. His last paper to the Royal Society discussed the application of his structural style to merchant ships. Though Brunel adopted it in the *Great Western* this seems to have been almost the only application.

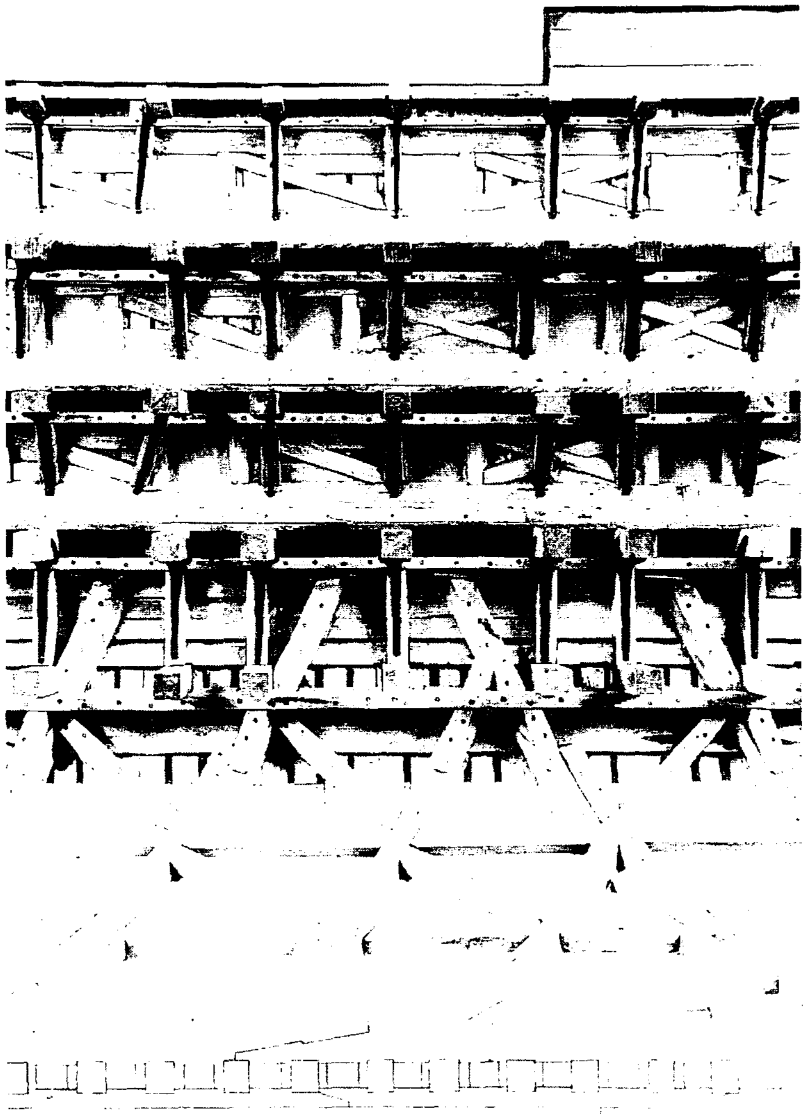

FIG. 1—A SCIENCE MUSEUM MODEL SHOWING SEPPINGS'S DIAGONAL FRAMING APPLIED TO A THREE-DECKER

The School of Naval Architecture

In 1791, a bookseller named Sewell came to believe that Britain was far behind France in the science of ship design and started a 'Society for the Improvement of Naval Architecture' as described by John Fincham, Master Shipwright, lecturer and a successful ship designer.[2] This soon attracted some 300 members, published many valuable papers and sponsored some interesting research. One of the most influential members was Admiral Middleton who, as Lord Barham, became First Lord in 1803.

Barham must have noticed that few, if any, Admiralty designers had belonged to the Society and decided that better educated men were needed. As a result, the School of Naval Architecture was set up in Portsmouth in 1811 with a number of novel features. For a start, admission was by competitive examination, by far the earliest such scheme in the Civil Service. The course was a demanding seven years with roughly half of each six-day week spent on theory and the other half on practical studies during which the students were encouraged to suggest better ways of carrying out the traditional shipwrights' tasks. Most of them spent some time at sea during the last year.

The School was very unpopular with some of the older Master Shipwrights as they realized that the young graduates were intended to supplant them. Naval officers were also opposed, seeing the new men as 'no gentlemen' and regarding sea experience as the prime necessity for a designer. Due to these pressures, the School was closed in an economy drive in 1832 after only 30 men had graduated. They were to supply many of the leaders of the Navy's industrial revolution.

During the 1820s and 1830s the Board devoted much time and effort to elaborate 'experimental sailing' or races in which different designers were allowed to challenge the establishment. While nothing of value came from these trials since there were too many variables and skill in sailing swamped any effect of hull form, it was another demonstration of the determination of successive Boards to improve the material state of the Navy. Seppings's introduction of the round bow and stern strengthened the ship against raking fire and permitted more guns capable of end-on fire.

Steam

The first, unsuccessful, attempt at a steam warship for the Royal Navy was in 1793 when the Earl of Stanhope built the *Kent* as a private venture. She had a Watt engine driving feathering paddles, *not* wheels.[3] During the wars two steam-operated but non-self-propelled dredgers were built for the Dockyards. The next attempt, proposed by Rennie and backed by Barrow in 1816—the *Congo* for exploring the river of that name—was another failure.

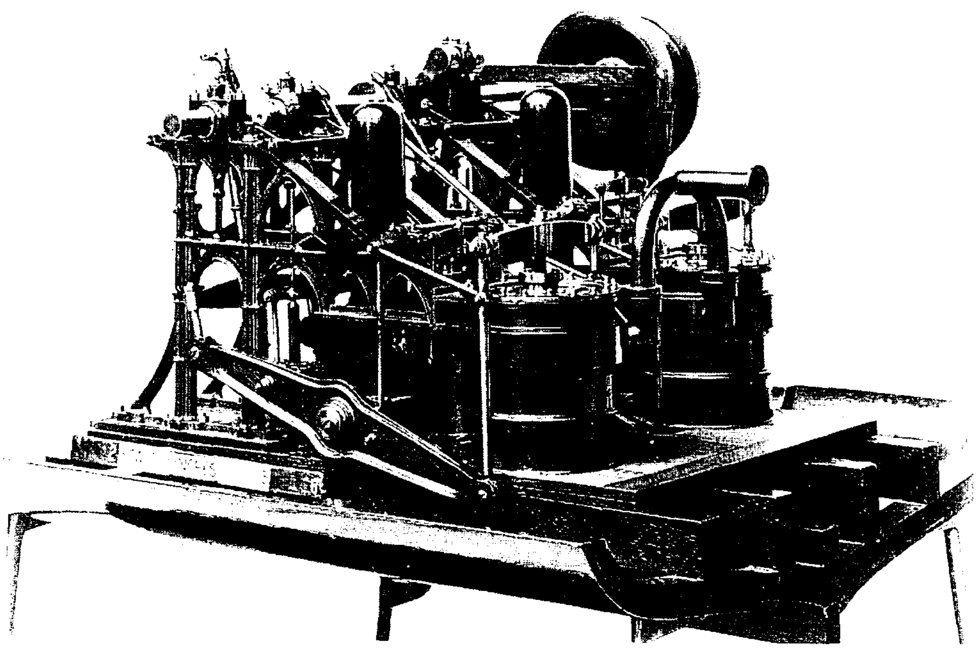

FIG. 2—THE SIDE LEVER ENGINE OF 'DEE', 1831. NOTE THE GOTHIC FRAMEWORK, INTRODUCED BY MARC BRUNEL. THIS MODEL WAS PROBABLY MADE BY HENRY MAUDSLAY

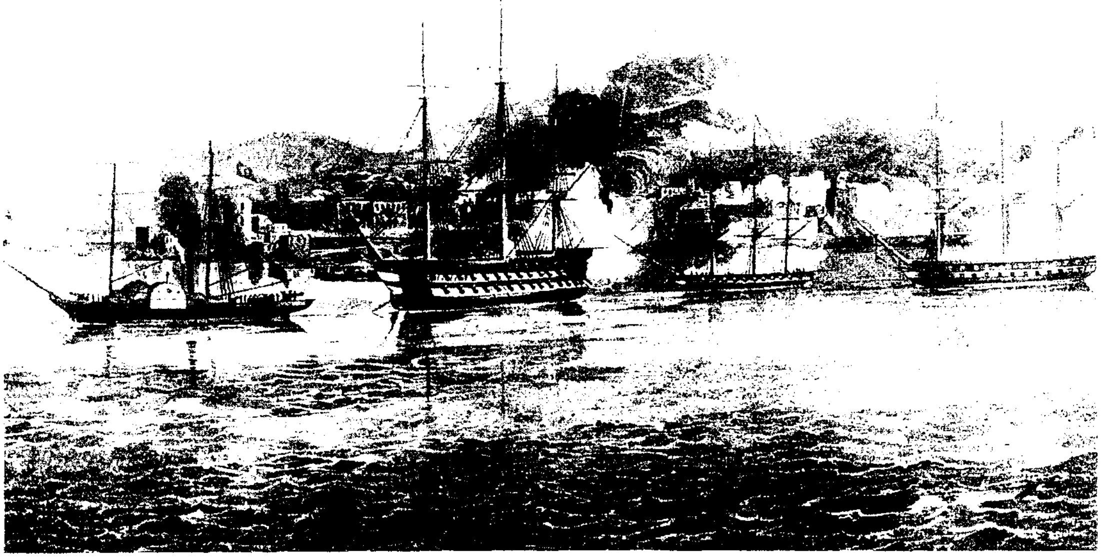

FIG. 3—THE BOMBARDMENT OF SIDON, SEPTEMBER 1840. THE STEAM PADDLE SLOOP 'HYDRA' LEADS THE SAILING BATTLESHIP 'THUNDERER' AND TURKISH AND AUSTRIAN FRIGATES

The machinery and coal supply weighed so much in these early days that there was little chance of carrying guns as well. Following some trials with chartered ships, mainly at the instigation of Marc Brunel and supported by Barrow, the Board recognized the value of steam tugs to tow sailing ships in calm or contrary winds and built their first steamship, the *Comet*, at Deptford Dockyard in 1821. She was 115 ft long and her two-cylinder engine, which cost £5050, worked at 4 lb/in^2 and burnt 10 cwt of coal per hour. The engine was of the side lever type (FIG. 2), roughly the classic Watt's beam engine with the beam cut in half longitudinally and dropped down either side of the machinery to reduce height.

Comet worked as a tender on the Thames and as a survey vessel, rated as 'HMS' from 1831, until she was broken up in 1868. During the 1820s the Admiralty built a number of generally similar vessels, mainly designed by Oliver Lang, Master Shipwright of Deptford Dockyard, one of which, *Lightning*, accompanied the expedition to Algiers in 1824, the first operational deployment of a steamship by the R.N. The Board was encouraged by developments elsewhere; the East India Company used the *Diana* in the Burma war of 1825–25 and the Greek ship *Karteria*, built in England and commanded by Captain Hastings, R.N., played a prominent part in the Greek war of liberation.

During the 1830s steam ships grew in size and number and began to carry a worthwhile armament (FIG. 3). In 1833 *Rhadamanthus* was the first British steamship, commercial or naval, to cross the Atlantic. It is noteworthy that, at a time when most of the Navy's ships were laid up in reserve, steam ships were continuously employed except for a routine replacement of boilers every three years or so. The boilers were rectangular tanks, full of sea water, with big flues passing from furnace to funnel. Every watch, the bottom layer of very salt brine would be blown out to sea, a hazardous operation until Mr Kingston of Woolwich Dockyard invented his valve. Such machinery was still big and heavy (TABLE II) but it was very reliable or at least easily main-

TABLE II—*Machinery and fuel weights in H.M.S. 'Medea' (1832), in tons*

Total displacement (light)	1142
Engines	165
Boilers	35
Water in boilers	45
Coal	320

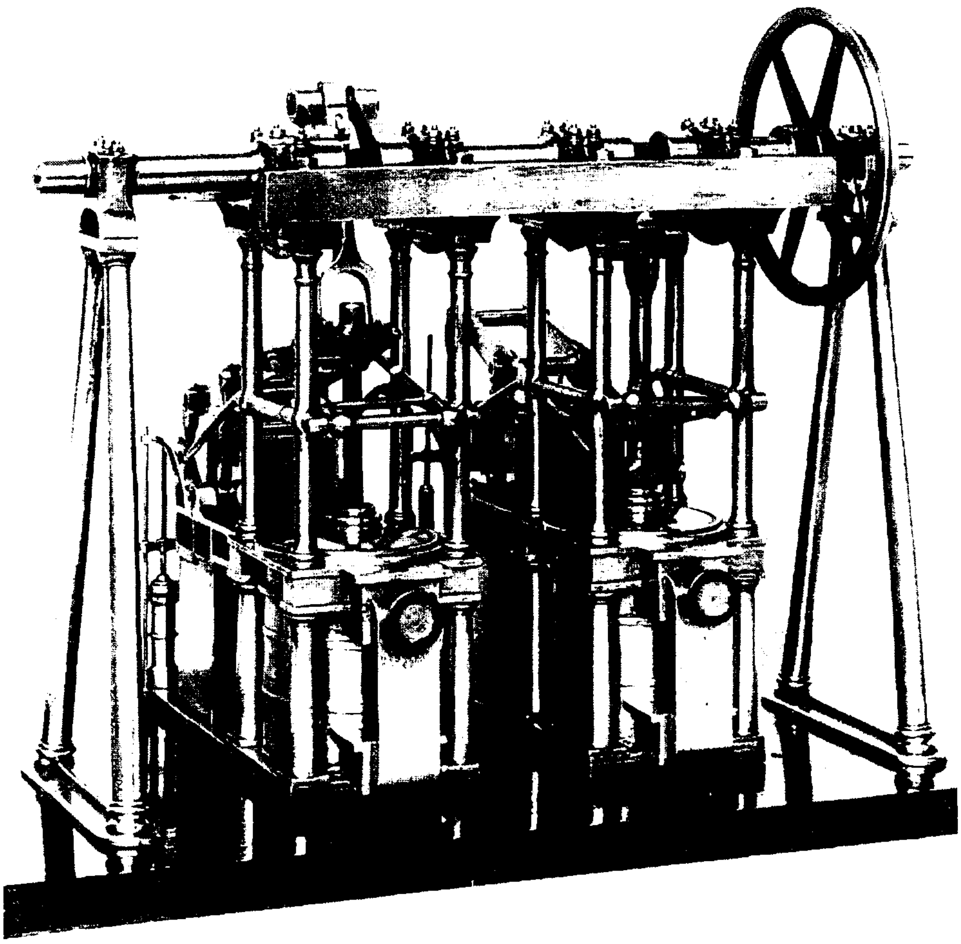

Fig. 4—'Gorgon's engines by Seaward and Capel

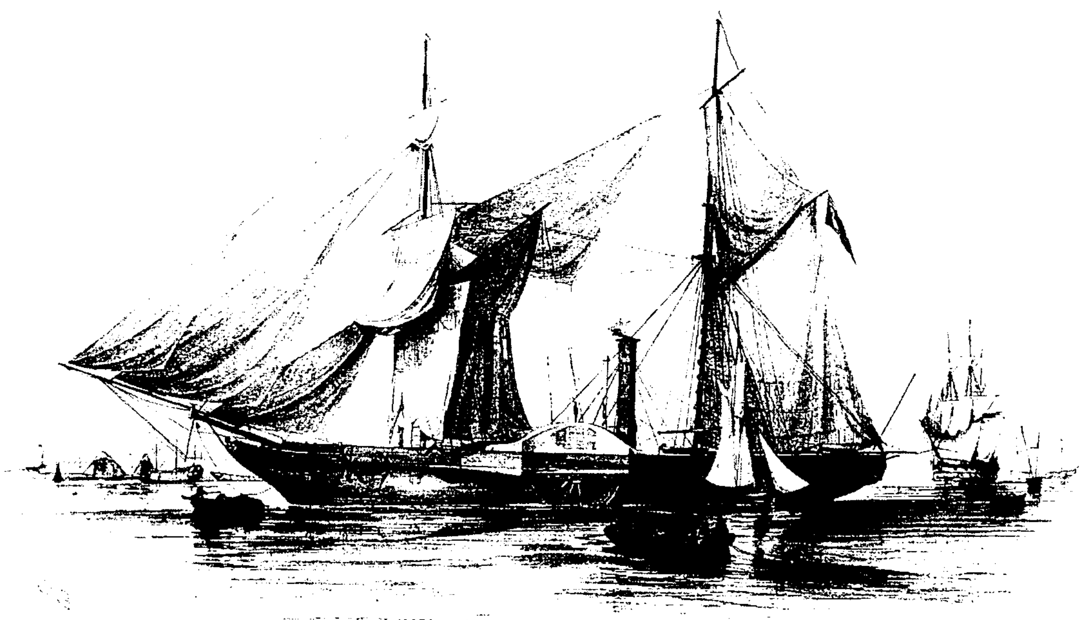

Fig. 5—'Gorgon'. Note the high freeboard and the lower deck gun ports, which were never used

tained. *Medea* was in the West Indies from February 1834 to October 1837 during which time all repairs were carried out by the ship's staff. The Steam Factory at Woolwich was opened in 1836 and, with a series of outstanding Chief Engineers, played a major role in training naval engineers as well as leading in technical development.

The side lever engine was inefficient as well as heavy and the Admiralty encouraged the development of improved engines. In 1837 Seaward and Capel offered a direct acting engine of much greater power (FIG. 4) for the *Gorgon*. This engine worked fairly well though the short connecting rods led to heavy vibration. *Gorgon* (FIG. 5) was a great success and some 25–30 generally similar ships were built, mainly carrying six very heavy guns on the upper deck. She was just a little smaller than Brunel's *Great Western*.

The paddle warship grew into a large and powerful fighting ship such as the *Terrible* (FIG. 6) of 1850 tons, 800 nominal horsepower and carrying eight 56 and eight 68 pounder guns. Because the paddle boxes obstructed the broadside, paddlers usually carried a relatively small number of the biggest guns. It was thought that they could engage at long range and destroy bigger ships but this was an impractical idea as guns could not be moved quickly enough to correct for motion in a seaway.

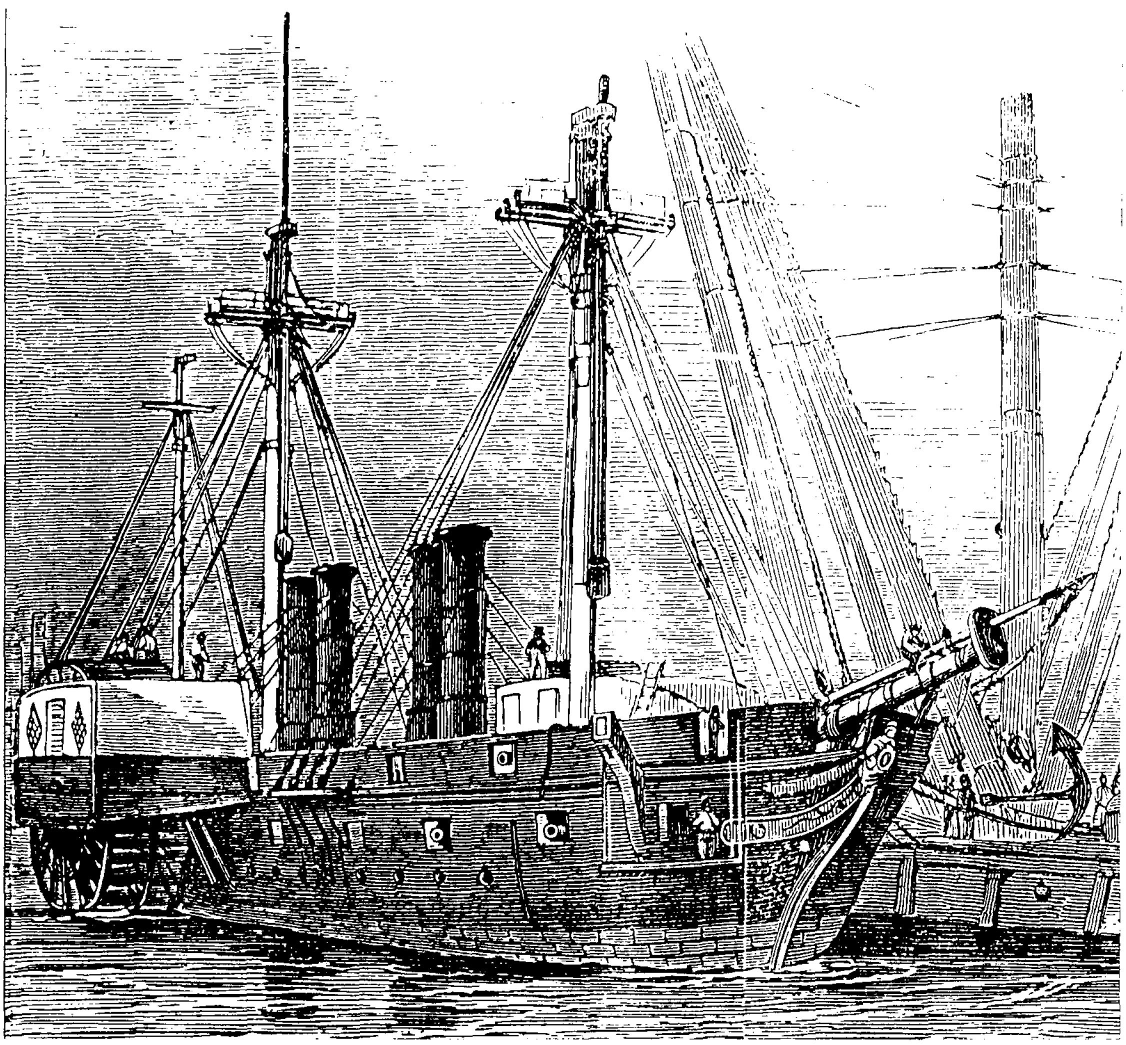

FIG. 6—'TERRIBLE' FITTING OUT AT WOOLWICH DOCKYARD. NOTE THE SMALL COPPER PLATES FITTED AS SHEATHING. HER BOILERS GAVE MUCH MORE STEAM THAN THE ENGINES COULD USE AND HALF OF THEM, WITH TWO FUNNELS, WERE REMOVED. SHE WAS ONE OF THE LARGEST PADDLE WARSHIPS BUILT UNTIL THE U.S.N. CARRIERS OF WORLD WAR II (U.S.S. SABLE AND WOLVERINE)

Contrary to general belief, then and now, paddle wheels were not unduly vulnerable to gunfire. There were at least two cases in which one wheel was smashed and the ship was able to carry on at little diminished speed on the other. However, it was a clumsy and obstructive device. The paddle wheel did introduce the Navy to steam power and the value of being certain to arrive at a given time and place almost regardless of the wind. The files are full of letters from Commanders-in-Chief praising the steam ship and asking for more.

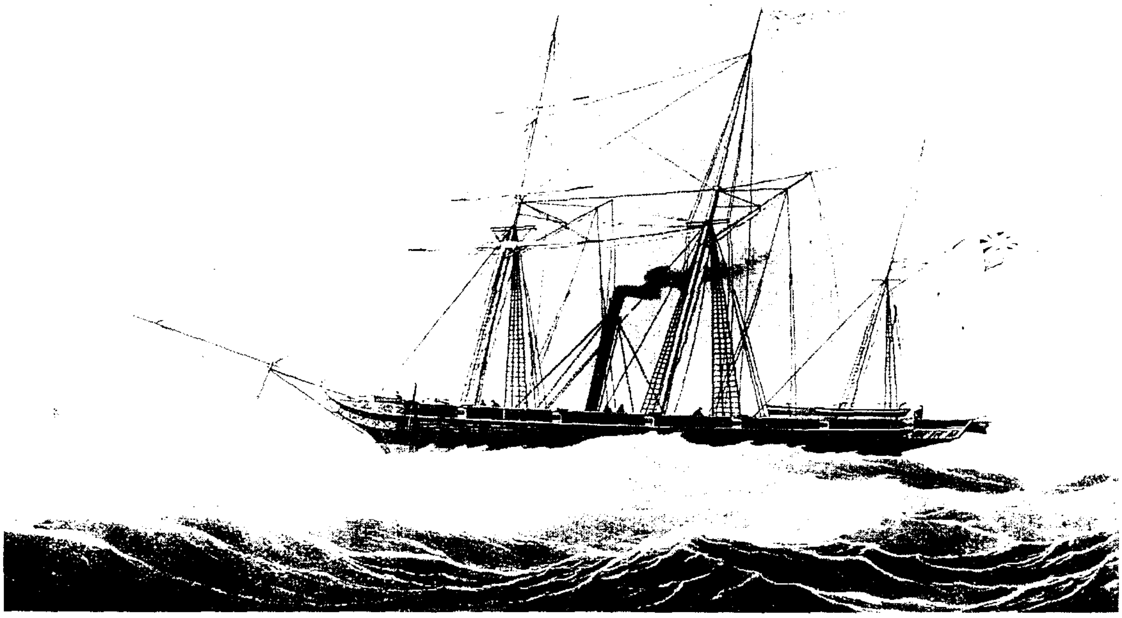

FIG. 7—'ARCHIMEDES', PETIT SMITH'S TRIALS SHIP. THE GUNS ARE PROBABLY FROM ARTISTIC LICENCE

The Screw Propeller

There were many early attempts at screw propulsion[4] notably one by Shorter. It was tried in 1802 on the transport *Doncaster*, worked by eight men on a capstan, and gave a speed of 1½ knots. Despite enthusiastic reports by Captains Aylmer and Keats it was not adopted.

In 1836, Ericsson, a Swedish engineer living in England, and Petit Smith, a farmer, independently developed screw propellers and offered them to the Admiralty. Ericsson was unlucky in that his application went to the Surveyor, Symonds, almost the only real reactionary of the whole era, and was rejected. Smith, advised by Barrow, went to the Steam Department and got a much more enthusiastic response. After some promising trials on a small launch, Smith built the *Archimedes* of 237 tons which was borrowed by the Admiralty for a series of races against the fastest paddle mail packets of the day (FIG. 7). The trials report by Captain Chappel and Thomas Lloyd, a graduate of the School of Naval Architecture and Chief Engineer at Woolwich, was most enthusiastic and the Board decided to build a screw warship for comparative trials.

There are distinct signs of over-enthusiasm and the story is confused. The first ship ordered by the Board with a screw was *Bee*, a tender for the Naval College. She had paddles as well, worked off the same engine, and the two propulsors could be worked in opposition (Push-me, Pull-you?). Despite step-up gearing, the propeller turned too slowly and the paddle won this onehorse race. The screw yacht *Mermaid* was purchased and, as *Dwarf*, carried out a valuable series of trials with different propellers and stern shapes from 1845 onwards.

Rattler was built as the first real screw warship for comparison with the very similar paddler, *Alecto*. Smith was engaged as a consultant but the Board then confused matters by engaging Isambard Brunel as well. Brunel had carried out his own trials on *Archimedes* and, as a result, converted *Great Britain* to screw propulsion. Brunel, Smith, Lloyd and Lang (who was to build *Rattler*) were all outstanding men and like many such, had strong and independent views. Their early quarrels have been reported in many books; what is usually missed is that they were quarrelling about how to get the job done quickly and well. Before *Rattler* went to sea they had resolved their personal problems and appear to have become lasting friends.

Fig. 8—'Rattler's propeller, now on display at the R.N. Museum, Portsmouth

One of the main causes of their early difficulties was a proposal to give *Rattler* finer stern lines. Brunel was convinced that this was his idea and was angry when Lloyd made a similar proposal suggesting that his plans had been pirated. Lloyd was more experienced in screw propulsion than Brunel and showed a keen interest on the effect of hull shape in trials with *Dwarf* and, though there is no firm evidence, it seems likely that these two fine engineers reached the same technical solution independently. There seems to have been no opposition to the screw though Symonds's incomprehension was a continuing irritant.

Rattler ran preliminary trials in 1843 and the following year carried out 28 trials with propellers from five manufacturers covering a range of pitches, diameters, length (along the shaft axis) and number of blades. Such numerous and expensive full-scale testing was inevitable as there was no theory of propeller action or of how to scale from models. The most successful screw was one of Smith's and it is now displayed at the Royal Naval Museum (Fig. 8).

In 1845 she carried out a series of competitive trials—races—against her paddle half-sister *Alecto* under steam alone, sail only and using both together. Each ship then towed the other. Trial data was carefully recorded and modern analysis shows it to be consistent; Lloyd arranged for a thrust meter to be fitted to *Rattler* at a cost of £100. The apparent superiority of the screw was much exaggerated since *Rattler*'s engines (FIG. 9) developed more power than those of *Alecto*. However, the screw was a better propulsor than the paddle wheel and its other advantages, such as the unobstructed broadside, made it clear that warships should rely on screw propulsion. It would seem that the famous tug of war, so often portrayed, in which *Rattler* and *Alecto* were fastened stern to stern (FIG. 10), was a public relations exercise to convince any remaining doubters. By the time it took place the Board had already ordered six screw frigates and several smaller ships, and the first steam battleships were being planned.

There were still real problems to be overcome such as the heavy vibration excited by a two-bladed propeller working in the very irregular flow behind the bluff stern of wooden ships. This vibration led to very rapid wear in the

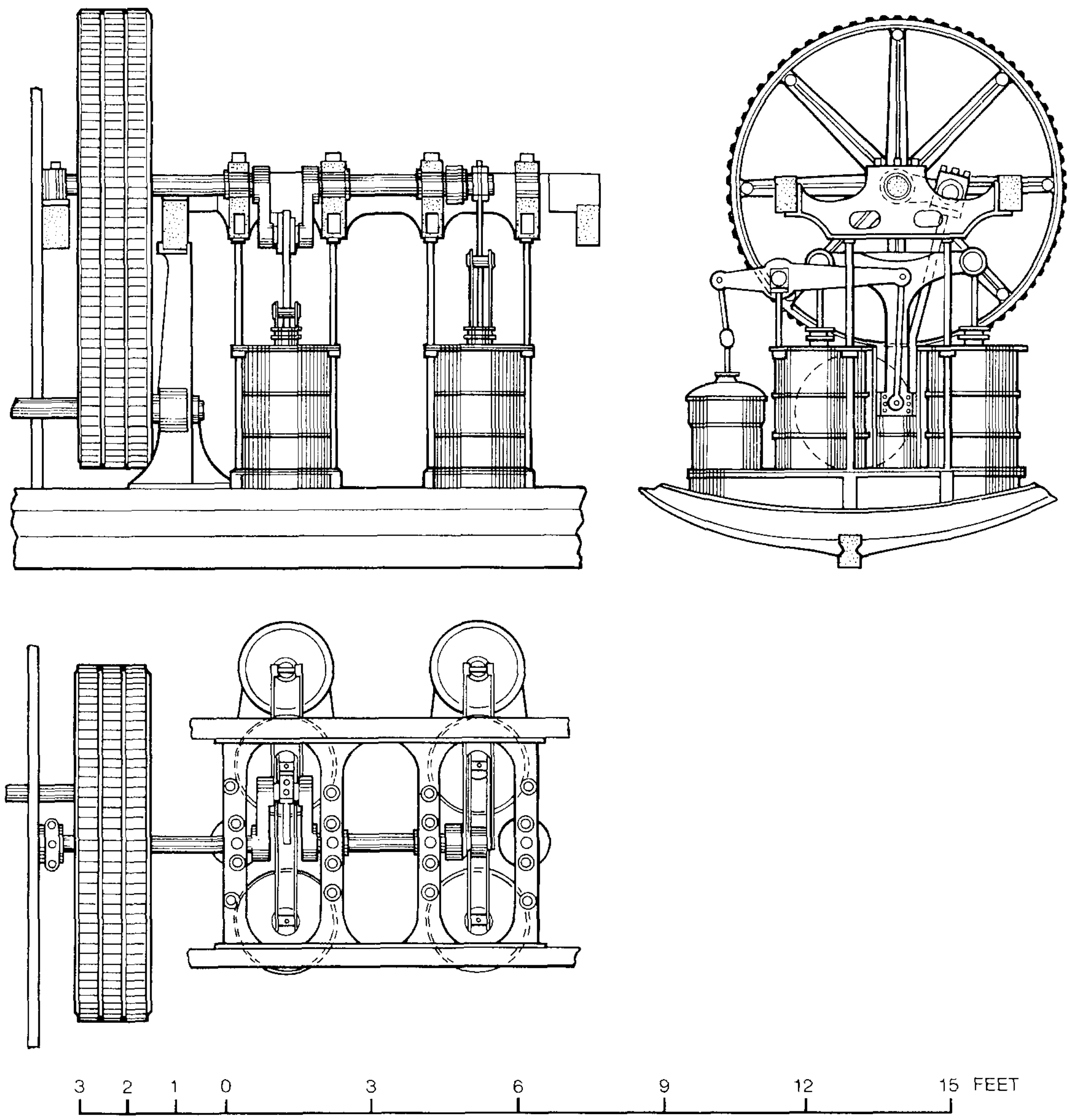

FIG. 9—'RATTLER'S ENGINES, BUILT BY MAUDSLAY. FOUR CYLINDERS, 40⅛ IN DIAM., 4 FT STROKE, 200 H.P.

brass stern glands, to such an extent that in 1856 the battleship *Royal Albert* had to be beached to stop her from sinking due to leakage through the gland. This problem was partially cured by Penn's introduction of lignum vitae bearings but the full cure was the iron hull permitting much finer stern lines and a still more rigid hull.

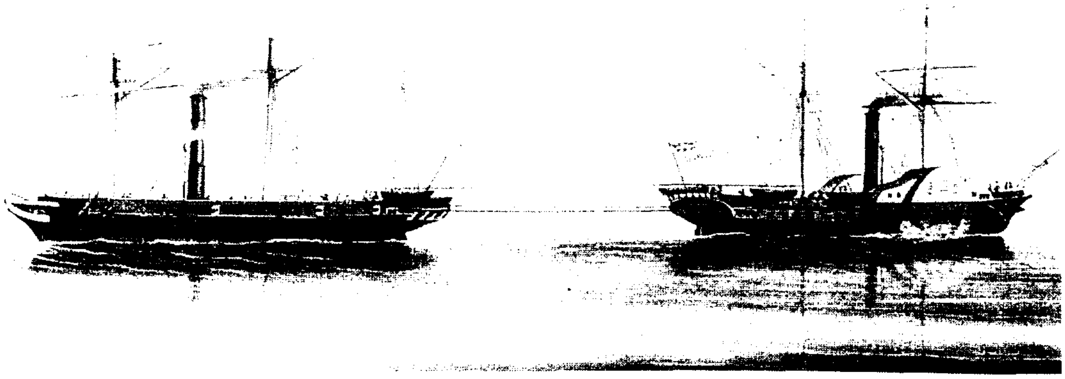

FIG. 10—TUG OF WAR: 'RATTLER' (LEFT) BEATS 'ALECTO'

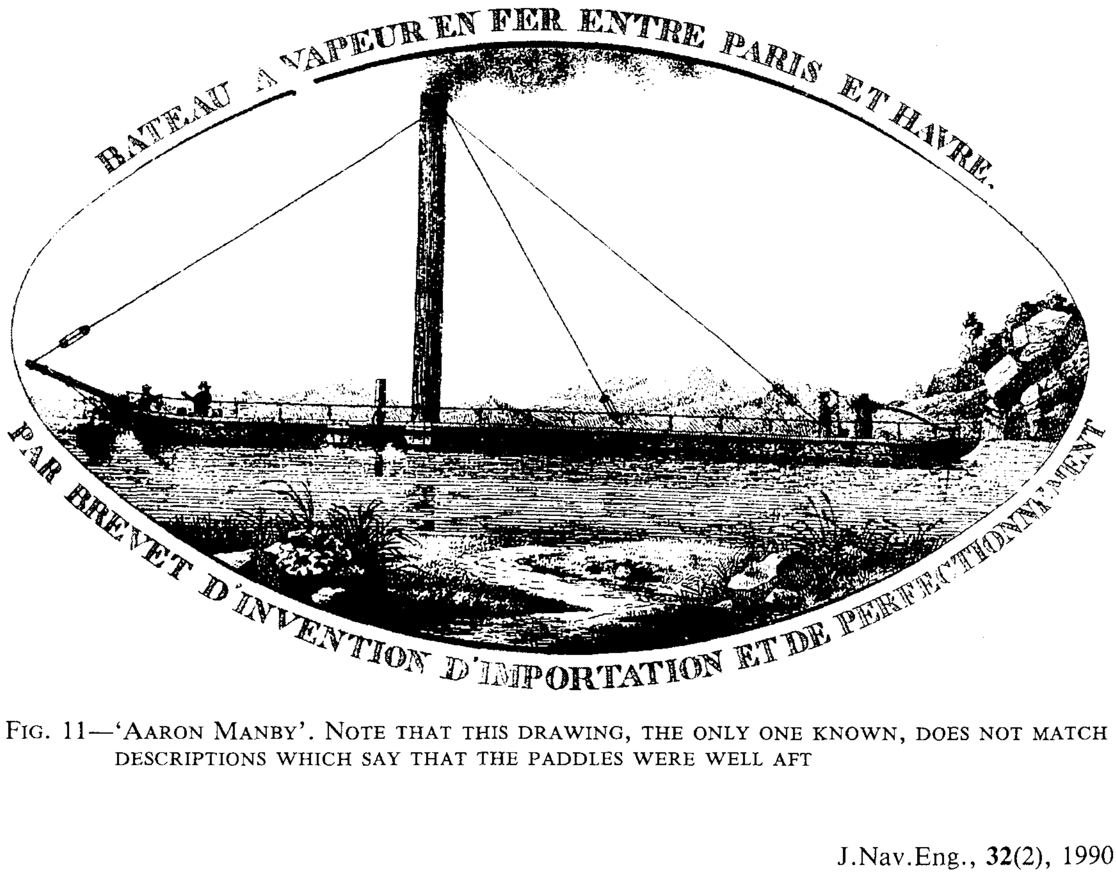

FIG. 11—'AARON MANBY'. NOTE THAT THIS DRAWING, THE ONLY ONE KNOWN, DOES NOT MATCH DESCRIPTIONS WHICH SAY THAT THE PADDLES WERE WELL AFT

Iron Hulls

Iron canal barges were introduced round about 1787 and soon demonstrated that their lighter and stronger hulls could carry more payload. A later but similar barge may be seen at Ironbridge. A small iron steamship, the *Aaron Manby* (FIG. 11), was built in 1821 for service from London to Paris but fell foul of French laws. A number of river and coastal steamers were built in the following decade but no iron ship could go far out of sight of land.

All ships needed an accurate magnetic compass for navigation and this could not work in an iron ship. The problem was first encountered in trials with iron masts in *Phaeton* in 1827 and the increasing use of iron brackets and straps in warships made a solution more urgent. The Admiralty made several attempts to solve the problem—an early example of research objectives—and finally succeeded in 1839 when the Astronomer Royal, Airy, published a paper to the Royal Society on compass correction.

This was one of the most influential papers on marine transport ever published as it made possible the sea-going iron ship[5]. The Admiralty took a cautious step and ordered the packet *Dover*. Her running costs were carefully recorded and compared with similar wooden ships though the results were rather inconclusive. Brunel changed design of the *Great Britain* from wood to iron but it was the Honourable East India Company who ordered the first iron warship *Nemesis* (FIG. 12). She was a paddle gunboat of 660 tons, 184 feet long and carried five 6 pounder guns and a rocket launcher. On her maiden voyage she ran ashore off Cornwall due to compass problems and was repaired in Portsmouth Dockyard. While there, she was inspected by Creuze of the School of Naval Architecture who sent the first of many enthusiastic reports on *Nemesis* to the Admiralty (FIG. 13).

Her Captain, W. H. Hall, had an interesting career. He joined the Navy in 1812 as a master's mate and was promoted Master in 1823. Like some other officers he took a course in 'Steam' and was lent to the East India Company. His success in *Nemesis* led to him rejoining the R.N. in 1841 as lieutenant counting his Indian time for seniority, becoming commander in

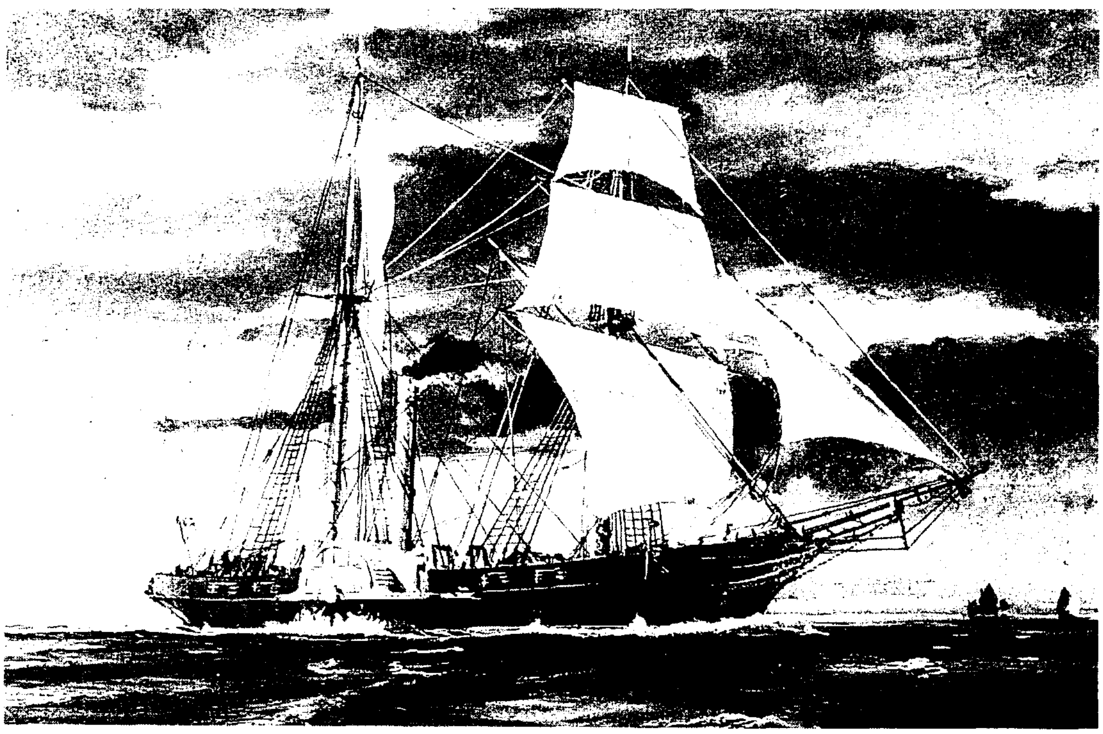

FIG. 12—H.E.I.CO.S. 'NEMESIS', BUILT BY LAIRD AT BIRKENHEAD; A MODERN DRAWING

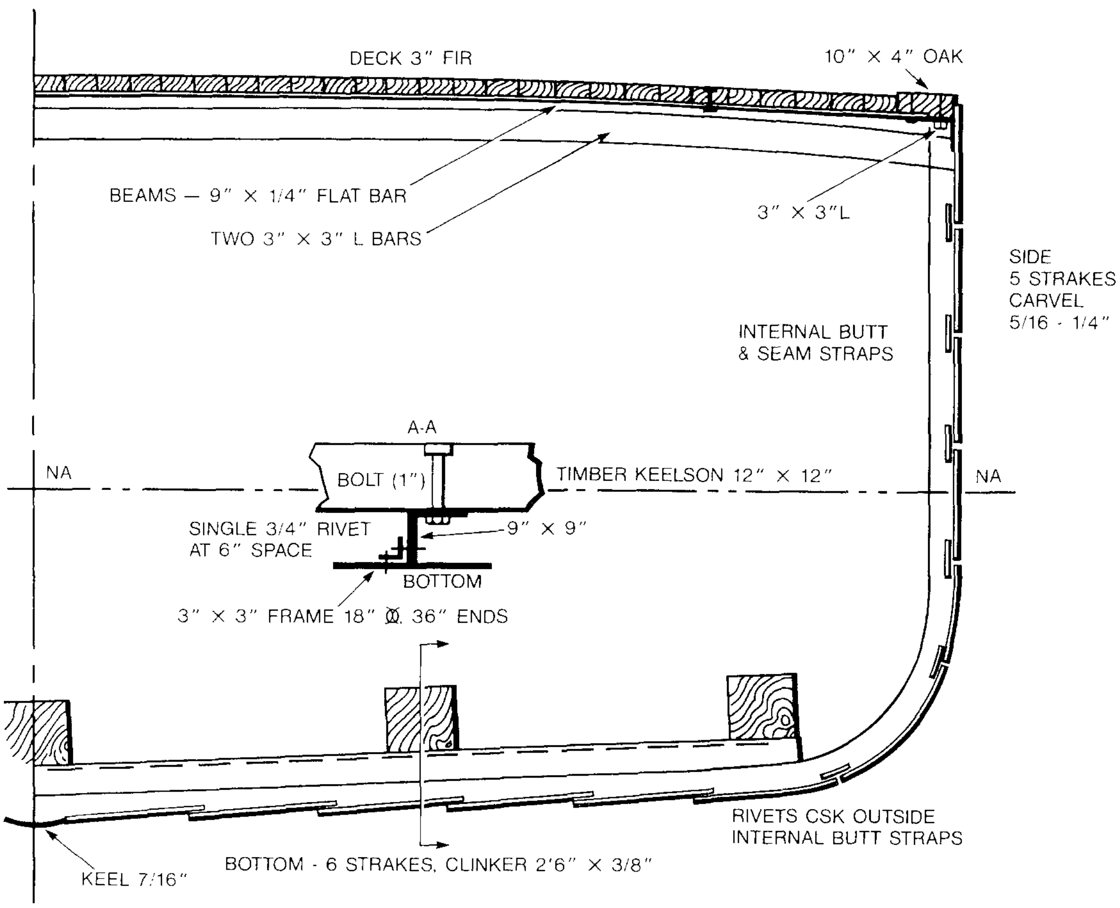

FIG. 13—'NEMESIS'S STRUCTURE BASED ON CREUZE'S SURVEY REPORT. NOTE THE SHALLOW DEPTH AND THE LACK OF IRON IN THE DECK

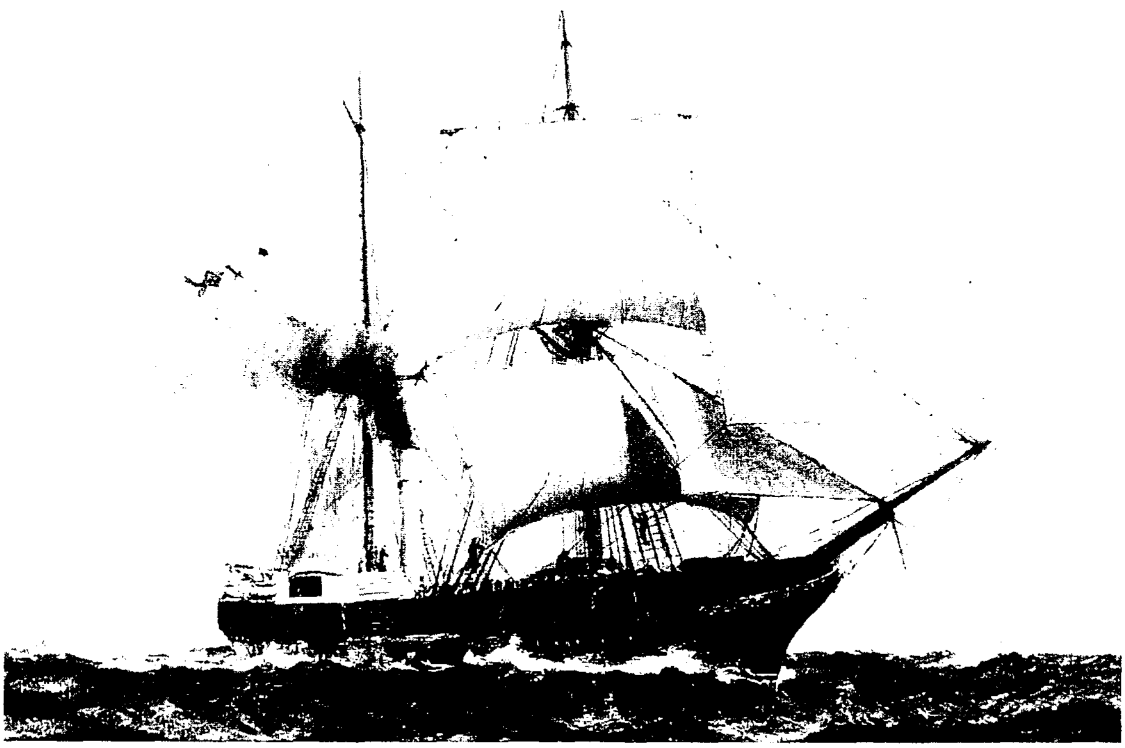

FIG. 14—'BIRKENHEAD', ANOTHER LAIRD IRON FRIGATE. SHE WAS CONVERTED INTO A TROOPSHIP AND SANK OFF SOUTH AFRICA IN 1852 WITH THE LOSS OF 455 LIVES

1843 and captain in 1844 and retiring as rear-admiral, K.C.B. and Fellow of the Royal Society in 1869. Though unusual, his career shows that merit and understanding of new technology was appreciated in the first half of the 19th century.

Nemesis almost broke in half during a gale off South Africa due to stress concentrations at poor structural details and then wandered rather vaguely across the Indian Ocean, still plagued by compass problems. She joined the R.N. squadron for the first China War where her performance was outstanding largely due to her shallow draught of 6 feet, a consequence of her lightweight iron hull. She was repeatedly in action, hit many times and ran aground from time to time. On her return to Bombay, the survey report showed her hull as in excellent condition.

These enthusiastic reports from *Nemesis*, supported by others from Captain Charlwood, R.N., commanding the Mexican iron frigate *Guadeloupe*, persuaded the Tory Board to start a major building programme of iron warships including five big frigates (Figs. 14, 15). This programme became a party political issue but when further tests of the effect of shot on iron plates were held at Woolwich Arsenal, the results were shattering. Unlike the results in battle, both the shot and plate broke and gave off showers of lethal splinters, and shot at low velocity, corresponding to long range, tore jagged holes, almost impossible to patch.

These results were so unexpected that it has often been suggested that they were faked. The true explanation came only in 1986 when John Bird of ARE, Dunfermline, tested some wrought iron from *Warrior*. He found that the strength perpendicular to the plane of the plate was always low and that

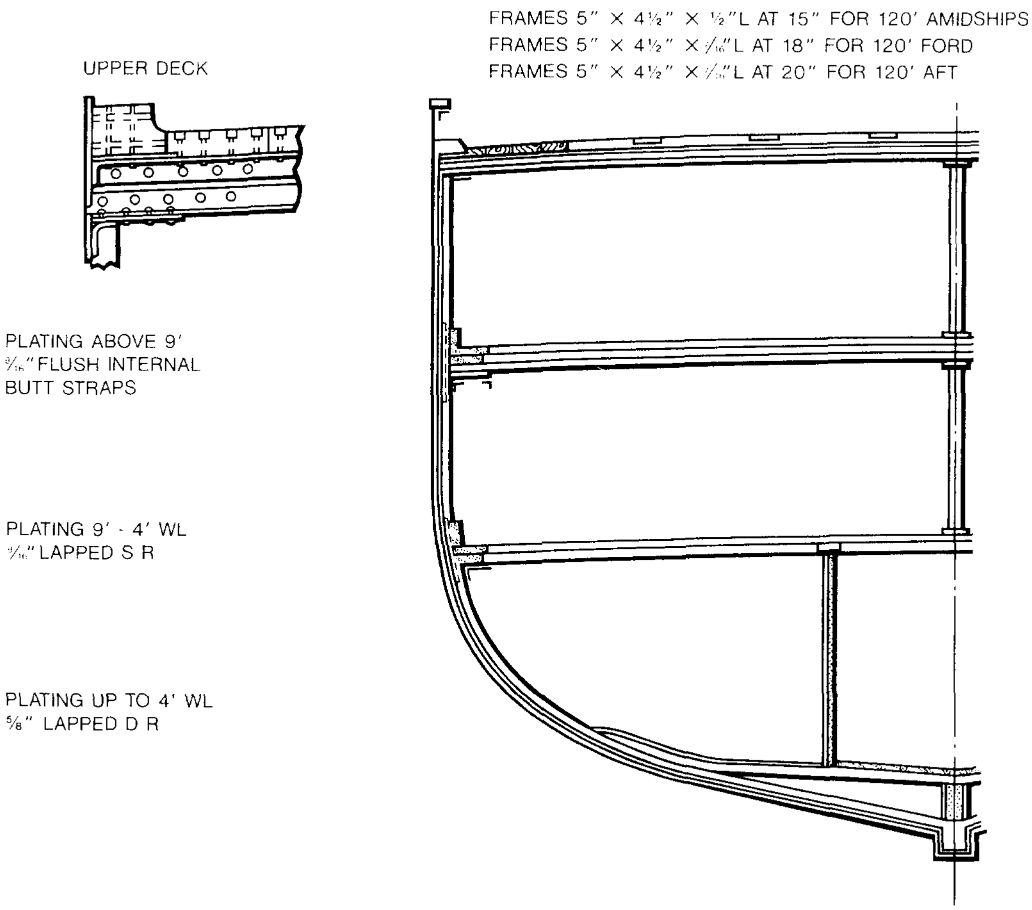

Fig. 15—Midships section of 'Birkenhead'

the brittle/ductile transition temperature was between 10° and 20°C. It so happened that iron ship battles were fought in warm waters; the Woolwich trials were in December.

These real technical problems left the Board in no position to resist political pressure and the iron frigates were converted to troopships or sold, though the smaller gunboats gave good service for many years. A further careful set of firing trials in 1850 using targets representing sections of the iron frigate *Simoon* (FIG. 16) confirmed the problems of impact resistance. One cannot disagree with the conclusions of Captain Chads of *Excellent*. 'Iron is not a suitable material for ships of war'. It is interesting that the iron ship programme, the only technical failure of the era, failed through over-enthusiasm rather than reaction. One cannot blame the Admiralty for missing the effect of temperature as it was not really recognized by engineers until after the Second World War.

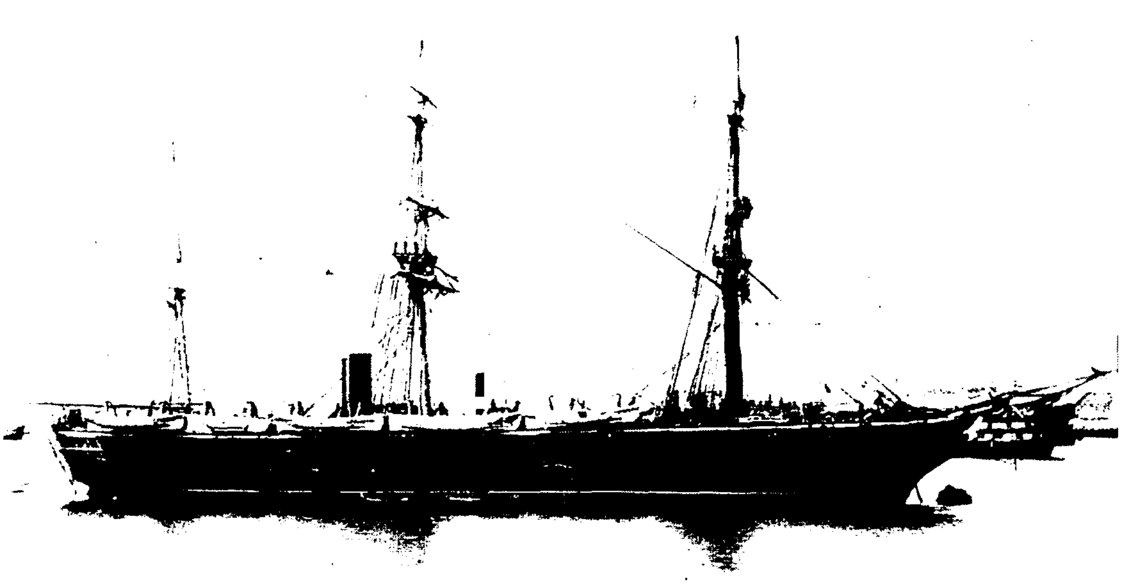

FIG. 16—'SIMOOM', AN IRON SCREW FRIGATE, CONVERTED TO A TROOPSHIP

The Steam Fleet

Meanwhile the Admiralty was building on the success of the screw propeller. The first two steam battleships entered service in 1846. They were converted from elderly 74 gun sailing ships and were originally conceived as mobile coast defence batteries. It seems that Corry, the political secretary, was the leading figure in the manoeuvrings which led to them completing as seagoing battleships (FIG. 17). Reports from sea were enthusiastic, notably from Captain Chads, and were confirmed by the manoeuvres of 1850 in which some screw frigates joined. One of these frigates, *Arrogant*, was the first ship to be fitted with Penn trunk engines (FIG. 18).

The first new screw battleship design was by John Edye and after one or two changes emerged in 1852 as the *Agamemnon*, just after a very similar French ship, *Napoleon*, designed by Dupuy de Lôme. *Agamemnon* was a classic design; some 13 ships, virtually all the purpose-built wooden screw battleships, were derived from her.

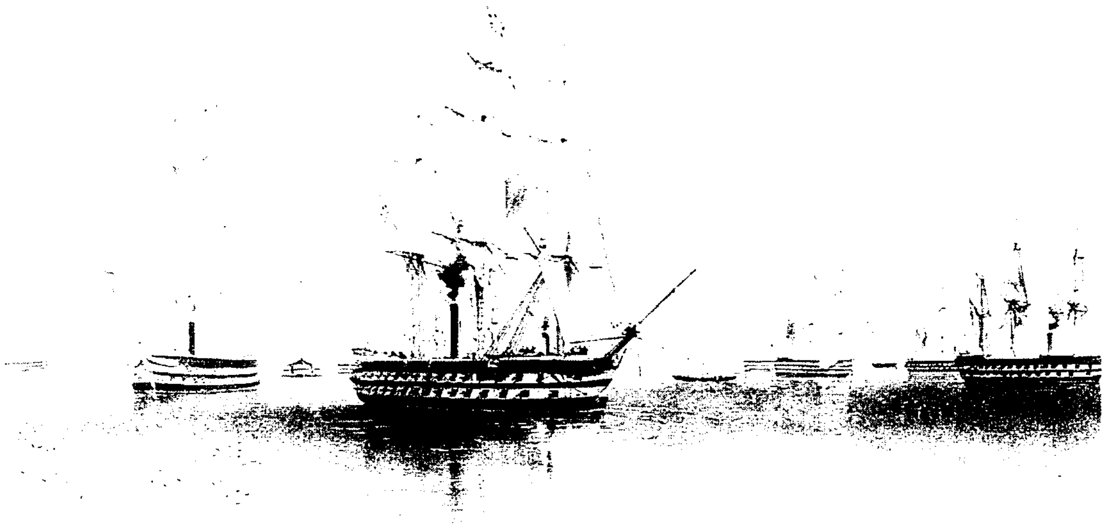

FIG. 17—'BLENHEIM', THE FIRST SCREW BATTLESHIP, WITH OTHER STEAM BATTLESHIPS IN THE BALTIC, 1855

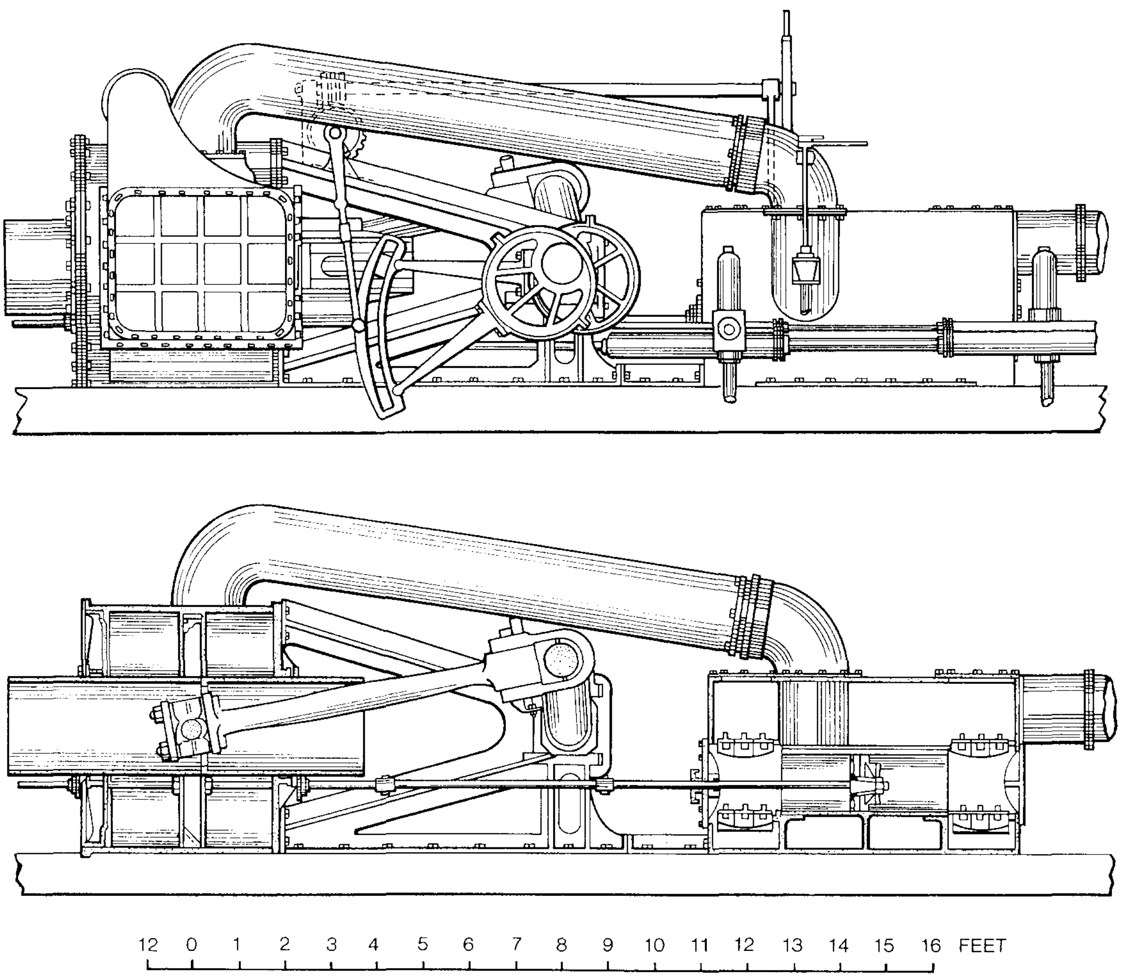

FIG. 18—PENN TRUNK ENGINE AS FITTED IN THE WOODEN SCREW FRIGATE 'ARROGANT' IN 1848. TWO CYLINDERS, 55 IN DIAM., 3 FT STROKE, 360 H.P.

By the time the Crimean War broke out it was clear that the future lay with the screw steamship; a view endorsed by the experience of war. It was the tactical and strategic mobility of the steam ship which made it so superior to a sailing ship. The war has recently been described in this *Journal*[6] and will not be covered in detail here. One great success was the introduction of mass production of engines by Penn and Maudslay relying on sub-contractors producing identical and interchangeable components. (FIGS. 19, 20).

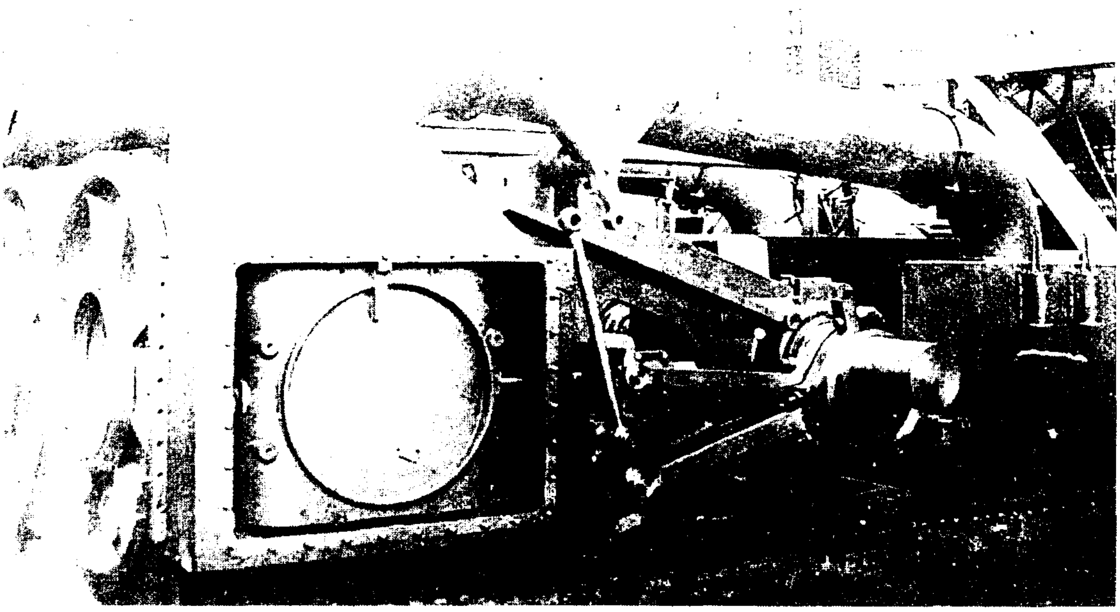

FIG. 19—AN ENGINE BEING ASSEMBLED AT PENN'S GREENWICH WORKS

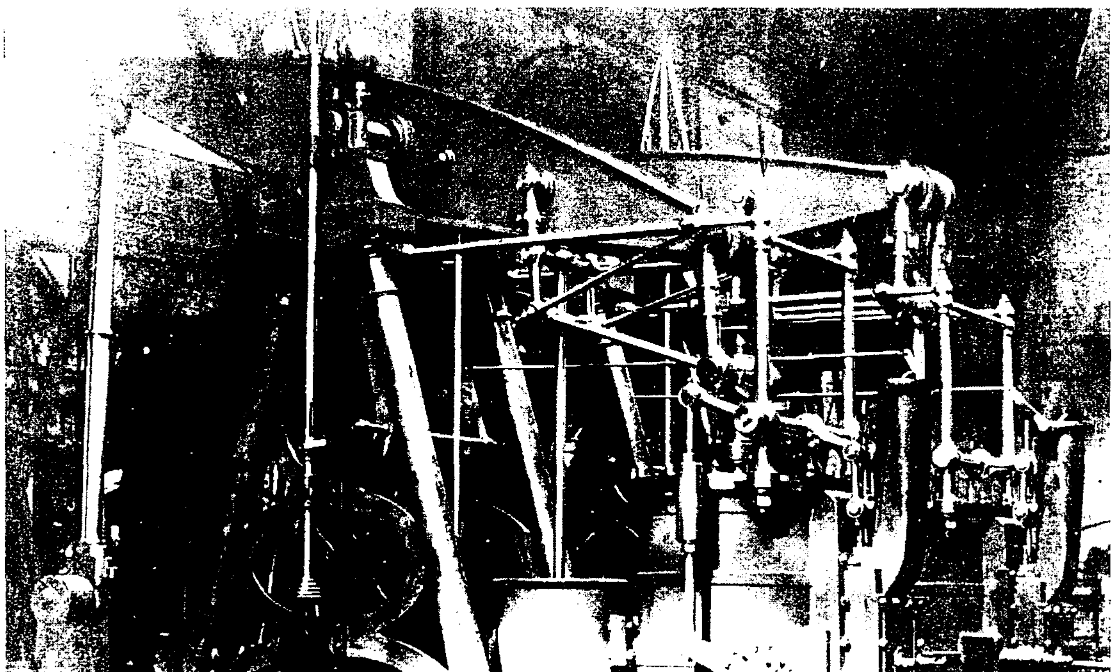

FIG. 20—MAUDSLAY'S FACTORY AT LAMBETH

Armour

Another development, which was to lead to the last of the great changes of the era, was the introduction of armour. The initial proposal came from Napoleon III and he, with his Naval Architect, Dupuy de Lôme, intended to use boxes of cannon balls along the side to keep out shells. Lloyd suggested plate armour which was tested near Paris and adopted by the French. The equivalent British ships were delayed because the First Lord, Graham, confused the problem of using iron for armour with that of unarmoured iron hulls and insisted on further tests at Portsmouth despite the clear evidence from Paris. It was Graham who closed the School of Naval Architecture and its successor; his inability to understand technical matters cost the Navy dear.

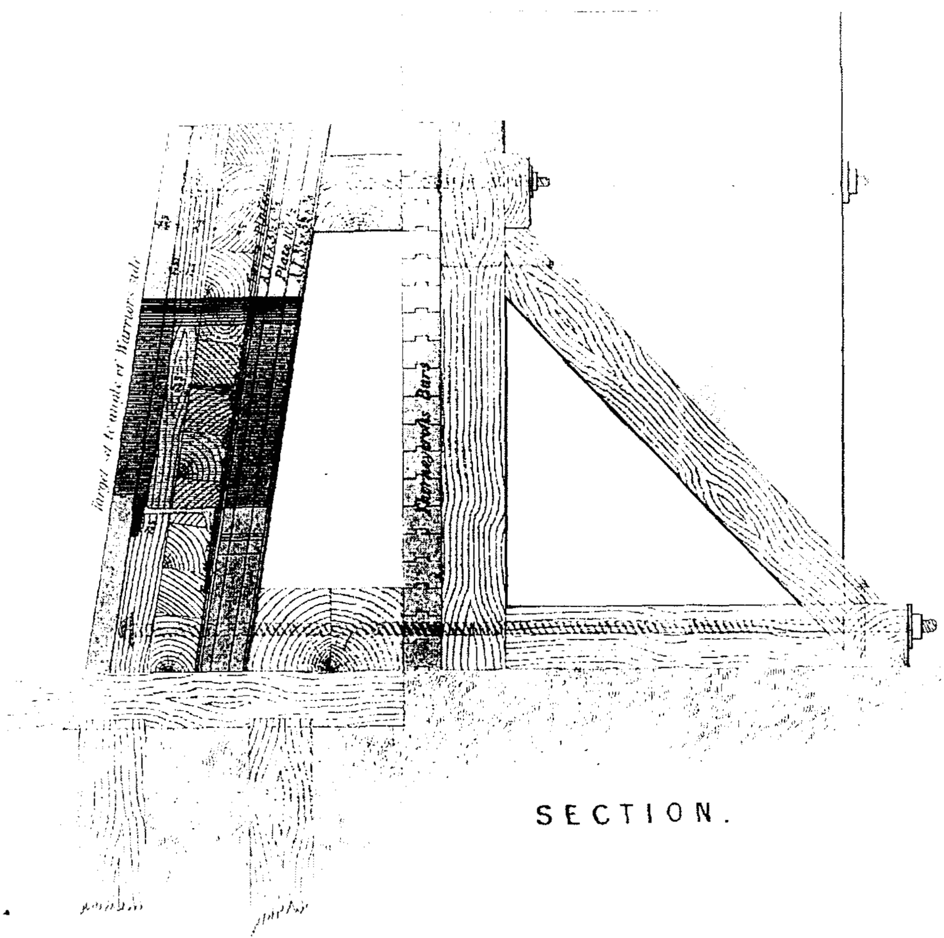

FIG. 21—TESTS OF 'WARRIOR'S ARMOUR

In the years after the war a number of tests were carried out on various arrangements of armour, its backing and supports. The main problem was that the through bolts securing the armour to an iron hull would break under the impact of shot. Plates bolted to wooden hulls or supported by thick wood backing did not suffer from this problem. The problem was not understood at the time but it is now clear that the impact initiated a compressive shock wave in the bolt which was reflected as a tensile wave at the free end causing failure. Thick wood damped out the shock wave (FIG. 21).

These tests enabled a protection system to be built for *Warrior* which would keep out all projectiles in service or planned but which was very heavy and expensive.[7] *Warrior* was the overwhelming reply to Dupuy de Lôme's *Gloire*, a wooden-hulled armoured battleship. (In the terminology of the day both these ships were described as frigates since they had only one covered gun deck.) *Warrior* brought together reliable steam engines driving an efficient screw propeller, a rigid iron hull (FIG. 22), armour and heavy guns. Her very success unleashed a flood of innovation which brought her to early obsolescence.[8]

Warrior (FIG. 23) also marked the final success of the School of Naval Architecture. Her designer (Isaac Watts), his assistant (Large), and the Chief Engineer of the Navy (Lloyd) were all graduates, as were most of the Master Shipwrights. Others were high in the Board of Trade, Lloyd's Register and universities.

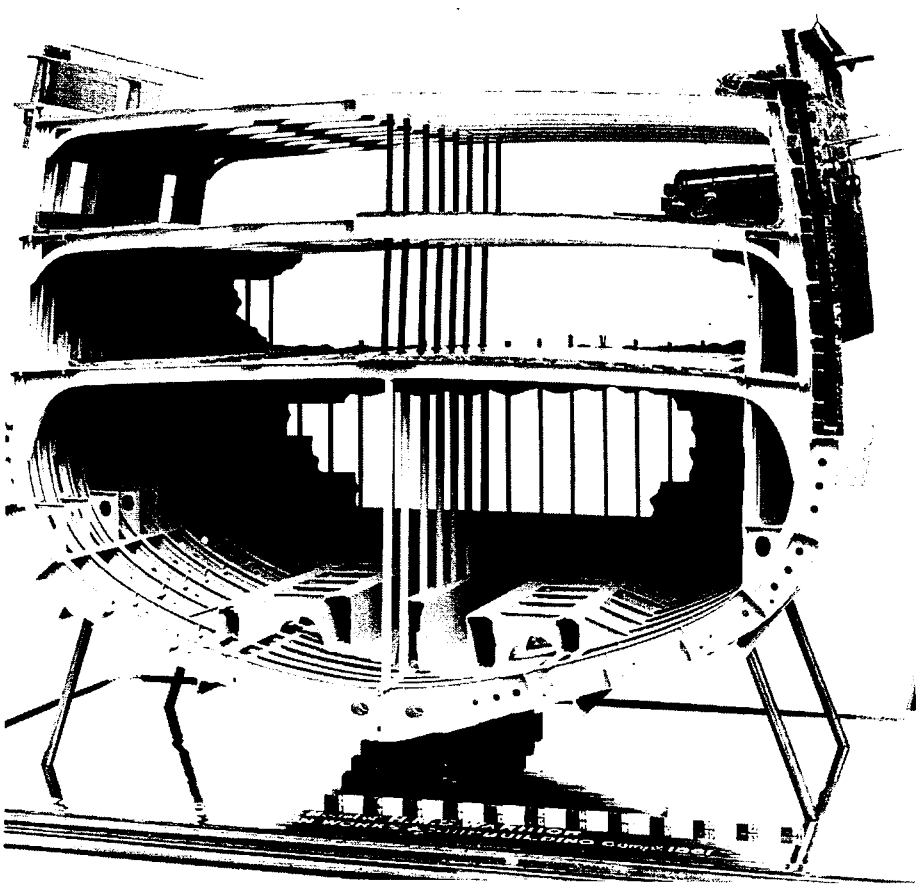

FIG. 22—'WARRIOR'S STRUCTURE, A MIXTURE OF LONGITUDINAL AND TRANSVERSE STRUCTURE. A CAUTIOUS BUT SOUND DESIGN

Conclusion

The one common factor in all these developments is the enthusiasm shown by almost all concerned, engineers, politicians and seamen officers. The reactionary statements so often quoted are, in at least one well-known case, a much later fabrication or the utterances of ancient mariners who had not been to sea since Waterloo. There were so many men who contributed that any short list is bound to be unfair but one must look at the Board under the Earl of Haddington 1841–46. The senior naval member was Admiral Cockburn who seems to have taken delight in being rude to engineers but was most progressive in his actions. The political secretaries were Herbert followed by Corry and it would seem that the drive behind the screw and iron ship programmes came from them. Corry was to return later and influence the introduction of *Warrior*. Sir John Barrow, the permanent secretary was an early and strong advocate of steamships and gave support to Smith's work on propellers.

The Admiralty's own constructors, Seppings, Fincham, Lang, Edye, Watts and, most of all, Lloyd were outstanding men, all making major contributions, and they were supported by some able staff. Many innovations came from outside such as Laird and Fairbairn on iron construction, Smith and Brunel for propellers and many others. Penn and Maudslay have a special place in machinery development as not only did they build so many sets themselves but they also trained many first-rate men, some of whom later formed their own rival factories. Admiral Sir Baldwin Walker was Surveyor for many years and was a grand team leader. To a large extent he wrote the 'Staff requirements' for the wooden steam battleships and for *Warrior*.

There were very few opposed to change, rather more who could not keep up the pace, but most were keen and effective. If only today's Ministry was as 'reactionary' as the Admiralty of 1815–60.

Acknowledgement

My thanks are due to the Trustees of the Science Museum for many of the illustrations.

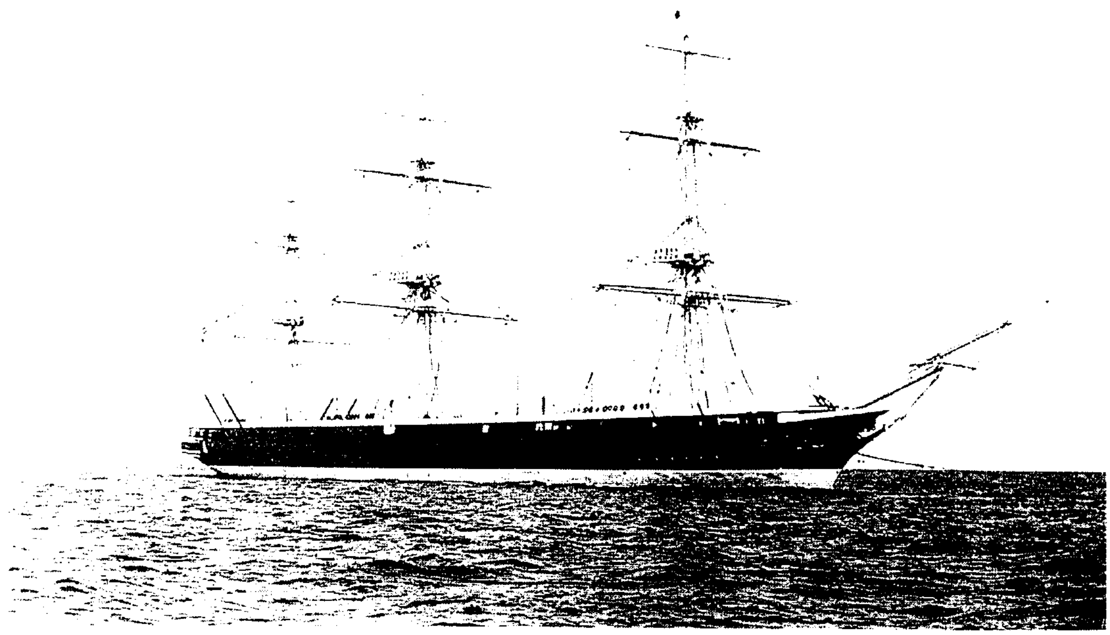

FIG. 23—'WARRIOR' COMES HOME; PORTSMOUTH 1887

References

Much of the material in this article is based on original papers in the Public Record Office, the Naval Library and the Brunel collection in the University of Bristol. A few easily accessible references are given below. The topics are discussed at length and fully referenced in the author's new book, *Before the Ironclad* (Conway Maritime Press, 1990).

1. Wright, T., Young, T. and R. Seppings. The science of ship construction in the early 19th century. *Joint meeting of the Royal Institution and the Society for Nautical Research, Science Museum, 9 December 1981.*
2. Fincham, J.: *A history of naval architecture* . . .; London, 1851. Reprinted London, Scolar Press, 1979.
3. Cuff, E. C.: The naval inventions of Charles, Third Earl of Stanhope, 1753-1816; *Mariner's Mirror*, vol. , no. , 1952, pp. .
4. Brown, D. K.: The introduction of the screw propeller into the Royal Navy; *The Naval Architect*, Mar. 1976, pp. 47-49.
5. Brown, D. K.: The introduction of iron warships into the Royal Navy; *The Naval Architect*, Mar. 1977, pp. 49-51.
6. Brown, D. K.: The Royal Navy in the Crimean War—technological advances; *Journal of Naval Engineering*, vol. 30, no. 3, Dec. 1987, pp. 630-649.
7. Brown, D. K.: Developing the armour for HMS Warrior; *Warship*, no. 40, Oct. 1986, pp. 265-272.
8. Brown, D. K. and Wells, J. G.: HMS Warrior—the design aspects; *Trans. Royal Institution of Naval Architects*, vol. 129, 1987, pp. 1-16.

See also: Lambert, A: *Battleships in transition* . . .; London, Conway, 1984.