HMS 'WARRIOR' 1860 MARINE ENGINEERING

BY

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This article is based upon 'HMS Warrior 1860—a study of the machinery installation, operation and performance' presented by the authors at the Institute of Marine Engineers on 23 October 1990.

ABSTRACT

HMS *Warrior* was the largest and fastest warship in the world when completed in 1861. Good machinery selection, professional engineering and proper trials made her reliable, easily maintained and of good performance. Competitive tendering was used and the ship's operating profile under steam was found to be little different to today's.

Background

Machinery Development (1830–1860)

In the 1830s machinery development centred upon boiler design, followed in the 1840s by development across a broad front. In 1843 *Penelope* was the first HM Ship to be fitted with smoke tube boilers. She was also fitted with surface condensing, though this had to be abandoned because of engine lubricant carry-over blanketing the tubes and because of the corrosive nature of the condensate being fed to the boilers. The early 1840s also saw the transition from paddle to screw propulsion in *Rattler* and John Penn and Son's patent for their direct acting horizontal marine trunk engine.

Following a decade of innovation the early 1850s became a period of consolidation; then at the middle of the decade some 90 ships of the Royal Navy, predominantly gun boats for service in the Crimea, were fitted with cyclindrical smoke tube boilers operating at 60 lb/in^2 (gauge). However these ships saw limited service and little is known of their operation, though later ships reverted to lower pressure rectangular boilers which may imply there were unacceptable problems. Development of the compound steam engine gathered momentum and by the end of the decade the advantages of superheating were understood but, for reasons of safety and inability to measure in practice the claimed theoretical gains, engineers chose to remain unconvinced.

By the late 1850s naval architects had become experienced in calculating engine power for ship form and speed, using Admiralty Coefficients derived from trials with earlier ships fitted with similar machinery. Naval engineers had also become adept at calculating engine size, i.e. Nominal Horsepower (NHP), to give the required Indicated Horsepower (IHP). This is illustrated by the many references to the multiplier required to NHP to give IHP. This varied (1860) between 4 and 6.

It was also during the 1850s that Thomas Lloyd, a progressive and exceptional engineer, who had been appointed Chief Engineer and Inspector of Machinery of the Admiralty in 1847 (in 1850 restyled Chief Engineer of the Royal Navy and in 1860 Engineer-in-Chief of the Navy), built a department of professional standing. He engaged professional engineers and was clear on priorities for naval machinery—Reliability, Ease of Maintenance, Economy in Performance, and Weight—in that order. He fostered development and technical specifications, design codes, standards and practices, and stringent test procedures were methodically documented. He required his staff know the shipbuilding and marine engineering industries, as he did. He was alive to the need for experienced engineers at sea, instructions for the care and operation of machinery were concise and complete and he ensured that experience at sea was fed back to his department ashore. By the end of the decade Thomas Lloyd's department was in 'good shape'.

Launch of 'Gloire' and the British response

When in March 1858 France, Britain's traditional naval rival, laid down *Gloire*, a large fast steam/sail frigate (5600 tons; 256 ft bp, the limit of timber hulls; 12·8 knots), there was outcry for response. Admiral Sir Baldwin Walker, Surveyor of the Navy with responsibility for naval shipbuilding (in 1860 restyled Controller of the Navy but with status remaining Head of Department), immediately directed Isaac Watts, Chief Constructor, to produce a design of armoured iron hull frigate of superior speed to *Gloire*. Despite the encounters of the Crimean War confirming the superiority of steam ships and the vulnerability of timber hulls, Walker's directive caused influential bodies, both within and without the Navy, to argue, often with much emotion, for the continuation of timber hulls. Others questioned if Britain could afford such ships and proposed the fitting to existing timber hulls of armour plate and engines to give 6 knots, noting that engines of higher power led to frequent refitting of hulls, and many spoke of the large number of ships laid up awaiting new boilers after three years' service.

Whilst the Board of Admiralty vacillated, Walker remained steadfast and in January 1859 requested the Board to approve Watts's design for a 34 gun, 8000 ton armoured iron hull frigate with a speed under steam of 13·5 knots—a frigate for which Walker, in concert with Watts and Thomas Lloyd, had *de facto* written the Staff Requirements. The Board approved Watts's design subject to it being proven against competitive designs. This approval did nothing to quell the controversy; rather the estimated cost of £250 000 (£6.7 M at 1989 prices), three times the cost of a 34 gun timber hull steam/sail frigate, added fuel to the fire.

By mid-April Watts's design had been assessed against 15 competitive designs submitted by private shipyards and royal dockyards with the conclusion that Watts's design was the superior. On 29 April the Board endorsed this conclusion and on 11 May a contract was placed with Thames Ironworks and Shipbuilding to build *Warrior*, the largest warship of her time, at a cost of £190 225 (£5.14 M at 1989 costs) ex-machinery. The contract stipulated that the ship was to be launched within 11 months and ready for completion, ex masts and rigging, three months later. The contract carried a penalty clause of £50 000.

General Description of 'Warrior'

Warrior (FIG. 1) displaced 9180 tonnes and her wrought iron hull (420 ft (or 380 ft bp) – 58 ft beam – 26 ft 7 ins mean draught) was armoured 6 ft below and 21 ft above the waterline for a length of 213 ft, with armoured athwartship bulkheads at the extremities of the side armour. The wrought iron armour, 4½ ins thick, was bolted to two layers of 9 inch teak laid crossways, which were then attached to the hull. Within the armoured 'box' were two stokeholds and the engine room separated by a shell room and magazines at each end. Water tanks around and above the magazines and coal bunkers outboard of the boiler rooms provided additional protection.

Below the main deck the hull was divided into 16 watertight sections with a partial double bottom under the machinery spaces. Her sail plan of 37 546 sq ft of sail on three masts was essentially that of a timber sail frigate. From the design initially approved by the Board changes were made to the armament, on completion it being ten 110 pounders, twenty-six 68 pounders and four 40 pounders. Compared to her timber hull predecessors, *Warrior* had fine lines and was a spacious ship with the ship's company of 705 living on the main deck and officers' quarters aft.

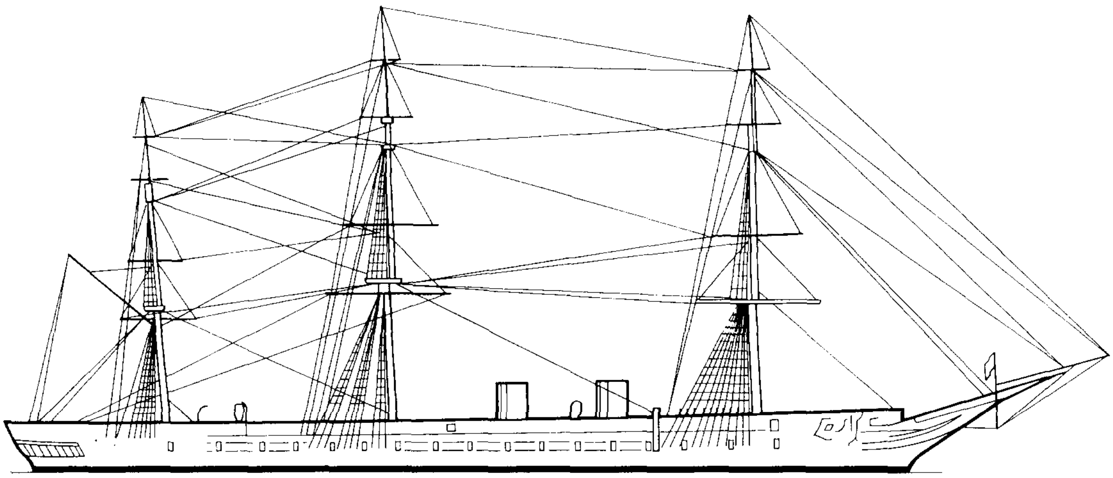

FIG. 1—HER MAJESTY'S IRON IRONCLAD SHIP 'WARRIOR' OF 1250 NHP

Machinery Installation

The machinery installation for *Warrior* provided a timely test for Lloyd's department. Lloyd proposed an installation centring upon a 1250 NHP engine, for which he favoured the Penn horizontal trunk engine, and smoke tube boilers, which from first fitting in *Penelope* had become the standard boiler for HM Ships.

In the competitive tender for *Warrior*'s machinery, Maudslay's price for an installation using their return connecting rod engine was marginally below that of J. Penn and Son, but Lloyd successfully argued that supply for this the most powerful engine yet to be built was best entrusted to Penn. It was the simpler design and he was particularly impressed by Penn's attention to detail in design and quality in manufacture and, further, Penn engines ranging from 20 to 1000 NHP were giving good service in over 100 vessels. Thus in May 1859 a contract worth £74 409 (£2·01 M at 1989 costs) was awarded to J. Penn and Son. The contract required the machinery to be ready in 11 months, with a further three months for installation after launch.

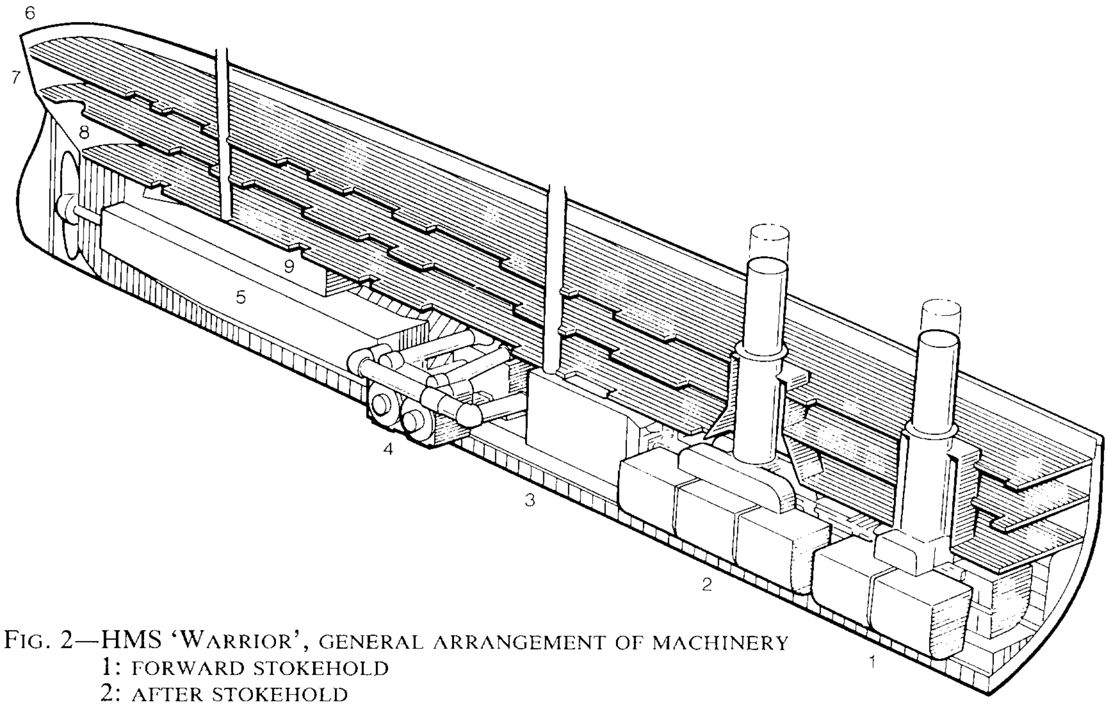

FIG. 2—HMS 'WARRIOR', GENERAL ARRANGEMENT OF MACHINERY
1: FORWARD STOKEHOLD
2: AFTER STOKEHOLD
3: AUXILIARY MACHINERY
4: MAIN MACHINERY
5: SHAFT PASSAGE
6: UPPER DECK
7: MAIN DECK
8: LOWER DECK
9: ORLOP DECK

The general arrangement of machinery is shown in FIG. 2, the essential features being:

- Ten smoke tube boilers, four in the forward stokehold and six in the after stokehold, exhausting to telescopic funnels, which were raised when steaming and lowered when sailing.

  This selection of boiler was not without criticism—'it should have been of higher working pressure', 'it should have been fitted with superheaters', 'there are designs now available which burn 20% less fuel'—but Lloyd was not moved.
- A single 1250 NHP double acting twin cylinder single expansion Penn horizontal trunk engine on the port side of the engine room exhausting to jet condensers on the starboard side.

  This also was a selection subject to some criticism, principally that Maudslay's engine was the cheaper. Again Lloyd was not moved.
- A single two-bladed bronze propeller. The blades, of larger than hitherto blade area ratio, were bolted to the hub providing for adjustment of pitch. Provision was made for lifting the propeller when sailing by housing it within a banjo frame. Propeller thrust was taken on a multicollar thrust bearing.
- A donkey engine in the auxiliary machinery space between the after stokehold and engine room, to pump bilges, provide sea water for the firemain, drive fans for the forced ventilation system and to hoist ash buckets from the stokehold to the upper deck for disposal overboard.

Auxiliary machinery and systems comprehended:

- A tiller steering system (a responsibility of sailing masters).
- An extensive pumping and flooding system throughout the 16 watertight sections of the ship.

- A forced ventilation system ducting air to main and lower deck accommodation spaces, main gun battery and cupola.
- Two Grants ¾ ton/hour water-jacketed multi-tube steam condensers for production of domestic water.
- A crab engine for working cables.
- A Cupola to provide molten metal fill for Martins 68 pounder shells.
- A fully equipped workshop for self maintaining the ship.
- A stores inventory of some 1500 line items included boiler furnace plate, bearing brasses, pump spares and canvas and fearnought for stokers' suits.

TABLE 1 summarizes machinery weights in the contemporary divisions and compares them to the data in Burgh's marine engineering textbook[1] of 1867, which shows that *Warrior's* machinery was marginally overweight.

TABLE I—*Summary of machinery weights*

	'Warrior' weight		*Burgh*[1] weight
	tons	cwt/NHP	cwt/NHR
Engine	248·49	3·97	3·0 to 3·35
Boilers	334·75	6·35	4·0 to 4·3
Water in boilers	171·72	2·75	2·5 to 2·7
Propeller and shafting	88·72	1·42	1·75 to 2·0
Coal bunkers	10·88	0·17	0·4 to 0·5
Coal	853·00	13·65	13·5
Spare gear	40·22	0·64	0·7 to 0·75
Total		27·95	25·85 to 27·1

Building and Fitting Out

From the outset progress did not accord with launch within 11 months, the shipbuilder claiming delay due to changes by the Admiralty and late delivery by subcontractors. To urge the shipbuilder toward launch in October 1860 the Board of Admiralty visited the slipway but, after inspection, decided it was not the ship they wished for and instructed that work stop whilst they deliberated. Two days later they concluded 'After laying out so much money upon her it will be as well to see what we can make of her. Thus whilst we are wasting our energies upon the doubtful experiment the Emperor of France has tested his *Gloire*, the performance of which have again been reported as having given great satisfaction'. The controversy was kept on the boil.

In an attempt to quell the more emotive arguments the January 1861 issue of *Cornhill Magazine* carried an article 'The Warrior and La Gloire' which included:

> Having now compared the principal features of the French and English ships, we proceed to review the peculiarities of Warrior's construction. Peculiarities which have been severely criticised. Warrior's construction involves novel considerations which the Lords of the Admiralty cannot be expected at once to grasp the complicated conditions of the problem. For this construction of armour-cased warships is a scientific question—and profoundly scientific in some of its parts. We are now just passing through a great crisis in our Naval history and it will need all our national good sense—and all our scientific skill to carry us securely past it.

Launch eventually took place on 29 December 1860 and on 4 January 1861 Mr William Buchan took up his appointment as Chief Engineer. After seven years in the merchant service Buchan joined the Royal Navy in 1848, first serving in *Malacca*. Then, having distinguished himself as Chief Engineer of *Orlando*, Lloyd transferred him to *Warrior*. In no time Penn's engineers readily accepted this dour Scot, though he did not constrain himself to superintending the fitting out, but also took an active part in installation and testing.

Installation of the machinery took seven weeks and at the end of February 1861 steam was raised for the first basin trial. It was not, however, until 19 September that *Warrior* was completed and sailed for Portsmouth. Her final cost was £377 589 (£10·19 M at 1989 prices).

Steam Department Complement and Watchkeeping Duties

The Steam Department complement of 95 engineers and ratings is detailed in TABLE II. *Warrior* was the first of HM Ships to carry two Chief Engineers, introducing the styles of 'Chief' and 'Senior'.

TABLE II—*Steam department complement*

Chief engineer	1	Head of department. The 'Chief'
Chief engineer	1	Assistant chief engineer. The 'Senior'
Engineers	3	Engineer officers of the watch (EOOW)
Assistant engineer 1st class	3	Second EOOW, stationed in engine room
Assistant engineers 2nd class	3	Third EOOW, stationed in boiler room
Chief petty officers	2	One boilermaker, one founder
Petty officers 1st class	11	1 blacksmith, 1 plumber, 9 leading stokers
Stokers and coal trimmers	48	
2nd class stokers and coal trimmers	18	
Seamen ratings	4	One blacksmith's mate, one tinsmith, two engineers' servants and cooks

When under steam the department worked in three watches, the engine room watch being the Engineer Officer of the Watch (EOOW), 2nd EOOW, Leading Stoker and Stoker; and the stokehold watch consisting of the 3rd EOOW and one or two Leading Stokers and Coal Trimmers as required for the number of boilers alight. The Assistant Engineers and Stokers not on watch operated auxiliary machinery, and attended to maintenance, cleaning and preservation of machinery and machinery spaces.

Care and Operation of Machinery

By 1861 the principles for the care and operation of machinery were well established and 'Instructions to Engineer Officers' were laid down in *Queen's Regulations and Admiralty Instructions*. The instructions ranged, on one sheet of paper, all matters for which Engineer Officers had responsibility; exceptionally boilers commanded detailed attention. They required logs to be maintained recording usage, the operation and maintenance of machinery and the employment of Steam Department personnel.

Sea Trials and In-Service Life

Warrior's acceptance full power trial was carried out on 17 October 1861, when the engine developed 5468 IHP at 54·25 rev/min giving a ship's speed of 14·354 knots (TABLE III). The trials report stated that all machinery performed satisfactorily, but expressed some doubt as to the efficiency of the steering gear and unease at the large turning circle, particularly at slow speed. *Warrior*, the largest warship afloat, was also now demonstrably the fastest by a comfortable margin.

TABLE III—*Acceptance trials*

Full power and with six and four boilers			
	17.10.61	25.10.61	25.10.61
Boilers in use	10	6	4
Boiler pressure (lb/in^2)	22·0	19·75	20·5
Condenser vac (in Hg)	25	26·125	27·5
Engine (IHP)	5468	2868	1988
Shaft speed (rev/min)	54·25	44·5	38
Ship's speed (kn)	14·354	12·174	11·04
Calculated efficiencies at full power			
Boiler	70·4%		
Engine	6·28%		
Overall	4·42%		

During Open Sea Trials Mr Buchan and his engineers were quick to grasp the potential advantages in economy and reduced maintenance which would accrue from steaming at reduced boiler pressure with a reduced number of boilers connected and controlling main engine revolutions by link setting only i.e. throttles wide open. On the last passage of the trials *Warrior* achieved her maximum recorded speed of 17·5 knots whilst under steam and sail, the wind being on the port quarter. The trials report concluded that *Warrior* was most satisfactory under steam, but again expressed concern about the steering gear.

In January 1862 *Warrior* sailed for Lisbon and Gibraltar for an experimental cruise. Whilst unmooring ship in Lisbon the foremost capstan 'gave out'. Then, whilst on passage to Gibraltar under steam/sail, the forward main engine cover cracked. Steam pressure was reduced, the cover shored, and *Warrior* continued making an average passage speed of 14 knots. Cracks were also noted to be developing in the engine valve chest pillars and condenser. Also the donkey engine crosshead fractured. The cylinder covers were demonstrably inadequate and subsequent to emergency repairs in Gibraltar a modified design was fitted. The other deficiencies were repaired or replaced by the shipbuilder.

Ship and Machinery Usage

During her service life *Warrior* (TABLE IV) covered some 87 000 miles; 51 000 during trials and two commissions in the Channel Squadron, and 36 000 in the First Reserve.

TABLE IV—*HMS 'Warrior'—chronology of active life*

8 August 1861	Acceptance from shipbuilder. Started trials and first commission Channel Squadron
22 November 1864	Paid off for refit
1 July 1867	Complete refit. Started second commission Channel Squadron
15 September 1871	Paid off for major overhaul
1 April 1875	Entered First Reserve squadron
31 May 1883	Paid off. Remained on effective list

During operations in the Channel Squadron the proportion of distance run under her various modes of propulsion were:

- Steam 36%
- Steam/Sail 42%
- Sail 22%

Whilst under steam alone the ship's operating profile is illustrated in FIG. 3. Consistent with this profile, for the greater proportion of time four or six boilers were connected steaming at 15 lb/in^2 (gauge).

Whilst under steam/sail the practice was to use 'Easy Steam' i.e. a few boilers alight and the engine used as requisite to maintain desired ship's speed.

During a typical year, steam was raised for around 2000 hours and the main engine in use for some 900 hours.

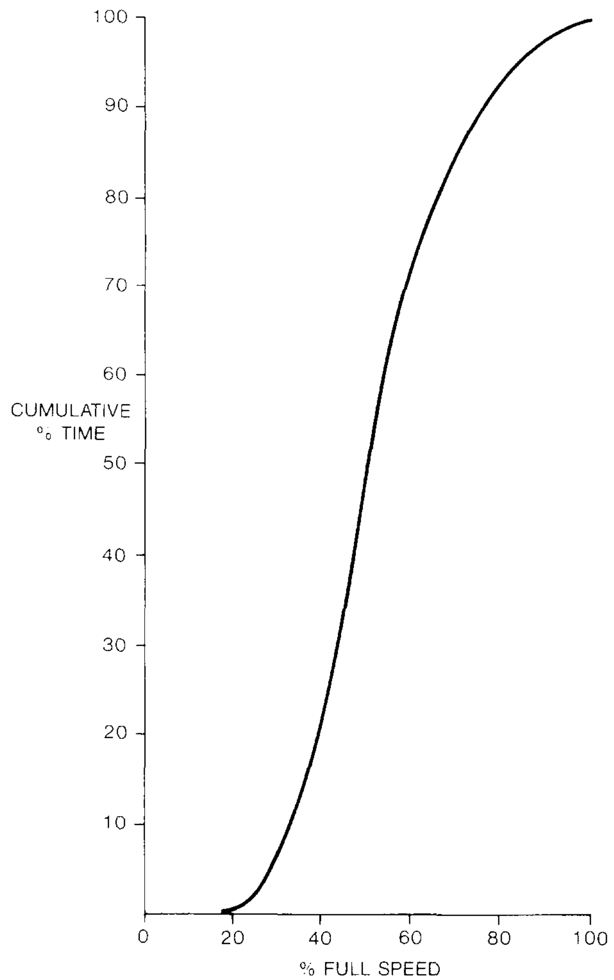

FIG. 3—HMS 'WARRIOR' OPERATING PROFILE UNDER STEAM ALONE

Machinery Maintenance

After the modifications and repairs already mentioned as carried out at Gibraltar during the experimental cruise, the main engine operated throughout *Warrior's* service life without notable defect other than a fractured air pump cover, the only significant work being at the major overhaul (TABLE V).

In the first year of operation a new plate had to be fitted to one boiler and in early 1863 ferrules were fitted to the combustion chamber ends of the after stokehold boiler smoke tubes to combat deterioration. These defects apart, the

TABLE V—*Estimated costs (£) of defect list for major overhaul (1872–1875)*

Work	*Estimated costs*	
Hull	Survey hull, repair and paint double bottoms, caulk decks and topside, clean bottom and re-coat with Hay's compound, fit poops, modify bowsprit, relay upper deck	20 250
Machinery	Survey engines, rebore cylinders, strengthen engine valve slide faces and steam ports, modify expansive valves to give earlier cut off, alter propeller pitch, install new boilers with superheaters, modify uptake casing, re-run main and auxiliary steam piping and modify other pipe runs, repair damage to rudder head, fit steam winch	21 540
Rigging, stores and boats	Masts and yards Rigging and stores Boats	1927 5752 593
Grand total		50 062

boilers operated without notable defect during the first commission, and at the first refit renewal of 148 smoke tubes and renewal of top sections of funnels were the major items. In the second commission, after two years of relatively trouble-free steaming, furnace crowns, smoke tubes and boiler mountings were beginning to give trouble and essential repairs became necessary. In conjunction with these repairs the bridges of the after stokehold boilers were modified in order to burn mixed coal, this being cheaper than the Welsh Coal burned hitherto. In December 1870 it was decided that the boilers should be renewed at the major overhaul and, subsequently, that superheaters be fitted. Throughout the ship's time in the First Reserve the boilers operated satisfactorily with minimal maintenance.

Across the remainder of the machinery, the only matters which gave cause for concern during the first commission were the spasmodic slackening back of the propeller blade locking arrangements and the inadequacy of the steering arrangements. The former was rectified at the first refit and the latter led, in 1863, to the fitting of a hydraulic steering system. However, this change did not improve ship control and was beset with mechanical problems. The system was subsequently removed and the ship control problem remained throughout *Warrior*'s service life. Towards the end of the second commission, replacement of pipe lengths and repair of valves and valve joints became an increasing problem and thus renewal of pipe work became a major item at the overhaul (TABLE V). During time in the First Reserve there is no evidence to suggest that the auxiliary machinery performed other than satisfactorily with only routine maintenance.

In general terms the logs indicate that the Steam Department were routinely busy with only the occasional need to work long hours; assiduous compliance with the Instructions for care and operation of boilers and boiler maintenance being the most significant load for engineers and stokers alike. Throughout the ship's life, except for refit and overhaul, Dockyard assistance was requested on only 80 days, which included rectification of initial engine defects and deficiencies at Gibraltar, the fitting of the hydraulic steering gear and essential boiler repairs in the second commission. This fact supports the contention that the on-going maintenance load was sensibly within the capacity and capability of the Steam Department.

TABLE VI—*Dockyard costs (£) for first refit (1864–1867)*

	Materials	*Labour*	*Sub-totals*
Hull	18 148	26 219	44 367
Masts and yards	3057	142	
Rigging and stores	17 368	215	20 782
Indirect charges	11 366		11 366
Engines and engineers fittings	1192	813	
Boilers and engineers fittings	1634	1207	
Engineers stores	1566	3	6415
Indirect charges		595	595
Total			83 525

TABLE VII—*'Upholding' (i.e. overall) maintenance costs from commissioning in 1862 to 18 February 1872, including the first refit*

	Capital (i.e. building) costs	*Maintenance costs*	*% Capital costs/yr*
Hull	282 284	61 800	2·2
Machinery	74 409	11 176	1·5
Engineers stores	891	5753	6·5
Masts and yards	3756	3873	12·5
Rigging, boats and rigging stores	15 952	20 046	12·5
Miscellaneous	297		
Total	377 589	102 648	2·6

Dockyard costs for the refit and major overhaul are given in TABLES V and VI, and TABLE VII shows the Upholding (through-life maintenance labour and material) Costs to 10½ years from acceptance. The major overhaul and subsequent costs increase the Machinery Upholding Costs across *Warrior's* full in-service life to 2·4% Capital Costs/year (from 1·5%) or, using an alternative comparative term of the day, £2·10.9d/NHP/Year. This latter figure might be compared to the 1854 figure of £5·17.6d/NHP/Year for the Rennie engine fitted in HMS *Vulcan*.

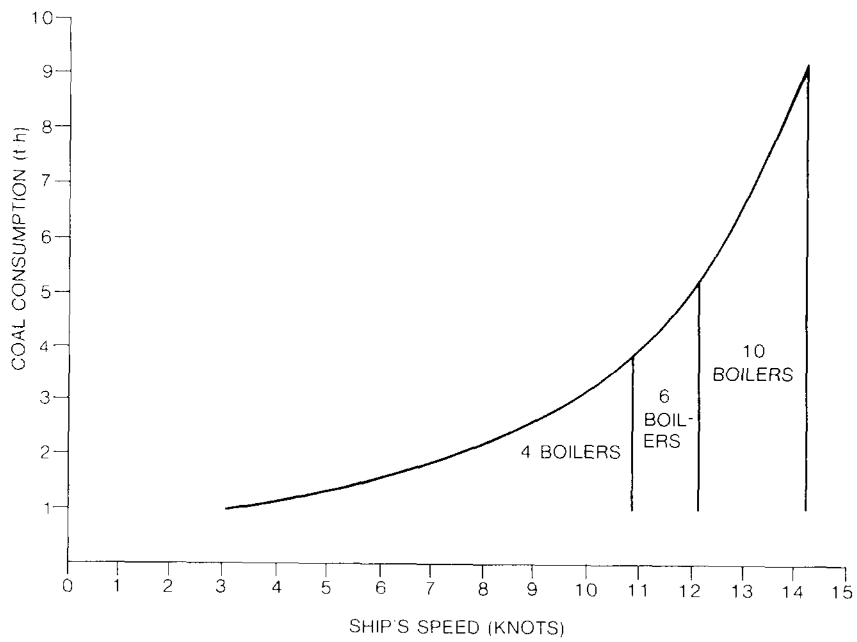

FIG. 4—COAL CONSUMPTION V. SHIP SPEED

The evidence on material deficiencies and defects reveal the familiar bathtub curves and, when taken in conjunction with the costs and loading on the Steam Department, a good measure of reliability.

Performance

From discerning use and detailed analysis of available data a good measure of confidence is placed on the ships' speed coal consumption relationship as drawn in FIG. 4 for the ship at mean displacement, with a reasonably clean bottom and burning Welsh coal (as burned during Acceptance Trials and for most of the time in the Channel Squadron). The relationship gives an economical speed of 5·9 knots and, with 853 tons coal bunkerage, a range of 3570 miles.

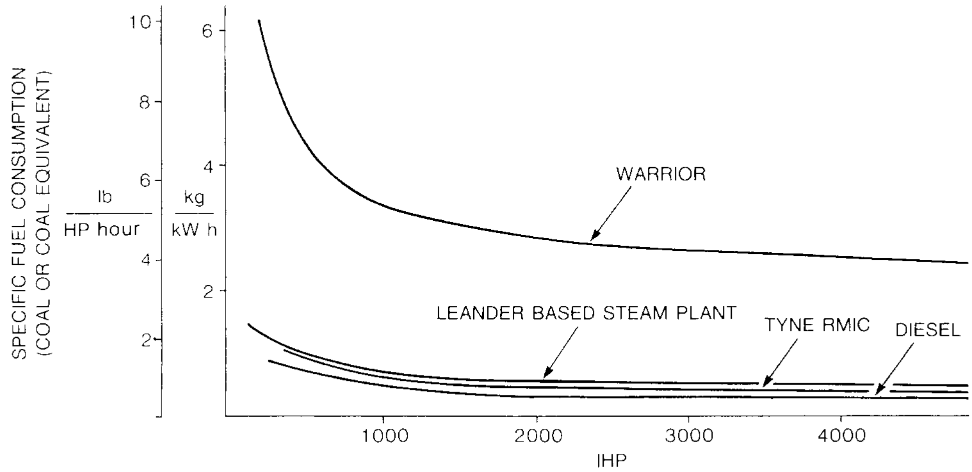

FIG. 5—SPECIFIC FUEL CONSUMPTION OF HMS 'WARRIOR' COMPARED WITH MODERN MACHINERY

Comparison of *Warrior's* specific consumption of 3·8 lb/IHP/hour at full power (FIG. 5) with Durstan and Milton's[2] criteria of 3·75 lb/IHP/hour as 'good performers' and 5·0 lb/IHP/hour as 'poor performers' places *Warrior* well up in the 'good performer' bracket.

Overall Assessment

Lloyd's priorities for naval machinery were well satisfied: *Warrior's* machinery was reliable, easily maintained, and of good performance but marginally overweight.

Discussion

Warrior was born in a sea of controversy. She was not the ship their Lordships wished for, but within two years of entering service no one doubted she was the ship the Navy needed. Evidence from the US Battle of the Ironclads in Hampton Roads (1862) promoted an early end to the controversy of hull materials; Isaac Watts and Thomas Lloyd, practising naval architect and marine engineer, under the leadership of their Head of Department, Admiral Baldwin Walker, had seen the Navy safely through the crisis.

Warrior revolutionized warship design and laid the foundation for successive generations of warships. But in this revolution there was sparse new technology; rather *Warrior* was the warship in which naval engineering in its various facets, theory and practice, first all came together in the professional integration of state-of-the-art technology into the largest, fastest and most formidable warship yet to be built.

The machinery installation was vital to the success of *Warrior* and credit for this must go to Thomas Lloyd and the engineers who operated and maintained her. Lloyd was an eminent, many would judge the pre-eminent, Naval Engineer of his day, particularly he was shrewd at getting his technical decisions in tune with the scenario and need of the day, a facility well illustrated in his decisions on the machinery for *Warrior*. Criticized as these were at the time, the success of *Warrior*'s machinery in service and the pace of development which it generated vindicate his decision. By the time Lloyd retired in 1869 the compound steam engine, supplied with superheated steam from cylindrical boilers and exhausting to surface condensers, was in service and the machinery for *Devastation*, the first twin screw and mastless vessel, was being built. Two years later *Warrior* completed her last commission before relegation to the First Reserve; within a decade she had been rendered obsolescent by the developments she had generated.

In achieving the subsequent advances of the 1870s it could be argued that the greatest single factor was the advent of mineral oils, for they permitted use of the surface condenser thereby providing the good quality feed water, (as opposed to sea water/condensate mix from jet condensers) as necessary for higher pressure and higher forcing rate boilers.

In the century which has followed, technology has continued to advance and ships have become increasingly technology-led but the fundamentals which Thomas Lloyd embodied in his department remain—professionalism, priorities, codes of practice, standards, testing and trials, Instructions to Engineer Officers have all stood the test of time. They have developed to accord with the evolving state of the art, sometimes blurred at the edges and shrouded in bureaucracy, but they have not fundamentally changed. Competitive tendering and through-life costing are also Victorian.

The same can be said of the professionalism of Engineer Officers, Artificers, (which Lloyd was instrumental in introducing in 1867) and Mechanics at sea. But, alas, Instructions for the care and operation of machinery, are no longer containable on one sheet of paper.

The advance of technology during the last century is readily illustrated by comparing *Warrior* machinery with currently available options of automated plant for the same duty as *Warrior* (FIG. 5 and TABLE VIII).

Insufficient data is available (to me) to remark on comparative reliabilities of the options, but the dramatic reduction in weight and significant improvements in fuel consumption are self-evident. As to costs perhaps the figures of most interest are, despite the scale of the reduction in complement, that people costs have changed but little. This is because in real terms stokers pay has increased by a factor of 11 to 12. The factor, however, diminishes with rank; for two star officers it is nearer to 50%!

TABLE VIII—*Comparison of 'Warrior' machinery with modern plant*

	Warrior (4·08 MW)	*Gas Turbine* (4·0 MW)	*Diesel* (4·5 MW)
Machinery weight (tons)	875	57	67
Cost machinery delivered dockside (£M)	2·01	2·225	1·09
Fuel weight for endurance as *Warrior* (tons)	853 (coal)	165 (Dieso)	116 (Dieso)
Cost of this amount of fuel (£)	23 630	13 365	9936
ER dept complement	93	8	8
Annual salary bill (£)	125 000	113 500	113 500

Costs are at 1989 prices

It is not without interest to note that the ship's operating profile under steam, economical steaming speed (40% full speed), range and machinery operation to achieve economy and minimize maintenance, are factors and means which have changed little throughout the life of steam-driven warships.

Our research and study echo the conclusion of other researchers that *Warrior* was 'one of the most influential ships ever built', to which we would add 'and, with Thomas Lloyd, holds a particular place in naval engineering history'.

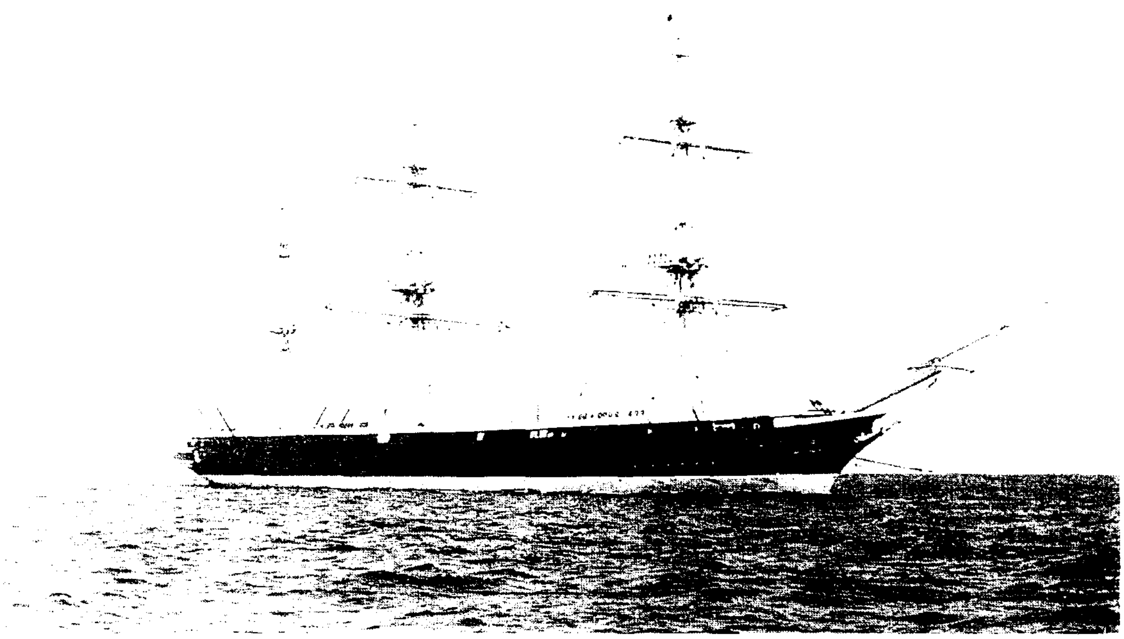

FIG. 6—HMS 'WARRIOR' IN 1987

HMS 'Warrior' 1860—The Final Word

After being paid off in 1883 *Warrior* remained idle on the effective list until 1902 when she became a depot ship for torpedo boat destroyers. Then in 1904 she was converted, which included removal of all machinery, for service at the torpedo school training ship (*Vernon III*). Finally, in 1929 she was towed to Milford Haven for use as a fuel pontoon hulk, where she remained until in 1979 she was transferred to the Maritime Trust for restoration at Hartlepool.

Today HMS *Warrior* 1860 (FIG. 6), restored to her first commission configuration, with her pristine stokeholds and Jimmy Wilson's* replica engine majestically turning at 2½ rev/min is one of the main attractions in the Maritime Heritage Area of Portsmouth Naval Base.

Gloire did not survive for restoration. She was put in reserve 11 years after launch and broken up in 1879, having largely 'fallen apart'.

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