MARINE ENGINEERING IN THE R.N. 1860–1905

PART III. BATTLE OF THE BOILERS

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ABSTRACT

The higher steam pressures needed by triple expansion engines were best provided by watertube boilers. The initial choice, the French Belleville, was beset by problems, not all due to its design, and a boiler committee was set up which, after trials, selected designs that were to remain in use throughout World War I. The advanced steam conditions led to problems in condensers which took several decades to cure.

Forced Draught

Pushing more air through the furnace enabled more coal to be burned per unit of grate area and hence increase the output of steam which, to the engineers of the day, must have seemed very close to something for nothing. The intention was to use natural draught for cruising, with forced draught available to give a short burst of speed when required. The torpedo boat *Lightning* (1877) was one of the first ships to use forced draught, burning up to 100 lbs/sq ft/hr. Warships used the 'closed stokehold' system in which air was supplied under pressure to the boiler room. In consequence, access had to be through an air lock and loss of pressure in the stockhold would lead to a very dangerous flash back. Hawthorn LESLIE built two cruisers for China in 1878 and the torpedo vessel *Polyphemus* (1878) had locomotive boilers in a closed stokehold; forced draught came into use in the French Navy at about the same time.

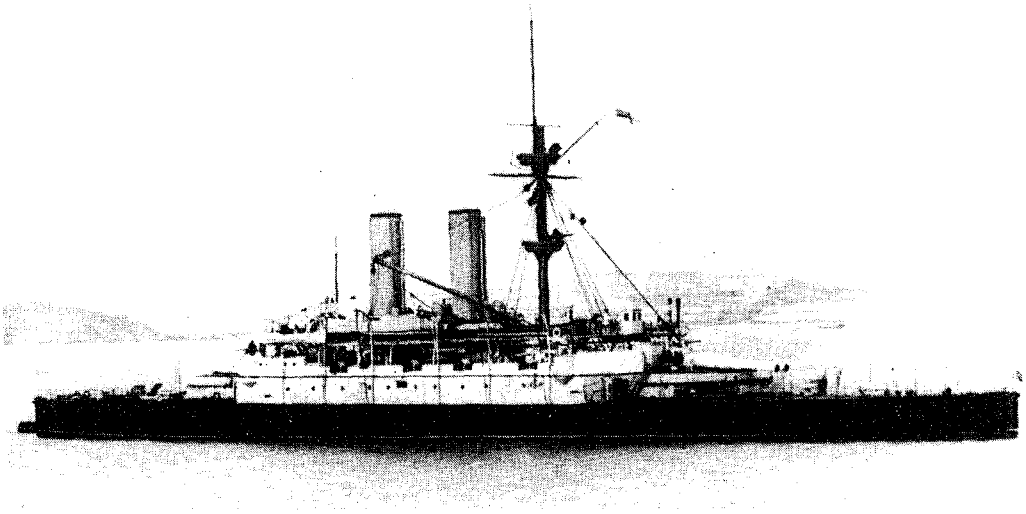

FIG. 1—'COLLINGWOOD', LAUNCHED IN 1882 WAS THE FIRST OF THE ADMIRAL CLASS, BRINGING A DEGREE OF UNIFORMITY TO THE BATTLE FLEET. SHE HAD TRIPLE EXPANSION ENGINES OF 9,600 ihp.

Collingwood (1880) (FIG. 1) was the first battleship with forced draught and, in her trials, the first of many problems became apparent. During her 6 hour full power trial, she reached 16.6 knots with 8369 ihp but, when forced, she made only 16.8 knots with 9573 ihp as the engines were unable to accept the extra steam. *Sans Pareil*, too, was disappointing. Hers was the only machinery contract offering a bonus for extra power, at £6 per additional indicated horsepower. She generated 14,482 ihp on trial, 4,000 above specification, reaching 17.75 knots while burning 45 lbs/sq ft of grate area but never reached anything like this in service. *Sans Pareil*'s short funnels were raised 17 feet to improve natural draught; it was estimated that 10 feet on the funnel would increase air pressure by 1/16 inch water gauge (wg).

Naval boilers were constrained in size to fit below the protective deck, with closely spaced tubes that restricted the circulation. They had a common combustion chamber with a relatively small heat absorbing surface, which led to high combustion chamber temperatures when forced, causing the tubes to leak. There was some improvement after 1889 due to increased use of separate combustion chambers and in 1892, the introduction of ferrules greatly reduced tube leakage. Even so, the use of full power, with forced draught, was 'generally attended with anxiety' and could not be maintained for long.

It was visualised that maximum power would be used only rarely and then for a comparatively short time. This was reflected in the conduct of contract trials which consisted of a 4 hour maximum power trial with forced draught (1 in wg air pressure), followed by 8 hours at maximum power with natural draught (½ in wg) which was 80% of that under forced draught; there was then a 30 hour trial at 50% maximum, known as continuous sea-going power.

ENGINEER REAR ADMIRAL BODDIE gives an interesting account of a full power trial in the *Golliath* in 1908.[27] For full power trials only, olive oil was the specified lubricant as it was superior to early mineral oils though these were adequate at lower speed. This particular trial was aborted when the starboard propeller shaft fractured. A trial later in the year was also abandoned when sea water entered the boiler.

WHITE[28] gave the following performance figures:

TABLE 6—*Forced Draught*

	Howe		*Medea*	
Condition	**ihp**	**Speed**	**ihp**	**Speed**
Forced draught, trials	11,600	16.9	10,000	19.9
Natural draught, trials	8,200	15.9	6,300	18.0
Continuous service speed	4,500	13.5	3,500	15.75

In service, there were periodic trials with 4 hours at maximum natural draught and 20 hours at continuous power. Maximum forced draught would only be used under favourable conditions, and then briefly.

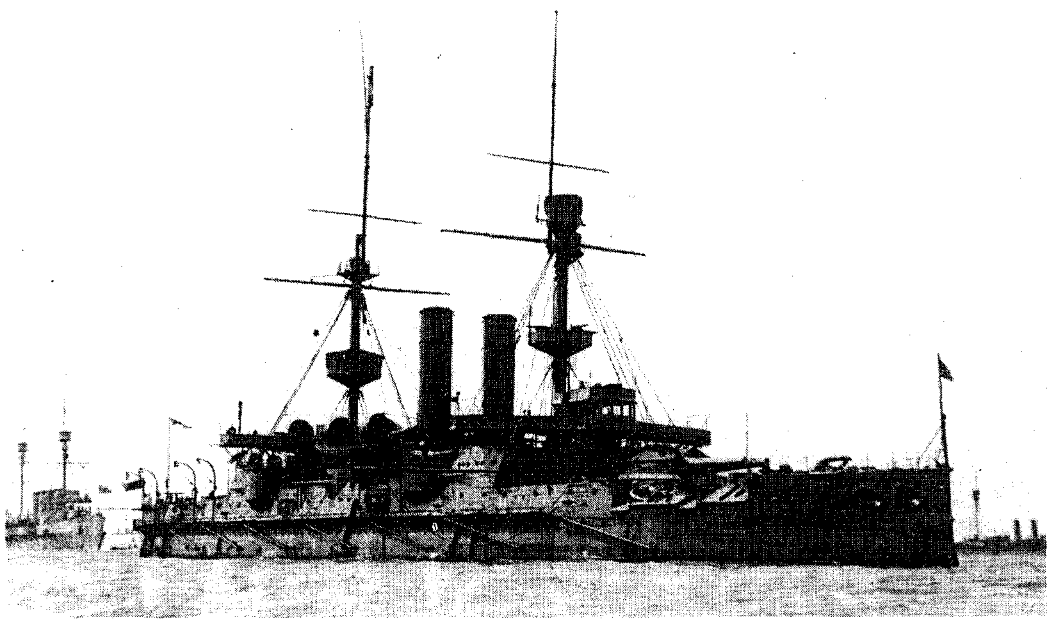

FIG. 2—'EMPRESS OF INDIA', THE ROYAL SOVEREIGN CLASS, DESIGNED BY WILLIAM WHITE, INTRODUCED A NEW ERA IN BATTLESHIP DESIGN. HER 11,000 ihp TRIPLE EXPANSION ENGINES WORKED AT 155 psi.

The *Royal Sovereign* (FIG. 2) was designed for 13,000 ihp (forced) at 108 rpm but it was later decided to adjust the valve gear for 11,000 ihp at the same revolutions. *Royal Sovereign*, herself, was tried at the original settings and developed 13,000 ihp, forced with 9,000 ihp at natural draught.

In general, one watch of stokers could develop close to the maximum natural draught power. In action, there would be two watches in the stokeholds who would have little difficulty in achieving a 20% increase in power for a limited period.

ADMIRAL FITZGERALD, writing in 1897 of the early 1880s said:[29]

> 'There was never a period during the development of boilers for warships when their general behaviour has been so unsatisfactory and when they have given so much trouble and been the cause of so much anxiety as during the past ten or twelve years. The cylindrical and marine type locomotive boilers have proved themselves unequal to the demands made upon them. Anything like rough usage, corresponding to war requirements, has caused them to fail.'

A boiler design committee was set up in 1892 to consider whether, in the light of these problems and the difficulty in maintaining the desired purity of feed water, operating pressures should be reduced. The committee took account of the fuel economy achieved by using triple expansion engines working at 155 psi compared with compound engines at 60 psi which was about 21% at full power and 18% at 1/10 power, (merchant ships claimed 25%). Triple expansion engines were also said to be smooth running and free of vibration (by the low standards of the day).

Clearly, such benefits could not lightly be thrown away and the committee concentrated on a number of detailed but important recommendations:

- Increased heating surface.
- Reduction in the pressure differential between forced and natural draught. (1 in wg for forced, ½ in wg for natural).
- Reduction in grate length.
- Separate combustion chambers in single ended boilers.
- Re-consideration of tube separation.
- External means of circulating water.
- Increased provision of distilling apparatus and fitting grease extractors.

They also recommended that two ships should be fitted with 'tubulous' boilers without delay. Ships ordered in the 1890s generally had boilers of larger dimensions and engines of more substantial construction than those of the Naval Defence Act (1889).[30]

Induced Draught

This involved sucking air through the furnace using fans in the uptake rather than blowing as in forced draught. The *Gossamer* (Torpedo gunboat) was tried with the Martin system on her two forward boilers and with forced draught to the after pair. The induced system needed considerably larger fans and their situation in the uptake was less favourable. There was no effect on boiler wear and tear, but the absence of air locks made communication much easier and the temperature in the stokehold was lower. In consequence stoking was better, leading to a reduced fuel consumption.[31]

As a result, induced draught was used in the *Magnificent* and *Illustrious* (1893). There was no difference in fuel consumption, the fans overheated and, as Belleville boilers did not need forcing, induced draught was not pursued.

Water Tube Boilers

The great advantage of water tube boilers for warships was seen as flexibility, the ability to alter rapidly the rate of steam supply, up or down. Valuable savings in weight and space were also expected and, since such boilers could be dismantled, large openings in the protective deck would no longer be needed. Water tube boilers had been tried by the Royal Navy many years earlier. In 1844 *Janus* had been fitted with watertube boilers of Lord COCHRANE's design and, though these were a failure, the design was further developed by his son and Cochrane boilers were fitted to *Oberon, Chanticleer, Audacious & Penelope* around 1865-70. Shore tests at Woolwich showed an 18% benefit compared with service boilers. It is said that the low steam pressure in use was unsuited to such boilers, as due to the high specific volume of steam they were unduly prone to priming and the design was abandoned, partly for this reason and partly due to difficulties in firing. PERKINS showed the value of very high pressures, 300-500 psi, and a boiler of his design was ordered for H.M.S. *Pelican* in 1875 but was not completed due to problems with a sub-contractor.[32]

There were a number of installations in the merchant navy from 1857, mainly by Rowan of Glasgow and by Howden but they proved difficult to maintain and were removed. Most of these problems were associated with lack of purity in the feed water.

The first successful watertube boiler in the Royal Navy were those installed by Thornycroft in the second class torpedo boat 100, completed in 1886. In 1891 it was decided to build the torpedo gunboat *Speedy* with similar boilers which had two lower cylindrical water drums connected by a large number of curved generator tubes, 1.25″ in diameter, to a steam drum above. The tubes entered the drum at right angles, above the water level, differing from most designs which used drowned tubes. *Speedy*'s carried out a long series of trials at sea during which the boilers were reliable and the greater flexibility of the machinery was amply demonstrated. A considerable number of Thornycroft small tube boilers together with similar designs by YARROW and NORMAN were used in torpedo craft. In 1889 J. I. THORNYCROFT produced the following table to justify the watertube boiler.[33]

TABLE 7—*Watertube Boilers ihp per ton weight*

	ihp/ton
Watertube boiler with all auxiliaries	68
Locomotive boiler, torpedo boat	48
Locomotive boiler in latest torpedo gunboat	43
Boilers in battleship *Anson* (cylindrical)	21.3
Boilers of P & O liners	16.6

As a result of a visit to France by the Director of Naval Construction, Sir William WHITE, it was decided in 1892 to fit Belleville boilers working at 245 lbs/sq in to the torpedo gunboat *Sharpshooter* in place of the existing, unreliable locomotive boilers. She ran a similar programme of trials to that of *Speedy*, including a number of 1,000 mile runs at different powers and her boilers were found to be reliable, economical, flexible in operation and able to maintain full power for long periods.

M. BELLEVILLE had tried his first watertube boiler about 1850 and by 1880 it had been very considerably developed (FIGS. 3A & 3B). It was used by all Messageries Maritime liners by about 1880 and after trials in the despatch boat

Voltigeur in 1879 and the small cruiser *Milan* in 1884-5 was generally adopted by the French Navy by 1889. A Royal Navy engineer from Jersey, Edouard GAUDIN, 'who could be mistaken for a Frenchman', was sent to Australia and back in a Messageries Maritime liner and his favourable report had much to do with the Royal Navy's selection of the Belleville.[34, 35]

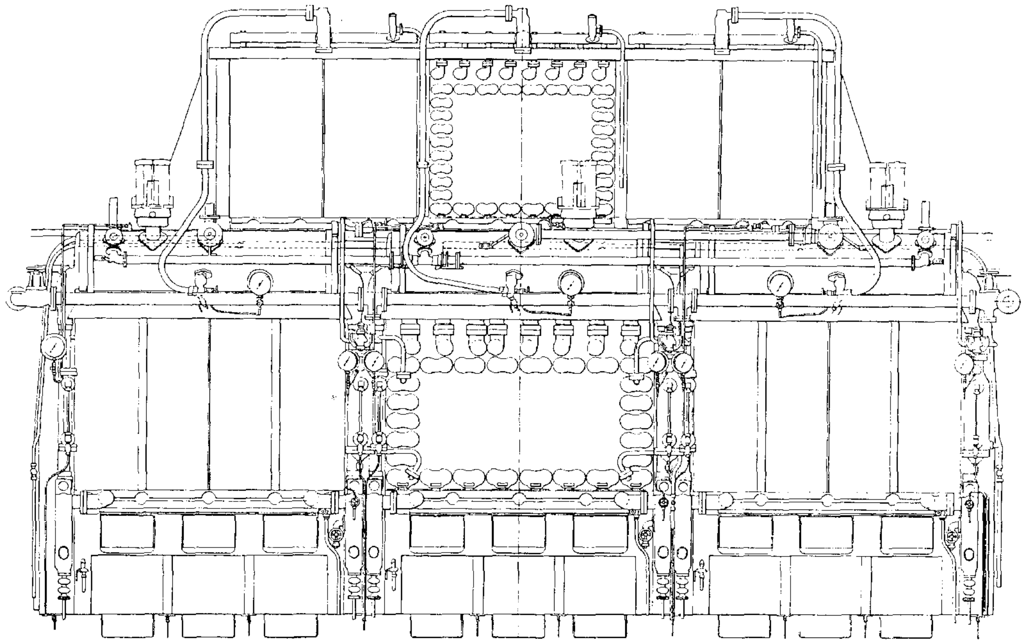

FIG. 3A—EXTERNAL VIEW OF A BELLEVILLE BOILER.
THE BELLEVILLE BOILER WAS THE FIRST WATER TUBE BOILER USED IN NUMBER IN THE ROYAL NAVY. IT WORKED AT 260 psi AND THIS HIGH PRESSURE CAUSED A NUMBER OF PROBLEMS FOR WHICH THE BOILER ITSELF WAS PERHAPS UNFAIRLY, BLAMED.

The Belleville was selected for the new 1st class cruisers, *Powerful* & *Terrible*, in 1892, without waiting for the *Sharpshooter* trial, and were to develop 25,000 ihp for short periods and 18,000 for 'as long as the coal lasted'. Each of the 48 boilers had 8 sets of 'elements'-groups of tubes-passing backwards and forwards ten times like a flattened spiral over the furnace and inclined slightly upwards. The mild steel tubes were 4.5″ diameter, with a thickness of 0.38″ (lower) and 0.19″ (upper) and a length of 7 ft. The ends of each group of tubes were screwed into malleable cast iron junction boxes, the lowest one being on rollers to allow expansion. At the top, the elements opened into a drum forming the steam collector. Lime water was introduced into the feed water precipitating solid impurities into a mud chest. Boiler pressure in *Powerful* was 260 lbs/sq in with 210 at the engine.

The trials in 1896 were very satisfactory, with consumption per ihp/hour of 2.06 at 20% power and 1.83 at 72%. The overall machinery weight was reduced due to the use of higher pressures but in the boiler room, the Belleville design showed a 20% saving over a cylindrical boiler plant.

Seamless steel tubes were used in all small tube boilers and their use was extended as larger tubes became available. Seamless tubes were first made in 1871 and became readily available as a result of the bicycle boom in 1884. *Powerful* & *Terrible* were retubed in 1900.

Bellevilles were adopted for all new construction battleships and cruisers but other large tube designs were tried in torpedo gunboats e.g. Niclausse in *Seagull* and Babcock & Wilcock in *Sheldrake*. Later Bellevilles were fitted with economizers, a small set of additional tubes above the main bank, giving a considerable reduction in consumption at higher powers.

TABLE 8—'Diadem' *1898, first with economizers*

% Power	lbs/ihp/hr
100	1.76
75	1.59
20	2.25

Note: Bellevilles developed full power with natural draught, not forced. To opponents of watertube boilers, this was seen as a weakness.

The Battle of the Boilers[36]

These excellent trials results were not repeated in service: there were some failures and many cases of excessive fuel consumption which were blamed on the Belleville though most problems were caused by leaks in the steam system associated with the high pressure rather than the boiler design itself. For example, *Hermes* in 1900 had to return home after only a year in commission, *Spartiate* in 1903 broke down on trials due to leaky condensers (discussed later) and bearing troubles. *Europa*'s passage to Sydney took 88 days, 58 under steam and 30 coaling due to leaky condensers and joints; hence an excessive consumption on the distillers, giving an overall consumption rate of 5 lbs/ihp/hr, and there were many other such examples.

From about 1900 there were attacks on the Belleville boiler in Parliament, led by Sir William ALLEN, and in the press, notably by the magazine *Engineer*. As a result the Admiralty were forced to appoint a committee of enquiry under ADMIRAL Sir Compton DOMVILLE into the use of watertube boilers. The only other Admiralty representative on this committee was Chief Inspector of Machinery, J. A. SMITH, the other members having a merchant navy or Lloyds background.

In their interim report of 1901[37] the committee saw water tube boilers as having important advantages:

- Ability to raise steam rapidly.
- Reduced risk of action damage to boilers.
- Easier to replace a damaged or worn out boiler as they could be broken down into small units.

However, they also listed the following principal defects which they saw in the Belleville, though SMITH disagreed:

- Defective feed water circulation.
- The necessity of an automatic feed 'of a delicate and complicated kind'.
- Feed pressure greater than the boiler pressure which, in turn, was much greater than the working pressure at the engines.
- False reading of gauge glasses.

They also raised a number of minor points which had caused trouble and concluded by saying that the cost of maintenance had proved much greater than that of cylindrical boilers. Finally, they suggested that the economizer tubes corroded very rapidly and that the extra power per ton given by the economizer was too dearly bought.

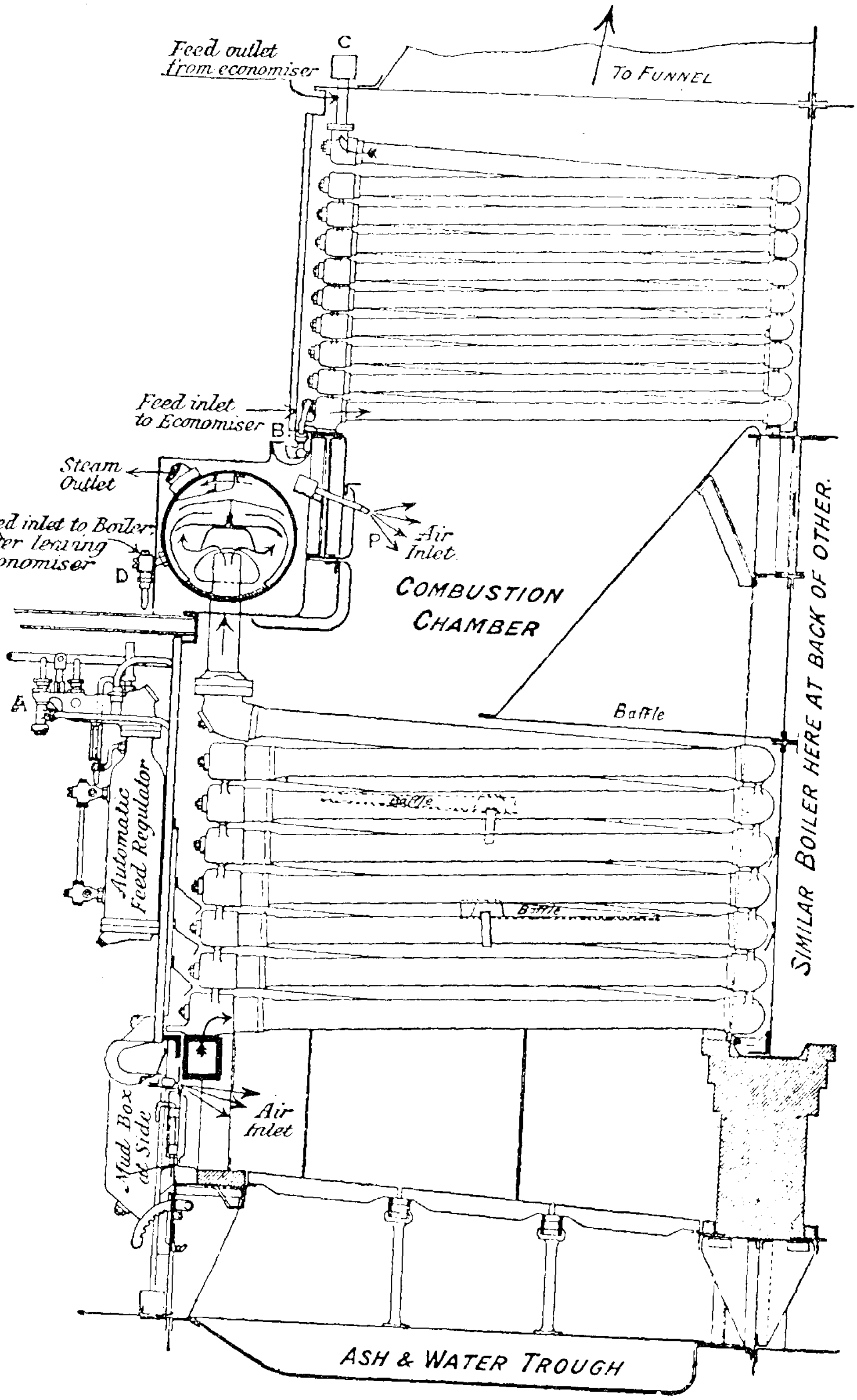

FIG. 3B—A SECTION THROUGH A BELLEVILLE BOILER.

They recommended that Bellevilles should not be fitted in new ships, unless they were already committed, and that Yarrow or Babcock large tube boilers should be used for battleships. They also recommended a mixture of watertube and cylindrical boilers, a policy adopted to a limited extent, and which proved to be one of many mistakes.

SMITH concurred in the report except for the recommendations saying:

> 'I am satisfied, from considerable experience, and from the evidence of engineer officers who have had charge of boilers of this type (Belleville) in commissioned ships, that it is a good steam generator, which will give satisfactory results when it is kept in good order and worked with the required care and skill'

He also pointed out the successful and reliable use of Bellevilles in the Messageries Maritimes ships. He agreed that other boilers should be tried but saw no reason to change in ships already designed for Bellevilles.

With hindsight, one would see that the committee was wrong on almost all these points: circulation was very good and the 50 foot travel of the steam and water which alarmed the committee was exceeded in most later boilers. The automatic feed of the Belleville was sensitive and needed careful operation but was basically sound. In general, the committee were opposed to automation in principle and preferred hand control.

In their final report, in 1904[38], the committee confirmed their earlier views and described trials with alternative designs of watertube boilers (discussed later). The most telling comment came in ADMIRAL DOMVILLE's covering letter to the report. He was by then flying his flag in the *Bulwark* with Belleville boilers.

> 'My experience with Belleville boilers on the Mediterranean station has been very favourable to them as steam generators, and it is clear to me that the earlier boilers of this description were badly made and badly used. We have had no serious boiler defect in any of the ships out here, and the fact that two ships are about to be recommissioned with only the ordinary repairs undertaken shows that their life is not so short as I originally supposed. However, the second commission of these ships will be a very good test of the staying power of their boilers'.

For ships with small tube boilers they recommended the Yarrow design but insisted that the tubes should be straight. To meet this condition, the lower drums were D shaped which led to many failures during World War I (known as 'wrapperitis'). During the war GAUDIN was asked to explain these problems to the First Lord, A. J. BALFOUR, who asked him:

> 'Who is responsible for this widespread defect?'

GAUDIN replied:

> 'You are, sir' . . . 'When you were Prime Minister, sir, you appointed a committee of people who knew nothing of naval boilers, to investigate. Amongst their recommendations they said 'All boiler tubes must be straight'. Hence the 'D' shaped drums and cracks at the junction of the tube plate and wrapper'.[39]

There were a few minor problems with the design of the Belleville but these were easily solved. Much of the problem with the automatic feed was due to a misguided attempt at economy, replacing the Belleville patent packing in the gland with a substitute. There were problems with the single anchor bolt holding the bottom of the tube elements to the feed box which required care rather than brute force in maintenance and there were also problems with the fusible plugs intended to blow if the water level reached danger point.

The real problem was there had been little attempt to re-train builders, engine overseers or the operators and there was not even a 'Belleville' handbook. Departure from the French operating procedures were permitted-or not noticed. Such problems were exacerbated by excessive efforts to save space making access for maintenance difficult while the higher steam conditions made the engine room very hot and steam leaks common.

With more experience, the Belleville became both reliable and economical in service: on *Terrible*'s (FIG. 4) voyage to China in 1902 she had averaged 11.8 knots burning 200 tons of coal a day but in 1904 she made the same voyage at 12.6 knots burning only 100 tons per day. Some elderly ships with Bellevilles

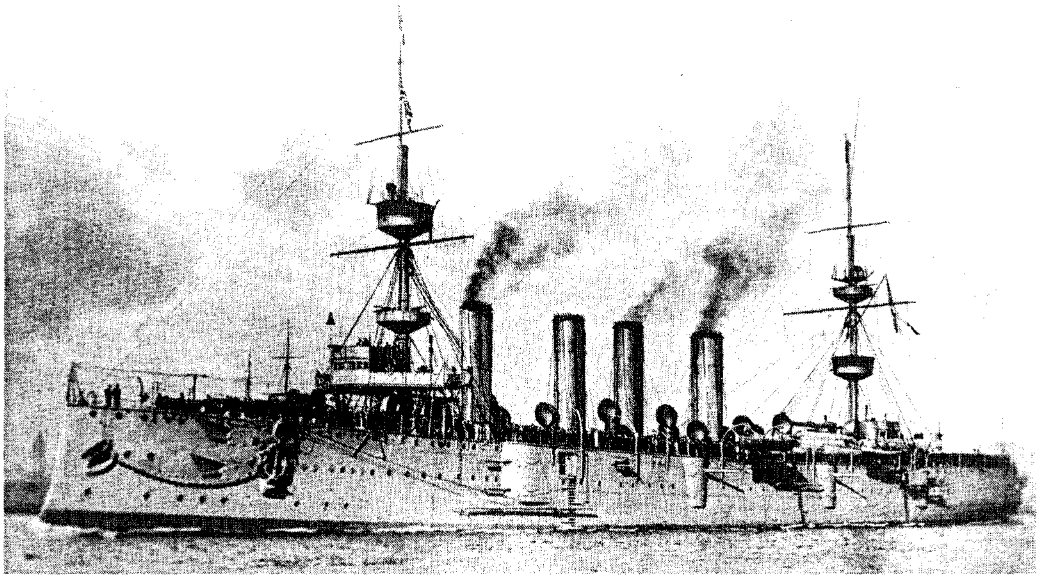

FIG. 4—'TERRIBLE', LAUNCHED IN 1895, HAD BELLEVILLE BOILERS TO PRODUCE STEAM FOR HER 25,000 ihp TRIPLE EXPANSION ENGINES.

served through World War I without undue difficulty while the last ship to use this type, the *Victoria* and *Albert*, retained them up to World War II. BODDIE notes that olive oil was used as late as 1924 in the Yacht and, like Belleville spares, was difficult to obtain.[40]

The 'Battle of the Boilers' was fought with considerable bitterness but was largely fought on points which were irrelevant. The problems lay in lack of training and in the detail design of a steam system, to accept higher pressures without leaking and these problems were largely overcome before the committee assembled. They were correct in suggesting trials with alternative designs but their detail recommendations were over conservative and led to problems in later years.

Alternative Designs of Watertube Boilers

The committee in its reports of 1901 and 1902 had recommended trials on the following alternative designs:

Babcock & Wilcox
Niclausse
Durr
Yarrow, large tube

and, in their final report of 1904[41] they concluded that, as a result of trials extending over nearly four years that the Babcock and Wilcox as tried in *Hermes* and the Yarrow large tube as tried in *Medea* were satisfactory for large ships. In the Babcock the steam generator tubes were nearly horizontal while in the Yarrow they were nearly vertical and only prolonged service would show which was better. They noted that other types might be worth trying in the future and made no recommendation on the type of boiler for torpedo craft.

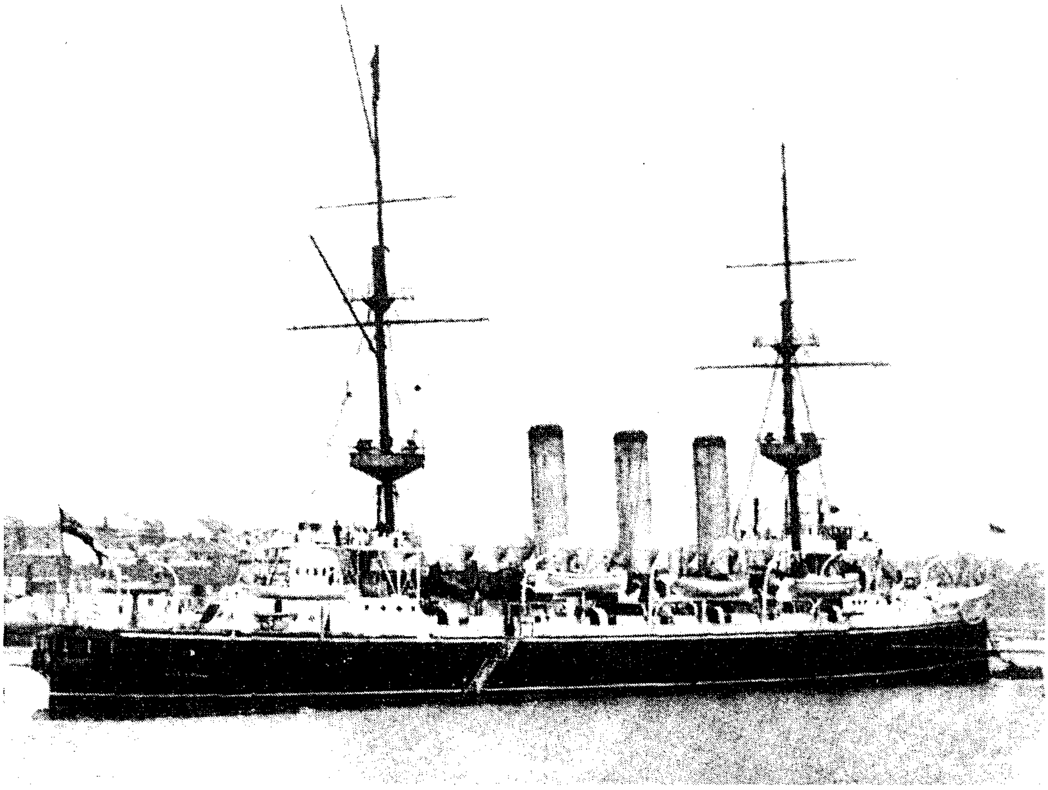

FIG. 5—'HYACINTH', LAUNCHED IN 1898, HAD BELLEVILLE BOILERS AND WAS USED IN A COMPARISON WITH ALTERNATIVE DESIGNS (TABLE 9).

Breakdowns during the trials of *Hyacinth* (FIG. 5) & *Hermes* reinforced the view put forward in May 1902 that stroke should be increased and rotational speed reduced compared with recent ships. The main results are summarised in Table 9.

TABLE 9—*Water Tube Boilers as fitted*

Ship	Type of Boiler	Wt of Boiler room Installation	Steam/hour 1000 lbs	Lbs steam/hr per ton Boiler room wt
Minerva	Cylindrical	558	156	280
Hyacinth	Belleville	454	179	394
Medea	Yarrow	330	158	478
Medusa	Durr	314	158	503
Hermes	Babcock	481	182	380
Sheldrake	Babcock	125	44	351
Espiegle	Babcock	95	25	261
Seagull	Niclausse	135	48	359
Fantome	Niclausse	77	23	297

The highest efficiency was obtained with the Babcock of *Hermes* which, at full power, burnt 21 lbs/sq ft of grate area over 29 hours with a thermal efficiency of 77.8% and was also quite efficient at lower powers. The Yarrow boilers of *Medea* and, indeed, the Bellevilles of *Hyacinth* differed little in efficiency but the Durr, Niclausse and cylindrical boilers were significantly less efficient. Trials in small ships showed that the Babcock design was still developing with improved furnace baffles. The Babcock and Yarrow also gave steam which was less wet and lost less feed water.

The committee paid considerable attention to ease of cleaning in which the Yarrow was clearly the best. All others were more difficult and the Durr and Niclausse needed more space into which the tubes could be withdrawn. There were also problems with the tubes bending seriously in the Durr and Niclausse. A trial was carried out in the Yarrow boilers of *Medea* in which the tubes were deliberately slightly bent and it was recommended that all future boilers should have tubes with a one inch bow. There was no significant corrosion in any of the boilers.

It was found that the Yarrow could be 'severely forced without danger' and that the Babcock to the extent shown in the detail reports. Somewhat more severe limits were imposed on the Durr and even more on the Niclausse. All watertube boilers needed more skilled stoking that did the cylindrical design though the Yarrow was the best due to its smaller grate and better design of combustion chamber. The committee also looked at the feed water supply and at the effects of contamination by salt and found no problems. ENGINEER LIEUTENANT W. H. WOOD was thanked for his work on behalf of the committee and his efforts drawn to the attention of the Board.

In World War I the Babcock and the smaller number of Yarrow large tube boilers proved very reliable though large and heavy compared with the Thornycroft-Schultz small tube used by the German big ships.

TABLE 10—*British and German Machinery*

	Dispt	SHP	Areas (sq ft) Boiler Rm	Engine Rm	Largest Space	M/C wt	Ship/Ton
Tiger	28500	85000	11900	6970	76400	5900	14.4
Hindenburg	26513	72000	9480	5110	36000	3632	19.8

The German machinery was described as cramped but the weight saving contributed much to their thicker side armour.

As mentioned earlier, the Yarrow small tube, used in smaller ships, was less reliable due to insistence on straight tubes. Following the committee's recommendation, boiler pressure was reduced from 300 to 210 lbs/sq in but was soon increased to 250 where it was to remain for many-perhaps too many-years.

Condenseritis

The original surface condensers introduced in the 1860s leaked so badly that one can hardly regard them as part of a 'closed' feed system. Over the years steady progress was made and in 1874 cast brass or gunmetal replaced cast iron for the condenser shell with brass tube plates. The tubes were of 70/30 brass from 1870.

Leakage continued to be a problem, becoming serious with rising steam pressure about 1890. Leakage could occur at the gland, or to the tube as a result of splitting or perforation by corrosion or erosion. The Admiralty's demand for higher standards was resisted by the tube manufacturers, then a craft industry,[42] but, under Admiralty pressure, improvement was made.

Gland leakage and splitting were virtually eliminated by improvement in the accuracy of fit and detailed design. Perforation was never cured and was to be a serious problem in World War I (and too common in World War II), but was reduced by metallurgical and other changes. In 1890, 1% tin was added and the copper used in the brass alloy had to be at least 99% pure. Dimensional accuracy standards were tightened and tests involving heating and 'jarring' were introduced. In 1894 another test was introduced to ensure that the tubes were sufficiently hard to stand up to packing when holding a 30 lbs/sq in water pressure.

Troubles continued and between 1894 and 1900 a requirement was introduced for boring and turning the tubes before the final draws to ensure concentric tubes. Further tests were introduced in 1901 and all tubes were to be drawn over a mandrel. In 1904 the test pressure was raised from 300 to 700 lbs/sq in (later to 1,000), surface defects were to be machined off the cast billet and tolerances on dimensions and on purity were tightened.

Up and Down

In the twenty years between the introduction of the triple expansion engine and its replacement by the turbine there were considerable reductions in the weight and space required by machinery. Steam pressure rose from 135 to 250 psi, piston speed from 700 to 1,000 ft/min (1300 in destroyers) and shaft rpm from 100 to 140. The most powerful reciprocating machinery for the Royal Navy was the 4 cylinder, twin shaft installation for *Drake* (1898) which developed 30,000 ihp.

There were steady improvements in balancing and forced lubrication, first tried in the destroyer *Syren* in 1899, and was used in battleships from 1903. Conditions in the engine room of a high powered, reciprocating engined ship were still frightened, noise, vibration-despite the improved balancing-steam leaks, hoses playing on hot bearings etc.; no wonder that ADMIRAL FISHER compared conditions with a snipe marsh:

A life in the engine room,
An odour of oil and grease,
A rattle of valves and rods,
Never a moment's peace. (Boddie)

Used hard, the triple expansion engine was never very reliable (e.g. frigates and corvettes of World War II[43]). In November 1905 the Second Cruiser Squadron steamed from New York to Gibraltar at 18½ knots. Only three of the six ships completed the run and all required extensive repairs to both engines and the hull whose rivets had been loosened by vibration.

Attempts were made to improve economy by cutting out cylinders at lower powers or, as in *Blenheim*, by using two engines per shaft, one being disconnected for cruising, but none of these schemes were found worthwhile. A superheater giving 50°F extra was tried in *Britannia*. Water measurement tests on both main and auxiliary machinery were carried out during sea trials from 1897. The first such trial in *Argonaut* was concerned principally with the main engine and measured water consumption under different conditions of jacketing, steam pressure and rate of expansion and ended a long standing debate by showing that the use of jackets actually increased consumption by 20%, a result confirmed by other trials in *Diana* and *Hermes*.[44]

The importance of using the exhaust steam from auxiliaries working with simple expansion was demonstrated and their exhaust was used in the main engines, in the evaporator or for feed water heating, resulting in much better economy in harbour and low speed cruising.

Auxiliary machines increased in number, size and in reliability. The Weir feed pump was introduced in *Magnificent* in 1884. The distillers introduced in 1867 were of limited capacity while the so-called double distillers of 1884 were still limited though giving better purity. From 1890 evaporators were installed which could meet the demands of watertube boilers.

FIG. 6—RICHARD SENNETT, ENGINEER-IN-CHIEF 1887–1889.
A BRILLIANT ENGINEER WHO RESIGNED TO GO INTO INDUSTRY BUT DIED SOON AFTER.
Reproduced by courtesy of RNEC Manadon

Sir James WRIGHT retired in 1887 '. . . a man who had lived through marine engineering since its commencement in warships' (William WHITE[45]). WHITE also wrote:

> '. . . he had adopted the course of fixing limits of space and weight, and fixing what he conceived to be the essential conditions to be fulfilled in the design in regard to the quality of materials, the factors of safety for the various parts and matters of that nature'.

Richard SENNETT (FIG. 6) then became the first naval engineer to become Engineer-in-Chief and he was also the youngest, being only 40 on appointment. He trained at the Devonport Steam Factory before going to the Royal School where he graduated in 1870. His career was a good mix of seagoing, dockyard and headquarters appointments, including lecturing at the new Royal Naval Engineering College which led to his book 'The Marine Steam Engine'. He was very highly regarded but resigned after only two years to join Maudslay; his health then failed and he died soon after in 1891. WHITE wrote of him[45]:

> '. . . a man who by what he had done and dared had helped the cause of marine engineering in many ways, and in a manner which had yet to be fully recognised'.

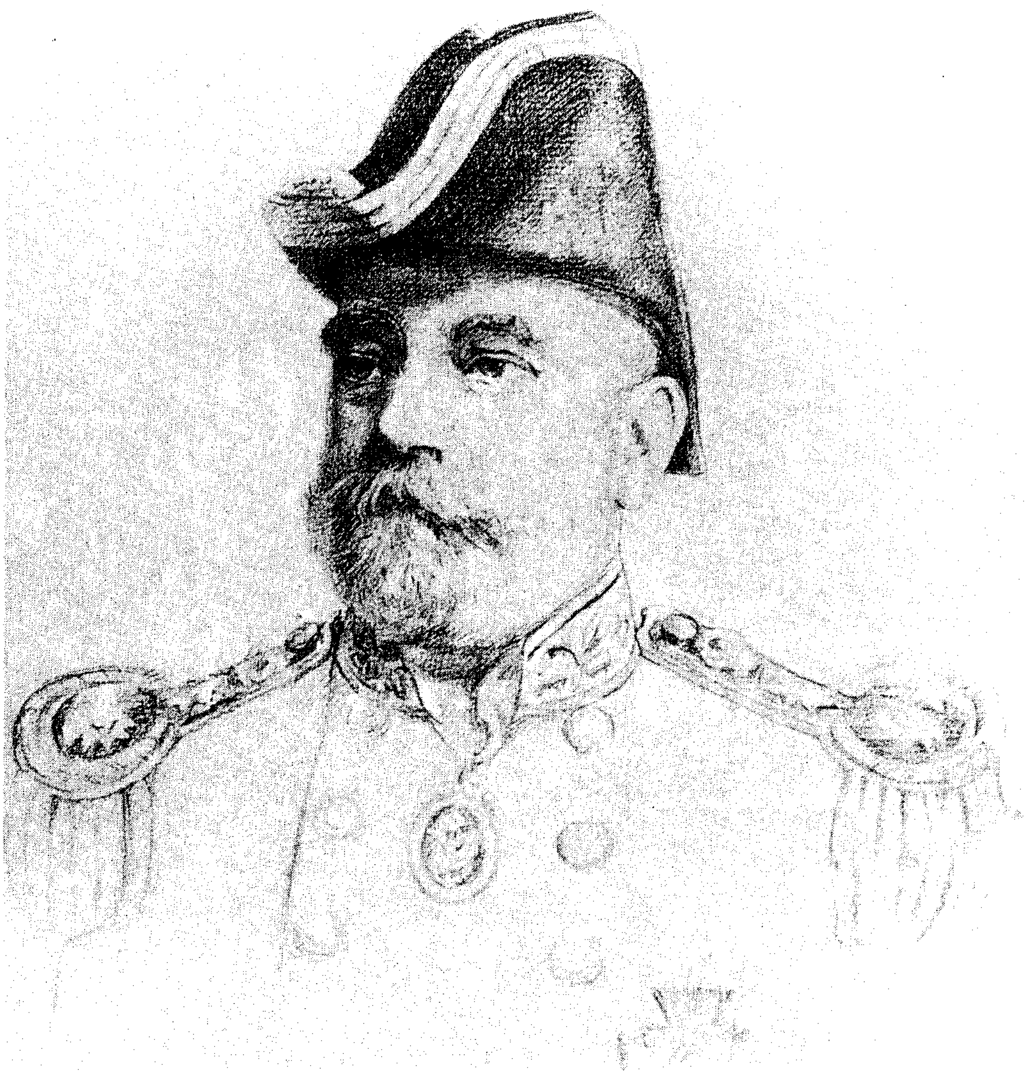

FIG. 7—ENGINEER VICE ADMIRAL SIR ALBERT JOHN DURSTON
BECAME ENGINEER IN CHIEF IN 1889
Reproduced by courtesy of RNEC Manadon

The next Engineer-in-Chief (1889) was Inspector of Machinery, later ENGINEER VICE ADMIRAL, Sir Albert John DURSTON (FIG. 7), another graduate of the Royal School, who led the navy into watertube boilers and turbines.

The Naval Defence Act Ships

Two papers by DURSTON[46, 47], describe in great detail the characteristics and performance of the machinery on the 70 warships ordered under the Naval Defence Act of 1889. Modern readers would be amazed at the detail revealed of the most modern ships and even the President of the Institution of Civil Engineers, Sir Robert RAWLINSON commented:

> '. . . he would not be at all surprised to learn that foreigners would be exceedingly pleased to have the opportunity of studying it. . . . he did not know that secrecy in any Department had ever served any State'.

On the other hand, he said later that an American had said to him:

> '. . . it is very generous of you to give us all this information; but I beg to tell you that we know it. There is nothing new. You tell us what you have done, but you do not tell us what you are doing now.'

The story was one of gradual refinement, most of which has been covered in previous sections. There were some interesting figures on the use of forged steel rather than cast steel for the engine columns showing that savings of up to about 10 tons per engine were possible. Mention is made of the successful introduction of forged steel liners in the HP cylinders and either forged steel or hard, close grain, cast iron in the IP and LP. Pistons were steel with wrought steel and phosphor bronze rings.

In service fuel consumption was close to that achieved on trial.

Ship	**ihp**	**Hours**	**Lbs/ihp/hr**
Royal Sovereign	8180	72	1.84
Royal Arthur	8821	72	1.85
Sans Pareil	7051	50	2.23
Sirius	4555	66	2.03

The discussion was lengthy with comments from industry, merchant navy operators etc. and there was very little criticism, about the only one being a suggestion that oil fuel should be adopted. To some extent, this lack of criticism may reflect a symbiosis between the Engineer-in-Chief and industry but there was no sign that the latter or anyone else saw the Royal Navy as technically backward.

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