MARINE ENGINEERING IN THE R.N. 1860–1905

PART IV. TORPEDOES AND TURBINES

BY
DAVID. K. BROWN MENG CENG FRINA RCNC
(*Consultant Naval Architect and Historian*)

ABSTRACT

Torpedo boats and destroyers were designed for ever increasing speeds which pushed the triple expansion engine to, or even beyond, safe limits. The Parsons steam turbine, backed by successive Engineers-in-Chief determined to overcome the difficult operating problems, was introduced in destroyers and, in a brave decision, rapidly adopted for the battleship *Dreadnought*. Experiments continued, with eventual success, into the use of oil fuel. From 1860–1905 the British Admiralty, in close association with industry, led in almost all developments in warship machinery.

Torpedo Craft

A limited number of HARVEY towed torpedoes were used by the Royal Navy around about 1870 but, in 1871, the Admiralty purchased manufacturing rights for the WHITEHEAD 'automobile' torpedo. The early, small torpedoes could be used from ships' steam launches which were carried by most big ships. Torpedoes were also launched from major warships and H.M.S. *Shah* was the first to use a torpedo in action against the Peruvian *Huascar* in 1877.

Initially, it was unclear what type of vessel was needed to launch torpedoes. The *Vesuvius* (FIG. 1) of 1873 was designed as a stealth craft; the twin shaft

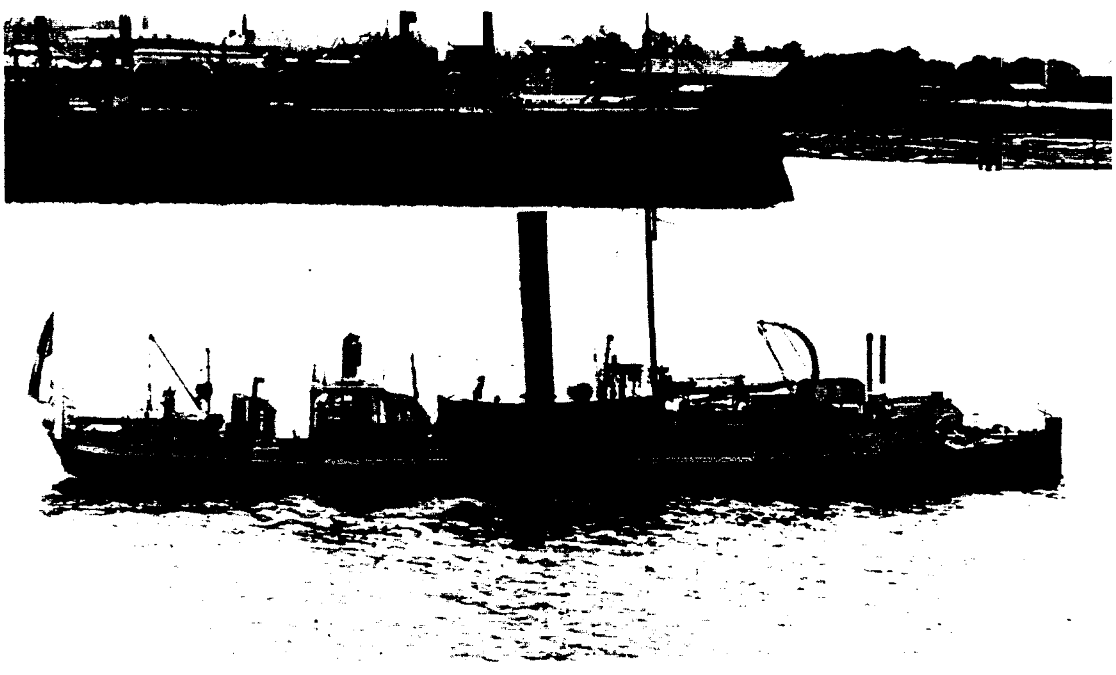

FIG. 1—'VESUVIUS' (1873) AN EARLY STEALTH CRAFT

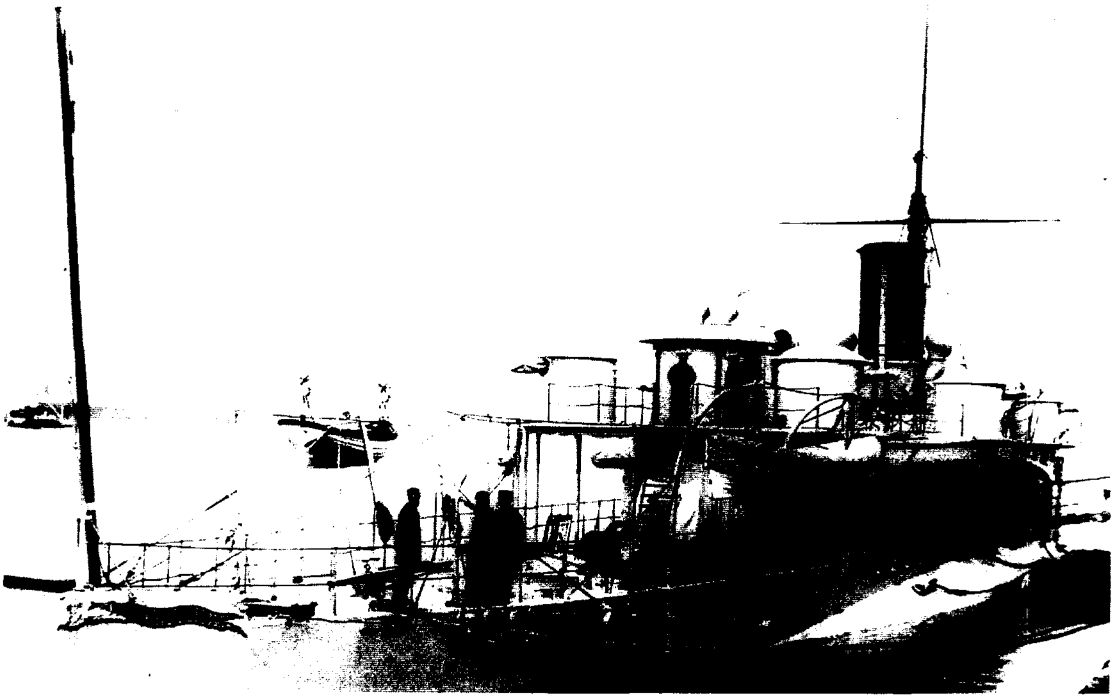

FIG. 2—'POLYPHEMUS' (1881)—A FAST 18 KNOT ARMOURED SHIP

compound engines were designed to be very quiet and burnt coke to reduce the release of smoke which was discharged through side ducts. Her speed of 9.7 knots was thought inadequate and it does not seem that she was ever even exercised in an operational role. A larger and faster version developed into the *Polyphemus* (FIG. 2) with a very low freeboard, cigar shaped hull the exposed portion of which was armoured. She carried 5 submerged torpedo tubes; the cap of the bow tube being a bronze forging which could also be used as a ram. During model testing, FROUDE found that this ram considerably affected the resistance of the vessel as it was, in effect, a bulbous bow. At 18 knots, (forced) she was a very fast ship for her day with two sets of compound engines supplied with steam from locomotive boilers in a closed stokehold.

However, the torpedo boat and the later 'Torpedo Boat Destroyer (TBD)' (usually now but not then abbreviated to destroyer) developed from the fast launch, *Lightning* (1876), rightly, or as many have come to believe, wrongly, putting the emphasis on speed. *Lightning* (FIG. 3) herself was of 32 tons with a

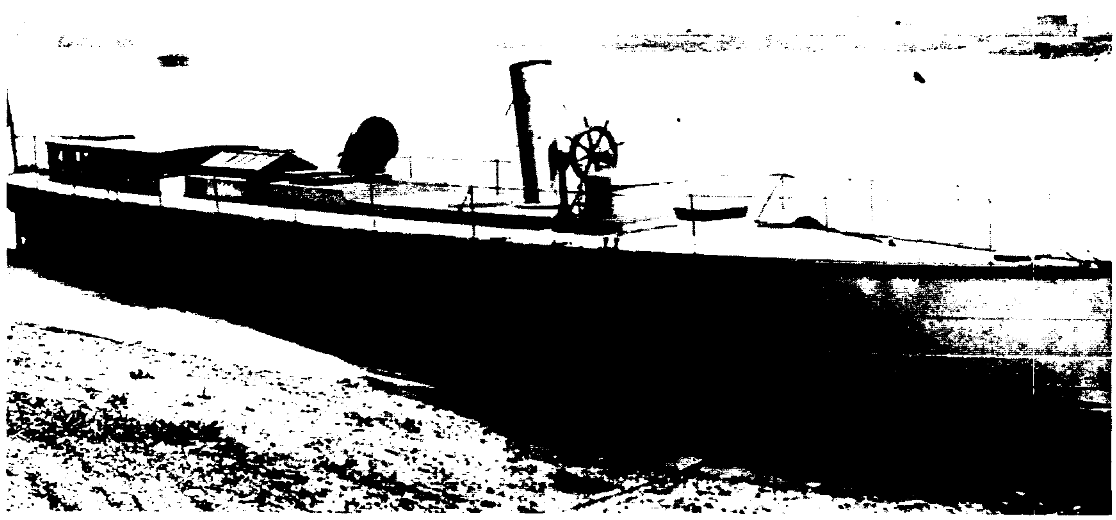

FIG. 3—THE TORPEDO BOAT 'LIGHTNING' (1876)

speed in calm water of 19 knots. She had one locomotive boiler with 525 sq ft of heating surface, working at 125 psi and a compound engine (cylinders 12¾", 21" dia., 12" stroke) which gave 400 ihp at 350 rpm for a wet weight of 10.8 tons. Many bigger and improved craft were ordered from a number of builders and by about 1885 a typical torpedo boat would displace 60 tons, have a trial speed of 20 knots and mount 5–14 inch torpedo tubes. Even bigger craft of up to 200 tons and 25 knots followed.

The similar torpedo boats of foreign powers, France in particular, following the doctrines of the so called '*Jeune Ecole*', built very large numbers of fast torpedo boats. Despite their lack of success in minor wars, these were seen by the Royal Navy as a serious threat. The first counter measures were the torpedo gunboats, miniature cruisers (700–800 tons), which could make about 19 knots on trial, though they lost much less speed in a seaway than the smaller torpedo boats. Most had locomotive boilers which, when forced, were unreliable and their speed in service was thought to be inadequate to catch torpedo boats.

There was an interesting paper by YARROW in 1891[48] in which he sought to show how the problems of leaky tubes in locomotive boilers could be overcome. DURSTON did not agree and thought the problems were more fundamental while J. I. THORNYCROFT, in congratulating YARROW on his ingenuity, said:

> "It really delays the day when we shall use a boiler which is better adapted to the purpose of forced draught." (i.e. watertube)

Attention switched to the TBD, said to have been conceived in a conversation between ADMIRAL SIR John FISHER and SIR Alfred YARROW in 1882, which were enlarged torpedo boats of higher speed and heavier armament. In 1892 two were ordered from Yarrow and two from Thornycroft. The first, *Havock* (FIG. 4), had locomotive boilers to hasten completion when she reached 26.1 knots on trial: while the other Yarrow boat, with 8 Yarrow watertube boilers made 27.6 and the Thornycroft boats had 3 of their watertube boilers, each with 3 water drums and one steam drum. *Daring* reached 28 knots.

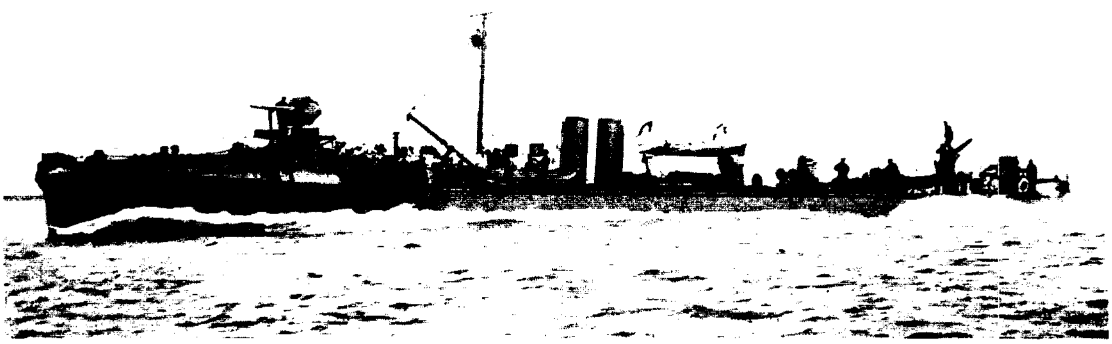

FIG. 4—'HAVOCK'—THE FIRST DESTROYER DESIGNED AND BUILT BY YARROWS. LAUNCHED IN 1893

In all, 42 generally similar destroyers, often referred to as the '27 knotters', were completed by 1896. They had a variety of boilers, mostly watertube, marked by funnels from 1–4 in number; all had triple expansion engines and two shafts:

Number of boats	Boiler design
6	Locomotive
10	Yarrow WT
8	Thornycroft WT
3	Blechynden
4	White
8	Normand
2	Reed
1	Du Temple

It was rightly said that a TBD or TB was a 'machine constructed to run a trial trip'. There was a financial penalty if the trial speed was below specification, rejection if much below. The penalty in early destroyers was £1000 per knot, about 2½% of the total cost, and there was sometimes a bonus for going faster.

Technology was pressed to the limit, and sometimes beyond, whilst every means of improving the trial speed, described in an earlier part, was employed. Thornycroft's *Boxer* was briefly the record holder at 29.17 knots but was surpassed by the Russian *Sokol*, built by Yarrows of HT nickel steel, which was the first past 30 knots. The leading French builder, NORMAND, responded with *Forban* which is said to have recorded 31 knots, though there must be some doubt about this speed as none of her sisters reached anything like it.

The Royal Navy followed with 60–70 '30-Knotters' of 310–370 tons and about 6000 ihp. Their trial speeds have little meaning as a report of 1900 gives the service speed of the 27 Knotters as 19–22 and that of the 30 Knotters as 26–27 knots, both in calm water. In 7 ft waves, 17 knots was an extreme speed, accepting damage, and 8–10 knots a sensible speed.[49] In one trial in a moderate sea a 27 knotter proved slower than one of the despised torpedo gunboats.

Many TBD had great difficulty in meeting the contract speed due mainly to cavitation losses on the high rpm propellers. This phenomenon was identified by PARSONS during the trials of *Turbinia* (later) and it was accepted that very much bigger blade area was needed under these conditions, but there was little theory or experimental method to guide designers until World War II. It is frequently suggested that PARSONS and R. E. FROUDE were in disagreement over the performance of propellers in the cavitating regime; this is untrue, their frequent and friendly correspondence, held at Haslar, makes it clear that, though PARSONS led in the work, there was no disagreement, but neither produced a useable design method.

TABLE 11—*Experimental Destroyers, Triple expansion engines.*

	Arab	*Express*	*Albatross*
Builders	Thompson	Laird	Thornycroft
Length, ft	227.5	235	225.5
Displacement, tons	470	465	430
Boilers	4 Normand	4 Normand	4 Thornycroft
Boiler pressure lbs/sq in	250	240	250
Grate area sq ft	296	264	248
Heat surface sq ft	16 080	17 020	16 020
Cylinders, diameter, ins			
HP	22	23	22
IP	33	36	33.5
2LP	35	38	36
Stroke ins	18	21	20
Revs/min	390	400	380
Indicated horsepower	8600	9250	7500
Machinery weight, tons	208	208	190
Speed, kts	30.9	30.9	31.5

Many destroyers ran trial after trial, with different propellers, before they achieved the design speed or the builders gave up. The ultimate reciprocating engined destroyers were three experimental boats ordered in 1896, intended to reach 33 knots though none exceeded 31½.

Vibration with fast moving machinery and cavitating propellers was very severe. The engines were the major problem as YARROW showed, in about 1884, by running at full rpm with the propeller removed. In 1892, YARROW showed in discussion of SCHLICK's paper,[50] that by fitting balance weights worked by eccentrics off the crank, shaft vibration could be much reduced. The engine of a 1st class torpedo boat had been fitted with two vertical 'bob weights' reducing the maximum amplitude of vibration at 248 rpm from 27/64″ to 7/64″. There is a pair of photographs, which unfortunately will not reproduce, of this trial. The torpedo boat is stationary with propellers removed, and without balancing makes a conspicuous wave pattern on the water; when balanced the waves are very small.

A destroyer's machinery at full power was an awesome sight with pistons moving at 1100 ft/min, cranks rotating 400 times a minute and steam leaking at 250 psi.

> 'There was heat, noise and vibration everywhere, while in the engineroom men worked in a smother of oil and water thrown off by the rapidly revolving cranks.' It was often a case of 'pour on oil and trust in Providence.'
>
> Anon.

Providence did not always prove worthy of such trust. *Foam* had a cylinder break in 1898, the connecting rod going through the bottom. *Bat* broke the bottom end bolt on a connecting rod and a piston came through the deck before falling into the sea. *Bullfinch* on trial in 1899 broke a connecting rod at nearly 30 knots which fractured a cylinder, the escaping steam killing 11 men. There was an interesting sequel; ERA 4th class, HOWARD was the first rating to be advanced by Board order.[51]

In 1904, *Chamoix* lost a propeller blade at high speed. The out of balance forces broke the shaft bracket and the whirling shaft ripped open the bottom, sinking her (FIG. 5). This led to the introduction of an involved, semi-empirical procedure for the design of shaft brackets, assuming one blade missing, which remained in use until the computer age.

The RIVER class of the 1901–2 programme were required only to reach 25½ knots on trial, at load displacement, but they had a high forecastle and a more robust hull enabling them to maintain speed in a seaway. The engines, too, were more reliable.

The Royal Navy ordered its first class of submarines in 1902, with petrol engines, but, as the history of submarines falls outside the time scale of this paper, they will not be mentioned further.

Electrical installations

Mention has already been made of the introduction of searchlights (1876) and internal lighting (1881). A little over a decade later DEADMAN[52] reviewed the progress made in electrical installations in the Royal Navy, pointing out that by 1892, all battleships, 1st and 2nd class cruisers and many other ships to a total of 300 had electricity for searchlights or lighting and usually for both. In reviewing this achievement, it should be realised that the Naval Estimates in the 1890s were very small.

Early dynamos, their engines and searchlights came from many different manufacturers, each to their own design, but gradually a common specification was evolved. The engines were usually from Willans or Brotherhood. Early dynamos suffered from poor insulation, often associated with insufficient care in manufacture, and from overheating of the armature. Dynamos were sited low down for protection, often in the engine room where the hot and humid

FIG. 5—'CHAMOIX' SINKING IN THE GULF OF PATRAS (1904)

environment contributed to these problems. Later ships had a 'peace' dynamo sited in a well ventilated space, high up. About 1890, D. W. LANE, the Electrician of Portsmouth Dockyard, designed and built his own dynamo delivering 400 amps at 80 volts. It was driven by a 56 ihp compound engine designed by J. T. CARTER, Chief Engineer of Portsmouth, the complete plant weighing about 5 tons compared with the 8 tons of earlier units and a number of these were installed.

Searchlights had been standardized at 24 inch (20 inch in torpedo boats) with parabolic mirrors replacing the dioptric lenses of the early sets. The mirror had to produce a sharp, cylindrical beam, must not crack if showered with sea water or rain and withstand the concussion of gunfire. The carbons had to produce a steady arc without flaming or excessive hissing. While the advantages of automatic feed were recognised, no satisfactory solution had been found; a point challenged in discussion. Both mirrors and carbons were purchased from France (then the potential enemy) as, despite trials, no English manufacturer could match their quality.

The original lighting circuits consisted of lightly insulated supply and return wires run inside a wooden casing. Failures of the insulation due to salt water were frequent, often setting fire to the casing. Lead covered cables had been introduced which were expected to make a great improvement. Lighting was not confined to the 'habitable' spaces but included store rooms and magazines. Instruments such as compass cards, telegraph dials as well as gun sights had their own illumination. Lane had also developed a switch board which was widely used.

Portable lighting was available on the upper deck for use during coaling. DEADMAN also pointed out that Portsmouth Dockyard's record of building more quickly and more cheaply than any other yard, Royal or commercial, was largely due to the extensive use of temporary lighting in both new construction and repair. This improved workmanship and supervision, as well as contributing to the health and comfort of the workmen. The cost of the temporary lighting in the cruiser *Royal Arthur* was about £1,200, little more than the cost of the candles used previously.

Electrical firing of guns had been introduced about 1874 and of torpedoes in 1879. Quite elaborate interlocks had been designed so that the firing circuit was broken if the breach was open or if the gun was trained outside safe firing arcs. Signal lanterns were in use but mechanical semaphores with illuminated arms were preferred.

A meeting was held in 1886 to set policy for internal communications and a number of trials were carried out. Electric bells to alert personnel to a call on a voice pipe were found very useful, but the telephones tried were not thought of value. Electric engine room telegraphs and helm indicators showed promise. Trials of electric motors for ammunition hoists etc. had been carried out but DEADMAN was 'not very sanguine' as to their immediate use.

During the discussion, several speakers suggested that the Admiralty could have moved faster, a view vigorously rejected by WHITE, the Director of Naval Construction (DNC), who blamed commercial equipment for many of the problems. In particular, WHITE drew attention to the Admiralty's efforts to develop and train both electricians and workmen in the new technology.

Another decade on, the FANE committee of 1901, in considering the work of the RCNC expressed satisfaction but recommended that an electrical engineer and two assistants be recruited. These appointments were made in 1903 but, regrettably, not into the Corps. The engineer was C. H. WORDINGHAM who up to 1918 made a great contribution to naval electrical engineering. When appointed, the latest battleship, *Formidable*, had 800 kW, a decade later the *Royal Sovereign* had 2400 kW. He introduced the ring main at 220 volts after it had been 'proved' that a 220 volt shock was unpleasant but not dangerous. (See also [53] and [54])

Turbines

The steam turbine was one of those ideas which occurred to many people, all at the same time, probably because materials and machine tools were available to make possible an old dream. The Honourable Charles PARSONS was the first to patent a workable design in 1884 and as all early Royal Navy turbines were of his design, other great designers will not be mentioned. PARSONS' earliest turbines were intended to drive dynamos (as in H.M.S. *Victoria* 1885) but in 1894 he set up the Marine Steam Turbine Company at Wallsend.

After some careful model experiments[55], he built an experimental steam yacht, *Turbinia*, now preserved at Newcastle. Her steel hull is 100 feet long and 9 feet in beam with a displacement of 44.5 tons. She had a watertube boiler with a grate area of 22 sq ft and 1100 sq ft of heating surface working at 210 psi with up to 12 wg draught. Initially there was a single shaft machinery installation with a radial flow turbine developing 960 shp at 2400 rpm. Despite many changes, she was limited to 19.75 kts by cavitation.

In 1896 she was re-engined with three parallel flow turbines, HP, intermediate and LP, each driving one shaft with three, widely spaced propellers on each shaft. She finally reached 34.5 knots with 2.230 shp at 2000 rpm on trials attended by Sir John DURSTON and Sir William WHITE, showing the keen Admiralty interest in this development. The following year, she was permitted to give a demonstration at the Diamond Jubilee review, steaming up and down the long lines of ships four knots faster than any other ship.

The Admiralty reacted quickly and in March 1898 ordered the destroyer *Viper* of 370 tons. Her specified speed was 31 knots but under the contract conditions of load and fuel consumption she reached 33.38 and, running light, completed a one hour run at 36.5 knots. *Viper* had 4 shafts, each carrying two 20in diameter propellers, the wings being driven by the HP turbines and the inners by LP. The inner shafts had separate astern turbines. At 31 knots specific coal consumption was 2.38, as good as the 30 knotters, but at lower speeds consumption was very high.

TABLE 12—*Coal consumption (lbs/hp/hr)*

Speed	*Viper*	Average 30 knotter
15	2.5	1.2
20	4	2.5
22	5	3.3

In service, *Viper* could make 26 knots with half her stokers at work and, using them all, 31½ for a short time, 30½ knots for half an hour. There was little or no vibration (by the standards of the day), steering ahead was good but, though there was plenty of astern power, she could not be kept straight and would circle.

ARMSTRONG built a somewhat similar destroyer for 'stock' which, despite an adverse survey report by Mr PINE, constructor, was purchased for the Royal Navy in 1900, subject to stiffening. Her four shafts each mounted three propellers, 12 in all, a record. It was decided that 48 stokers would be needed out of a total complement of 84 but she had accommodation only for 70 men. In June 1900 she made nearly 35 knots on trial. In September 1901 she broke in half on her delivery voyage (FIG. 6).[56, 57]

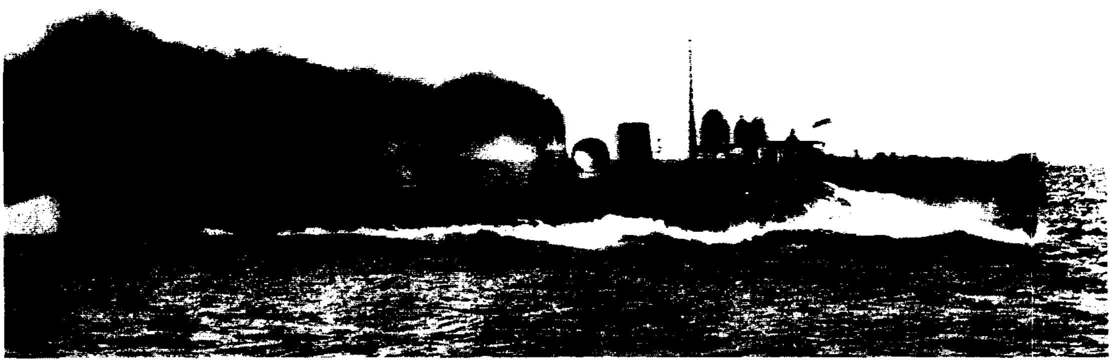

FIG. 6—'COBRA' THE SECOND TURBINE ENGINED DESTROYER (1899).
SHE BROKE IN HALF ON HER DELIVERY VOYAGE IN 1901

Velox was purchased in 1902 with:

4 shafts (8 propellers), the outers having HP turbines, the inners LP.

and:

Small reciprocating engines for cruising.

She was intended for 27 knots which she reached on trial (34½ light). Fuel consumption was very heavy even at full speed and the reciprocating engines which gave 10 knots were not very economical either.

Despite these problems, the Admiralty decided to order the *Eden* of the RIVER class with turbine engines in 1901. *Eden* had three shafts with two propellers on each, while her reciprocating sisters had 2 shafts and two propellers, running at much lower rpm. The cruising turbines were arranged with the HP on the port shaft and the LP to starboard. At speeds below 14 knots steam passed through the HP and LP cruising turbines and then fed into the main turbines. Between 14 and 19 knots, the HP cruising was cut out, steam entering the LP cruising engine and then to the main turbines. Above 19 knots, only the main turbines were used.

She could steam 3.39 nm/ton at full speed and 17.33 nm/ton at 13½ knots (12 hr trial), the latter figure comparing badly with the reciprocating boats which achieved 24–31 nm/ton under similar conditions. Later, she carried out a series of comparative trials with *Derwent*, also built by Hawthorn LESLIE.

TABLE 13—*Excess coal by* 'Eden' *over* 'Derwent' *in 4 hours at 20.5 kts*

	Tons
Average over 4 hours	4
First hour	1.5
Last hour	0.15

It seems that this trial was seen as encouraging for the turbine! The next step was the light cruiser *Amethyst* (Appendices I & II (Part 1)) which, tried against her sister *Topaze*, showed that development had made the turbine the more economical at speeds of over 15 knots. At the same rate of consuming coal, *Amethyst* (FIG. 7) reached 23.6 knots, *Topaze* 22.3 knots.

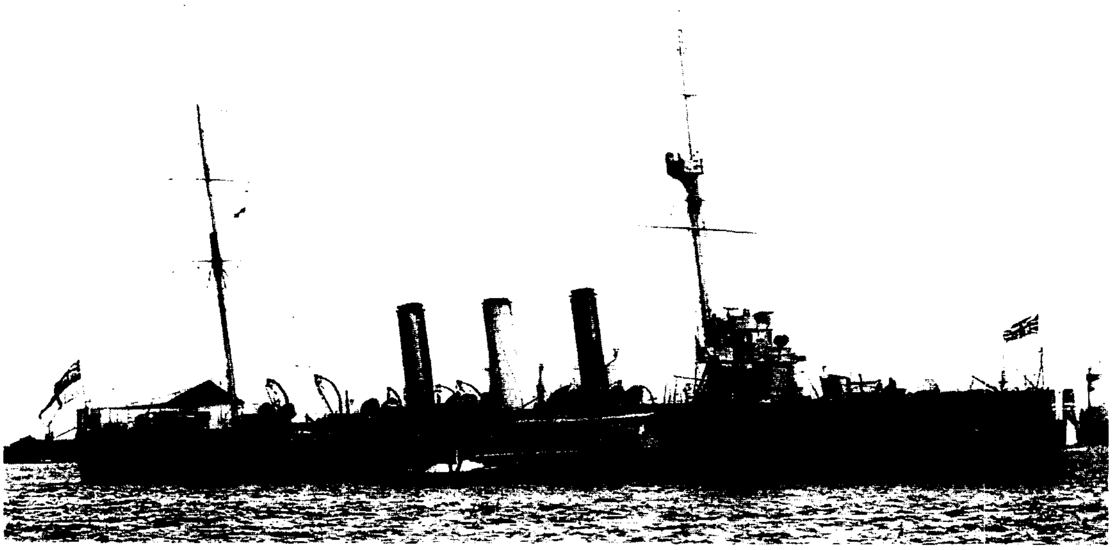

FIG. 7—TURBINES WERE INTRODUCED TO CRUISERS IN THE THIRD CLASS 'AMETHYST' IN 1903

'Dreadnought' (FIG. 8)

The early studies for FISHER's 'All big gun battleship' assumed triple expansion engines but ADMIRAL DURSTON pressed strongly for turbines despite the very limited and not very favourable experience. He was strongly supported by the new DNC, Phillip WATTS, who said:

"If you fit reciprocating engines, this ship will be out of date in 5 years".

There were still doubts over the astern power available from relatively small, high revving propellers but evidence from PARSONS, supported by R. E. FROUDE, showed that it would, at least, be adequate and the brave decision was taken to

FIG. 8—'DREADNOUGHT'—THE FIRST TURBINE ENGINED BATTLESHIP

install turbines in *Dreadnought*. Turbines offered a direct weight saving of 300 tons but, since such savings permitted consequential reduction in hull weights, the overall saving may have been nearer 1,000 tons. Indeed, it was only the savings in machinery weight and also the lighter hull that made it possible to build such a fast and powerful ship without a major jump in size.

Constructors had gradually been reducing hull weight at least since *Majestic*, partly by improved structural design and partly by an insistence on lighter fittings. Watertight subdivision, too, had been gradually improved up to *Dreadnought*. The loss of *Victoria* in a collision on the 22 June 1893 and the near loss of the other ship involved, *Camperdown*, showed that watertight doors and bulkhead valves could be very difficult to close after an incident, which might be a torpedo hit, and even if already shut were very likely to leak. In a paper of 1896 CAPTAIN Lord Charles BERESFORD listed the following numbers of watertight doors:

TABLE 14—*Watertight doors*

Ship	Compartments	Doors
Agincourt	29	17
ADMIRAL class	121	95
Royal Sovereign	187	148
Magnificent *	150	208

* CAPTAIN BERESFORD'S ship

In particular he drew attention to the hazards of the machinery spaces in which *Magnificent* had 19 doors low down in both longitudinal and transverse bulkheads. He pointed out that the French battleship *Jairegibery* had no such doors and necessary communication was by voice pipe. He accepted the need for doors into coal bunkers, even though it was often impossible to close them as the seals were blocked with broken coal. In discussion, WHITE made a somewhat unconvincing defence of the doors explaining that the navy had found them necessary and that, when closed, they were as strong as the bulkhead and fully watertight. Hindsight supports BERESFORD, but doors are still found low down in merchant ships and R.F.A.s.

In *Dreadnought*, the bulkheads were unpierced below a line 9 feet above the waterline and it was necessary to go up to a deck above this line and down again to pass from one machinery space to another; electric lifts being provided to make this less tedious for watchkeepers. A longitudinal bulkhead was fitted outboard of the magazines and machinery as torpedo protection, except in way of the wing turrets. With hindsight, it may be that it was not quite as good as it sounds. The longitudinal bulkhead was fitted with doors to the bunkers and the loss of *Audacious* in WW I showed that too many pipes did not have bulkhead valves.

Vickers were the main machinery contractors but the turbines were built by Parsons at Wallsend. She had four shafts, each with a single propeller, and had 2 LP, 2 HP and 2 cruising turbines on the LP shafts. Astern turbines were fitted to all 4 shafts.

Soon after completion *Dreadnought* went to the West Indies to work up and carry out some tests and on the way home she steamed 7,000 miles at 17½ knots without any difficulty. (Compare the 2nd Cruiser Squadron run to Gibraltar, mentioned earlier) A similar, and only slightly later ship had a machinery complement of about 7 officers and 224 ratings.

Oil fuel

The same committee on designs which initiated the *Dreadnought* also set out the design parameters for the first battlecruiser, *Invincible*, also with turbines, and for the TRIBAL and COASTAL destroyers. The two latter classes were to burn oil fuel and though the service use of oil falls outside the time scale, the development work which took place makes a forward looking end to this article.

Some very early trials had been carried out at Woolwich between 1867 and 1870 on a system devised by CAPTAIN SELWYN.[58] He used creosote sprayed over bricks in a furnace designed for coal and, though some success was achieved, work was abandoned when Woolwich closed in 1870. The amount of smoke made was claimed to be useful for smoke signals (obviously in the TRIBAL class!) At that time there was a requirement that any liquid fuel should be heavier than water so that it would sink if the tanks were damaged.

There was little point in working on oil fuel until it became available in quantity and nothing of significance was done until trials began under CAPTAIN DIGHT at Haslar in 1898. It was recognized that oil was very convenient to use and that it gave off 30% more heat than the same weight of coal. Great difficulty was experienced in designing nozzles which would give the correct fuel/air mixture for proper combustion and many of the early trials in the destroyer *Surly* (FIG. 9) (1898) covered Spithead in black smoke, a sign of inefficient combustion. These problems were solved and from 1909 all destroyers were oil fired, bigger ships following. Both in turbines and in the use of oil fuel, the Royal Navy was ahead of most major navies.

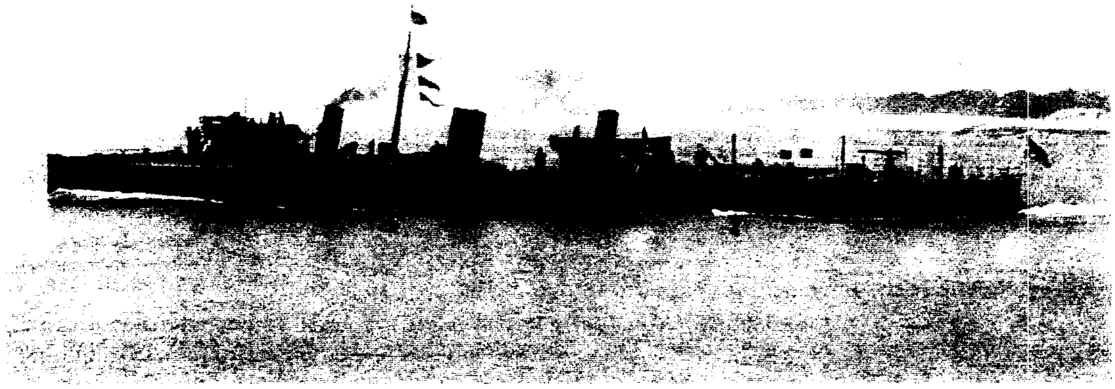

FIG. 9—'SURLY'—MAKING LESS SMOKE THAN USUAL

Standardization

From *Drake* (1904) onwards, considerable efforts were made to standardize components of machinery between ships of a class, making spares support easier.

Conclusions, hindsight and comment

The Royal Navy had been committed to an all steam fleet well before 1860 but by the 20th century both the installed horse power and the consumption of coal had risen dramatically.

TABLE 15

	1860	1900
Installed horsepower	541,000	2,985,400
Coal consumption, tons pa	100,000	900,000

This increase was driven by demand but was made possible by the skill and dedication of naval engineers; LLOYD, WRIGHT, SENNETT and DURSTON rightly take much of the credit but they had strong support.

TABLE 16—*Engineering personnel*

	1860	1900
Officers	1,092	970
Ratings	3,797	24,805

The successive changes from simple expansion engines taking steam from box boilers through compound and the triple expansion with cylindrical boilers to turbines and watertube boilers were well handled. The Admiralty's engineers supported development in industry, were quick in trying promising ideas and, by demanding specifications, forced the pace. New machinery frequently appeared first in merchant ships in experimental form but the Royal Navy was usually amongst the first to adopt successful schemes for general service and, in most cases, was well ahead of other navies, with a lead often measured in years, though in getting oil fuel into battleships the lead over the United States Navy was measured in days. The installation of machinery in warships was much more difficult than in merchant ships due to the limited headroom (FIGS. 10, 11 & 12). In the light of the Admiralty's success in designing and building ships it is a little surprising that they did not, at least officially, build engines—though one or two early refits bore little relation to the original. A full time test site or an Research & Development establishment would have been valuable.

The pace was quickening; at the end of this era and beyond, the introduction of the turbine was followed by oil fuel and gearing. A great deal of credit must go to the Woolwich Steam Factory which trained the earlier engineers and to the Royal School of Naval Architecture and Marine Engineering who taught the next generation. The day of Keyham was yet to come. It is probably a pity that the constructors became exclusively civilian and the marine engineers all uniformed, separating two professions who needed to work very closely together.

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(The numbering of the references is continued from Part III)

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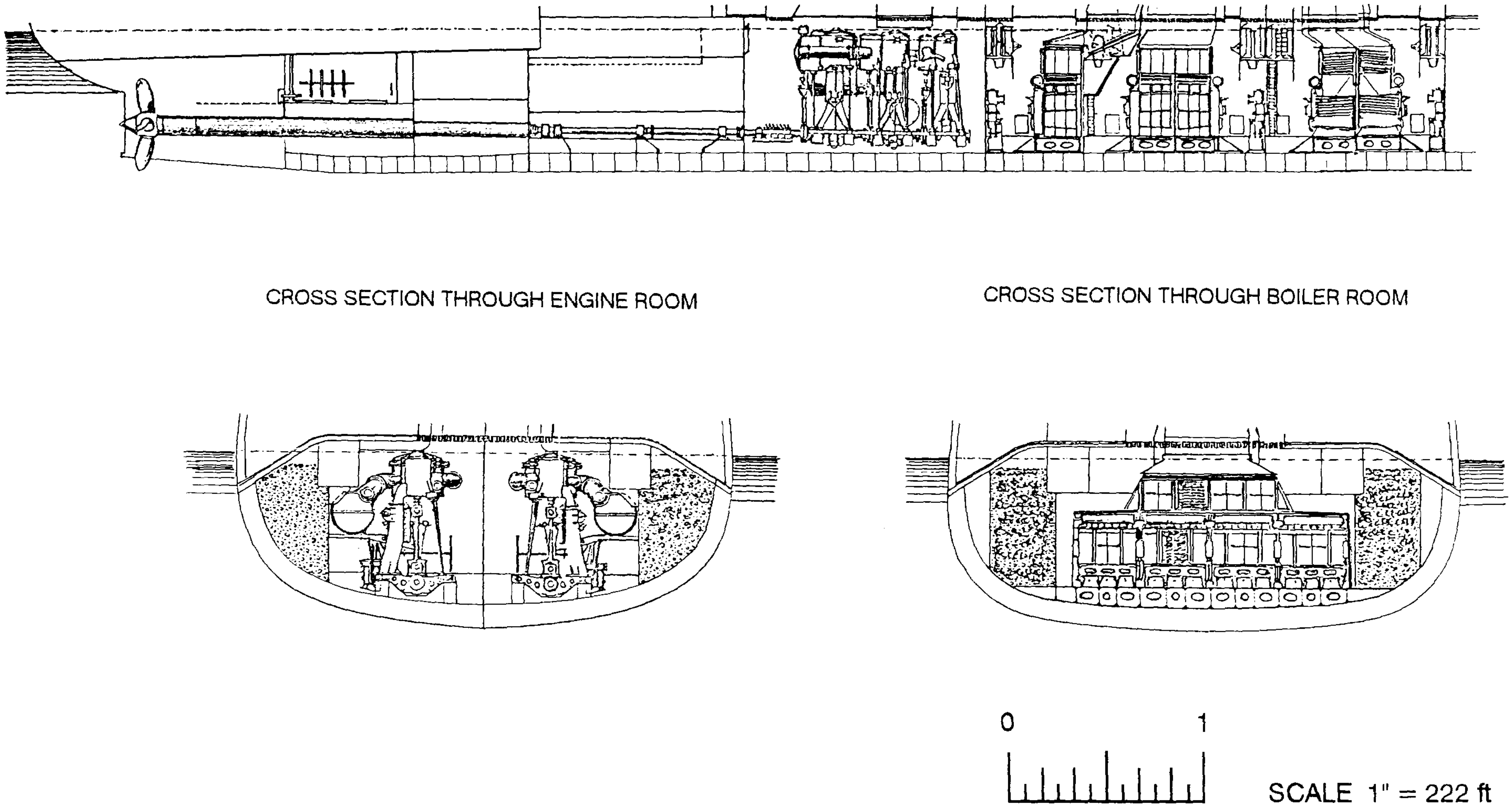

FIG. 10—'CANOPUS'—GENERAL LAYOUT (THIS AND THE TWO FOLLOWING FIGURES SHOW THE LIMITED HEADROOM IN WARSHIPS)
LAUNCHED 1898—ENGINE TRIALS 1899—TRIPLE EXPANSION ENGINES AND BELLEVILLE BOILERS

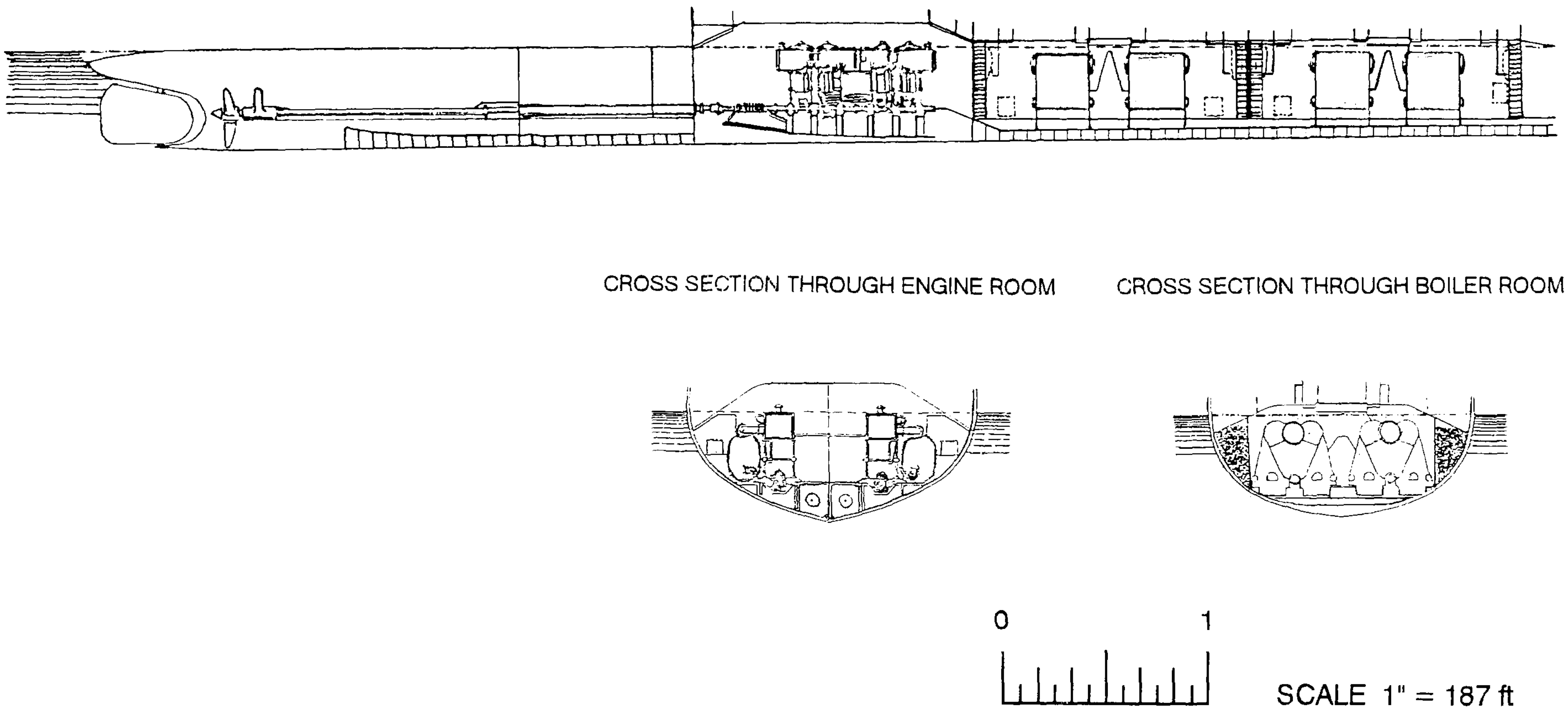

FIG. 11—'PIONEER'—GENERAL LAYOUT

3RD CLASS CRUISER LAUNCHED 1899—TRIPLE EXPANSION ENGINES AND THOORNYCROFT WATER TUBE BOILERS

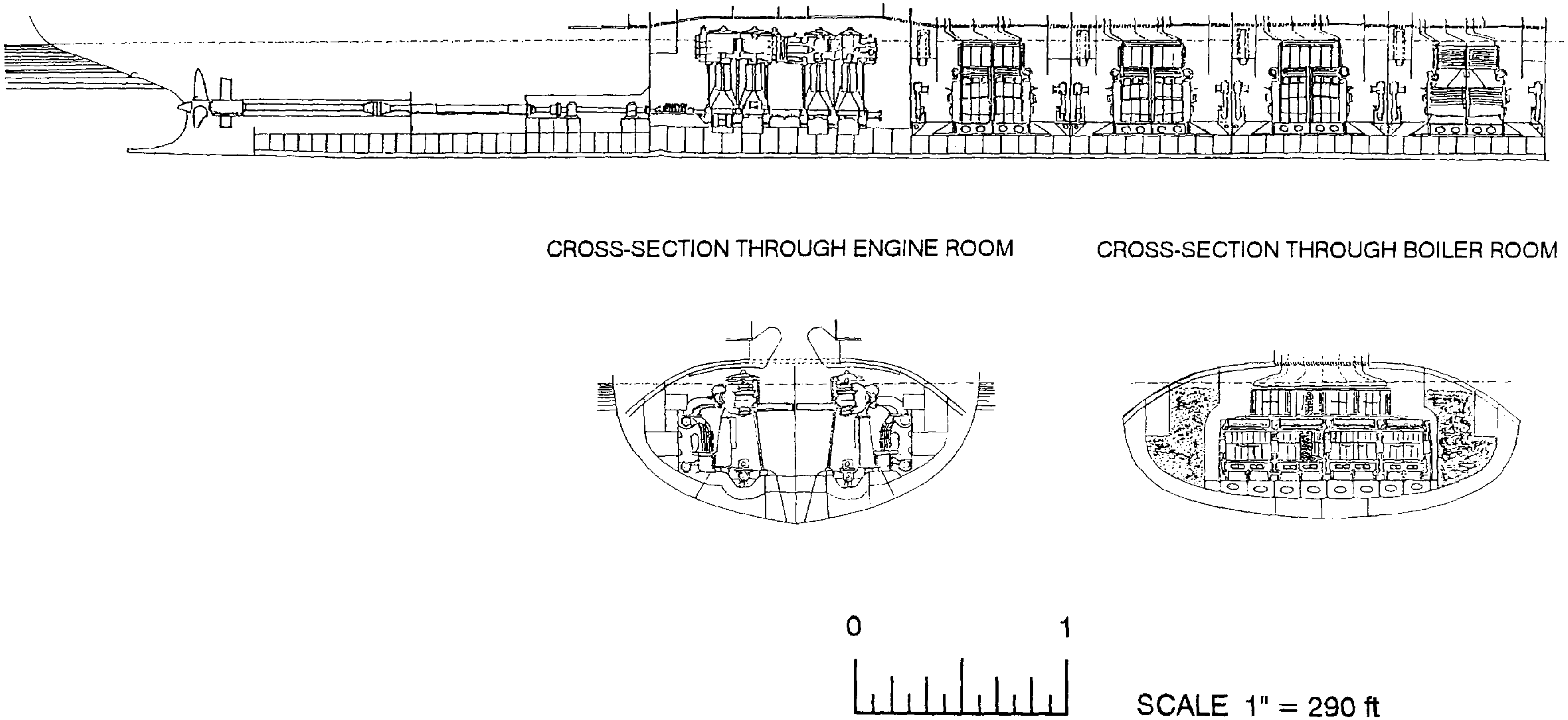

Fig. 12—'Argonaut'—general layout

Water measurement trials 1897—triple expansion engines and Belleville boilers