Fifty Years' Evolution in Naval Architecture and Marine Engineering.¹

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AFTER Watt's invention of the separate condenser, many years elapsed before the next considerable step in marine engineering—the introduction of the compound steam-engine. This was natural, as steam pressures were too low to make compounding profitable. The first record I can find of compounding was John Elder's *Brandon* in 1854, and progress thereafter was not very rapid; but when I began my apprenticeship, in 1876, the old box boiler had been replaced by the now highly appreciated Scotch circular return-tube boiler, supplying steam to two-cylinder compound engines at about 60-lb. pressure. It was not then found profitable to carry more than about 25 in. of vacuum. Auxiliary machinery was almost non-existent.

As to types of marine engines—in the Navy, for protection reasons, horizontal machinery was not uncommon, while in the mercantile marine, for screw ships, the vertical type was practically universal. In paddle-steamers for river and coast service, of which there were many, the beautiful oscillating engine, which had the advantage of taking up little room lengthwise, was still built; but the diagonal engine was more common, either with single cylinder and haystack boiler or compound two-cylinder.

Returning to sea-going vessels, the *Propontis*, a vessel built in 1864, was re-engined at Fairfield with triple-expansion three-crank engines designed by the late Dr. Kirk in 1874, with boilers working at 150-lb. pressure; but the boilers, Rowan's water-tube, proved unsatisfactory, and in 1876 new Scotch boilers of 90-lb. pressure were fitted. The first really successful triple-expansion three-crank job, the *Aberdeen*,² was built in 1880 by Robert Napier and Sons, and fitted with engines and 125-lb. pressure boilers designed by Dr. Kirk. The re-engining of the *Propontis*, however, marked the opening of a new era, which only developed slowly at first, due in some measure to the then rules for the thickness of the boiler shells and furnaces.

The next great step was the introduction of the Parsons turbine. None can forget the tremendous interest created by the appearance of the 34½-knot 100-ft. *Turbinia*, at Spithead Review in 1897. I felt that here was the engine we had been looking for to use in fast cross-Channel work, and it was a great gratification when Sir Charles Parsons and Captain John Williamson arranged with my firm that we should join in a venture to build and run a Clyde river-steamer fitted with turbines; the *King Edward*, put on service in the spring of 1901, was the result—the first commercial turbine. Before that, however, in 1898, the Parsons Marine Steam Turbine Company received an order from the Admiralty to build the *Viper*, and Messrs. Armstrong, Whitworth, on their own account, built the *Cobra*, engined by Parsons. Both of these were torpedo-boat destroyers, and the *Cobra* was purchased by the Admiralty.

Following the *King Edward* and *Queen Alexandra*,

the *Queen* for the Dover-Calais service and the *Brighton* for the Newhaven-Dieppe service were the first cross-Channel turbine steamers put in service in 1903. They also were most successful, and the turbine as a commercial engine was fairly launched, a great tribute to the genius of Sir Charles Parsons and his courage in overcoming the many initial difficulties. The decision, taken early in 1905, to fit turbines in the large Cunarders *Lusitania* and *Mauretania*, built by Messrs. John Brown and Messrs. Swan and Hunter respectively, was a very bold and momentous one fully justified by the success of these vessels; it was a tremendous step to take from the smaller vessels already built and tried, to these leviathans crossing the stormy Atlantic. In 1905 the Admiralty also decided on the general introduction of turbines in all classes of warships.

The earlier turbines were all fitted as direct drives and hence to vessels of fairly high speed, when the revolutions were not too low to spoil the efficiency of the turbine or so high as to spoil the efficiency of the propeller. But from the first it was felt that some means of gearing down the propellers was absolutely necessary; Sir Charles Parsons' conversion of the *Vespasian* in 1909 from reciprocating to geared turbine gave the answer required and marked another new era.

In 1897 Dr. Diesel began developing his internal-combustion engine, depending for the ignition of the charge of heavy oil not on electric sparks, hot tubes, or bulbs, but on the heat generated by compressing the air charge. Immense developments have taken place in this direction. Initially the greatest progress was made with this type of engine on the Continent. My information is that the first successful ocean-going motor-ship was the *Vulcanus*, built in 1911 by Werkspoor of Amsterdam for the Anglo-Saxon Petroleum Oil Co., while the first completed in Great Britain was the *Jutlandia*, built in 1912 by Barclay, Curle and Co.

While Great Britain may have been slow at first in taking up the Diesel, certain types—such, for example, as the Doxford and the Cammell Laird-Fullagar—are purely English. Another purely English one (which, being a combination of steam and oil, is exceptionally interesting) is the Still engine, of which that on the *Dolius*, built by Messrs. Scott of Greenock for Messrs. Alfred Holt and Co. of Liverpool, has been successful. The first double-acting four-stroke cycle marine engine in Great Britain was developed at the North-Eastern Marine.

While the turbine developed from the fast passenger-vessels direct driven, to the slow cargo-boat with gearing, the Diesel started in the slow cargo-vessel and is developing towards the faster liner, of which the *Aorangi* of the Union Steamship Co. of New Zealand, built this year by the Fairfield Co., is, at the time I am writing, the most notable example.

The foregoing is the briefest of brief outlines of the changes in the main engines of ships, but the development in auxiliary machinery has been of tremendous importance and extent. In no direction has advance been greater than in the use of electricity on board

¹ From the presidential address delivered at Southampton on August 27 before Section G (Engineering) of the British Association.

² Messrs. Augustine Normand, Havre, have now proved to me that Benjamin Normand fitted a Seine passenger steamer with triple-expansion engines in 1871, and fitted at least two more successfully before 1874.

ship. In 1884 the *Arava* and *Tainui* were fitted with incandescent electric lighting with stand-by oil lamps. The total power used was about 30 horse.

What developments there have been since then! Instead of the feeble 20 kilowatts, hundreds of kilowatts are now in use on a vessel of the same size, and the current is used not only for lighting, but also for ventilating, local heating, cooking, and for driving small machinery of all kinds, including frequently many of the important engine-room auxiliaries; in fact, in some vessels practically all the auxiliaries are driven by electric motors.

The fuel consumed in developing the power of these auxiliaries is now such an important proportion of the total fuel consumed that their design and installation is becoming, to a certain extent, a separate branch of engineering. To show the importance of a thorough study of this auxiliary-power question on board ship, I have been informed that in a large intermediate passenger-ship the consumption of fuel for auxiliaries is reported as exceeding 10 per cent. of the total consumption, and that 15 per cent. or more is not uncommon in some other vessels.

In types of boilers the development has gone from the old box form with safety valve opening inwards to prevent them collapsing when cooling, to the well-known and most extensively used Scotch marine circular boiler with return tubes. But always there were inventors working at the water-tube boiler, and several were constructed which proved successful. The Haystack was an early example, and those of Yarrow, of Thornycroft, and of Babcock and Wilcox may be named as types. In my own experience Yarrow and Babcock have each been used in fast cross-Channel steamers with absolute success, and, apart from the great user of water-tube boilers, the Royal Navy, water-tube boilers are being used increasingly in oversea merchant-ships. For land stations they are in great demand, fitted with mechanical coal-stokers or with pulverised coal or oil firing, in units of such enormous size and with steam pressure so high that steam drums have been built and used 34 ft. long, 4 ft. internal diameter, and 4 in. thick. Shall we see such boilers on board merchant-ships? I have no doubt we shall, though I would not care to express any opinion as to the ultimate highest steam-pressure which will be used, but 500 lb. is in sight.

Superheating of steam was early recognised as a very desirable thing, but it took many years to produce a reliable superheater, and then there were lubrication and other difficulties in reciprocating engines which had to be surmounted. In the case of turbines certain of these difficulties were non-existent, and turbines are peculiarly suited to the use of superheated steam. Another economical advance is pre-heating of air, which is now being pushed much further than ever, but with which the name of Howden will always be associated. Stage feed-water heating is also being very fully carried out.

Fuel-oil firing of boilers has been very largely adopted in steamships, with a marked gain in speed and, when oil is marketed at certain figures, with economy of cost as compared with coal, not only on account of its relatively smaller weight consumption, but also on account of the reduced crew required and the more regular

speed obtained, hence shorter time at sea. But in considering the relative advantages of steam- and motor-driven ships one must remember that an oil-fired steamship, in the event of oil soaring in price, may be converted to coal-burning, while in a motor-ship the owner has not that option.

As to powers developed by the main engines in any one steamship, from the 2000-3000 I.H.P. in good class passenger-ships of 1875 to the 75,000 I.H.P. we now find in the most powerful merchant-ships, or more than 140,000 in naval vessels, is a stupendous step.

Turning now to the ship herself and to naval architecture. I crossed to the United States to see ships' behaviour in heavy weather in December of 1882 in the *Parisian*, of the Allan Line, and returned in the same month by the *Alaska*. The latter was the "crack ship" at that time, and was 500 ft. long, the former was 440 ft. long, and they were considered enormous ships. The *City of Rome* was 560 ft., but was not so fast as the *Alaska*. They were all single-screw ships.

Mr. Foster King read a paper at Philadelphia, U.S.A., in 1912, in which he divided ships into three groups:

- (a) Atlantic passenger-ships (the longest ships).
- (b) Passenger-ships on all other routes.
- (d) Cargo-ships.

He obtained from the owners and registry books particulars of thousands of ships, and plotted them on diagrams on a base of years and with lengths of ships as ordinates. From these diagrams he concluded that the growth of "the largest ships in the world" might be fairly represented by straight lines in each group; that group (a) ships grew at the rate of 66 ft. in ten years, and group (b) 50 ft. in ten years. He observed, however, that after 1897 special vessels in (a)—namely, the fast Atlantic ferry—grew much more rapidly, at the rate of 150 ft. in ten years. For cargo-vessels (d) the rate of growth was about 30 ft. in ten years.

Taking Mr. King's (a) line, in 1875 the longest ship was about 475 ft., while, owing to the above-mentioned offshoot of the Atlantic ferry-boats, in 1912 it was round 900 ft. The *Majestic*, the present longest ship, is 915.5 ft. Reading from the (b) line, in 1875 the longest ship was round about 425 ft. In 1912 it should have been 610 ft., but was actually 570, and he remarks in explanation that "one of the usual pauses was occurring." The *Oronsay*, on the Australian trade, is the present longest (b) line boat at 633.6 ft. The *Empress of Canada*, on the Pacific, is 627 ft. long. As to cargo-ships—general traders—in 1875 a 3000 dead-weight carrier was a large ship; the more usual size was 2000-2500 tons. Now, 7000 to 8000 is the ordinary size, 10,000 is not uncommon, and many exceed that latter dead-weight.

In dealing with the growth in breadth of ships, Mr. King remarks that about 1875 the fashion in passenger-ships was about ten beams to length, but that after 1880 proportionate breadth became rapidly greater. An analysis of data available to me confirms this view, and that it is not now uncommon to find a proportion of eight beams to length, or even seven and a half.

The draught increased along with the increase in length, and the ports were constantly improved in depth, while new dry docks and floating docks kept

pace. Perhaps no better example can be given than the port of Southampton with its "longest in the world" floating dock.

Increase in draught is usually the most economical way of increasing carrying capacity or speed, hence the desire of naval architects for ample depth in ports and canals. When a curve of draught for the same proportion of depth to length is drawn with length as a base, it is seen at once that draught is proportionately less for the longer ship, and, as Lloyd's original tables were based on the current practice of the day, it is to be presumed that practical sea experience is responsible for this. Mr. Foster King's 1912 analysis of practice, as might be expected, shows the same thing. In the early 'eighties, however, experience was limited to about 400 ft. in length, and subsequent experience has shown that these and the longer steamers might safely be loaded deeper than the original rules contemplated.

Let us now turn to consider the change in the provisions for the comfort and convenience of the passenger. In the earlier days of steamships the first-class were in a poop, and the accommodation was very much in the style of the old sailing-ship—a row of cabins at each side with the dining-tables in the centre. There was an open-ended bridge and a fore-castle, where the officers and men were accommodated. Gradually, in later vessels the poop joined the bridge, and then the bridge joined the fore-castle, and the vessels became awning-deckers or spar-deckers. Then in later ships fore-castles again appeared, and midship houses developed into bridge-houses; then poops were fitted, to go once more through the same programme. Thus, as size increased, deck after deck has been added, until in the largest vessels the old names of bridge, upper, main, lower, and orlop no longer suffice, nor are they truly descriptive, and the decks are lettered A, B, C, D, etc.

The navigating bridge of a modern high-class steamer is an inspiring sight, with gyro compass probably fitted with an automatic quartermaster, "tell-tales" from the engine-room giving the revolutions of the engine and the direction of turning, similar "tell-tales" to the rudder head showing the angle of the tiller; the steering gear, now fitted aft, is controlled by a "telemotor," first invented by A. B. Brown of Edinburgh; wireless rooms, wireless direction-finder, and it may be underwater microphones for finding the position from underwater land bells; probably an outfit of telephones communicating from the bridge to the various chiefs of departments; automatic indicators showing the water in all holds and ballast tanks, and means for closing all water-tight doors below deck in event of fog or collision.

Returning for a moment to the cargo-steamer—I have already dealt with the growth in size, but there are many other changes in these ships. Sails having practically disappeared, we find the place of masts taken by Samson posts and ganties; indeed, very many modern vessels, built for special trades, look more like a building berth in a shipyard than a sea-going steamer. The equipment has much improved both in the engine-room and on deck, and cargo appliances are quite different. But an important change is in the question of fullness of

block. For a considerable time the shipowner seemed to think in terms of £'s per ton dead-weight. This inevitably led to fuller and fuller blocks, until 0·83 was not uncommon; result—a low speed and a great uncertainty as to date of arrival at a port if any bad weather was encountered. Of course, block must be coupled with length, for the longer ship may have a fuller block, but round 400 ft. a block of 0·76 is now much more fashionable, with the result that, while the dead-weight lifted at one time on the same length of vessel is less, yet the higher speed and the greater regularity of time on the voyage, due to the ability to keep up a reasonable speed in bad weather, make the finer vessel a more economic proposition.

A most interesting and important type of special trader is the bulk-oil carrier or oil-tanker, which has developed quite a special technique in design, construction, and fastenings. Originally oil was carried in cases, but, starting with quite small bulk-oil carriers, we now find oil-tankers among the mammoth dead-weight carriers of to-day. Bulk grain, coal, and especially ore carriers, involve also quite special considerations in stability, and strength to resist concentrated loads in the last mentioned, of which type the highest development is to be seen on the Great Lakes of North America.

I have not referred at all to the tremendous changes which have taken place in the Royal Navy; that in itself would take more time than I have at my disposal. In main engines, however, the lines of development have been much the same as in the mercantile marine, while in the vessels themselves their purpose is so different that no comparisons can be drawn. But their design has not been without its influence on the merchant-ship in many details, and there are several directions in which the work at the Admiralty has had a commanding influence on naval architecture in Great Britain.

We may now turn to the technical training of the marine engineer and naval architect. Until the founding of the John Elder chair of naval architecture and marine engineering at the University of Glasgow, the technical education available to apprentices in private works was provided practically entirely by evening classes under the South Kensington Science and Art Department. Many of those men who, for at least a generation, were responsible for the great strides made in the technical efficiency of the twin industries received their professional education at these classes. These classes are still doing good work. Of course even before special chairs were established, B.Sc. courses in engineering were open to students, but only a few bursary or moneyed students could take advantage of them. For generations the Royal dockyards have taken care of the technical instruction of their apprentices, and schools for their instruction were, and are, at work in every dockyard. I can only stop to note the foundation of the Royal School of Naval Architecture and Marine Engineering at South Kensington. The best students from each dockyard were sent there for the first time in 1864, to receive a training in higher science and mathematics of a severity unmatched in any college.

Without proper technical education an efficient corps of designers and of research workers could not be main-

tained, and considerable and important has been the research work guided by the Admiralty, by our technical institutions, by Lloyd's Registry, and by many private firms and individuals.

In research, to no two men are we more indebted than to Dr. Wm. Froude and his son, Mr. R. E. Froude, for the experimental work done by them on ships' resistance and screw propellers. The British Association in 1868 appointed a committee to consider stability, propulsion, and sea-going qualities of ships, and of that committee Dr. Froude was a member, the others being Merrifield, Galton, and Rankine. The committee recommended experiments on actual ships, but Dr. Froude dissented and gave it as his opinion that model experiments were of value and were much cheaper to carry out, describing some he had made in 1867. In 1868-69, on the suggestion of Sir Edward Reed, then Chief Constructor, the Admiralty agreed to bear the cost of the construction and the working costs of the tank at Chelston Cross, Torquay. This tank started work in 1871, Dr. Froude acting as chief, and he gave his services gratuitously as long as he lived. On his death Mr. R. E. Froude took over charge, continuing and expanding his father's work. The results were freely communicated by him, with the full consent and encouragement of the Admiralty, to the Institution of Naval Architects in a series of valuable papers. The Torquay tank was ultimately dismantled and transferred to Haslar, where the good work is continuing.

There are now, besides the Government tank at Haslar, the following Froude tanks in Great Britain, in the order of age—Denny (Dumbarton), Brown (Clydebank), William Froude (Teddington), Vickers (St. Albans), and Parsons' have also a smaller open-air tank at Newcastle: that is six; and there are in Italy, Germany, France, Sweden, Russia, Austria, Japan, and the United States other eleven, a total of seventeen, and it may be claimed that tanks have had more far-reaching effect on design than any other means of research.

Yet, when one considers the research carried out on ferrous and non-ferrous metals, that claim may be disputed. Time fails me to do more than indicate to you the history of mild steel. While steel had been used in shipbuilding at an earlier date, our present material came into daily use in merchant-ship building in the late 'seventies of last century, and I can remember the interest taken in the *Buenos Ayrean*, the first steel Atlantic ship, built in 1879. With the considerable reduction in scantlings allowed by the Classification Societies, mild steel rapidly displaced iron in ship construction. But still we were warned that it was unreliable if worked at a blue heat, and some failures were recorded. Further improvement in manufacturing methods, however, finally gave us a material of great reliability and easily worked. The limits of 28-32 tensile strength and 20 per cent. extension in an 8-inch specimen have been standard now for many years, though steels of greater carbon content and higher tensile strength have been used: and as Young's modulus is practically the same for all ordinary carbon steels, these higher tensile steels could be used in conjunction with milder steels without disadvantage. But there is now another mild carbon steel on the market which has a higher elastic limit, the use of which

is just beginning; it is claimed that it will ensure further advantageous developments in reduction of weight of hull.

Sir Robert Hadfield's invention of high-manganese steel gave a fresh impetus to research in ferrous alloys; and now we have alloys of nickel, chromium, vanadium, tungsten, and other metals, each with its own special use either in construction of ships and their machinery or in the machine-shop for tool-steel, thus still further advancing the science and art of shipbuilding and marine engineering.

Other powerful factors in the development of the merchant marine were the Board of Trade, the Classification Societies, and the technical institutions and societies.

The Board of Trade is charged by statute with the duty of seeing that ships are safe and sufficient for navigation. The individual surveyor is legally responsible, and it is he who must certify safety and sufficiency; but, for co-ordination purposes, there is a Consultative Branch at Whitehall which issues "Suggestions and Instructions" to the surveyors as to how they should carry out their duties. These "buff books" have in practice largely the same effect as the rules and regulations of the Classification Societies.

Practically every maritime nation has a Registry or Classification body or bodies of its own, but in Great Britain that type of organisation has been earlier and more fully developed than in other countries. Lloyd's Registry has a world-wide name and has had a profound influence on design not only in this country but also all over the world. This leads me to speak of standardisation in shipbuilding and engineering. The first work of the B.E.S.A., when it was established in 1901, was the standardising of ships' sectional material. Order was thus brought out of chaos, the number of standards, sections of all kinds and sizes, was fixed at 175, and the steelmakers reported that a saving of at least 5s. per ton was the result. A revision in 1918 reduced the standard sections to 115. A recent piece of work of the B.E.S.A. is the standardising of the tail-shafts of ordinary cargo-vessels, which standards may also be applicable to many passenger-ships. The taper of the shaft to take the propeller boss is also fixed. It can easily be seen what a saving this would mean in the case of damage at a distant out-port, where, were these standards adopted, only a few spares need be kept, or even the spare of one steamer could be used for another with the same diameter shaft, and thus in the case of damage the present long delays in an out-port waiting for replace parts would be avoided.

The influence of the Institution of Naval Architects on the progress of design cannot be exaggerated. Founded in 1860, there has been a constant stream of valuable papers read and discussed at the annual meetings; naval architects and marine engineers were glad of the opportunity of presenting the results of their experience to their fellows and of profiting by the discussion of their ideas. Now there are all over Great Britain—at Liverpool, Newcastle, Southampton, Glasgow, and other centres—similar institutions, contributing to the advance of the science by their meetings and published transactions.