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Twenty Years' Progress in Marine Construction

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I SHOULD like at the outset to say how much I have appreciated the invitation to deliver the twenty-first James Forrest lecture. The late Sir William White, I understand, had been asked to do so, and I fully realise how valuable and instructive a lecture has been lost to us through his untimely death. I feel it to be a very high honour indeed which has been paid me, and I may say that it was only after a considerable amount of misgiving that I undertook the task.

The subject prescribed by your Council—that of twenty years' progress in mercantile marine construction—is so comprehensive that it would require a whole course of lectures to do it adequate justice, whereas I must compress it within the limits of an hour's address. I have therefore only dealt with the subject in a general manner, and have not entered into details.

In order to appreciate fully the progress which has been made during the last twenty years in the design and construction of vessels for the mercantile marine, it will be useful to consider briefly the factors for and against advance, so as the better to realise in what direction forward steps have been and may still be possible. The driving forces towards all progress are healthy discontent with what has been done and the satisfaction derived from greater achievement, quite as much as the hope of material gain. The aim of the shipowner, the naval architect, and the marine engineer is ever towards increased comfort, speed, and economy.

Increase in size is undoubtedly the most valuable resource of the naval architect, as it is directly conducive to the attainment of these three desiderata. The greater the length of the vessel in proportion to her total weight, the smaller becomes the power in relation to her displacement and speed. Greater size gives more deck space for passenger accommodation, greater height above water, and less disturbance due to wave motion; hence, greater comfort. The earning factors, space and displacement, are increased in greater ratio than the cost factors, and thus economy is obtained.

A concrete example illustrative of these principles may possibly be of interest. I will take the case of a cargo vessel having a speed of 13 knots at sea over a 3000-mile voyage. On a length of 400 ft. we can construct a vessel weighing 3,700 tons, which would carry 4,000 tons of cargo and consume 500 tons of coal. Each 100 tons of cargo therefore involves $92\frac{1}{2}$ tons of constructive material, and $12\frac{1}{2}$ tons of coal per voyage. A vessel 500 ft. in length would weigh 6,750 tons, would carry 8,700 tons of cargo, and consume 700 tons of coal. Each 100 tons of cargo in this case requires only $77\frac{1}{2}$ tons of vessel and eight tons of fuel.

The practical success of the large vessel depends, of course, upon the volume of passenger and cargo traffic she can command, and these vary greatly on the different trade routes. They are notably greatest upon the Atlantic, and it is in this trade that we find the greatest growth in dimensions.

It is the continual aim of the naval designer to realise the greatest dimensions which the shipowner can utilise on the least possible weights of hull, machinery, and fuel. Every improvement in the quality of his materials, every advance in the better distribution of those materials towards the end in view, every reduction in the weight of machinery and of fuel in relation to horse-power, and every progression towards the more effective use of the power developed, is a step towards the ideal large, powerful, and comparatively light vessel.

The introduction of iron about the year 1820, of steel about 1870, of the compound engine in 1854, and of the triple-expansion engine in 1881, were the most notable epoch-makers of the first eighty years of steam navigation. The study of the strength problem by means of the "girder" theory, and the labours of the classification societies, have shown how to combine strength with lightness. The introduction of the experimental tank method of research gave us a definite means of designing form and propellers so that the least possible amount of power is wasted and the greatest possible amount usefully applied.

Up to the beginning of the period under consideration the changes which had taken place in marine engineering had been shown in a gradual development of the simple type of reciprocating steam-engine. The growing knowledge of the theoretical principles involved in design, the higher standard of materials available for construction, and the steady improvement in machine-tools, had enabled engineers successfully to make use of higher steam pressures. The advance marked by the successful introduction of the compound engine about the year 1854 had been followed, in 1881, by the introduction of the triple expansion type of engine, and the three-crank design of the latter proved itself so fit a variation that it has survived, unchanged in all essentials, to the present day. Thus twenty years ago the triple-expansion engine was in the position of rapidly superseding the compound type in almost all services, and was being successfully constructed to work in conjunction with steel cylindrical boilers working at a pressure of 160 lb. per sq. in.; both engines and boilers being, in general design, not greatly different from those of the same type which are being built at the present time. I can best convey to you the condition of marine construction at the beginning of the twenty-year period immediately under review by recalling some of the most notable achievements of that time.

On the Atlantic the premier vessel was the *Campania*, then regarded as a "monster" ship. It was thought by many that the limit of size had been reached, and that so large a vessel could never be made commercially successful. She was 600 ft. in length, with a beam of 65 ft. and a depth of 41 ft. 6 in. Her gross tonnage was 13,000, her trial speed 22 knots, and her horse-power 30,000. She was, of course, fitted with twin-screws, and her engines were of the triple-expansion type, with five cylinders working on three cranks. The condensers were of cast iron, and, as was usual at that time, formed part of the engine framing. No arrangements were made for balancing the inertia effects of the reciprocating parts. The main boilers were of the double-ended cylindrical type, with a working pressure of 165 lb. per sq. in. She burned about $1\frac{1}{2}$ lb. of coal per indicated horse-power per hour, and 480 tons daily. Of her displacement, $48\frac{1}{2}$ per cent. was devoted to weight of hull, $21\frac{1}{2}$ per cent. to machinery, $14\frac{1}{2}$ per cent. to fuel, $4\frac{1}{2}$ per cent. to passengers, stores, and water, and 11 per cent. to cargo. She carried 570 first-class, 300 second-class, and 600 third-class passengers, and a crew of 400. Her first-class public rooms were six in number; they occupied a total area of 9,214 sq. ft., or an average of about 16 sq. ft. per passenger, while the average state-room area was about $17\frac{1}{4}$ sq. ft. per person. The average number of persons per room was 3.2. Second-class passengers had each but 8 sq. ft. of public room, and 14 sq. ft. of state-room. Compared with most modern vessels of large size the *Campania* was shallow in relation to her length, the ratio of length to structural depth be being 14.45. In consequence of her shallowness as a girder the scantlings of her gunwale and bottom had to be very heavy in order to obtain the necessary longitudinal strength, and it was some years before ships were built in which the upper member of the strength girder was raised to a higher deck. The *Kaiser Wilhelm der Grosse*, built in 1897, surpassed the *Campania* in length by 25 ft.; but although her sides amidships, as in most subsequent vessels, were plated one deck space higher than in the *Campania*, the plating was comparatively light, the deck to which it extended was not plated over, and the top member of her strength girder remained at the upper deck, the length-depth ratio being slightly in excess of that of the *Campania*. Her ocean speed was about $22\frac{3}{4}$ knots, with 30,000 indicated horse-power. Her coal capacity was 4,600 tons. She had accommodation for 600 first-class, 300 second-class, and 800 third-class passengers.

In 1900 came the *Deutschland*, 663 ft. in length, similar in appearance and structural arrangements to her immediate predecessor, her length-depth ratio being over 15, and the main girder stopping at the upper-deck level 44 ft. above the keel. Her horse-power was in the neighbourhood of 35,000; capacity for 4,800 tons of coal was provided, and her ocean speed was about $23\frac{1}{4}$ knots. Her engines were of the greatest actual dimensions reached in the reciprocating type, and were of the four-crank quadruple design. The *Deutschland* accommodated 700 first-class passengers in 266 rooms, an average of about 2.6 persons per room; 300 second-class, and 290 third-class passengers. Luxuries were beginning to creep in, some of the state-rooms having private bath-room attached, while for the suites as much as £250 was charged for a single voyage.

In 1901 length was increased by 20 ft. in the *Celtic*, built for the White Star Line. She was 680 ft. in length, with a beam of 75 ft., and a depth of girder of about 52 ft. In this, as in most vessels of the White Star fleet, only a comparatively low speed was provided. The consequent smallness of horse-power reduced both first cost and fuel consumption, while the fuller form gave roomier deck spaces and greater dead-weight carrying capacity. Since the total dead-weight was augmented, and the proportion given up to coal reduced, there was a twofold source of increase in the weight of freight-earning cargo. Speed is an expensive item. On the length of 680 ft. a 16-knot vessel can carry 12,000 tons of cargo on an expenditure of 2,000 tons of coal over an Atlantic voyage, while an advance in speed to 22 knots would reduce cargo to 3,000 tons, and involve a coal consumption of 3,500 tons, besides raising the first cost by about 25 per cent.

Next year came the *Kaiser Wilhelm II.*, 684 ft. long and $44\frac{1}{4}$ ft. in depth to her upper deck, but with her sides plated all fore and aft up to the level of a continuous promenade deck $8\frac{1}{4}$ ft. above the upper deck. Her depth of girder was thus $52\frac{1}{2}$ ft., and he length-depth ratio only 13. A better distribution of structural material was realised and excessively heavy local scantlings avoided. Besides having her main structural weights higher than usual, she had one deck more above her main structure than any of her predecessors, and these additions to the weight and height of her upper structure necessitated a proportionate increase in breadth, which was made 72 ft., as compared with the *Campania's* 65 ft., and the *Deutschland's* 67 ft. Similar increments in transverse dimensions in relation to length have characterised all subsequent advances, and the number of superstructures has steadily increased in order to afford deck space for the greater numbers of public rooms and more spacious cabin accommodation by which each successive vessel was rendered more attractive than the last. The *Kaiser Wilhelm II.*, had four engine-rooms, in which were developed about 45,000 indicated horse-power, and a speed of over $23\frac{1}{2}$

knots was maintained at sea. Her coal capacity was 5,000 tons. Accommodation was provided for 770 first-class, 350 second-class, and 780 third-class passengers; £400 was charged for a suite of rooms.

The power transmitted per shaft in this vessel was about 25 per cent. greater than in the previous unit, and two three-crank quadruple engines were fitted to each line of shafting in order to reduce the dimensions of the cylinders and working parts, a scheme which lent itself naturally to more complete subdivision into water-tight compartments. This arrangement, which was also tried in some naval vessels, was, however, not repeated in later practice. The machinery of this ship represents the largest power of any installation of reciprocating engines in the merchant service, the next advance in total power being with turbine machinery.

Within the next few years there appeared the *Cedric*, *Amerika*, and *Kaiserin Augusta Victoria*, all about 680 ft. in length, and carrying still further the development in number and extent of superstructures, public rooms, and in luxurious cabin accommodation. The *Amerika* had six decks above the water-line as compared with the *Campania's* four. In none of these vessels was high speed attempted.

The further development of the reciprocating engine since the beginning of the period under survey has been in the use of still higher initial pressure, and in the extension of the series-expansion principle in the quadruple-expansion type of engine. The use of higher pressure followed naturally upon the success of the triple engine, and for pressures above 180 lb. per sq. in. the quadruple type became necessary in order to take the fullest advantage of the increased heat energy available in the steam.

Compared with the gain in fuel economy effected by the triple-expansion over the compound engine, the further improvement due to the increase in steam pressure to 215 lb. or 220 lb. is naturally small, being about seven to eight per cent., and against this has to be put the increased weight, cost, and upkeep of the quadruple type. For ships trading on long voyages, and more especially for passenger ships, or large units, where a four-crank engine would be fitted, in any case, on account of its greater smoothness in running, the quadruple engine has now superseded the triple-expansion type, but in the case of cargo-carriers, where low first cost and easy supervision are primary conditions, the triple engine still holds its own.

In the essential design of the reciprocating main engine, improvements seem difficult to attain. Some changes, however, may be noted. Condensers are now usually kept separate from the main framing, and, in order better to withstand extremes of temperature are frequently constructed of mild steel, instead of being cast as formerly; much more attention is also given to their design with a view to better the thermal results. Air-pumps have been improved in design, and in most large or fast-running machinery are now fitted as separate auxiliary engines instead of being driven from the cross-heads. Attention has been directed to devising means of balancing the engines in order to reduce vibration troubles. The first attempt to solve the problem of balancing was made by Messrs. Yarrow, and the method known as the Yarrow-Schlick-Tweedy system is now adopted in most engines of the four-crank type. This method consists in arranging the relative positions of the various reciprocating and revolving masses, by adjusting the angles between the cranks, so that the inertia effects are reduced to a minimum. Reduction in fuel consumption has been obtained by the collective effect of a number of small savings; by the improved condenser and air-pump; by the utilisation of the auxiliary exhaust for feed-heating; and by heat economy in various ways.

In the constant endeavour to provide greater intensity in power production, increase in piston speed and rate of revolution has been achieved through experience in design and a better quality of material and workmanship, but, where conditions of exceptional power, or lightness per unit of power, or both of these, have to be considered, the limitations of the reciprocating type of engine become apparent. In addition to the difficulties of construction and management of very large units, the reciprocating engine had, as already remarked, reached a point where further improvement in steam consumption was not easily attained; while further reduction in weight involved increase in speed of rotation, with its attendant difficulties. Thus the introduction of the steam turbine proved opportune, by providing a way to further progress in economy, lightness, and the construction of very large units, while at the same time eliminating vibration troubles and relieving difficulties of engine-room management.

The turbine entered the Atlantic lists in 1905, when the *Victorian* and *Virginian*, 520 ft. in length, took up their stations, and in 1905 the 650-ft. *Carmania* also used the new motor.

The 700-ft. mark was passed in 1906 by the building of the White Star liner *Adriatic*, 709 ft. by 75 ft. by 56 ft., with twin-screw quadruple-expansion engines of about 15,000 indicated horse-power. Her speed was but 15 knots, and she carried 450 first-class, 500 second-class, and 1,400 third-class passengers, 2,500 tons of coal, and 6,500 tons of cargo. Of her total displacement, the hull claimed about 56 per cent., machinery 10 per cent., fuel eight per cent., cargo 21 per cent., passengers, stores, and water about five per cent. A comparison of these approximate figures with those already given for the *Campania* shows that, per annum, the *Adriatic* could carry twice as many passengers, and three and a half times as much cargo per ton of fuel as the *Campania*. This well illustrates the cost of speed, and justifies the enhanced rates charged those availing themselves of the faster vessels.

The turbine, having proved its worth in the realm of high power and fast steaming, was boldly adopted by the Cunard Company in the *Lusitania* and *Mauretania*, built in 1907. These vessels surpassed all others with a length of 760 ft., a beam of 88 ft., and a depth of girder of $60\frac{1}{2}$ ft. The girder ratio was thus about $12\frac{1}{2}$, and for the first time high tensile steel was utilised in the upper member to meet the higher stresses. Some lightening of structure was thus obtained. These ships were the first mercantile vessels to have four lines of shafting, and practically the whole of the vessel's length was occupied by boilers, machinery and fuel. About 68,000 horse-power was developed, and an ocean speed of between 25 and 26 knots regularly maintained, on an expenditure of about 5,000 tons of coal per voyage. Although already surpassed in dimensions, these two vessels retain their supremacy in speed unchallenged.

In 1908 a further step was taken, with a view to securing a greater reduction in steam consumption per effective horse-power. This consisted in the combined use of the reciprocating steam-engine and turbine in order to retain the low speed of revolution of the reciprocating engine with its accompanying favourable propeller efficiency, while at the same time effectively utilising the expansion of the steam down to the condenser pressure. The first ship to be thus fitted was the *Otaki*, a vessel of 464 ft. in length and about 9,900 tons dead-weight capacity; and a comparison of this ship with a sister ship fitted with ordinary twin-screw quadruple-expansion engines showed a difference of about 20 per cent. in steam consumption per effective horse-power in favour of the combination type of machinery.

The system is principally suited to vessels of fairly large power, moderate speed, and for service on long voyages. The usual practice has been to fit the reciprocating engines on the wing shafts, and the exhaust turbine on a centre shaft, an arrangement being made for exhausting the steam from the reciprocating engine direct to the condenser, and thus cutting out the turbine during manœuvring. Combination machinery, as compared with all reciprocating machinery, involves more complexity and cost, and a slight increase of weight in the engine-room; but the improved economy realisable allows of reductions in the boiler capacity, and in boiler-rooms and fuel weights, which more or less compensate for this. The influence of the last item is dependent on the length of voyage.

In 1911 a length of 850 ft. was reached in the White Star liner *Olympic*. This luxurious vessel measured 852 ft. by 92 ft. by 64 ft., and has a speed of 21 knots with 46,000 horse-power combination machinery driving three screws. She carries 735 first-class, 674 second-class, and 1,026 third-class passengers, and has the following public rooms; gymnasium, reading and writing-room, lounge, smoke-room, verandah and palm-court, restaurant, reception room, dining saloon, racquet court, swimming bath, and Turkish baths. Her finest suites each consist of sittingroom, two bedrooms, bathroom, and clothes-room, and each occupies a space of 1,600 sq. ft., or 40 sq. ft. per person accommodated.

To-day the largest vessel afloat is the *Imperator*, 880 ft. by 90 ft. by 63 ft. Her girder ratio is 10.7, and she has eight decks above her water line. With boilers of the Yarrow type and turbines of 62,000 horse-power driving four shafts, she has an ocean speed of 22½ knots. She carries 900 first-class, 800 second-class, and 2,700 third-class passengers, with a crew of 1,200, or 5,400 persons in all. Her accommodation is the latest word in spaciousness and luxury. For first-class passengers there are two large and three smaller dining-saloons, restaurant, grill-room, ladies' room, ball-room, winter garden, smoke-room, gymnasium, swimming bath and Turkish baths, the total area given up to public rooms being 36,000 sq. ft., or about 40 sq. ft. per passenger. She has 446 first-class staterooms, including twelve suites, the average number of persons per room being thus practically two, and the average room area 80 sq. ft. per person.

In the all-turbine installation for the merchant service the turbines have been mostly of the compound type—that is, with the steam passing through two turbines in series; the usual arrangement being a three-shaft one, having one high-pressure turbine and two low-pressure turbines, with the exhaust from the high-pressure turbine passing through the two low-pressure turbines in parallel. Only in some few cases has a twin-screw arrangement been adopted—that is, with the high-pressure turbine on one shaft and the low-pressure turbine on the other; but a similar arrangement, duplicated, has been applied to many of the largest installations, both naval and merchant, by fitting two independent sets, of two turbines each, working on four lines of shafting. With a view to improving the steam economy in the all-turbine system, a further development has been introduced in some recent ships of large power having a four-shaft arrangement, by passing the steam through three turbines in series. The steam passes through the high-pressure turbine to an intermediate-pressure turbine, and then through the two low-pressure turbines in parallel, there being one turbine on each line of shaft. The result of this is that for the same over-all length of each turbine unit (a matter of some practical moment) the steam passes through a greater number of rows of blades, and a condition of improved efficiency is gained, while a reduction of the blade-leakage is obtained due to the relatively increased length of blade as compared with the alternative two-series design. The improved turbine efficiency resulting from this arrangement thus increases the range of speed at which an all-turbine set can successfully compete with the reciprocating engine. Several ships with turbine machinery of this three-series type have lately been put on service with very satisfactory results even at comparatively low speeds.

The rapid development of the large, luxurious, and fast liner, which I have just traced, has been due to the exceptionally favourable conditions of the Atlantic route. Here there is a large and steady stream of passenger traffic, a demand for expensive and luxurious accommodation, and a comparatively short distance between terminals. Fuel of the best quality can be readily obtained on both shores. Upon the other great ocean highways of the world these advantages do no exist. The Pacific line from Vancouver to Nagasaki is 67 per cent. longer than that from Liverpool to New York, Vancouver to Melbourne 148 per cent. longer, London to Melbourne 315 per cent., and Southampton to Cape Town 95 per cent. Neither Japanese, British Columbian, Australian, nor South African coal is equal to Welsh coal in calorific value; but on the Pacific oil fuel is easily obtained, and is already beginning to be largely used. In no case does the volume of passenger traffic approach that across the Atlantic. As a consequence, competition is less keen, there are fewer vessels, a less number of voyages per vessel, and the vessels themselves are smaller and of less speed. Nevertheless, considerable progress has been made in size, accommodation, comfort, speed, and economy, although the advance in speed has not been so marked as that between Britain and America.

No less interesting than vessels of the "liner" class are those smaller passenger carriers known as "cross-Channel" steamers. Between different ports in the United Kingdom and between Britain and Continental ports there has always been a large passenger traffic, and the competition between the various railway and other companies has developed a large fleet of small vessels whose speeds vie with those of Atlantic liners, and whose ratios of speed to square root of length are greatly in excess of "liner" practice. The conditions of these cross-Channel services differ materially from those of the liners. The distances are much shorter, ranging from 21 to 120 miles only, and the number of times the vessels enter harbour is much greater.

The amount of fuel which must be carried is therefore much less, and economy of consumption is relatively of less influence. It is of greater importance to keep down tonnage, to save dues, and to reduce weight wherever possible, in order to obtain high speeds upon small dimensions. Very few of the vessels are classed, and the scantlings, in all cases, are kept as low as possible. In many cases harbour accommodation imposes severe restrictions upon length and draught. Twenty years ago the majority of these vessels were paddle-steamers. These were gradually replaced by twin-screw steamers, and these again were superseded by turbine-propelled craft, which to-day are practically universal in the Channel services. Typical vessels in 1893 were the paddle-steamer *Calais Douvres* and the twin-screw steamer *Ibex*.

The *Calais Douvres* was 324 ft. in length, 36 ft. in breadth, and 14 ft. deep; of 1,065 gross tons and 6,000 indicated horse-power, she had a speed of 20.64 knots and a speed-length ratio of 1.15. She was unclassed, her hull weighing 805 tons, her machinery 650 tons ($9\frac{1}{4}$ indicated horse-power per ton), and she carried 103 tons of coal. Her weight was accounted for as follows:—

	Per Cent.
Hull	48
Machinery	39
Coal	6
Passengers, stores, and water	7
	100

Her accommodation consisted of ten deck state-rooms, furnished with sofas only, and large open saloons below deck. She carried 580 first-class and 300 second-class day passengers.

The *Ibex*, of 1,062 gross tons, measured 265 ft. by $32\frac{1}{2}$ ft. by $15\frac{1}{2}$ ft., and with 4,200 indicated horse-power realised a speed of 19.37 knots, the speed-length ratio being 1.19. Her machinery developed $10\frac{1}{4}$ indicated horse-power per ton, and her weight was thus accounted for:—

	Per Cent.
Hull	60
Machinery	30
Coal	$4\frac{1}{2}$
Passengers, stores, and water	$5\frac{1}{2}$
	100

Her accommodation consisted of two private cabins and a number of open saloons with sleeping accommodation on sofa berths. She carried 292 first-class and 265 second-class day passengers. Other notable vessels of this period were:—

Comparison of Fuel Consumption and Weight of Machinery, 1893-1913. *For same Effective Horse-Power.*

—	—	Relative Fuel Consumption.	Relative Machinery Weight.
	1. ATLANTIC PASSENGER SHIP.		
1893	Twin-screw triple-expansion engine ; cylindrical boilers	100.0	100.0
1913	Four-screw triple-series turbines ; cylindrical boilers	90.0	81.0
1913	Four-screw triple series turbines ; water-tube boilers	94.0	60.0
	2. INTERMEDIATE LINER.		
1893	Triple-expansion reciprocating engine ; cylindrical boilers	100.0	100.0
1913	Quadruple - expansion reciprocating engine ; cylindrical boilers	92.5	91.0
1913	Combination, reciprocating and turbine ; cylindrical boilers	80.0	94.4
	3. CHANNEL STEAMER.		
1893	Twin-screw triple-expansion engine ; cylindrical boilers	100.0	100.0
1913	Three-screw direct turbines ; cylindrical boilers	87.0	74.2
1913	Twin-screw geared turbines ; cylindrical boilers	74.4	82.0
1913	Twin-screw geared turbines ; water-tube boilers	76.0	60.0
	4. CARGO TRAMP STEAMER.		
1893	Single-screw triple-expansion engine ; cylindrical boilers	100.0	100.0
1913	Single-screw triple-expansion engine ; cylindrical boilers, with super heater	85.4	100.0
1913	Single-screw geared turbines ; cylindrical boilers	76.0	84.4

During the succeeding ten years many other similar vessels were put into service, their length ranging from about 270 ft. up to 300 ft., and their speeds from 19 to 24 knots. The most remarkable of these were perhaps the four screw steamers *Connaught*, *Leinster*, *Munster*, and *Ulster*, which on a length of 360 ft. attained a speed of $24\frac{1}{4}$ knots, a speed-length ratio of 1.28, and the *Empress Queen*, 360 ft. in length, still the largest paddle vessel in this country, and of $21\frac{1}{4}$ knots speed.

In 1903, encouraged by the success of the turbine-steamers *King Edward* and *Queen Alexandra*, built respectively in 1901 and 1902, for service on the Firth of Clyde, the first turbine Channel steamer, the *Queen*, was placed on the Dover-Calais route. This notable vessel, 310 ft. by 40 ft. by 25 ft. of 1,676 gross tons, has turbine machinery of about 8,500 horse-power, and attained a speed of 21.8 knots, equal to 1.24 times the square root of her length. In the same year the turbine-steamer *Brighton*, 274 ft. in length, steamed 21.37 knots, giving a speed-length ratio of 1.29. The success of these two vessels led to a rapid development of turbine propulsion, and the almost total abandonment of paddles and twin-screws in the Channel services. In 1905 the *Princesse Elizabeth*, with turbines and water-tube boilers, made 24 knots on 357 ft., and the *Dieppe*, with turbines and cylindrical boilers and classed at Lloyd's, brought the speed-length ratio up to 1.31, with 21.65 knots and a length of 274 ft.

To attain high speeds in relation to length, saving of weight is of vital importance, and the advantages of water-tube boilers in this respect are considerable. All that prevented their more general adoption was their lack of robustness and the greater care and skill required in handling them, as compared with the well-tried and well-known Scotch type of steam-raiser. By their use in the turbine-steamer *Newhaven*, built in 1910 as successor to the *Dieppe*, a trial speed of 23.85 knots was obtained on a length of 292 ft., the speed-length ratio being raised to 1.4. This result was made possible by the extreme lightness of the machinery installation in relation to the power developed, 13,000 horse-power being obtained from a weight of only 590 tons. Thus 22 shaft horse-power was got per ton, about $2\frac{1}{2}$ times that obtainable from paddle machinery, and double the output of twin-screw engines. The total displacement of the *Newhaven* was 1,510 tons, or only about 200 tons in excess of that of the *Dieppe*, although the later vessel was 18 ft. longer and twice as powerful.

The outstanding difficulty in applying the steam-turbine to marine propulsion has always been that while high speed of rotation is necessary to obtain the maximum turbine efficiency, the propellers are most efficient at very much lower speeds. Electric, hydraulic and gear-wheel transmission have each been tried in order to combine a high-speed turbine with a slow-running propeller, and thus to obtain the maximum efficiency of each.

Where a suitable gear-ratio can be adopted, not only can improved propeller efficiency and decreased consumption of steam per unit of power developed be obtained, but it is possible, by overspeeding the turbines at full power, to maintain the economy over a larger range of the ship's speed than could be done with a direct-coupled turbine. With the mechanical method of speed reduction, that of gear-wheel transmission, a considerable amount of experience has now been obtained, and, up to the present, two small cargo vessels and seven cross-Channel steamers have been put on service, while four sets, each of about 12,000 horse-power, are at present under construction, two for ocean liners and two for swift coasters.

In 1911 the Channel steamers *Normannia* and *Hantonia* were each fitted with four turbines, two running at 2,000 and two at 1,400 revolutions, and connected by means of toothed-wheel gearing to two propeller-shafts running at 310 revolutions per minute. The experiment was a notable success, the coal consumed per trip being only 43 tons, as compared with the 70 tons used by the immediately preceding ships, which were of the same capacity, but propelled by direct twin-screw turbines.

Last summer the Channel steamer *Paris*, 293½ ft. in length, and having geared-turbine propulsion, attained the remarkable speed of 25.07 knots on a run from Newhaven to Dieppe, the speed-length ratio working out at 1.47—a result which has only been surpassed by torpedo craft.

The introduction of toothed gearing for the main drive has been looked upon by many as a retrograde step. The conditions are, however, in no way similar to those in which formerly gearing up was necessary, and where a very valuable turning moment in the reciprocating engine had to be contended with. The loss in transmission is small, being probably not more than two per cent. of the power transmitted, and the wear on the teeth is inappreciable. Some objection has been raised to the noise caused by the gearing, but, although doubtless not so silent as the direct-driven turbine, yet the geared-turbine installation can compare favourably with the reciprocating engine in this respect. The actual vibration transmitted through the structure of the ship is inappreciable; the effect of the gearing being felt altogether in an air vibration in the engine-room itself, and this will be reduced to a minimum with the more accurate methods of gear-cutting recently introduced.

The large speed reduction which can be effected makes the system suitable for ships of low speed and moderate power, and it is almost certain that this method will greatly extend the usefulness of the steam-turbine for marine propulsion.

In Germany the hydraulic transmitter invented by Dr. Fottinger has lately been developed. The principle of the transmitter is that of combining a high-speed turbo-centrifugal pump with a water-turbine designed for a lower speed of revolution. The former is coupled direct to the steam-turbine and the latter to the propeller shaft, the pump and water turbine being placed in one casing, and they are so designed that the frictional and eddy losses are reduced as far as possible. Some small transmitters have been fitted for marine purposes, and lately a transmitter has been tested with a load of 10,000 shaft horse-power. It is proposed to fit several large German vessels with the system. A transmission efficiency of about 90 per cent. is claimed at full load, with a slight reduction at light loads. The ratio of primary to secondary speed is normally about 5:1, but transmitters could be designed for larger ratios.

Electrical transmission has now been applied to several vessels. Alternative schemes have been tried in which the power is generated by steam turbo-generators, and by generators driven by Diesel oil-engines, and applied to the propeller by alternating-current motors. Considering the transmission efficiencies likely to be attained and the increased weight and initial cost of the installation, it does not appear probable that a system of this kind will be able to compete successfully, in ordinary cases, with the direct-driving engine or mechanically-geared turbine. Where, however, power has to be provided for other than propelling purposes (in which case the same generating plant could be available), it is possible that this system would have advantages.

Within the period under review vessels built solely for the purpose of carrying cargo have undergone notable development. The principal object of the owner of such vessels is to secure improved economy in each successive addition to his fleet, speed and accommodation being secondary considerations. And here again I have the same story to tell—the story of increase in dimensions and of reduction in fuel-consumption in relation to work done.

The following table shows the steady advance in the vessels of one well-known line of cargo tramps:—

Year.	Dead Weight. tons
1895	6,400
1899	7,200
1905	8,200
1912	9,300
1913	9,600

The speed has remained practically constant at 11 knots; but while the 6,400-ton dead-weight carrier of 1895 developed 1,400 indicated horse-power, and consumed 24 tons of coal daily, her successor of to-day can carry 9,600 tons and steam at the same speed on an expenditure of only 32 tons daily for 2,300 indicated horse-power. Fifty per cent more dead-weight is carried and 64 per cent. more power developed, but only 33 per cent. has been added to the fuel consumed. The coal rate has fallen from 1.6 lb. per horse-power per hour to 1.3 lb., while for a 3,000-mile voyage the dead-weight carried per ton of coal has increased from 23.5 tons to 26.4 tons.

Rapid loading and discharge of cargo are of vital importance to the tramp vessel, and it is evident that the less the cargo has to be moved horizontally along holds and 'tween decks before coming under the hatchways to be lifted, the more rapidly can it be handled. Hatches have therefore increased greatly in size, and in some vessels are now almost continuous, and in breadth nearly equal to half the vessel's beam. With the same object of facilitating the passage of cargo to and from the hatchways, hold pillars have almost disappeared, and in place of the double row of slender pillars at intervals of about 4 ft., we find large open holds and decks supported by continuous longitudinal girders under the beams, and only four large plate-and-angle pillars.

The steam-winch still remains the best means of handling cargo, being more robust and less complicated than either electric or hydraulic plants. The winches themselves have been greatly improved, and instead of a single 6-in. by 10-in. winch at each hatch and chain falls, we find a pair of 8-in. by 12-in. machines, with helical gearing and wire-rope pendants. The normal derrick is now of Mannesmann steel tube for a 6-ton lift in place of the old 3-ton wood derrick, while a special steel derrick at each end of the vessel can handle a load of 30 tons. At the same time the size of the drums has increased from 12 in. to 24 in., and the working pressure from 50 lb. to 100 lb. Larger wearing surfaces have been provided, and locomotive-type valves fitted, so that the cargo-winch of to-day is not only more powerful and more rapid than its predecessor, but has also greater immunity from breakdown.

Crew's accommodation has been greatly improved. Comfortable mess-rooms are now provided separately from sleeping quarters; galvanised-iron berths have replaced wooden bunks; steam-heating and stoves are provided; each man has a locker fitted with drawers for his clothes, and his chest goes to a separate store-room; there are plunge and shower-baths for seamen and for firemen, as well as for the captain, officers, and engineers, and a well-equipped hospital is provided.

The triple-expansion engine still holds its place in the engine-room of the cargo-tramp. The fourth cylinder of a quadruple engine would mean additional complication and one or two additional engineers. Three main boilers of equal size are used, two under forced draught for propulsive purposes, the third under natural draught for dealing with cargo and to assist the others in cases of emergency when a little extra speed is called for.

In comparison with the 1,000 tons of coal consumed daily by the swift liner, the 30 tons of the cargo tramp appears so small that it would seem hardly worth while to attempt to reduce it; but the $\frac{1}{2}$ lb. of oil per brake horse-power per hour of the Diesel engine, together with the saving in weight and space and in time for bunkering, is already attracting the attention of the owners of cargo vessels, and the economy of the geared turbine proposition is also being considered.

In numbers and dimensions there has been a rapid development of vessels built for the carriage of petroleum in bulk. In 1893 Lloyd's Register contained the names of 47 vessels engaged in carrying oil cargoes, and 17 were in course of construction. The largest on service was the *Turbo*, 350 ft. in length, and capable of carrying 5,000 tons of oil in bulk. To-day there are 370 vessels on the Register, the largest being the *San Fraterno*, 530 ft. in length, and loading 15,700 tons of oil.

Vessels specially fitted with refrigerated holds for the carriage of perishable cargoes, such as fruit and meat, have also been greatly developed and improved.

The steam-yacht has passed through structural changes not dissimilar to those which have affected mercantile vessels. Dimensions have generally increased and super-structures have been added. The weather-deck is now further above water, and the principal accommodation and public rooms carried out to the ship's side in place of being confined to a long deck-house. Turbine propulsion has in many cases been adopted with success in place of reciprocating engines.

I regret that within the limits of the time at my disposal this evening I cannot refer in detail to many other notable changes which have taken place during the past twenty years, such as the disappearance of the sailing ship, the wide application of engine-power to fishing-boats, barges, and other small craft, and the remarkable performances of the hydroplane boat. These would of themselves take up an entire evening.

Name.	Machinery.	Length.	Tonnage.	Speed.	Speed-Length Ratio.
		ft.		knots	
Princesse Henriette ..	Paddle	300	1100	20.50	1.18
Leopold II.	,,	340	1367	22.00	1.19
Princess May	,,	280	1123	20.00	1.19
Tamise	Twin-screw	269	892	21.35	1.30
Frederica	,,	265	1059	19.50	1.30

With regard to the changes in boiler design and construction, these have been small. The cylindrical boiler has remained almost unchanged in general design during the last twenty years. Boiler shell-plating, owing to the higher pressures now adopted, is much heavier, and where weight is a consideration is often of high tensile steel. Boilers of the water-tube type, which have entirely superseded those of the cylindrical type in warships, have made but little progress in the favour of the average shipowner, and have been adopted only to a very limited extent in merchant ships in this country. Recently, however, their great advantages in lightness have secured their adoption in several channel steamers, and some small Australian vessels have been fitted with boilers of the Babcock and Wilcox type. A considerable departure has been made in the fitting of the large German Atlantic vessel *Imperator* with boilers of the Yarrow type; and in a large liner at present under construction on the Clyde, Babcock and Wilcox water-tube boilers are being adopted. The increasing cost of fuel, and the economy obtainable by the use of superheated steam, has tended to hasten development in that direction; and a fair number of ships, including the liner under construction just referred to, are being fitted with superheaters. A saving of from 10 to 15 per cent. in fuel consumption has been shown to be possible, and it is likely that superheating will be much more widely adopted in the near future.

With regard to the gain in fuel economy, brought about by the developments which have taken place, it is difficult, owing to the varying factors involved, to state this in general terms. Taking, however, the classes of ships separately, the average values are given in the table on the preceding page.

The problem of mechanical stoking, which has been successfully solved for the less severe conditions of land practice, still awaits solution as regards conditions afloat. Ideal conditions in this respect would be more easily reached by the extended use of liquid fuel, the advantages of which are obvious. Much progress has been made in perfecting apparatus for the proper combustion of oil, and its use would very rapidly be extended but for the sufficient reason that the present relative prices of oil and coal are such as to make the use of oil for burning in furnaces, except in specially favourable instances, out of the question commercially. On the general economic question of the oil supply depends also the rate of future progress of the latest development in marine propulsion of the large internal--combustion engine.

The application of the internal-combustion engine to marine propulsion is no new development, small engines having been constructed for this purpose more than twenty years ago. Durthe last decade, however, rapid progress has been made with small engines using the lighter petroleum spirits and oils, and the extent to which the steam-engine has been superseded in small craft, such as launches and pinnaces, is apparent. For this class of work the advantages of the internal-combustion engine in lightness, smallness, and general convenience are such as to make the steam-engine almost obsolete. The problem of producing a reliable engine of the internal-combustion type of larger power, without undue complication of design, and sufficiently low in first cost and maintenance to be able to compete successfully with the steam-engine or geared turbine, is a much more difficult one. Much experimental work has been done with this end in view, and there are many attractive possibilities.

Comfort on shipboard has vastly improved during the past twenty years. Spring mattresses and brass bedsteads have replaced the old wooden bunks, improved systems of heating and ventilation have been introduced, sanitary arrangements are greatly superior both in quantity and in quality, while the furnishings of the public apartments and the attractions of the dining-saloon vie with those of the finest hotels on shore. Third-class passengers have now separate cabins each for four, six, or eight persons, in place of large open 'tween-deck spaces filled with tiers of iron beds and accommodating hundreds. In place of benches and tables along the sides of the sleeping quarters, separate dining-saloons, smoke-rooms, and music-rooms are provided.

Anti-rolling devices have been greatly developed. The use of free-water chambers, first suggested by Sir Philip Watts in 1875, and adopted in H.M.S. *Inflexible* and the *City of Paris*, have been reintroduced on an exact scientific basis by Herr Frahm; while Herr Schlick in Germany, and Mr. Sperry in America, have successfully applied the gyroscope to the reduction of rolling motions.

Wireless telegraphy, introduced in 1896, is now fitted in over 1,800 ships and 270 shore stations. By its agency each steamer can keep in direct touch with her sisters or with the shore. Already this power of communication over long distance has proved of inestimable value to vessels in distress by enabling them to summon immediate assistance. Wireless telegraphy is probably the greatest boon ever given to those in peril at sea.

As a preventive means, submarine sound-signalling has proved itself to be of immense value, especially where the mariner is surrounded by his most dangerous enemy—fog. It is well known that during fog both light and ordinary sound-signals become very unreliable, whereas the state of the atmosphere has no effect upon sound transmitted through the sea. The first submarine bell was installed in 1901, and to-day there are about 140 fixed bell-stations and over 1,000 vessels fitted with listening apparatus.

The important questions of freeboard, subdivision, and life-boat accommodation have all received a considerable amount of attention in recent years, and special committees have lately been appointed to investigate each of these intricate problems, so that nothing that human skill can devise may be left undone to secure the safety of human life and property entrusted to the vessels of our mercantile marine.

The 1892 Bulkhead Committee set as its highest standard the ability to remain afloat with any two adjacent compartments simultaneously flooded. The *Campania* was one of the first vessels to comply with the conditions laid down, and the *Scot* was also a "two-compartment" ship. Since that date not many ships have fully met the requirements, which were found in many cases to interfere too much with passenger and cargo facilities. The new *Empresses* on service in the Far East and the new Allan liners have been made into "four-compartment" vessels, and it is more than probable that the new Bulkhead Committee will set a higher standard of safety than their predecessors.

One of the most appalling dangers at sea is that of fire, and in recent years many new systems of meeting this emergency have been introduced. The now universal replacement of candles and oil illumination by electric light has eliminated one of the most frequent causes of conflagration; and should fire occur, systems of piping led into every part of the ship can quickly convey water, steam, carbonic-acid gas, sulphurous vapour, or the exhaust gases from the funnels, so as to deprive the flames of the oxygen which is their life.

In the course of my remarks I have made no reference to failures, as these have been but rare among so many notable successes. Nevertheless, much has been learned from failure, as each one, if read aright, indicates something to be avoided in future work. The solid progress recorded, with but little assistance from that manual labour which to-day claims to be the sole producer of wealth, has been the inevitable result of the persistent intellectual effort, amounting at times to genius, of the many men whose names are as household words among us, and will live imperishably in the annals of our profession. It is impossible to review the history of marine construction without being forcibly impressed by the greatness of the debt we owe to such men as James Watt, Scott Russell, Brunel, John Elder, Sir William Pearce, Sir William White, Dr. Elgar, the Froudes, the late Dr. Denny, and many others who have passed away, as well as the Hon. Sir Charles A. Parsons and others who are still fellow-workers with us. Active and daring minds have ever been questing forwards, and no opportunity for advance, no probability of new development, has been allowed to pass without thorough sifting and examination. The needs of the coming years have been anticipated, the engineer has ever been in the van, and not in the rear, of material progress. We have seen how the ocean liner has steadily advanced in dimensions and speed. The only apparent obstacles to continued increase are those connected with finance and with the sizes of docks and harbours. In view of past experience, he would be bold indeed who would place any limit upon what the future will bring forth.

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INSTITUTE OF MARINE ENGINEERS.

The following were elected at a meeting of Council held on Thursday, October 9th, 1913:—

As Members.

David Bissett, Association of Engineers, Singapore.
George J. Carter, Messrs. Cammell, Laird and Co., Ltd., Birkenhead.
Alfred J. Elderton, 222, St. Vincent's Road, Dartford, Kent.
Joseph H. Gibson, Messrs. Cammell, Laird and Co., Ltd., Birkenhead.
James Henderson, Chief Inspector, Machinery Department, Brisbane, Queensland.
John M. Kidd, Association of Engineers, Singapore.
Engr.-Lieut. G. S. D. Lord, R.N. (ret.), 34, Victoria Street, Westminster, S.W.
James S. Marshall, 88, Sunny Bank, Hull.
Frank Nicholls, 19, Eccles Road, Clapham Junction, S.W.
Oliver Richards, 26, Tower Hill, London, E.C.
Edward A. Thomson, 2, Falkland Avenue, Church End, Finchley, London, N.

As Associate Members.

David Gordon, School of Engineering, Poplar, E.
Alexander Hayes, 165, Strand, London, W.C.

Elected on Thursday, November 6th, 1913:—

As Members.

James D. Cameron, 30, Gayton Road, Hampstead, N.W.
Martin O. Davies, Riverside, Kidwelly, South Wales.
James M. Dewar, 9, Victoria Street, Westminster, S.W.
James W. Fairley, 48, Valentine's Road, Ilford, E.
David W. Fulton, 149, Great Western Road, Glasgow.
James A. Goddard, 75, Bewick Road, Gateshead-on-Tyne.
Robert L. Logan, 63, Margery Park Road, Forest Gate, E.
Thos. McLellan, Woodside Lane, North Finchley, N.
Alexr. R. Reid, Association of Engineers, Singapore.
William G. Riddell, Messrs. John Hastie and Co., Greenock.
George H. Williams, 3, Sandringham Drive, New Brighton.

As Associate Members.

Thomas O. Lisle, "Braemar," Ruskin Walk, Herne Hill, S.E.
Frank E. Palmer, 142, Caledon Road, High Street, N., East Ham, E.
John Kerslake Thomas, Ireland Island, Bermuda.

As Associate.

Donald F. Call, 51, Chesterton Road, Putney, S.W.

As Graduate.

Arthur G. Raitt, 9, Clydeview, Whiteinch, Glasgow.

As Companion.

James Brodie, 41, Museum Street, London, W.C.