Papers of the Greenock Philosophical Society.—No. 8.

"WATT ANNIVERSARY" LECTURE

14th JANUARY, 1887.

IN HONOUR OF THE BIRTHDAY OF JAMES WATT.

MR. ROBERT DUNCAN

ON

"EVOLUTION IN NAVAL ARCHITECTURE DURING THE REIGN OF QUEEN VICTORIA."

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"Evolution in Naval Architecture during the Reign of Queen Victoria."

THE Annual Lecture under the auspices of the Greenock Philosophical Society, in honour of the birth of James Watt (January 19), was delivered on Friday evening, 14th January, 1887, by Mr. ROBERT DUNCAN, Shipbuilder, Port-Glasgow, in the Museum Lecture Hall, his subject being, "Evolution in Naval Architecture during the Reign of Queen Victoria." The importance of the subject drew together an audience which filled the large hall in every part. Mr. JOHN RODGER, Banker, occupied the Chair.

The CHAIRMAN, in introducing the lecturer, said—Ladies and gentlemen, to-night we begin the second half of our twenty-sixth session. As the full syllabus is in your hands, I do not intend to take up your time with the details. It has been framed to meet the varied tastes of the members, and I trust will be as successful as the first half. Our constitution provides that "an extraordinary meeting of the Society shall be held every year, in January, in honour of the anniversary of the birth of James Watt." We do this, in the words of the inscription on the statue in the library, "Not to extend a fame already identified with the miracles of steam, but to testify the pride and reverence with which he is remembered in the place of his nativity." And in accordance with this, and through the kindness of our esteemed friend and neighbour, Mr. Duncan of Port-Glasgow, we have been enabled to arrange for the usual Watt lecture. On previous Watt anniversaries we have enjoyed the services of Professor Joule, Sir William Thomson, Professor Fleming Jenkin, Mr. Scott Russell, and others; but on no occasion, I think, have we had a Watt lecturer who was both a native of Greenock and a member of the Society. Mr. Duncan is certain to handle in an able manner the subject he has undertaken.

Mr. DUNCAN, who was warmly received, said—When your committee did me the honour to ask me to deliver the "Watt Anniversary" lecture to your Society, I felt that in accepting the invitation, the responsibility, for me, was of no ordinary kind. Among my earliest recollections is the laying of the foundation-stone of the James Watt Monument with which this hall is connected; and when a few years after, in the early part of the reign of Queen Victoria, I received a considerable part of my education within the same building, literally at the feet of James Watt, I felt that his venerable face and pensive head were ever present with me; and his power and influence in after years on the world in which I have lived, have been such as to deepen all my early impressions into something more than veneration for his far-reaching mind, and wonderful, inventive, genius. It is quite possible that the same feelings may have influenced the lives of more than one of my old school-fellows. I know that for one of them I have built a steamer called the "James Watt," and that he has never lost an opportunity of putting that venerated name in the van of Greenock progress. As a Scotchman, James Watt is something more to us all than to the rest of the British Empire. As a townsman he is something more to me —and to most here, I hope—than to other "brither Scots." If seven cities contended for the honour of Homer's birthplace, why should the natives of Greenock not glory through all time in the immortal name of James Watt?—for *his* birthplace can never be disputed. James Watt was undoubtedly the prince of engineers and inventors, but he was fortunate in his time. The world was ready for him, and sprang to meet him; hence the greatness of his work and fame, and its influence on the fortunes of his country and the world during the last century. How great that work has been, we of this time can fairly appreciate. James Watt was essentially the epoch-maker of this modern world.

The heroes of civilisation were not "the great names at which the world grew pale." They were not the warriors, the priests, nor the politicians, who for long centuries bound the souls as well as the bodies of the people in chains. The true benefactors of the race have been the men of letters, of arts, and industries; the poet, the historian, the man of science, and the mechanic. Among the greatest names of the ancient world, apart from Scripture, were Aristotle in philosophy, Euclid in mathematics, and Archimedes in mechanics; but these men left no successors, and the struggle for existence went fiercely on for the next two thousand years. To my mind there have been only *four* epoch-making men in all past time, and those four are comparatively modern—they were Laurenz Coster the printer, Copernicus the astronomer, Columbus the discoverer, and James Watt the engineer. Coster revolutionised the world of letters, and put books and learning within the reach of all. Copernicus revolutionised the knowledge of the heavens, and made a way for Kepler, Galileo, Sir Isaac Newton, and modern science. Columbus revolutionised the knowledge of the earth, and opened the way for the bold adventurers who have made the modern world. And James Watt revolutionised the world of mechanics and gave to man, and to his countrymen above all men, the empire of the earth, of the land, and of the sea, with a greatness and a power of which the most daring imagination of all past ages never dreamed.

EVOLUTION IN PROPULSION.

The invention of the steam engine is the foundation of all the changes that have taken place in the naval architecture of this country. Spasmodic attempts had been made in the last quarter of the last century—after the adaptability of Watt's engine to mining and manufacturing purposes had been fully established—to apply it to the propulsion of small vessels with paddle-wheels, but no commercial venture in this direction was made in this country till 1812, when Henry Bell's "Comet" began a regular passenger service between Glasgow, Greenock, and Helensburgh. The example thus set was speedily followed, and in a few years steamers with paddle-wheels were plying regularly with passengers and cargo and even as tugs on all the rivers in Britain, and to Ireland and the Continent. Marine engineering was fairly begun, and the necessary adaptation of engines and boilers with greater strength and power for seagoing purposes, stimulated invention in the kind and quality of the tools and general appliances for manufacturing such machinery, as well as in the machinery itself.

In the marine boiler shop of that period we have the origin of the iron ship. The boilermaker began to think that if the shell of a boiler would keep water in, it would keep it out. Iron boats of small size had been built before for canal purposes, but the time was now ripe for a radical change in the vessel itself to adapt it specially to the change in the mode of propulsion.

Up till the year of Her Majesty's accession no systematic attempt had been made at ocean steam navigation. Like the galleys of old, the paddles still crawled along the shore, never being able to go far from their supplies of coal; and being generally full-rigged ships, using their sails on all occasions, an Atlantic voyage seemed beyond the reach of steam alone. Many learned men had declared it a commercial impossibility. Many things are practically and scientifically possible that, under the existing conditions from which they are considered, may at the same time seem commercially impossible. Ocean steam navigation in 1837 seemed a very doubtful business, and with comparatively good reason. The steam engine of that day was, from our present point of view, a rather crude affair, especially in the boiler department, where the waste of fuel was enormous. It was considered a great achievement, by John Bourne in his "Treatise on the Steam Engine," published in 1846, that the consumpt of fuel for sea-going purposes had been reduced from nine lbs. of coal per indicated horse power per hour to six lbs. In the presence of such vast waste of coal, ocean steam navigation might well appear impossible, except in very large vessels, the success of which at that time might naturally seem more than doubtful. Hence the enormous size of the "Great Eastern" at a later date—built to carry sufficient coal for an Australian voyage—a speculation in naval architecture in which the designer and constructor were not much influenced by commercial or prudential considerations.

THREE RADICAL CHANGES IN TWENTY-SEVEN YEARS.

In 1837 also, you will remember that the screw-propeller had no existence except in an experimental form, and we are thus brought face to face with three radical changes in shipbuilding and the modes of propulsion within twenty-seven years from the starting of the Comet—two of the most important of which were in the first three years of Her Majesty's reign. In 1812 steam shipbuilding began. In 1837 the first iron vessel made its appearance in Lloyd's Register, and in 1840 the screw-propeller made its first experimental trial in the Archimedes round the coasts of Britain. Before 1812 sails were the only modes of propulsion on the sea, and oars on narrower waters. Very quickly the steam engine worked its way to the front, and speedily drove the sailing packets out of their trade. By 1837 river, coast, and channel steam trades may be considered as fairly established; and conjointly with the railway system, which began in 1829, they were of great service in opening up and developing the internal commerce of this country. But more was wanted. Increased facilities and power of production internally, demanded increased facilities and expansion abroad. Rapidity and regularity of communication are the first conditions of commercial expansion. Mail services by steam had been established with the Continent, the Mediterranean, and even with India in a way, with very satisfactory results; and in 1838 the first Atlantic steam communication began. The Sirius and the Great Western made the voyage to and from New York at the same time in the middle of that year, in fourteen and seventeen days respectively, under steam all the way. The difficulty of ocean steam navigation was solved; and the further expansion which has since been accomplished was only a question of time and adequate means. What those adequate means were we have now to consider.

EVOLUTION IN MATERIAL FOR CONSTRUCTION.

Before the steam engine came into existence, the commercial intercourse between the nations was comparatively trifling. People had to be in the main content to have their wants supplied by the soil on which they lived; all else were luxuries scarce and dear. Money to purchase any but the actual necessaries of life was far from plentiful, and the mineral resources of this country, upon which the great prosperity of the last century has been built, had reached their limit of development, as there was no power in existence fit to keep the mines free of water to admit of deeper sinking. Without the steam engine we should by this time have had neither coal nor iron, and been commercially arrested in the middle of the eighteenth century, depending upon wooden ships and sails for such carrying trade as we had by sea. Practically, the shipping and commerce of the country had come to a stand. A change was wanted which should not merely be a development, but a revolution. It came with James Watt, and the result we all know.

Up till the accession of Queen Victoria the change was comparatively slow but sure. The wooden ship and the wooden steamer grew and multiplied; their development received a fresh start from the new conditions, and they went on again as far as wood—with iron, brass, and copper fastenings—could safely go. But that combination also has its limits, in dimensions, in strength, in cost, and in durability. It reached its limit of greatest development nearly forty years ago in the large Atlantic steamers of the Cunard line, built here by Mr. Steele, and the opposition Collins line in America. Beyond the sizes of those vessels iron and steel only could safely go; and iron was growing so fast that the fate of the wooden ship, and especially of the wooden steamer, was a foregone conclusion. Henceforth progress and development in wooden vessels was arrested, and a process of degradation set in, which we also know. There are few wooden vessels of large size now belonging to this country, and scarcely any built in it but the very smallest coasters. The sea-going wooden shipbuilding of the United States and Canada is also to a large extent extinct, and the foreign commerce of those countries is mostly carried in iron vessels built and owned in Britain.

In 1837 there were only 230 merchant vessels over 500 tons belonging to Great Britain, and only one iron vessel over fifty tons register. That one iron vessel was the beginning of the evolution in naval architecture—the parent of the new species destined to revolutionise the naval and merchant shipping of the world. I daresay this early specimen did not look much like its great destiny. It had probably more the look of the missing link than of the more perfect type of later days. I remember as a little boy looking with great surprise, not unmixed with contempt, at the first specimen of the genus "iron vessel" I had ever seen. It was sent from Glasgow to Greenock to get wooden beams and decks put on it by my father. The iron shipbuilder of the Clyde of that remote period could make the iron shell as like as possible to a long open boiler or tank; but putting a deck on it, with its necessary hatches and fittings, was a mystery he did not understand. It did not occur to him, nor to anybody else for a good many years after that, that an iron deck would do as well as a wooden one—in many respects better. It was the same thing with iron and steel masts and yards, and with wire rope. Nothing but timber would do, even for the masts of an iron ship, and hemp alone was suitable for rigging. Now all that is changed, and nothing but steel decks, steel spars, and steel rigging will serve our modern notions. It is wonderful how absurdly dense and conservative we are in many things which appear so obviously simple and proper after they have become established. The missing links in iron shipbuilding were comparatively few; the true type soon evolved itself from the conditions of the transition period. It was no sooner apparent that iron was suitable for shipbuilding than the services of the naval architect were at the disposal of the boilermaker; the former to supply the design and mode of construction, the latter to do the mechanical work, for which the wooden shipwright had neither the necessary tools nor training.

EVOLUTION IN WORK.

Here again we have an evolution in work, and a new class of artizans springing up to take the place of the shipwrights, who looked in some danger of being deprived of their living, as the spinners and weavers of an earlier time were rendered destitute by the introduction of the power-loom and the spinning jenny. Fortunately for the shipwrights many of them could and did adapt themselves to the new conditions of trade, as their employers had to do; and the expansion of that trade became so great and rapid that all readily found employment more regular and better paid than ever they had before.

EVOLUTION IN DESIGN AND PROPORTIONS.

The new departure did not much affect the design and proportions of ships for some considerable time. Science, outside of the naval dockyards, had scarcely any existence; and the technical literature of the shipbuilder dealt exclusively with timber; hence all the previously acquired and recorded knowledge of ship construction was valueless as applied to a totally different material, the qualities and quantities of which—sufficient for the work ships had to do—were quite unknown to all the recognised authorities on ships. The boilermaker triumphed in the mechanical department, and the speculative naval architect, as his assistant, found himself, for the first time, free from the leading-strings of authority, at liberty to make any design and arrangement of material he pleased sufficient for the vessel's intended trade. But in this freedom of design he was restrained by the conservatism of old associations with wooden ships, and the dimensions and proportions which had ruled the wooden trade long ruled the iron also. On account of the elasticity of timber, even in the large masses and combinations necessary in shipbuilding, wooden sailing vessels were rarely built of a greater length than three to four times their breadth, or about six times their depth. With wooden steamers this became extended to about seven times the breadth and ten times the depth; but with these extreme proportions in both classes the iron binding had to be of the most formidable character, otherwise they soon got out of shape and lost caste accordingly.

The naval architect in iron took some time to discover that proportions which were dangerously weak in wood, were perfectly safe in iron, and it was from the iron river steamer that the lesson was most quickly and effectively learned, and applied on a larger scale. Development in length, in proportion to breadth and depth, reached its limit about thirty years ago, when a length over ten times the breadth was attained, with the result that iron too was discovered to have a limit of strength, with manageable weight, on the arrangement of scantlings then common in iron ships, beyond which it was not profitable in the owners' interest to go.

This ten-breadths limit became almost a rule for nearly twenty years; but within the last ten years the researches of the late Mr. Froude, in his experiments on the models of ships of war, to determine the effect of proportions and form on resistance and speed, have had the effect of causing a reaction in favour of greater breadth, even for the highest speed types, and this reaction has affected the lower types to such a degree that the length of an ordinary cargo steamer, in proportion to breadth, is now very little over the proportion common to the largest iron sailing ships of this time.

INFLUENCES AFFECTING FORM.

Along with this retrogression in length—or rather in proportions—the forms of iron ships also became retrogressive, reverting to ancestral types. Various influences have been at work to this end. As in the natural world changing conditions have developing or degrading effects, in the commercial world similar effects follow similar causes.

The earliest influence on the change of form was the change of Tonnage Law in 1835, which was immediately followed by a style of ship as remarkable as it was peculiar. The square boxes of the older time gave place to long raking sharp bows and sterns, broad decks and narrow bottoms, which, coupled with the fiddle-shaped waists of the paddle-steamers of the period, made the strangest possible contrast with the prevailing types of a few years before. This could hardly be called progress, and it was not development. It was distinctly evolution of entirely new forms, with the changed conditions of the law regulating the measurement of ships.

With 1854 came another change of the tonnage law entirely for the better, and the forms of our ships immediately took shape accordingly. The extremes of the previous types gradually disappeared, and naval architecture, once more free in all directions, prepared to assert itself in improved forms adapted to all the varied requirements of trade. This freedom was short-lived as regards construction. In the following year, 1855, Lloyd's Register Committee issued their first rules for the construction of iron ships, and shipbuilders were again in leading-strings as far as the scantlings and distribution of material went. With great wisdom Lloyd's adopted the new tonnage law, as the basis for scantlings, leaving the shipbuilder and shipowner free to choose any dimensions and form of ship most agreeable to their taste or requirements. In 1862 the Liverpool Underwriters' Registry became a classification society, with register book and rules for scantlings for iron vessels only. This Registry took dimensions solely, as their basis for scantlings with a distribution of material, less in weight, and considerably different from Lloyd's. An early effect of this change of base for construction, probably not intended nor foreseen by the framers of the Liverpool rules, was a gradual reversion to the box shape for new vessels classed exclusively in that Registry. Nearly all the tonnage of the kingdom at that time was built under the oldest tonnage law, abolished in 1835, but still existing as a measure of price with builders, hence called "builders' tonnage." This law, taking no account of the depth or form, left the owner free to get the largest carrying capacity possible for his money. The consequence was that the ships built under that law were usually the deepest and squarest possible for their length and breadth. In a few years thereafter—about 1866—the old law was entirely superseded by the new as a measure of purchase and sale, but its effect remained in the rules of the Liverpool Registry. They had classification to sell, and they sold by dimensions, leaving the tonnage to the builder and owner; they required considerably less material in construction, which was to the further advantage of the owner in a cheaper ship and larger carrying ability, and the consequence was a steady increase in the demand for Liverpool class, much to the disadvantage of Lloyd's. This induced the committee of Lloyd's Registry, about 1870, to make an entire revision of their rules for the construction of iron vessels; but instead of reducing the material, and rearranging its distribution, on their former tonnage basis, they adopted a system based on dimensions and proportions chiefly, only influenced slightly by the form of the midship section, and thereby accelerated the reaction on the forms of ships which had already begun. So long as the two systems were in some antagonism, the older prestige of Lloyd's maintained the greater number of new ships in some reasonable symmetry; but as soon as the principles which governed the scantlings of both Registries became almost the same, and in the main erroneous, the reaction from long fine forms became intensified, and the box shapes of the old tonnage law again became the fashion. The amalgamation of the Liverpool Registry with Lloyd's in 1885 has concentrated the construction and classification of British shipping in that society, and, were it not for the conservative tendencies of all monopolies, I would be disposed to hope that a more scientific base for construction would receive their early consideration.

It is hardly too much to say that Lloyd's present arrangement of scantlings by dimensions and numerals, ignoring the form, is not satisfactory; the inducement remains to build vessels of the squarest shapes to the extreme limits of the "numeral" requirements, as the weight of ship per ton of capacity is thereby minimised. In my experience it is not difficult, within the range of any or all of the numerals, to reduce the load displacement—which ought to be the measure of the vessel's strength for her work—one-fourth to one-half, within the ranges of form as expressed in co-efficients of tonnage, still common in merchant steamers, especially where high speed is required, without receiving from the Rules any consideration in reduced scantlings for the diminished weight and strains the material of the hull has to bear. This can hardly be considered satisfactory from a practical and commercial point of view, and it certainly is not from the scientific standpoint of our present knowledge of the strength of iron and steel ships. The tenacity and safe working load of iron and steel for all structures on land are now perfectly well known, and the quantity of those materials required for any structure can be judiciously apportioned by all competent engineers to the strains and pressures the work has to bear. In boiler work, factors of safety in proportion to pressures, have long been recognised standards for the proportions of the parts of boilers, according to their size and shape. In ships alone the proportions of material required in construction are determined by combinations of figures in connection with dimensions, which have no relation to the form of the vessel or the loaded strains the material of the hull has to bear. Those strains are now as well known for ships as they are for boilers. Fair factors of safety have been determined with scientific precision by several competent authorities, and can be calculated without difficulty. There does not appear to be any reason why co-efficients of strength should not be imported into construction rules, as they have been into rules for loading. Much valuable knowledge and experience has been evolved from the practical working, and the literature, of the naval architecture of the last sixteen years, since Lloyd's existing rules were framed, and it is not expecting too much from the eminent scientific skill of Lloyd's principal administrative officers, to hope that we shall soon see an amendment of the rules for the construction of iron and steel vessels, worthy of their high position and reputation.

EVOLUTION IN SIZE.

In 1837, as I have already said, the vessels of the merchant navy were all small, very few being over 500 tons, and none except the ships of the East India Company—which were more men-of-war than merchantmen—were over 1,000 tons register. It is difficult to get at the dimensions of those early ships. Lloyd's Register Book did not record dimensions till 1863; but we have an idea from the usual proportions of wooden vessels under the old law, that a sailing vessel of 500 tons in 1837 would be very little over 100 feet long. The steamers of the same period were all of the same style. The Enterprise, the first steamer to make the voyage to India by the Cape of Good Hope in 1825 was only 122 feet long, and sailed as much as possible—not a very smart process, dragging paddle-floats—consequently she took 113 days on the passage to Calcutta. The Royal William, which was the first Atlantic steamer from Liverpool in 1838, was 175 feet long. The Britannia, the first of the Cunard Line in 1840, was only 207 feet long, and in other respects not unlike a 1,200 ton sailing ship of the present day. The largest of the wooden steamers built between that time and 1850—when they were entirely superseded by iron vessels—did not exceed 300 feet, and there development in timber ceased. With the building of the Great Britain at Bristol between 1839 and 1845—she took all that time to build—a large stride was made in the dimensions of iron ships—too large it was believed at the time. She was barely 300 feet long, and was considered so enormous that no less than six masts would serve her. She is still in existence, but in dimensions has long since been left behind. Besides being the largest ocean steamer of her time, she was designed the first of the ocean screw propellers. The iron ship and the screw were steadily working their way. The length increased by degrees, but it was not till 1870 that it reached 400 feet in the largest Atlantic steamers.

In 1872, as President of the Institution of Engineers and Shipbuilders in Scotland, I ventured the prediction that as the previous generation had doubled the length of ships, I saw no reason to doubt that the next generation might double that again; and reckoning by draught of water, and assuming twenty-five feet as the deepest safe draught at both working ends of the Atlantic voyage, I indicated the longest purely cargo steamer for profitable work at twenty times the draught, or say 500 feet. For mixed passenger and cargo traffic I assumed twenty-five times the draught, or a length of over 600 feet; and for purely passenger steamers I took thirty times the draught, or 750 feet long, and gave it as my opinion that it was "not problematical we might yet see steamers of 800 feet in length, the ferry boats of two oceans, making their regular passages in a week." This you will admit was a pretty long stride for the time, but already more than half of my prediction has been accomplished. Purely cargo steamers are now over 400 feet long. The mixed class considerably over 500 feet; and when the purely passenger expresses come to be built, it must be with a power and speed that shall throw all previous passages of the mongrel breed entirely into the shade.

On that same occasion I said that as steam pressures had been more than quadrupled in the preceding generation with the most beneficial results, it was not beyond the bounds of possibility that we might double and treble these again, with corresponding economy in coal consumption. In 1837 the highest pressure of steam afloat was ten pounds, and till the general adoption of the compound engine, about 1870, pressures had not advanced beyond thirty pounds. In that year they went up with a bound to sixty pounds, and at that time this looked very near a limit with the cylindrical tubular boiler, as steel, such as we have now in general use in ships and boilers, was unknown, and iron at much higher pressures than were then in use was unmanageable in size and unreliable in quality. Not half a generation has elapsed since 1872, and already my anticipation has been fully accomplished with the aid of the new material. At the present time there is scarcely a marine engine making of less than 150 pounds pressure, with triple expansion; and quadruple expansion engines and boilers have been built to carry 180 pounds pressure in regular work.

When we venture to prophesy we must have a large amount of faith leavening our knowledge. I had at that time, and I have still, sufficient faith in our engineers to believe that their ingenuity and efforts towards the extreme limit of economy in coal consumption are not exhausted. When we are looking forward to still shorter passages between Europe and America, it is quite unnecessary to trouble ourselves with doubts as to what may be accomplished within the bounds of possibility. We know very little of the possible. We know what has been done within the last fifty years, and how extremely impossible it would all have seemed to our grandfathers. About fifty years ago one steamer a fortnight began the Atlantic trade, burning four times the quantity of coal required by a modern triple expansion engine of the same power. Those vessels had no room for anything in their holds but coal, and carried only the lightest goods besides at rates that would make a modern shipowner's teeth water. But step by step the ships and engines grew in size and multiplied in number. Competition reduced passage rates and freights. Cargo took the place of coal, and the screw and the compound engine superseded the paddle, and now, instead of one steamer a fortnight, we have daily, almost hourly, sailings between Europe and America, and the time on passage has been reduced from fourteen days to seven. The size of the steamer has increased from 175 feet and 700 tons in the Royal William to 550 feet and 8,000 tons in the City of Rome; while the Servia, Etruria, and others of the Atlantic "greyhounds" are not far behind. Year by year we are more and more separating the passenger from the cargo traffic in all departments of commerce on land and sea, and inevitably in a few years the passenger traffic on the Atlantic must be carried in steamers built for that trade alone, and of very much greater speed than anything yet accomplished. Speeds have been accomplished in torpedo boats under very forced conditions, which until accomplished were believed impossible. It accords with all our past experience that what has been the miraculous speed of one generation has become the ordinary pace of the next; and it is quite within the bounds of possibility that Her Majesty's reign may yet see steamers of 800 feet long, the "Flying Scotchmen" of the sea, making their Atlantic passages at twenty-five to thirty miles an hour.

It must not be supposed that I originally proposed and now repeat such large dimensions from admiration of mere magnitude; neither do I advocate leaps in the dark beyond all past experience or present necessities. The demands of commerce ought to be met as they arise by means commensurate, and especially in shipping not greatly in excess, otherwise commercial failure is inevitable, as in the case of the Great Eastern. The time will come, in my opinion, when vessels of greater size than she is will be not uncommon; but they will be the result of steady development, not of "the vaulting ambition that o'erleaps itself." When, therefore, fifteen years ago, with the warning of the Great Eastern before my eyes, I ventured to predict that the next generation would see even larger vessels in regular employment on the Atlantic and Pacific Oceans, I did so in the full belief that such vessels would be evolved from the commercial requirements of their time, and with all the developments of the intermediate period necessary to insure their commercial success. It may be asked why I still adhere to my extreme lengths in the face of the reaction in favour of shorter lengths with which we have recently been made familiar, even for the highest ocean speeds. My answer is that our present highest speeds are not the highest possible on the sea, and that they are being achieved under uneconomical conditions. As a commercial element, "pure speed" of the highest order I have indicated must be conducted on the most economical principles, or it will fail of commercial success. In all my experience there is a minimum length in relation to which speed must be maintained, otherwise the economical relationship will be vitiated and power wasted. The rule for that minimum length is Mr. Scott Russell's, "that the length of every steamer should not be less in feet than the square of the speed in knots for which she is designed." More length is an advantage, less is a mistake. You will easily see by a very simple calculation that the length of all the highest-speed commercial vessels yet built is well over this economical limit for the highest speeds that have been accomplished. For example, if a speed of 10 knots is wanted, the square of 10 is 100, which is the shortest suitable length in feet for 10 knots speed.

If 12 knots be wanted,	the length	should	be		144 feet.
If 15	"	"	"	"	225 feet.
If 18	"	"	"	"	324 feet.
If 20	"	"	"	"	400 feet.

Those of us who have built vessels intended for such speeds are well aware of the difficulty experienced in approaching these results even with vessels considerably in excess of the limits, and we are well aware also that nothing approaching 20 knots is now afloat on the Atlantic passage even with much larger dimensions. It is quite true that in torpedo boats and torpedo catchers speeds of 20 to 25 knots have been obtained with very much smaller vessels, but these have not been commercial results. They have been achieved as specialties, regardless of all other considerations, at an expenditure of money and power, for limited periods of time, which would be simply ruinous if tried commercially in regular work. In business matters we must keep within the factors of safety and profit, as determined by past experience, if we would escape destruction. When, therefore, we speak of speeds that have not been hitherto attempted on the ocean, we must be prepared to accept all the conditions necessary to commercial success; and one of the chief of these conditions is that the length must be proportional to the speed. We have seen that for a speed of 20 knots we must have a length of 400 feet at least, which is not an excessive length in our experience, but when we go over 20 knots the length increases with startling rapidity by the square of the speed. Hence for a speed of 22½ knots we must have a length of 500 feet, and even that we have surpassed; it therefore only requires a slight change in the conditions of the ship herself to adapt existing dimensions for these higher speeds. It is when we come to higher speeds still that we get beyond our present limits and into the region of the extravagant; but, however extravagant the figures we have to face may appear, they must be met if the speeds required are to be realised. We have, therefore, for a speed of 25 knots, to have a minimum length of 625 feet; for 27½ knots we must have 756 feet, and for 30 knots 900 feet, and all those lengths with forms especially adapted for the speeds required. Hence the revolution that must take place in the Atlantic passenger trade if we are to get higher speeds than those now being accomplished by the largest vessels afloat. Cargo must be abandoned, and the vessels built expressly for mails and passengers alone. For the enormous power required they must have twin-screws, and with twin-screws the draught even of the largest need not exceed the present draught of the largest Atlantic liners. If it be said that the draught is too little for such extreme lengths, I again refer to experience as our safest guide. The fastest of our river steamers have a length over fifty times their draught of water, and the best of our Channel steamers have lengths from twenty to thirty times their draught. The fastest Channel steamer I have had to do with is a twin-screw steamer with a length exceeding thirty times her draught; and I venture to say that, irrespective of the breadth, where the draught of any high-speed steamer is greater than in this proportion to length, the result cannot be perfectly satisfactory. Hence, finally, the necessity for the great lengths I advocate in proportion to draught of water and speed, and I do not hesitate to again repeat that shorter lengths for the highest speeds involve waste of power, unsatisfactory results, and commercial failure.

EVOLUTION IN THE NAVY.

If we look now for a few minutes at the Navy we shall find an evolution as wonderful taking place in that department of British naval architecture. In 1837 the wooden ships of the Navy were not any longer than the merchantmen of that date, although of very much greater breadth and depth—or rather height—according to the number of gun decks they had above water. The Queen, three-decker, 110 guns, was only 204 feet long, and the French 120-gun ships of the same date were just 210 feet. The famous 74's were only 180 feet long, and the frigates 130 to 160 feet. They were veritable tubs, despite their sounding names and still more wonderful deeds; and with their primitive artillery, and the conditions of their equally primitive existence, they are now, as fighting ships, as extinct as the mammoth.

With the Crimean War in 1854 we entered on a new era in armour clad gunboats, which in 1860 developed into the wooden "ironclad" the Gloire in France of 252 feet long, and the Warrior and Black Prince in this country of 380 feet long, which are still among the half-dozen longest vessels of the British Navy. The armour of these vessels did not exceed 4½ inches thick, and at that time there was neither shot nor shell in existence that could pierce such armour.

That is just twenty-six years ago, and we have had no naval war since to test our strength; yet such has been the rivalry among the Powers of Europe, and especially between ourselves and our dear friends the French, that the whole system of our navy has undergone an entire revolution in ships and artillery, an evolution so extraordinary so far as the ship is concerned that it cannot in any sense be called development, and could only be paralleled in nature on the hypothesis that the monstrous reptiles of the dragon age of the world were evolved from the birds of the preceding epoch. Unfortunately, for the hypothesis in this instance, the birds in nature came after the reptiles; it may be, therefore, not unlikely, that when the present fighting saurians are played out, future generations may have an evolution in ærial navigation more extraordinary than anything we have seen, or can conceive of, on the sea; meanwhile the noble old ships of Nelson's day with their clouds of canvas have all disappeared, and in their place we have a hideous, scaly monster, with only its back above water, vomiting fire and smoke, sweeping along with irresistible, unseen force, and armed with powers of destruction of which Nelson and the heroes of his age had no conception.

The "Warrior" was a full-rigged ship, with four nine-ton and twenty-eight six-ton muzzle-loading guns behind armour four-and-a-half inches thick, and a speed of thirteen to fourteen knots. At present we have two ironclads, or rather steelclads, building, of 345 feet long, 73 feet broad, about 12,000 tons displacement, and 12,000 horse-power, with an expected speed of 16½ knots, carrying four 68-ton breech-loading guns, in two turrets, behind 20 inches of armour. We have other four of 10,000 tons displacement and 12,000 horse-power, to have a speed of 17 knots, with similar armament and armour, and three formidable monsters of the same size and speed, each carrying two 110-ton guns in two turrets; besides several smaller guns for minor service. In addition to these we have built and building seven "belted cruisers," as they are called, of 300′ × 56′ and 5,000 tons displacement, with 8,500 horse-power, for a speed of 18 knots. These vessels have a 10-inch armour belt round their waterline, and carry two 18-ton and ten six-inch breech-loading guns.

The enormous weight and power of recoil of such great guns renders great breadth of ships necessary for stability, and the enormous armour considered necessary to offer some resistance to the power of such guns renders it imperative that the vessels should be the shortest possible for the speed, to reduce the surface requiring protection. As it is, they have only partial protection, a belt of the thickest armour along the waterline to keep the shot or shell from piercing under water, and on the turrets to protect the guns; the rest of the armour —where there is any more—thinning off much too weak for the power of the largest guns. As a rule the overwater hull at the ends is very vulernable, and it seems an open question how long such vessels would be able to keep afloat in action against similar antagonists.

It is perfectly clear we cannot go on much longer in this this style. Everything above the deck—we might almost say above water—has been sacrificed to obtain thickness of armour to protect what remains. And what remains, covered with eighteen inches to two feet solid steel, is as vulnerable after all to the guns and shells they carry as the old wooden walls were to the artillery of their time. If all this has been accomplished in twenty-five years, what may we not expect in the next twenty-five? It would be needless to say that what has happened was not foreseen. It was both foreseen and predicted by those who knew how invariably history repeats itself, the conditions being similar. The power of attack must inevitably overcome the power of defence, intelligence and skill being equal. As the ironclad knight of the Middle Ages went down before the unprotected and light-armed footman and was extinguished by the gun, so will the armour and the guns of the new men-of-war inevitably kill each other, as they are now doing. We have, I believe, reached the limit of armour and guns afloat, unless we are prepared to go to vastly larger and more costly fabrics involving the expenditure and loss of several millions on each ship. Our newest will cost a million each, which will be —as every new development in the past has eventually been—so many additional millions thrown away so far as defence is concerned. Our most recent development has been in power and speed. We have discovered that the lumbering ironclad of low speed, is no match for the swift cruiser of high speed. Apart from the weight of armour and size of guns, the power of choosing position and distance, or declining action, depends on speed. We are therefore endeavouring to make our new ironclads as fast as the cruisers. But here again the light-heeled cruiser has the advantage with equal power. It becomes a race between an outrigger and a jolly-boat, with similar crews, which is what racing men would call "a moral." In the not very remote future our ironclads will be reserved for harbour defence at home, and in the colonies and coaling stations; they will be much better than permanent land works for places of this kind; while the defence of our mercantile marine will depend upon the swift cruiser with long range guns, to match the swift cruisers that will be sent against our merchant ships in time of war by our enemies, whoever they may be. With ironclads and guns they cannot fight us, and will not try. In merchant shipping we have everything to lose, and no other possible enemy has anything to speak of. In the next great war in which we are engaged, the lesson that the Alabama taught the world will not be lost sight of, aud will be applied against ourselves. Are we at present prepared? I rather think not. None of our 18-knot cruisers are yet ready. Our large and fast Atlantic liners would do for speed, but they are unsuitable for the carriage and recoil of the large guns required for the long-range service of the present day. Such guns have to be carried high with a free range, and for this purpose I doubt much the stability and capability of such vessels as protectors of our commerce. We want vessels of at least equal speed, specially designed for such service. Those we have will do so far, but we want more, and larger, and faster. I trust we may get them in time. For transport service our Atlantic "greyhounds" are all right; speed is the one thing needful there; and in this department our Government service is lamentably deficient. Our best, almost our only, transports, specially built for the purpose, are twenty years old, with speed of ten to twelve knots. It would be almost certain death to send a regiment of soldiers to any of our foreign stations in one of these in time of war.

They could not escape an enemy's cruiser, and they could not fight. Our Admiralty seem to have lost sight of the fact that their transport ships are hopelessly antiquated in point of machinery and speed, and that in the event of war they would be useless unless immediately re-engined for the highest speed of the present day.

Of the torpedo fleet and its possibilities in time of war, I need not speak. You have had that so recently before you in most attractive form that I can add nothing to it, except, that it is an evolution entirely of the ironclad period. It is the old story of striking the horse beneath to bring the iron-clad knight to the ground. It may be of service in the open sea, but for the torpedo apart from the fleet I have a very great respect, and have to express my confidence in it in the hands of the engineer, as the weapon of all others for harbour and river defence. If we were as alive to its value as our possible enemies are, there would be no chance for a French or Russian cruiser to enter or leave a British port at home or abroad in safety. At the present moment, unfortunately, this might be done with impunity. Let us hope it will not long be so.

EVOLUTION IN THE SCIENCE AND LITERATURE OF NAVAL ARCHITECTURE.

For fifty years before the accession of Queen Victoria, the science and literature of naval architecture had made no progress. What was of it was all naval. There was no science and no literature to speak of in merchant shipbuilding. Anything of the kind that did exist in this country was of foreign origin, chiefly French. Our countrymen of last century and the early part of this were quite content to beat the French—when they could catch them—take their ships, copy their models, and translate and apply their science. To the Admiralty authorities of those days nothing more seemed necessary, and nothing more was done; and in 1837, so far as British naval architecture was concerned, we were still in the age of Noah—indeed rather an age behind him—as there were no sailing vessels of any kind belonging to Britain of as admirable proportions for seagoing purposes as Noah's Ark.

In 1811 the first school of naval architecture in Britain was established at Portsmouth, for the training of the dockyard apprentices in the science and practice of naval construction, avowedly from the French books and models. This school continued till 1831, when it was abolished, the Government of the day not seeing any good use it could make of the scientific apprentices it had trained;

and these as they completed their education were naturally dissatisfied at being turned back to manual labour, without any opportunity being given them to show that they could improve on French fashions.

In 1848, in another enlightened fit, the Admiralty opened a school of mathematics and naval construction at Portsmouth, under Dr. Wooley, who is still alive; and again, in a relapse of economical ignorance, closed it in 1853. In the short time it existed, this school produced Sir Edward Reed, Sir Nathaniel Barnaby, and several others who have since made their mark on the naval architecture of Britain. In 1864 these alternate fits of intelligence and stupidity came to an end in the establishment of the Royal School of Naval Architecture at South Kensington, which was transferred in 1873 to Greenwich, where, as the Royal Naval College, it has some prospect of continuing, as one of the institutions by which the maritime supremacy of Great Britain will be honourably maintained.

In the South Kensington school were trained the men who are at present the heads of the Constructive Departments of the Government service. Mr. W. H. White, the chief constructor, is one of the ablest literary authorities on naval architecture in this or any other country. Professor Elgar, the first professor of naval architecture in Glasgow University, is now director of H.M. Dockyards. Professor Phillip Jenkins, his successor at Glasgow, and many others of the same school, but only less distinguished, are now doing good service to their country in these and other important positions in the naval and merchant service.

It is hardly likely that the Royal School of Naval Architecture at South Kensington, with its after developments at Greenwich, would have had any existence but for the establishment in 1860 of the Institution of Naval Architects in London. This Institution was founded chiefly by the active exertions of Sir Edward Reed, then plain Mr. Reed, editor of the *Mechanics' Magazine*, one of the Admiralty's scientifically trained apprentices for whose services they had no employment. Mr. Reed naturally became the first secretary of the institution in the foundation of which he had done such good service and continued to hold that position till the force of circumstances in the naval developments of France, compelled the Government to break through the conservatism of official routine, and appoint him over the heads of the older "barnacles" of the service, as the first scientific constructor of the British Navy. It is needless to say that the result justified the appointment. The British Navy became