THE ENGINEER AND SEA TRANSPORT

BY

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The seaports of the West Country will long be famed for the part their seafarers and small but sturdy ships played in voyages of discovery. Such enterprising expeditions opened up trade routes to new countries which have been developed to advantage by successive generations. By the end of the eighteenth century, however, the expansion of world commerce was only making slow progress. Hostilities between European countries reduced trade to a low level. In the absence of foreign competition British shipowners were complacent. Moreover, they were protected by Navigation Acts which compelled imports to be carried in British ships and by the monopoly of the rich Eastern trade by a chartered company. Healthy competition is, however, an essential factor in progress, and the stagnant conditions of those days removed incentive both in shipbuilding and ship operation.

Throughout the eighteenth century naval architecture remained static and improvements were negligible in both the speed and size of sailing ships. At the end of the period, the Americans, having achieved political independence, were the first to break with tradition in the design and construction of merchant ships. They exploited the merits of fast, sleek sailing ships in place of lumbering, heavily armed merchantmen, and this move soon proved a technical and commercial success. Their sailing clippers were superior in speed, size and construction and were produced at about half the cost of European ships. The American shipping companies therefore captured the trade of the Atlantic and Pacific and a considerable proportion of the desirable produce of the East reached Europe via Boston.

In 1816, they were the first to establish regular sailings, and a monthly service between New York and Liverpool commenced. The average times of Atlantic crossings were reduced by some 25 per cent and most companies averaged twenty-two days for the eastward run and thirty-five days for the return. These excellent services captured the major part of the immigration traffic to the North American continent, while British shipowners looked on with indifference. This outlook might have proved fatal, for, by the 1840’s, the American merchant fleet had increased until it was the second largest in the world and comprised sailing ships which were second to none. Moreover, their fifty years’ sole experience in the construction and development of speedy clippers gave them an almost unsurpassable lead in sail.

Pioneer engineers had other ideas of the best means for propelling ships and, as early as 1801, Symington patented his method of constructing a steam engine which provided rotary motion at a crankshaft through a piston rod and connecting rod, thereby eliminating the conventional lever or beam. A horizontal single-cylinder double-acting engine of this type was used to drive the crankshaft of the stern paddle-wheel steamer *Charlotte Dundas.* The successful trials of this first practical steamboat proved the potential merits of steam propulsion and inspired engineers on both sides of the Atlantic.

In 1807, Fulton employed British steam machinery to propel the paddle steamer *Clermont* on the Hudson River. This ship demonstrated the advantages of steam propulsion over sail for navigation on inland waterways, and early American developments concentrated on this aspect. In 1811, Bell introduced the famous paddle steamer *Comet* into service between the ports of the Firth of Clyde. Shipbuilders quickly appreciated the qualities of this ship and comparable vessels were soon building at all major British ports. With limited sheltered waters, these steamers were used largely for coastal service and, by 1826, appeared on the London to Portugal and Dublin to Bordeaux routes. The working pressures of boilers were below 5 lb/sq in and coal consumption of the steam machinery was little better than 10 lb/i.h.p. hour. In consequence the machinery and fuel occupied a large proportion of the available space in the ships and severely limited the freight-carrying capacity. Nevertheless, these steamers were a success, and in the 1830's few steamship companies lacked financial support. Owners generally ploughed profits back into the companies and rendered a valuable service to commerce and steamship development by increasing their total tonnage with new construction. The burden of this practice was heavy, but eventually proved sound policy, when, in 1837, the Government contracted private companies for the sea-carriage of mails.

Shipowners and engineers aimed at the conquest of the Atlantic by steam and so compete with the fast sailing ships for the steadily growing passenger and freight traffic. By 1838, improvements in steam machinery had reduced coal consumptions to 5 lb/i.h.p. hr and the total fuel necessary for the crossing could now be carried. In that year, the *Sirius* steamed continuously from Cork to New York in nineteen days, but within a few hours of her arrival the Bristol built *Great Western* arrived, having steamed continuously from her home port on a maiden voyage of only fifteen days. The latter ship undoubtedly stole the thunder and Sir John Rennie considered, at that time, that her performance was such that there seemed no bounds to the extension of steam navigation. That the first voyage of the *Great Western* was in no way abnormal, is evident from her eight years' service prior to being broken up ; a period in which she made seventy-four double crossings of the Atlantic with average outward and return times of sixteen and a half and thirteen and a quarter days respectively. Further, this ship operated at a substantial profit and left no doubts that the future of ocean-going ships lay in navigation by steam.

Constructional engineers and forge-masters had also been active since 1815, when a small sailing ship with a wrought iron hull plied the Mersey. This was followed three years later by an iron passenger boat, *Vulcan,* which commenced operation on the Firth of Clyde canal, while an iron steamer, *Aaron Manby,* navigated from Thames to Seine in 1822. Such small iron vessels were initially prefabricated in sections at the forges of the Midlands, for transportation and assembly at the ports. As confidence grew, larger ships were built in the shipyards, and by 1850 Lloyd's Register Book contained the names of no less than one hundred iron ships, more than half being steamers. Their size was generally below 550 tons, but the then colossal iron steamer *Great Britain,* of 3,618 tons, had already been in service for five years. Although a commercial failure, this venture was in many ways a technical success, establishing an inevitable trend to larger ships for ocean service. Moreover, her capacity to carry 1,000 tons of coal, 1,200 tons of cargo and 260 passengers represented a marked advance in the capabilities of the steamship.

The *Great Britain* was also the first large screw steamer to enter ocean service and, although at an early stage of development and less efficient than paddles, screw propulsion proved superior, since heavy seas could damage paddles and render them inoperative. The Admiralty were prejudiced against both iron construction and screw propulsion and on their instructions the early Cunarders which carried the Atlantic mails were wooden paddle steamers. It was not until the 1860's, when a reduction in the hazards of fire, grounding and collision had been attributed to iron construction, that relaxations were permitted. At the same time, experiments instituted by the Admiralty and improved the performance of propellers to a stage that these, too, could be accepted.

Each engineering achievement up to this time had been countered by the Americans, who maintained faith in the sailing ship. They produced bigger and faster clippers, and, although fighting a losing battle on the Atlantic, maintained superiority on the longer sea-routes. This was evident when passenger and freight traffic to Australia increased rapidly following the discovery of gold in 1854. British owners, freed from the restrictions of the Navigation Acts, purchased American clippers for their Australian services.

Although developed to a reasonable state of reliability, single expansion engines exhausting to surface condensers showed little improvement in fuel consumption. Steamers were, therefore, incapable, of making the long voyages to Australia via the Cape, and completion of the journey in stages was impracticable. Two alternatives were tried and both these were originated by the famous engineer Brunel and the equally eminent ship designer Scott Russell. The first was an iron ship, *Victoria*, of 3,000 tons, equipped with a small steam-engine driving a two-bladed propeller through gearing. The hull of the vessel was of greatly advanced design and a speed of ten knots could be obtained when the engines were operating, while six knots was maintained under sail. A voyage of sixty days from Gravesend to Adelaide won the Colonial Prize of £500 for the fastest journey. The second ship, the phenomenal *Great Eastern*, never confirmed the theoretical considerations on which her construction was founded. Brunel was of the opinion that this ship of 32,000 tons and carrying 10,000 tons of coal could steam the round trip to Australia without recoaling and, at the same time, carry sufficient cargo and passengers to provide a handsome return. The complete commercial failure of this ship is a well-known story, but she must be credited with laying more than 100,000 miles of cable, which established communications across the Atlantic and offered shipowners a convenient means of arranging cargoes and controlling the voyages of their steam ships.

It was abundantly clear that increased trade and traffic with the Far East and in the Pacific hinged on the improved economy of the main machinery of steamships. By 1854, advancement in the design and operation of iron boilers made working pressures of 25 lb/sq in possible and also enabled Elder & Randolf to produce a practical compound engine, in which the steam underwent a second stage of expansion. The first engine installed in the *Brandon* showed a fuel consumption of 3¼ lb/i.h.p. hr, but early engines of this type suffered from want of reliability. Two years later the Pacific Navigation Company put two paddle steamers, *Inca* and *Valpariso*, into service and each was fitted with compound engines. Three other ships of this company were then re-engined with this type and one of these ships, the *Bogota*, displayed a 50 per cent fuel saving after re-entry into service. Up to 1866, Elder & Randolf alone had built forty-eight sets of compound engines which were mainly operating in the Pacific. At the same time the P. & O. Company had ten ships propelled with compound engines in general operation and the Blue Funnel Line had three. The latter company was able to run 8,500 miles from England to Mauritius without coaling.

A century ago, Bessemer patented the converter process for the manufacture of steel and the products of early practice were used almost exclusively for hull construction, the quality not being found consistently reliable for boilermaking. Nevertheless, valuable experience was gained in the manipulation of steels in the shipyard and hastened the extensive use of the high quality and cheaper materials available in quantity by the later Siemens Martin openhearth process. Steels led to a minor revolution in shipbuilding and boiler and machinery construction. The superiority of steel over wrought iron permitted a 25 per cent reduction in the scantlings of principal component parts, representing a saving in weight of over 100 tons per 1,000 gross tons of ships, as well as reducing power plant weights. These savings were important at a time when steamers had to carry large quantities of fuel. An even greater effect of steel construction was evident in boiler practice, however, for within a few years, working pressures increased threefold and brought about improved economy and reduction of unit size, as well as enabling designers to develop more efficient and higher powered steam reciprocating engines.

Some indication of the progress which occurred in a twelve-year period may be observed by the comparison of typical liners. The iron ship, *Oceanic*, of 3,800 tons and completed in 1871, was one of the first on the Atlantic run to be equipped with compound engines. These engines of 3,000 i.h.p. received steam at 65 lb/sq in and provided the ship with a speed of 14 knots. The *Umbria* and *Ethruria*, of 8,120 tons, were both steel ships completed by 1884. Engines of similar type developed no less than 14,500 i.h.p. for a single screw, steam being supplied at 110 lb/sq in pressure. Whereas the *Oceanic* could cross the Atlantic in eight days, the latter were able to complete the same voyage in six days.

These ships represented the peak of the compound engine, in a relatively short but most important period of predominance. Increased boiler pressures enabled expansion of the steam to be carried a stage further, and triple expansion engines made an appearance. This engine appeared in 1872, but its true merits were first demonstrated in 1881 when the *Aberdeen*, of 4,000 tons, completed a spectacular voyage. This ship, which was also fitted with sail, had a three-crank triple expansion engine designed by Kirk and with steam at 125 lb/sq in produced an i.h.p. of 1,800. Carrying 4,000 tons of coal and cargo, this vessel steamed to Melbourne in forty-two days, replenishing the bunkers at the Cape. On long voyages the coal consumption averaged 1·7 lb/i.h.p. hr compared with $2\frac{3}{4}$ lb for compound engines. The triple expansion engine installation possessed the characteristics which provided the solution to sea trade with the Far East and expanded trade with these regions, as the compound engine had done in the Pacific and the simple steam engines in the Atlantic. In addition, this type of engine soon predominated other steam reciprocating types and has retained that position up to the present time.

During the 1880's, triple expansion engines superseded those of compound type on the Atlantic. At the same time, multi-screw propulsion was adopted to meet the demands of steamship companies for greatly increased power of single ships. Moreover, competition was keen for the trade and passenger traffic, and speed and size of ships were matters of international rivalry. It was these events which led to the realization of Brunel's conception when he planned the *Great Eastern*, but forty years of engineering progress had to pass before similar ventures could be undertaken without the risk of complete commercial failure.

Of the liners fitted with triple expansion engines, the twin-screw *Campania* of 1,950 tons and 601 ft in length, may be quoted. Built in 1893, the engines developed a total of 31,000 i.h.p. and propelled the ship at 22 knots. About the same time the quadruple expansion engine was evolved and offered further economy in operation. The largest steam reciprocating engines built were of this type and engined the liner *Kaiser Wilhelm II.* 43,000 i.h.p. was obtained with steam raised at 225 lb/sq in pressure in fourteen double-ended and seven single-ended cylindrical boilers. Power-weight ratios of large reciprocating machinery installations ranged from 6 to 7 i.h.p. per ton and the total weight of the quadruple machinery of the *Deutschland* weighed no less than 5,670 tons for 38,900 i.h.p. In addition, unpleasant hull vibrations were excited by the heavy reciprocating masses and were detrimental to the comfort of the passengers. For these reasons, steam reciprocating machinery was not entirely suitable for high-powered liners and the limit of total power of a ship had been attained so far as these prime movers were concerned.

It was not surprising, therefore, that Parson's *Turbinia* was acclaimed as an outstanding triumph, for it offered the solution to these problems. Nine years later, in 1905, the 30,000-ton liner *Carmania* was engined with steam turbines of 21,000 s.h.p. and after a further two years the quadruple-screw liner *Mauretania* was completed with turbines of 70,000 total s.h.p. A speed of 24½ knots won this liner the Atlantic record, which she retained for twenty-two years, signifying that she represented the end of the first era of national and international rivalry for the largest and fastest ship afloat.

During this era, shipowners had also been able to equip their fleets with ships of increasing size, for expanding trade had always proved their speculation sound. The British Merchant Fleet had increased by no less than 5,000 ships in half a century and in the latter half of this period other nations had recognized the achievements of British engineering and built up fleets of merchant steam ships for their own purposes. In consequence, there was now a tendency to adopt economical sizes of each type of merchant ship and many wondered whether a ship like the *Mauretania* could be a paying proposition.

For the engineer, the conquest of the trade routes by steam navigation was complete and the steam reciprocating and turbine machinery had attained a high degree of reliability with reasonable economy. His role had therefore changed from a pioneer to a consolidator ; adapting, modifying and developing the various types of machinery at his disposal to meet the many requirements of shipowners and operators.

By the end of the nineteenth century the supplies of heavy oil fuels were sufficient to warrant consideration as an alternative to coal for firing the boilers of steamships. The advantages of liquid fuels in respects of transportation, handling and storage were obvious, but it was not until 1894 that an oil-burning steamer, the *Baku Standard*, entered sea service. In the first half of this century, coal has been almost entirely replaced by oil for seagoing steamers and, so far as new construction is concerned, the change-over is virtually complete.

The next landmark in marine engineering was the oil engine, which was introduced as a main prime mover for ocean-going merchant ships in 1910, when the 1,179-ton tanker, *Vulcanus*, was completed and engined with a Werkespoor 6-cylinder 4 S.C.S.A. Diesel engine of 500 b.h.p. rating at 200 r.p.m. It may be of interest that this engine was still operating satisfactorily when the ship was sold for scrap in Japan, twenty years later. A greater advance was represented by the Burmeister & Wain Diesels which engined the twin-screw motorship *Selandia* of 5,000 tons. Completed in 1912, each 8-cylinder 4 S.C.S.A. engine developed 1,050 b.h.p. at 140 r.p.m. and showed that the problems of high-powered oil engines were being effectively overcome. The *Selandia* was in operation until 1942, when she was wrecked. During the life of this ship the oil engine had become the predominant prime mover for new merchant ships constructed in the world, and by 1939, engined more than one-quarter of the total number of ships afloat.

Following the 1914—18 war, shipowners were faced with the problem of rebuilding their total tonnages to make good the losses during the hostilities. They had struggled to achieve this without subsidy when trade eased and competition became keen to secure freights. Reductions in fuel costs were of vital importance, and it was this aspect which received the attention of engineers. The triple expansion steam engine then operating with saturated steam supplied by Scotch boilers of 200 lb/sq in working pressure, offered fuel consumptions of 1·6 of coal or 1·1 lb boiler oil/i.h.p. hr. Steam engine makers soon developed improved designs incorporating such features as poppet valve gear and uniflow exhaust of cylinders, and capable of operating with superheated steam at total temperatures approaching 700° F.

The inability of the reciprocating engine to utilize all the possible expansion of the steam, due to limits imposed on the size of the L.P. cylinders, was overcome by the fitting of exhaust steam turbines. This was no new feature, for Parsons used a reaction turbine, supplied with exhaust steam from two reciprocating engines, and driving an independent shaft directly, in the triple-screw steamship *Otaki* completed in 1908. Before this arrangement was superseded by the geared turbine for passenger ships, a number of other installations were completed, including those of the *Olympic* and *Titanic.*

The arrangement first fitted in a single-screw ship in 1926 was the Bauer-Wach system, in which the drive from the turbine was transmitted through double reduction gearing and a fluid coupling back to the reciprocating engine main shaft. Other manufacturers preferred electrical to mechanical transmission and in these cases the exhaust steam turbo generator, with either A.C. or D.C. output, supplied an electric motor mounted at a convenient position on the main propulsion shafting. Reheating of the steam before admission to the M.P. cylinder of the reciprocating engine also offered appreciable improvement in performance.

Each of the improved steam reciprocating installations had its own particular merits and champions. Fuel consumptions of just under 1 lb coal or 0·8 lb oil/i.h.p. hr could now be offered. Nevertheless, progress in the oil engine field had been so marked as to offer a serious rival to the steam reciprocator.

In 1914, Messrs. Doxford & Sons Ltd., of Sunderland, ran endurance trials on a single cylinder, 2-stroke cycle, heavy oil engine which embodied the opposed piston principle and developed 450 b.h.p. at 125 r.p.m. This represented a major advance in the power output of a single cylinder. During the 1914—18 war, the performance of both 4-stroke and 2-stroke oil engines progressed rapidly and this was assisted by the adoption of solid injection of the fuel ; an important departure from the Diesel principle.

By 1921, 2-stroke types of 4-cylinders were providing 3,000 b.h.p. on a single screw, but 4-stroke types nevertheless predominated in marine practice. Four years later, double-acting engines of the latter type displayed single cylinder outputs of 1,100 b.h.p. The twin-screw motorship *Gripsholm*, for example, was directly propelled by two 6-cylinder engines of this type, 33 in bore and 59·1 in stroke, with a total output of 13,500 b.h.p. at 125 r.p.m. Doxfords soon challenged this achievement by building engines of the 2-stroke type described and the 5,000 total b.h.p. represented 1,250 b.h.p. per cylinder.

At this time, many of the service problems experienced with 2-stroke cycle oil engines had been surmounted and a number of engine builders, who had previously favoured 4-stroke types, now regarded the former as a better proposition. In consequence the passenger liners *Britannic* and *Georgic*, completed in 1930 and each fitted with two 10-cylinder engines of 20,000 combined b.h.p., represented a peak in the progress of the 4-stroke type. Thereafter preference for the various 2-stroke engines prevailed until the present day, when they form no less than 80 per cent of the main oil engines fitted in ships. Further, the fitting of Buchi superchargers to engines of the 4-stroke type, although giving improved performance, had little effect on the predominance of the 2-stroke engines.

By 1934, 2-stroke engines were supplying up to 7,000 b.h.p. on a single screw and the replacement of cast-iron bed plates, entablatures and columns by welded fabrications in mild steel did much to reduce the weight and size of the engines. In addition, renewed attention was given to the use of exhaust gases to raise steam in waste heat boilers, which augmented the supply from the donkey boilers and reduced the overall fuel consumption of the auxiliary machinery.

After that time, the power of heavy oil engines continued to increase steadily. In post-war years, however, the successful adaptation of a moderate degree of supercharging in 2-stroke engines had provided 30 to 35 per cent increase in power with m.i.p.'s of up to 130 lb/sq in. Engines are already under construction with single cylinder outputs of 1,650 b.h.p. and further increases to 2,200 b.h.p. are contemplated. Large slow-running engines therefore develop 10,000 to 17,000 b.h.p. and offer a serious challenge to the geared steam turbine for the propulsion of single-screw tankers and cargo ships. Without increase in the weight of the installation, two medium-speed oil engines coupled through 2 : 1 reduction gearing to a single shaft have also been employed to develop these powers. The gearing is protected from engine excited torque fluctuations either by fluid or, more recently, electro-magnetic couplings installed between engines and pinions. Moreover, such arrangements show considerable advantages during manœuvring. Although 2-stroke engines are usually used for a propulsion unit of this type, highly supercharged 4-stroke engines are also available when slightly lower powers are required.

High speed, medium power 2- and 4-stroke supercharged engines of vee and delta type with up to 24 cylinders, are also available for merchant ship propulsion. Multiple units, geared or electrically connected to a single screw, offer advantages of reduced space and low total weight per h.p. developed.

Modern oil engines have excellent fuel consumptions of about 0·32 lb oil/ b.h.p. hr which correspond with overall efficiencies of 40 per cent. The most important feature of slow and medium speed engines has been their recent conversion for burning boiler or residual grades of oil, however. The use of these fuels can provide a saving in fuel costs of up to 30 per cent. This achievement has given the oil engine a substantial lead over rival prime movers, but the approach towards the theoretical efficiency leaves little scope for greater economy.

Before the 1914—18 war, water-tube boilers had superseded those of cylindrical types in warships and had proved superior in performance and operation. The working pressure of boilers in merchant ships advanced slowly during the first quarter of this century and the maximum employed was little in excess of 250 lb/sq in. Over this period the cylindrical boiler predominated throughout the whole power range of steam machinery. A considerable number of water-tube boilers were installed in merchant ships during the Great War, however, but their satisfactory service did little to dispel the prejudice against them, except in America, where war-time construction comprised the major part of the merchant fleet. The development of economical steam turbine machinery installations during the 1920's demanded H.P. inlet conditions which could no longer be met by cylindrical boilers and the water-tube type now controlled the field of high-pressure and high temperature steam production.

The benefits of advanced steam plants were soon evident by the appreciable reductions in specific fuel consumptions. The S.S. *Duchess of Bedford*, completed in 1928, was fitted with Yarrow boilers with a working pressure of 340 lb/sq in at 670° F. total temperature. The fuel consumption of the main machinery was recorded as 0·57 lb/s.h.p. hr. When compared with a Scotch boiler installation of eight years earlier, a fuel saving of at least 15 per cent was evident. Three years later, the *Empress of Britain* entered service and her full power of 60,000 s.h.p. was developed by turbines supplied with steam at 425 lb/sq in and 725° F. An appreciable advance in the use of higher steam conditions occurred in 1936, when construction started on the turbo-electric tanker *J. W. Van Dyke.* The two Babcock & Wilcox boilers of this ship were designed for a maximum working pressure of 675 lb/sq in, the superheater outlet steam being at 625 lb/sq in and 835° F. The fuel consumption of the main machinery was approximately 0·51 lb/s.h.p. hr. In the sister tanker *Robert H. Colley*, laid down in 1938, the steam temperature was raised to 910° F., which was the most advanced condition used in merchant ships in the pre and early war years.

Some remarkable high-pressure installations were also completed, notably the 3,200 lb/sq in of the Benson boilers in the *Uckermark*, 1,990 lb/sq in by Loeffier type in the *Conti Rosso* and the *Potsdam* with 2,650 lb/sq in working pressure. Such high pressures were rare, however, and the main object has since been for pressure below 1,000 lb/sq in with high degrees of superheat.

Water-tube boiler makers were active in design and by 1938 boiler efficiencies of 87 per cent were possible. Of equal importance were the increases made in total heating surface and the rates of evaporation produced by single boilers for this permitted boiler plant of reduced size and weight. In addition, high quality fusion welded joints replaced those of riveted type in the fabrication of boiler drums and by this means weight saving alone exceeded 1¼ tons per drum.

In America, the Scotch boiler had practically died out by 1939, for a year later special arrangements had to be made to supply boilers of this type for sixty cargo ships ordered by Britain. In Britain, however, the cylindrical boiler has retained some of its popularity for both main and auxiliary steam generation, due to its rugged characteristics, and it is usual practice to use water-tube boilers where steam pressures exceed 300 lb/sq in. Steam turbine installations at present engine ships of 50,000 s.h.p. per screw or 200,000 total s.h.p. and as greater powers will not be required for some years, it is natural that research should be concerned with reducing fuel consumptions well below 0·5 lb/s.h.p. hr and developing more compact plants. Economical units, incorporating one or more reheat points, are at present under consideration and it seems that gas-fired reheaters will supersede those of steam type. Increased steam conditions at the H.P. turbine inlet still present a major source for improved economy.

Of the ships at present under construction, all in excess of 20,000 tons will employ geared steam turbines for main propulsion. Within the size range 100 to 20,000 tons, 70 per cent will be propelled by oil engines, while the remainder, with isolated exceptions, will have steam reciprocating or turbine main machinery. Turbo or Diesel-electric transmission have not proved popular, although restricted gear-cutting machine capacity increased the number of installations of these types during the last war. In some instances, however, turbo-electric main machinery has been preferred for large oil tankers in order that the main generator could be used to supply the cargo pumps when in port.

Both tankers and ore carriers have increased in size to meet the needs of supplying the expanding oil, chemical and metallurgical industries. Vessels of these types at present rival large passenger ships in size, but retain single-screw propulsion. To meet these conditions, steam turbine manufacturers in particular have developed compact power plants developing up to 20,000 s.h.p. Further progress is continuing in this direction and double-reduction gearing in particular is the subject of extensive researches. The problems of successful transmission of gear tooth loads of two to three times recognized pre-war levels have not yet been satisfactorily solved and surface hardened and ground gears are at present under consideration.

The marine gas turbines at present under development for marine propulsion are of open cycle type. In general, the H.P. turbine drives an axial compressor as an independent unit, while the L.P. provides the useful output and exhausts through a heat exchanger which preheats the inlet charge to the combustion chamber. The designs vary considerably, but can be considered in two main categories. The first covers those of light-weight construction, under 7 lb/h.p. and developing up to 6.000 s.h.p. The H.P. inlet temperatures of about 820°C. limit the life of the hot parts to little more than 1,000 hours. Units of this type power light Naval craft only, for a satisfactory life in excess of 20,000 hours is required for the main engines of merchant ships. This is at present obtained by limiting the top temperature to below 700° C. in medium-weight plants of 25 to 30 lb/s.h.p. Both classes of gas turbine have overall efficiencies of about 20 per cent, but when the long service reliability of the latter has been established, advances in top temperatures and design should provide fuel consumptions below 0·5 lb/s.h.p. Since these engines cannot be run astern, either electric transmission, reversible pitch propellers or reduction gearing with reverse trains must be used. Of these, the last is receiving the greatest attention and is likely to predominate in future installations.

In France remarkable progress has been made recently in a power plant comprising a free piston gas generator and geared gas turbine. Turbine inlet conditions of four atmospheres pressure and less than 500° C. are used, as the peak temperature of the thermodynamic cycle occurs in the cylinder of the free piston gas generator. Overall thermal efficiencies therefore approach those of existing oil engines and are represented by a fuel consumption of 0·39 lb Diesel oil/s.h.p. hr. The problem of manœuvring does not apply in this instance as astern wheels are incorporated in the turbine shaft.

The size of the gas generator has been standardized so that equal reliability may be obtained with all units. High-power plants will, therefore, comprise multiple units supplying one or more geared turbines. The first main marine installation of this type was installed in the 800 tons d.w. *Cantenac*, completed in 1954, and other ships at present under construction will be similarly fitted.

The construction of two submarines for the U.S. Navy in which the heat developed in a nuclear reactor is used to raise steam for supplying both main and auxiliary turbine machinery, has resulted in wide speculation of the possible adoption of similar power plants for merchant ship applications. Indeed, such an impressive statement that the fissioning of 1 lb of uranium produces heat equivalent to 2,300 tons of coal or 300,000 gallons of oil, raises visions of revolutionary changes in the design of merchant ships and their machinery. As these changes would solve many existing problems, it seems that thermal reactors must eventually provide the energy for steamship propulsion. When this event will be possible depends on the rate of progress made in reducing to more attractive levels the weight, size and cost of reactors and screening, and the satisfactory solution of control and maintenance problems. It appears that the power-weight ratios of these units will be better suited to the higher powered plants of large cargo and passenger liners than to the many low powered installations in smaller ships.

In the submarine U.S.S. *Nautilus*, purified water under high pressure forms the primary coolant which extracts the heat from the thermal reactor. The steam then raised in heat exchangers is at relatively low pressure and temperature, probably not more than 180 lb/sq in and 440° F ; consequently, geared steam turbines of moderate thermal efficiency are used and high temperature is confined to the primary coolant section. In effect, the controlling factor is the rate at which heat can be extracted from the small volume of the thermal reactor, and providing this is adequate to meet the demands, thermal efficiency is of only secondary importance. Moreover, raising the thermal efficiency by adopting different type reactors and primary coolants which produce steam at higher temperatures and pressures, does not result in longer duration for the same amount of nuclear fuel as with oil-fired installations. It is related to the size of plant, however, and for this reason fast reactors and liquid metal primary coolants may be superior for steamships.

While the developments of main machinery installations in little over 150 years have made a substantial contribution to the expansion of world trade, auxiliary machinery has also played a part. The luxury of a modern liner stems, in part, from this source. It is just over seventy-five years ago that Inman first employed electricity on board ship to supply arc lamps fitted in the saloon of the *City of Berlin*. Large liners invariably employ steam turbines for both main and auxiliary purposes, but the installation of the Greek liner *Olympia*, completed in 1953, departed from this practice by employing steam turbines for main propulsion only, the auxiliaries being exclusively Diesel-electric. In cargo ships, a new departure has been the use of a free piston gas generator supplying the gas turbine of a turbo-electric set and a number of normal gas turbine sets are now under construction and will soon be in service at sea.

Many trades flourished with the introduction of refrigeration machinery for shipboard purposes. The meat trade originated in 1880 when the S.S. *Strathleven* arrived in London from Australia carring 40 tons of frozen meat. Prosperity was brought to Australia, New Zealand and South America, while the peoples of Europe were supplied with cheap foods, at least in pre-war years ! New Zealand alone exported 760 tons of meat in 1882, three years later the figure was no less than 15,000 tons and doubled again in another decade. It can truly be said that few engineering achievements have had such revolutionary effects on world trade and prosperity.

Until recently the holds of the ship were the refrigeration chambers, but a few companies are introducing separate refrigeration containers. In effect, these comprise large portable refrigerators requiring only an electrical supply. Containers of this type offer considerable scope for the handling of delicate low bulk cargoes, but they are unlikely to replace the existing system for storing bulk frozen cargoes.

An examination of the history of one particular field of engineering has indicated that the remarkable increases which have occurred in the prosperity of nations, during the last century and a half, can largely be attributed to the achievements of the engineer. It is also true that the countries which have encouraged engineers and industry enjoy the highest standard of living. Today, we aim to improve our living standard still further and, at the same time, assist other countries to do the same. That the engineer is continuing to play his part, is evidenced by the high rate of technical progress maintained during post war years.