DEVELOPMENT OF MACHINERY FOR 19TH-CENTURY ATLANTIC LINERS

BY

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Introduction

This paper gives a general outline of the changes in propulsion and auxiliary machinery fitted in Atlantic liners from the start of commercial steamer services in 1838 to the end of the 19th century. The material is covered in chronological order but does not deal with every ship. Major changes such as screw propulsion, compounding, boiler forced draught and the introduction of electricity are considered. No attempt has been made to cover the commercial operation of vessels concerned but the impact of changing technologies is dealt with in respect to the fuel savings it produced.

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The early Atlantic liners were simply enlarged versions of British coastal steamers, at least as far as their machinery was concerned. Brunel's "Great Western" (1838) was propelled by means of paddles driven by side-lever engines which were supplied with steam from flue-type boilers. Such machinery installation was "state of the art" and the height of the then current technology. In fact, with but a few modifications, that is the way it remained until paddle steamers became part of Atlantic history.

When she entered service, "Great Western" was the largest and the most powerful steamer in the world, her side-lever engines of 450 nominal horse power providing a speed of about 10 knots. Apart from their size the side-lever engines were of the same form as others then in coastal service but they did employ expansive working. A system of cams allowed the steam supply to the cylinders to be shut off at particular points of the piston stroke, thus allowing for a saving in steam and hence coal consumption. Such expansive working reduced the amount of coal which was required for an Atlantic crossing and made commercial operation possible. Even without a mail subsidy "Great Western" was a success, but competition from the subsidised Cunard steamers and the wrecking of "Great Britain" ultimately resulted in her removal from Atlantic service.

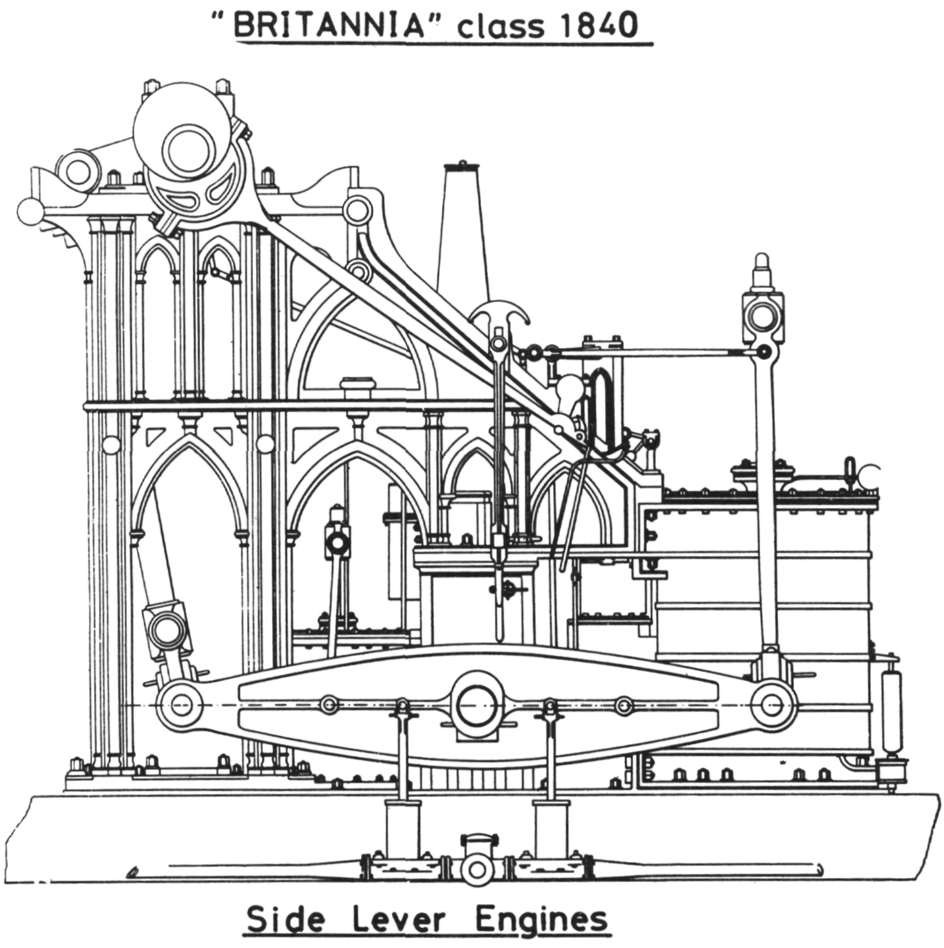

Fig. 1. – Typical side-lever engine.

Boiler pressure was low, a mere 5 psi (34.5 kN/sq m) gauge or 19 psi (136 kN/sq m) absolute, but most power was obtained because exhaust steam was condensed rather than directed to atmosphere. The resulting low back pressure meant that steam could be expanded down to about 3 psi (21 kN/sq m) absolute. This relatively low boiler pressure compared with stationary land plant or locomotives resulted from the use of flue-type boilers working with salt-water feed. Flat-sided flues could not support high pressures, and salt water formed scale which impaired heat transfer. Flue boilers were, however, relatively inexpensive and, as corrosion resulted in boiler replacement being required after about five years in service, they remained popular.

Salt-water feed was convenient and had to be employed where sea-water spray was used for condensing steam. Surface condensers, which kept steam and condensing water separate had been developed but they were expensive, were subject to

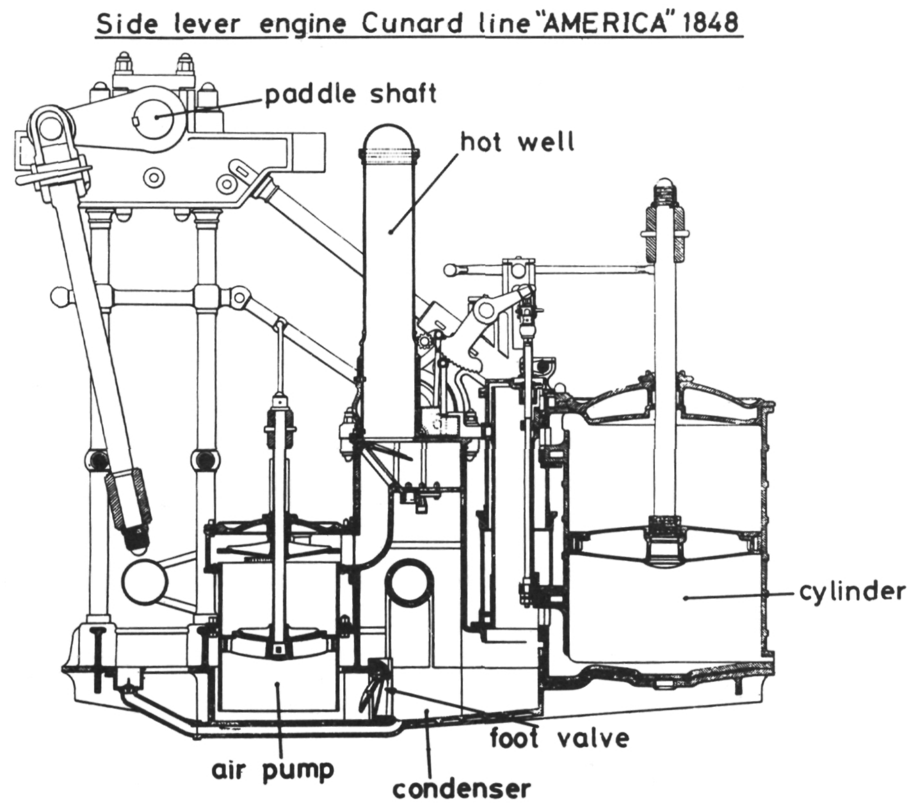

Fig. 2. – Section through side-lever engine.

blockage by grease entrapped in the exhausting steam and frequently leaked. Such leakage resulted in salt-water contamination of the feed water which the surface condenser was attempting to avoid. Leakage of steam required additional make-up water which with salt-water was easily obtained. Fresh-water feed employed with surface condensers meant that large quantities of fresh water had to be carried by the ship in order to make up for losses. Carrying water resulted in less bunker or cargo space and so was unpopular for ships engaged on long oceanic voyages, but found favour with coastal craft as fresh supplies could be readily obtained. One of the pioneer Atlantic liners, "British Queen", did make use of surface condensers but the problems of tube blockage and carriage of sufficient quantities of fresh water presented operational problems.

These were the conditions existing when "Great Western" and the other vessels inaugurated the Atlantic steamer services. The original Cunard ships were all similar to "Great Western" with side-lever engines and flue-type boilers [1].

[1] D. Griffiths, *Brunel's Great Western*, Wellingborough, 1985, p. 86 ; also *Engineering*, 8 February 1895, pp. 175-177.

Operation of steam plant ashore soon illustrated to marine operators that greater efficiency could be obtained from the expansion of steam if higher steam pressure was employed. Flue tube boilers were not suitable for increased pressure and tubular boilers soon found favour. Again "Great Western" was at the forefront when, at the end of the 1843 season, her four corroded flue boilers were replaced by a single five furnace tubular boiler operating at 12 psi (83 kN/sq m). This unit was certainly more efficient, resulting in coal consumption reducing from 6.25 lb per horse power (2.12 kg/kW) to 5.6 lb per horse power (1.9 kg/kW). In fact it was too efficient in terms of heat transfer as the funnel gas temperature was too low for an efficient draught to be maintained. Suggestions for improving the matter included the use of blast steam as on locomotives and air supply under pressure, an early idea of forced draught which found more ready application later in the century.

During the 1840s and 1850s a number of American owned steamships ventured onto the Atlantic but they were not particularly successful compared with their European counterparts. Side-lever engines turned their paddles although one, "Vanderbilt" (1857), was fitted with a walking beam engine, an overhead lever version of the side-lever engine much favoured by American river and coastal craft. American designers may not have been particularly adventurous in terms of engines but they made up for that with their boilers. Double banks of furnaces were popular, but probably not with firemen. The return flue boilers constructed by Stillman, Allen & Co. of New York for "Humbolt" (1851) had eight furnaces in two rows. A year earlier the same concern had constructed boilers for the Collins Line ships, "Atlantic", "Pacific", "Arctic" and "Baltic", and these also had double-row furnaces. The design was novel in that water tubes passed through the combustion chambers which were fed with hot gases from the furnaces [2].

"Franklin" (1850), a sister-ship to "Humbolt", was provided with return-tube boilers and it was that arrangement, although not that particular design, which found favour with British shipbuilders during that decade.

The British mail contract, held by Cunard, stipulated paddle drive and so side-lever engines remained until the last of the line, "Scotia", entered service in 1862. Her engines were larger and more powerful, 4,570 ihp (3,410 kW), than those of "Great Western", but in basic form they were the same. Boilers had changed and the box-type tubular form became standard as it was relatively efficient, easy to clean and could accommodate higher pressure. Boiler pressure did, however, remain relatively low, only 25 psi (172 kN/sq m) for "Scotia", but the use of wrought iron for construction and flat sides of the box-shell limited that pressure. Corrosion of iron also remained a problem as the mechanism of corrosion, and hence its prevention through effective boiler water treatment, was not then understood.

During the 1850s and 1860s the surface condenser returned to favour owing to a combination of circumstances. A fundamental change in concept resulted in cooling

[2] B. H. BARTOL, *Treatise on Marine Boilers of the United States*, Philadelphia, 1851, pp. 52-54.

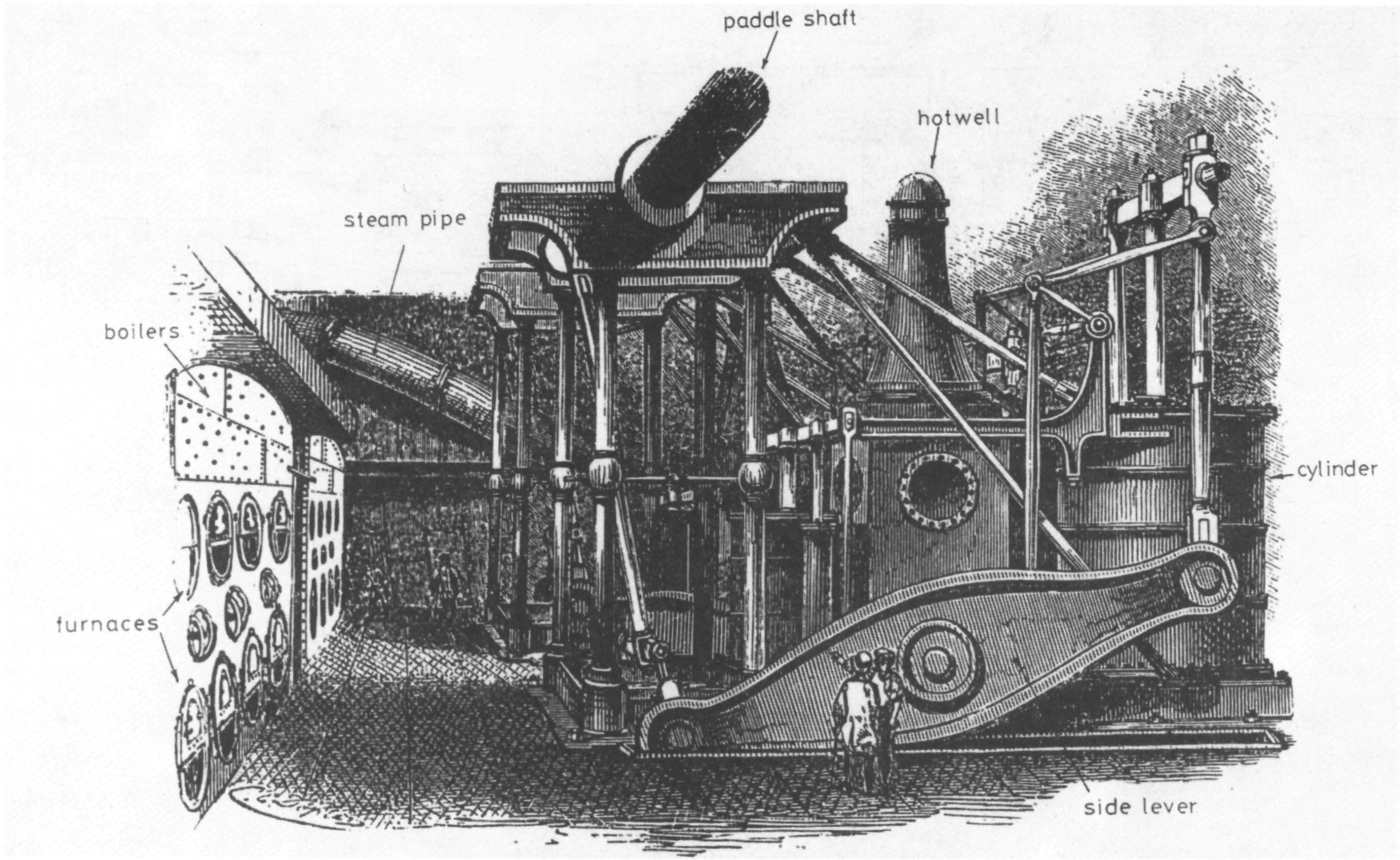

Fig. 3. – Engine room arrangement of Collins Line "Atlantic" from contemporary drawing.

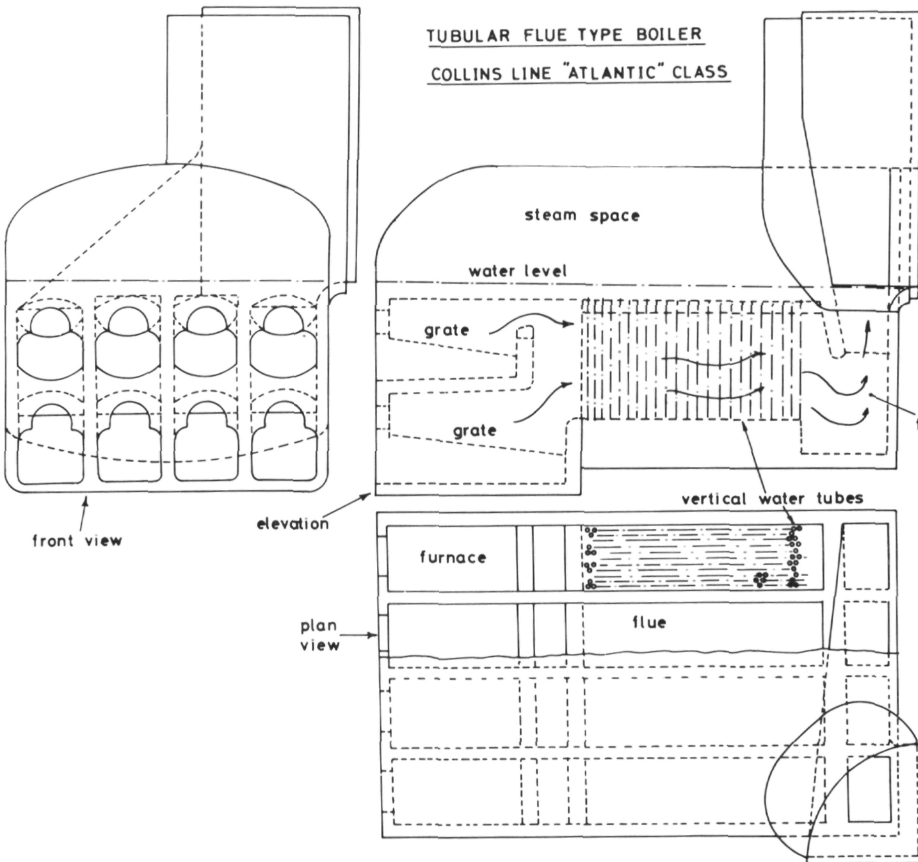

Fig. 4. — Tubular boiler as fitted in "Atlantic".

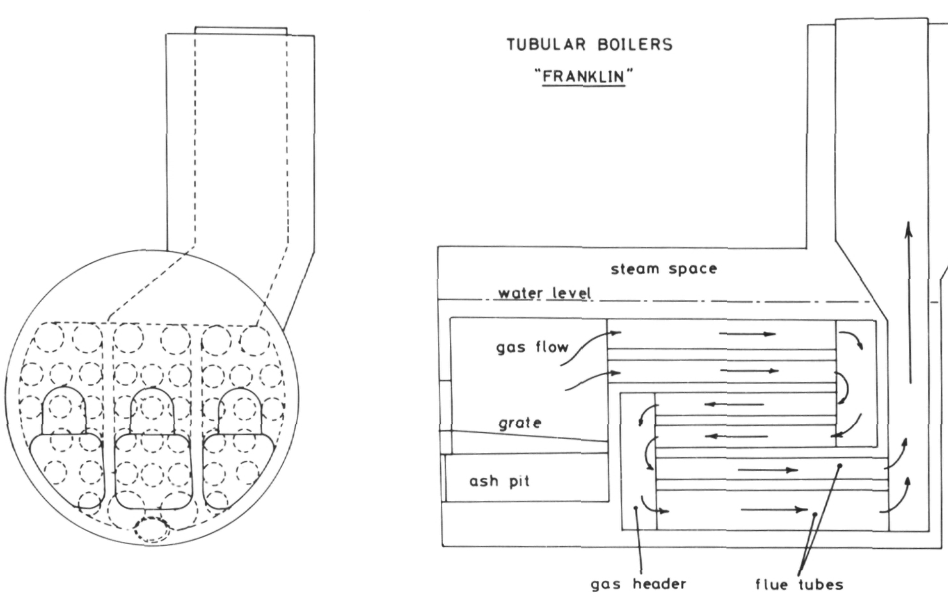

Fig. 5. — Tubular boiler as fitted in "Franklin".

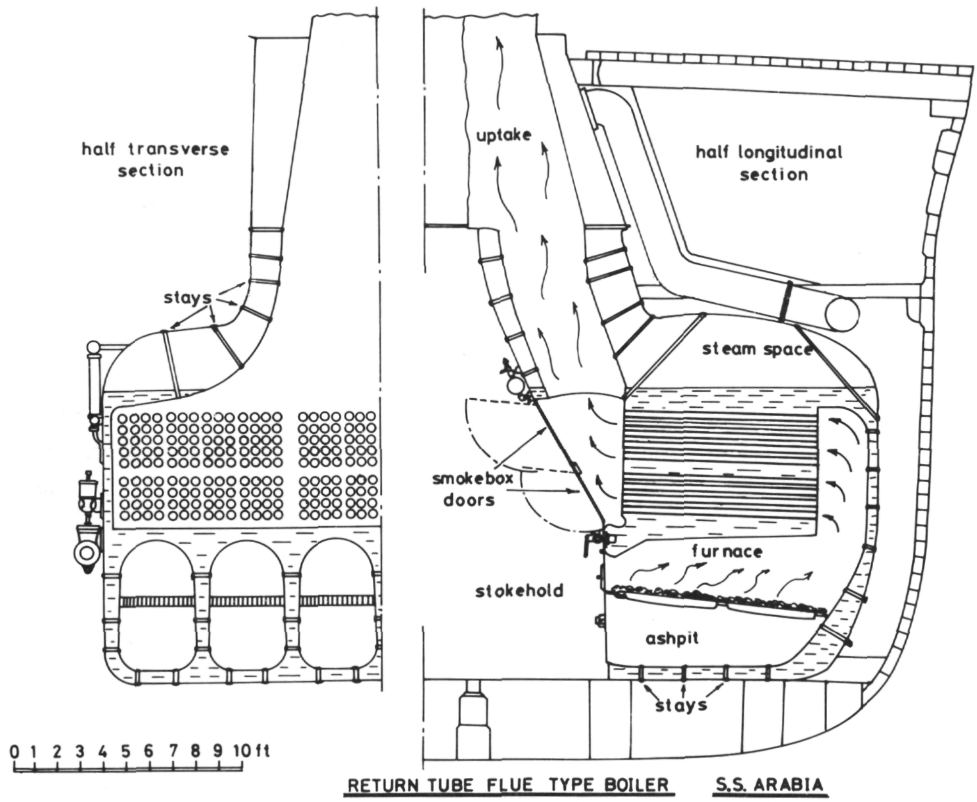

Fig. 6. — Typical return tube flue type boiler.

water rather than exhaust steam being passed through the tubes. Blockage of tubes due to grease was avoided, although deposits did form on the outside of the tubes and so had to be removed. Better sealing arrangements minimised the risk of tube leakage and larger ships had increased storage capacity for make-up feed water. The use of fresh- instead of salt-water feed minimised scale formation in the boiler and so allowed higher pressures to be contemplated.

Brunel's "Great Britain" introduced screw propulsion to the Atlantic but that experiment ceased with the ship's grounding in 1846 ; however, four years later Tod & MacGregor's "City of Glasgow" illustrated the true economics of the screw. It should be realised that screw propulsion found considerable use in coastal trade but large savings could be had on long voyages. Apart from the better propulsive efficiency of a screw compared with paddle wheels, there was the additional advantage in that during rough weather a screw maintained greater immersion than did paddles. Disadvantages included loss of screw blades and even broken screw shafts ; until the advent of twin screws, sails were retained as a safeguard.

Efficient screw propulsion required higher shaft speed than that used for paddles but engines of the period operated at relatively slow speeds. In order to achieve the higher shaft speeds some form of gearing was required. In certain cases, notably "Great Britain", a chain arrangement provided for that speed increase but in most cases toothed gearing was applied. Because of machining problems, wooden teeth were often used for such gear wheels, and it was only with the introduction of the direct-drive screw engine that such problems ceased [3].

"City of Glasgow" was fitted with an overhead beam-steeple engine which was similar to the side-lever type except that a single beam was placed above the cylinders rather than two alongside. The two-cylinder engine was placed athwartships with a 2:1 gear wheel drive to the centrally positioned propeller shaft. Using steam at a pressure of 10 psi (69 kN/sq m) the 66 in. (1,676 mm) diameter by 60 in. (1,524 mm) stroke cylinders could drive the 1,600-gross-ton ship at 8.5 knots with a coal consumption of 20 tons per day. Figures like that hammered home the advantage of screw propulsion, and of the cost of speed. The contemporary paddle-driven Cunarder, "Asia", carried a similar number of passengers but had space for only 500 tons of cargo against "City of Glasgow"'s 1,200 gross tons. "Asia"

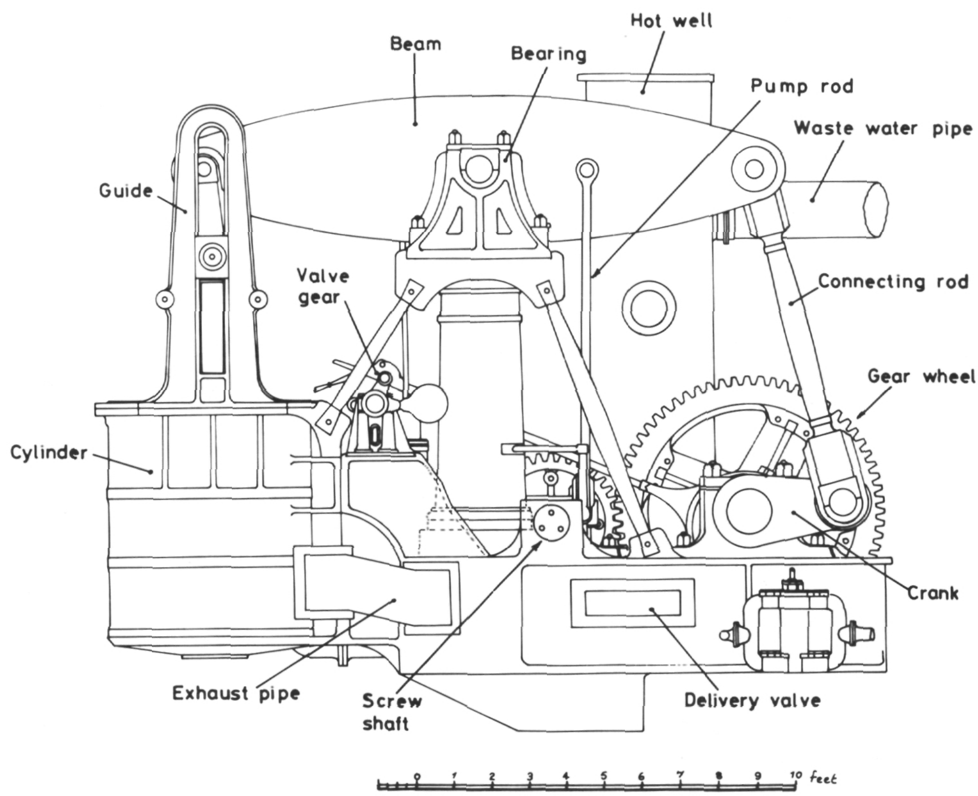

Fig. 7. — Geared screw engine as fitted in "City of Glasgow".

[3] A. J. MAGINNIS, *The Atlantic Ferry*, London, 1893, p. 178.

consumed 76 tons of coal per day for a speed of 12 knots. Economic facts like that were inescapable and screw propulsion gained ground. A lower coal consumption meant more space for cargo and an absence of paddle boxes made for easier berthing.

Mail contract conditions restricted Cunard's ability to embrace screw propulsion but it did not prevent its adoption. During the 1850s a number of relatively small screw-propelled steamers were constructed for secondary services, but it was not until 1862, when the 2,550 gross ton "China" was built, that direct comparisons were attempted with the mail steamers. This ship was smaller than the contemporary paddle-driven "Scotia" in terms of dimensions and tonnage, but she could carry 900 passengers, 750 in steerage and 150 in first class, compared with "Scotia"'s 275 first and second class. Both vessels had capacity for 1,000 tons of cargo. In order to drive her at 13.5 knots "Scotia" required 4,200-horse-power [hp] (3,133 kW) engines and a coal consumption of 164 tons per day. "China"'s geared oscillating engine of 2,200 hp (1,640 kW) could drive her at 12.5 knots on half the daily coal consumption of "Scotia". "China" required a bunker capacity of only 1,200 tons, allowing for large cargo and passenger spaces in a smaller hull. Screw propulsion had arrived and "Scotia" proved to be the last paddle-driven vessel built for Atlantic service [4].

In addition to smaller engines, screw propulsion also required a smaller boiler plant, and the reduced coal consumption meant that fewer stokers and coal trimmers had to be carried and paid. Lower operating cost were welcome but some owners appear to have adopted the view that, for the same costs, a higher power, and hence speed, could be obtained. Cunard with "Russia" and the Inman line with "City of Paris" provided screw-driven steamers which claimed the "Blue Riband" during 1867.

There was at that time no definitive design for screw engines, unlike the side lever for paddle propulsion, and many different arrangements were offered, usually as a way of avoiding the payment of royalties on a patented design. The Admirality insisted that machinery for warships be totally below the water line, and many engine builders adopted designs which allowed for this. Naturally, such engines could also be employed in commercial ships and "City of Paris" was fitted with a twin cylinder [89 in. (2,260 mm) bore by 42 in. (1,067 mm) stroke] engine developing 2,800 hp (2,090 kW) on 100 tons of coal per day. Her flat-sided tubular boilers operated at 30 psi (207 kN/sq m) [5].

Although Atlantic services attracted interest and speed, the ships were never really to the forefront of engineering innovation, many ideas being tried elsewhere before owners would risk them on their expensive and prestigious Atlantic "grey-hounds". Gradually, the directly coupled inverted cathedral form of engine, cylinders above the crankshaft, proved itself to be the most suitable arrangement for screw propulsion, but many variations in form were still produced in order to avoid infringement of patents, especially in relation to compounding.

4 MAGINNIS, *op. cit.*, pp. 46-49.

5 *Marine Engineering & Motoship Builder*, September 1926, p. 352.

Compounding, exhaust steam from one cylinder being further expanded in another, came late to the Atlantic. The advantages of obtaining more work from the same quantity of steam were obvious and had been exploited in stationary shore plan for many years, but marine application lagged behind. Compounding was more effective with higher boiler pressure but high pressures were restricted at sea if salt-water feed was employed, owing to scale deposits within the boilers. Adoption of surface condensers allowed use of fresh-water feed, and introduction of the cylindrical boiler avoided flat side-plates, which required substantial staying in order to withstand higher pressures. Use of steel plates rather than wrought iron also allowed higher pressures to be obtained but during the 1860s the steel industry was in its infancy and regular supplies of consistent strength steel could not be obtained. Many marine engineers preferred to stay with iron plates which they knew and trusted.

Compounding saved coal but on the relatively short Atlantic crossing it was not considered to be an essential for effective operation. Services to the east required a chain of bunker stations which had to be kept supplied with coal, usually from Europe. With transportation costs high, anything which would reduce coal consumption on long runs had to be an advantage which would outweigh the higher initial capital cost and increased engine space requirement.

The first compound-engined vessel to enter Atlantic service was Anchor Line's "India" of 1869. Purchased during construction, the ship was designed for operation in other waters but her Atlantic performance left no doubt that compounding was to be a major advance. At only 2,200 gross tons "India" was small compared with other Atlantic liners but she earned her keep. Maiden voyage coal consumption averaged 36 tons per day for an average speed of almost 11.5 knots. In order to avoid losses due to condensation of steam on entering the cylinders, these were jacketed with low-pressure steam in order to keep them warm, another feature borrowed from shore practice. Two cylindrical tubular boilers, a form later to become known as the "Scotch" boiler, supplied steam at 40 psi (276 kN/sq m).

Guion Line's 3,250-gross-ton "Wyoming" and "Wisconsin" of 1870 were the first compound-engined vessels actually laid down for Atlantic service. Design and construction of machinery lay in the hands of the shipbuilders, Palmers of Jarrow. A design was produced which avoided infringement of other compound-engine patents then existing and also allowed for a short engine, thus reducing the engine room size. High- and low-pressure cylinders connected to the same crank, the 60 in. (1,524 mm) diameter HP cylinder being positioned vertically above the crankshaft and the trunk-form 120 in. (3,040 mm) diameter LP cylinder horizontally. Instead of an eccentrically operated slide valve, Corliss drop-valves were fitted and the steam pressure was 70 psi (483 kN/sq m), high for that time. Although by subsequent standards the engine design was odd, it must have been fairly efficient as these ships retained the same machinery until they were scrapped in 1893 [6].

[6] MAGINNIS, *op. cit.*, p. 72.

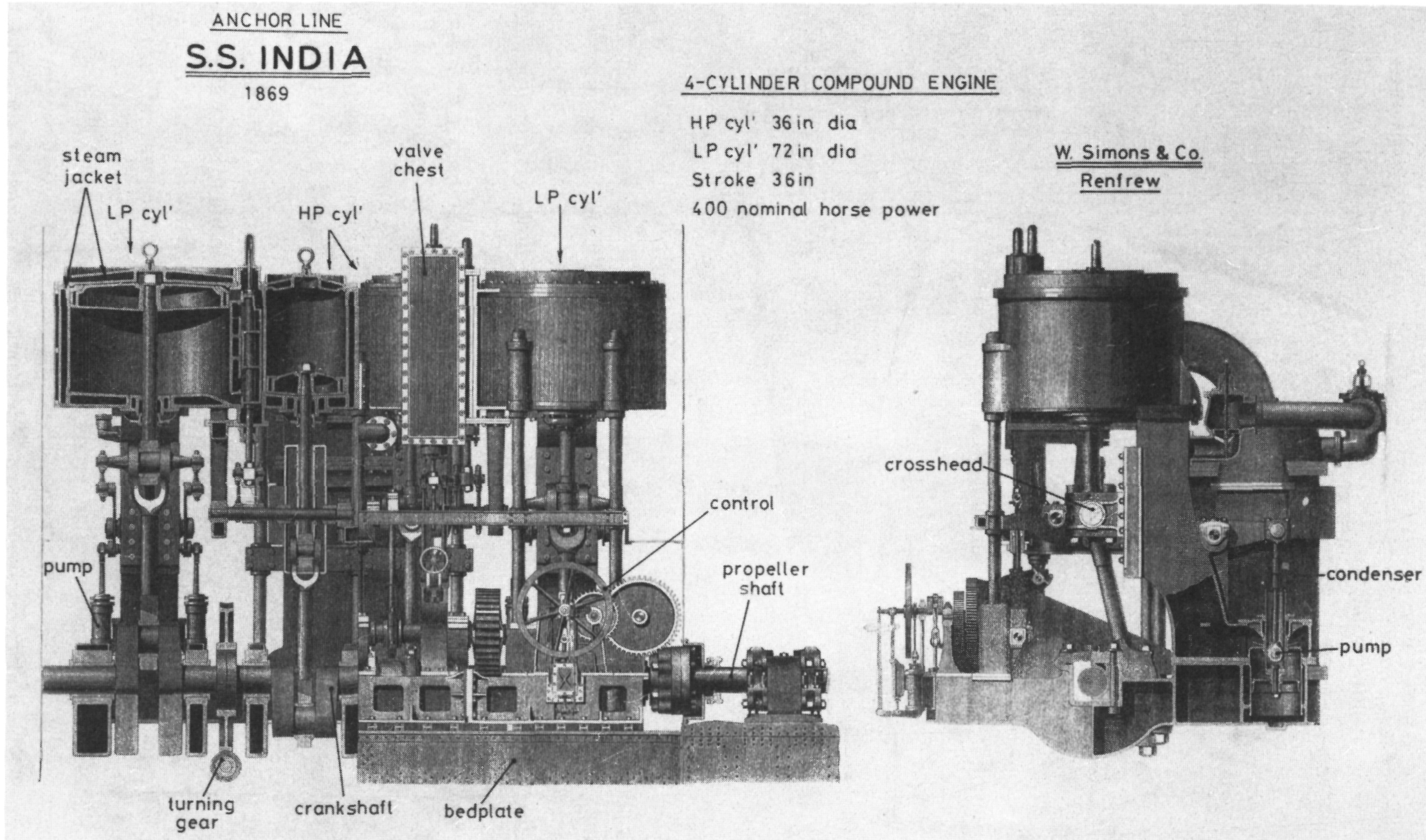

Fig. 8. – Compound engin fitted in "India".

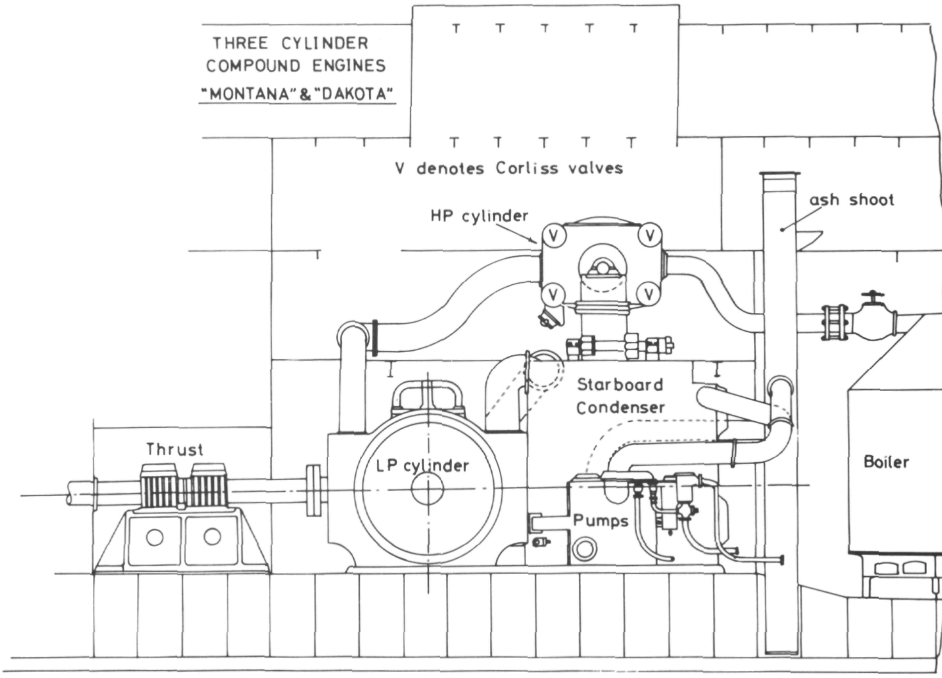

Fig. 9. – Section through engine room of "Montana" and "Dakota".

Flushed with the success of these ships, Guion returned to Palmers two years later for a pair of 17-knot steamers capable of capturing the "Blue Riband". This time responsibility for design of the engine plant was vested in the Company's superintendent engineer and not Palmers the shipbuilders. Without doubt he aimed at keeping the machinery space as small as possible whilst, at the same time, wishing to obtain maximum power. Neither in the engines nor in the boilers did he succeed.

The engines were similar to those installed in the earlier ships but had three cylinders on two cranks, a vertical 60 in. (1,524 mm) diameter HP cylinder on the forward crank and two opposing horizontal 113 in. (2,837 mm) diameter LP cylinders on the after crank. It was not, however, the engines which attracted most attention but the boilers. For high output from a compact plant it was essential to provide steam at a pressure above that then common and the plan was to supply steam at 100 psi (690 kN/sq m). Cylindrical boilers were not considered suitable and a water-tube design was adopted, the first to be put in an Atlantic liner. Few water-tube boilers existed ashore, let alone at sea, and so design problems might have been expected. That the boilers turned out to be little short of a disaster was no surprise to Palmers, who advised against their adoption.

Each ship was to have ten boilers arranged in five rows with pairs positioned back to back and stokeholds in the wings. There was no dividing wall between each pair, so in effect there were five double-ended boilers. An uptake, some 80 ft

(24.38 m) long, extended the whole length of the boiler room and led to a single funnel. Each boiler had 35 tubes 15 ft (4.57 m) long and 9 in. (228 mm) in diameter, these being arranged in five inclined rows, which connected with horizontal tubes at their ends. Vertical tubes were attached to the ends of the horizontal tubes, allowing for water circulation and for steam to rise to the steam space above. Three steam collecting drums positioned in the uptake provided a crude form of superheater.

"Montana" was the first of the pair to be completed but within 13 hours of the start of her delivery voyage from the Tyne to the Mersey a tube failed, causing serious

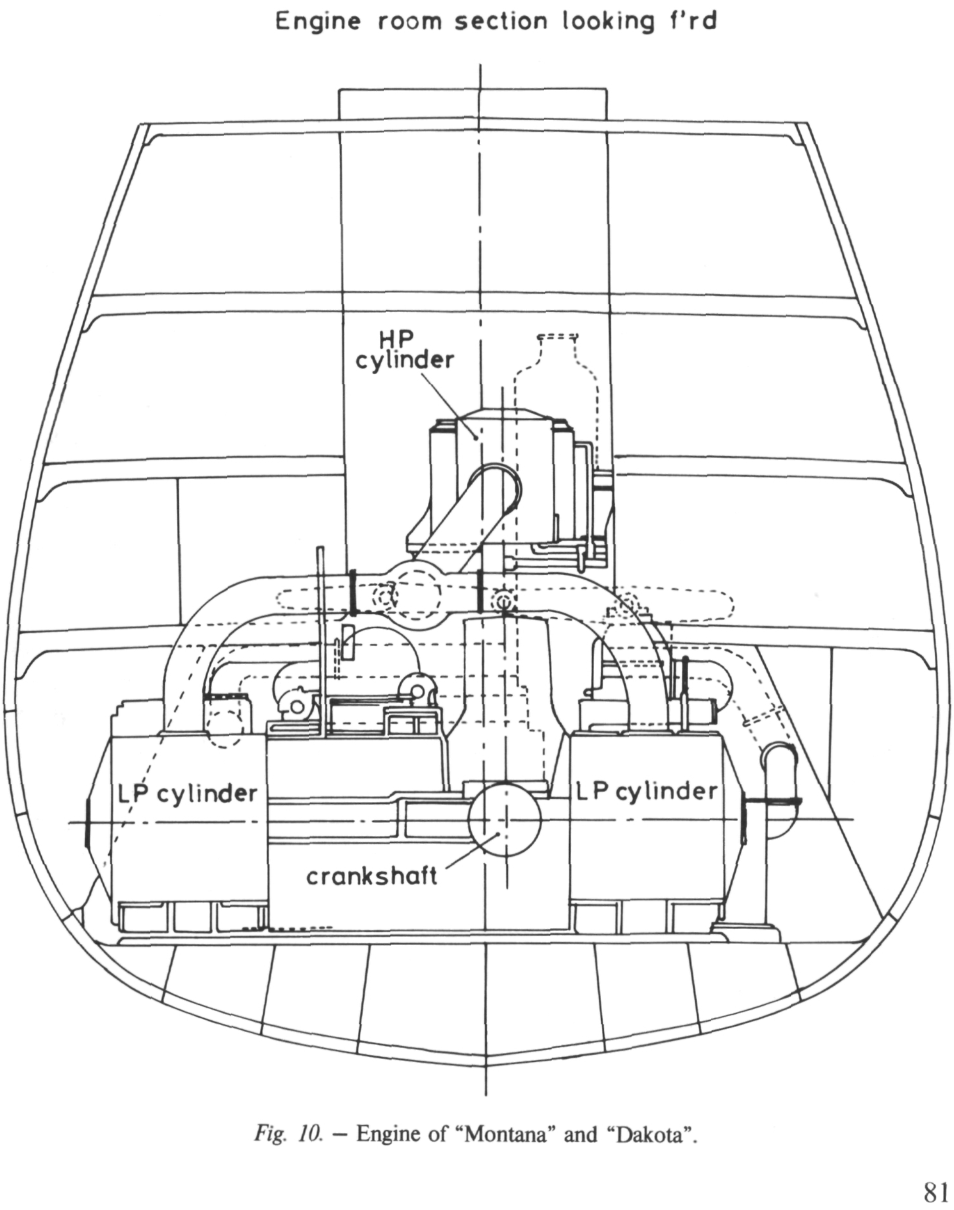

Fig. 10. – Engine of "Montana" and "Dakota".

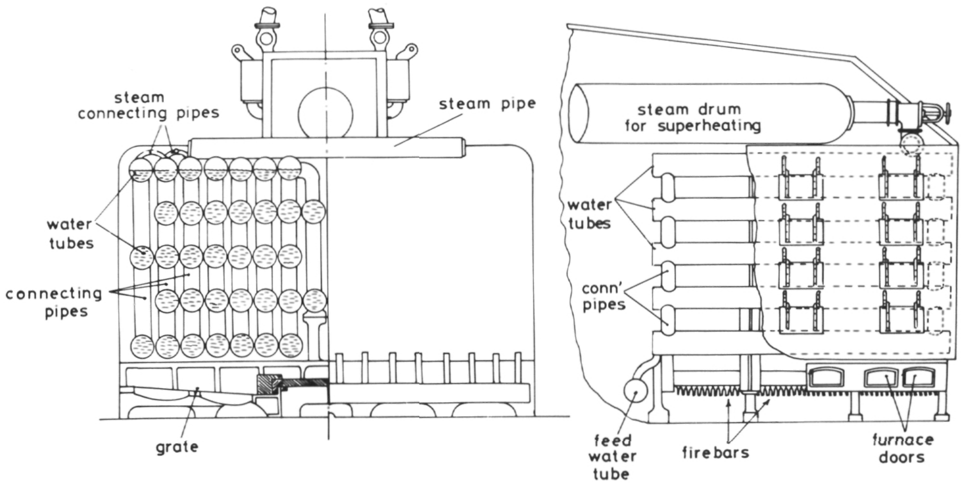

Fig. 11. – Watertube boiler of "Montana".

injury to a fireman. Within 24 hours five of the boilers were out of action owing to tube failure. Emergency repairs allowed "Montana" to reach Liverpool but during full sea trials in August 1873 further failures occurred. That ended the experiment, and the ship was reboilered, as was her sister, "Dakota", whilst still at the builders. This disaster cost the owners over £60,000 but much more in lost reputation. The cause of tube failure turned out to be faulty design with the generation of steam in the water circulation tubes causing overheating [7].

At this time wrought iron was still the most common material for boilers and ship's hulls, but steel supplies became increasingly available. Quality, however, was not consistent and most designers remained faithful to iron plates. Towards the end of the 1870s increasing availability of good-quality steel plate resulted in the possibility of higher steam pressure and the ability to expand steam in three stages rather than two ; more power could be obtained from a unit mass of steam. Before the introduction of triple-expansion engines a number of different forms of dual-expansion compound were developed, most designed to provide high power from the shortest possible engine.

Fast ships required large, powerful engines but these occupied considerable space, which could profitably be used for passengers of cargo. Engine builders adopted a variety of means by which high power could be obtained from a short engine and a much favoured arrangement was to connect HP and LP cylinders in tandem. In itself the compound engine was not subject to existing patents, though the way in which the cylinders were arranged could be, and several designers produced slightly different tandem systems in order to avoid infringing patents. In some cases HP was above the LP whilst in others the reverse was true. One of the most successful

[7] *Watertube Boilers of the Steamsip Montana*, in : *Nautical Magazine*, November 1873, pp. 922-931.

arrangements was that provided by the firm of Maudslay, Sons and Field, in which LP cylinders were positioned below the respective HP cylinders, pistons being connected by means of single rods passing through glands.

Harland & Wolff of Belfast originally had no engine building plant of its own and so outside manufacturers were subcontracted for machinery construction. Maudslay, Sons and Field had produced very reliable engines for some of the first batch of White Star Line steamers and the contract was placed with that concern for engines to be fitted in "Britannic" (1874) and "Germanic" (1875). As with the earlier ships these engines consisted of two tandem units but of larger size and higher power. Two HP cylinders of 48 in. (1,219 mm) diameter and two LP 83 in. (2,108 mm) diameter, each of stroke 60 in. (1,524 mm), were enough to develop 4,970 indicated horse power [ihp] (3,708 kW) from steam at 75 psi (517 kN/sp m). This gave these 5,000-gross-ton ships a service speed of 16 knots on a daily coal consumption of 110 tons [8].

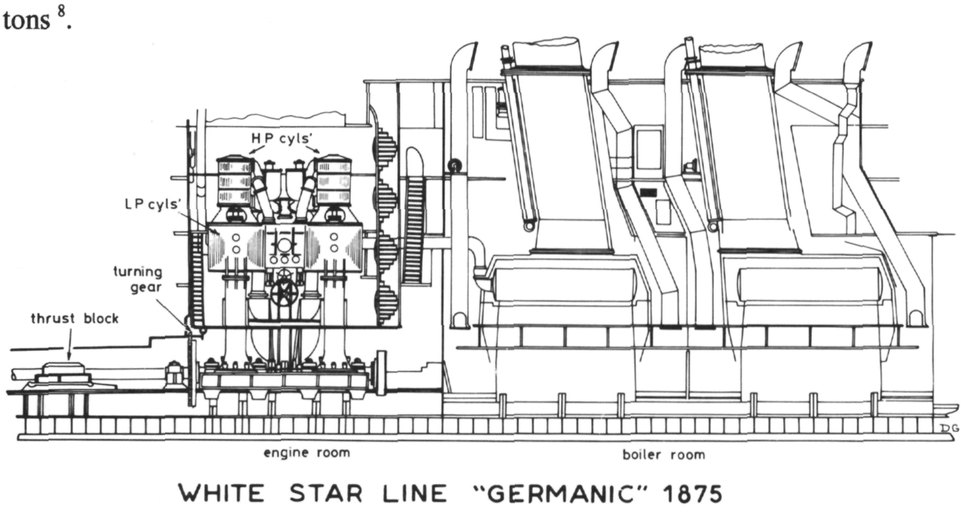

Fig. 12. – Section through machinery space of "Germanic".

Eight double-ended oval boilers supplied the steam, a steam collector drum in the uptake of each boiler acting as a crude superheater. The full extent to which efficiency could be improved by superheating was not then completely understood, but it was well known that by drying the steam in some way initial cylinder condensation losses could be reduced.

The 1870s saw a number of new vessels in service on the Atlantic, and most had something different to offer in terms of machinery. The growth in trans-Atlantic traffic produced a corresponding increase in the number, size and speed of vessels. Careful economic decisions had to be made regarding construction of new ships. Greater size allowed more passengers and cargo to be carried, but eastbound sailings were never

8 *The Engineer*, 24 June 1910, p. ii.

as fully subscribed as those westbound, especially in steerage, which housed the immigrants. Eastbound cargoes were also usually lighter. Speed attracted passengers who wished to cross the ocean as quickly as possible in order to conduct business, whilst others simply desired to minimise the time they would be subject to sea-sickness. Fast crossings reduced the food bill and allowed the ship to make more trips each year.

Passenger comforts aboard early steamers were somewhat primitive, but as competition increased owners had to consider more than simple transportation. Adequate heating was essential for an Atlantic crossing, especially during the winter months, and exhaust-steam heating systems were fitted in some ships in the 1850s. Lighting by means of candles and oil lamps presented a fire hazard and inconvenience due to the soot produced, though in the early years there was no alternative. In 1872 two of the original White Star steamers "Celtic" and "Adriatic" had been provided with plants for generating gas from oil. This was piped around the ship and provided a continuous means of lighting in many areas, including the engine room. Movement and vibration soon caused pipe joint failure with resultant leakage. Accordingly, the experiment was discontinued.

In 1879 the Inman Line steamer "City of Berlin" was fitted with a Siemen's electrical generating plant as a trial. This was so successful that two years later a full-size plant was fitted in the new ship "City of Rome". "City of Berlin" also took the lead in a number of other ways : many of her pumps were driven by separate steam engines (usually pumps were driven by means of levers from the main engine) and she was also provided with a MacFarlane Gray steam steering gear, the first in an Atlantic vessel apart from Brunel's "Great Eastern". As ships became bigger, some form of power steering had become essential in order to ease the burden on the helmsman and to ensure safe and effective manœuvring.

Auxiliary machinery, for passenger comfort and ease of operating, advanced considerably with each new ship during that time. The Guion liner "Arizona", built by Elder & Co. on the Clyde in 1879, was provided with an extensive electrical plant and a sanitary water supply for flushing water closets. In the engine room ash hoists were fitted to allow for easier disposal of ash overboard ; as ships became larger and more powerful, delivery of coal to the boilers and disposal of ash became a major problem : the steam generating rate was to be maintained. "Arizona" was also provided with an evaporator allowing fresh water to be made from sea water. Such home-produced water was only for boiler feed, domestic supplies being taken on board in port and stored in tanks. Distilled water from the evaporator minimised scale formation in the boilers, allowing them to function more effectively over longer periods. On deck, stream winches were provided for faster working of cargo, whilst a steam crane could be operated to lift the anchors on board after they had been raised by the steam windlass [9].

[9] *Engineering*, 3 September 1980, pp. 196-197.

With such additional plant the workload of the engineers, firemen and coal trimmers increased, and so did their numbers. The Atlantic liner was becoming even more a self-contained community. Provision of powered deck machinery allowed cargo to be loaded and discharged more quickly, which in turn enabled the ship to return to sea in a shorter time. Only whilst in motion did the ship earn money ; time in port cost money.

Atlantic liners may not always have been test beds for new equipment designs but they did pose problems for shipbuilders and equipment manufacturers. These problems often related to the power required from main engines and simply to increase cylinder size was not a solution. "Arizona"'s engine followed a pattern developed by Elders to reduce operational and manufacturing problems with large and powerful engines. Higher power dictated a larger HP cylinder and that of "Arizona" was 62 in. (1,575 mm) in diameter. A single LP cylinder for such an engine would have been difficult to manufacture and would have caused vibration problems in operation owing to unbalanced forces. Elders developed a three-crank compound design with two LP cylinders, one each side of the HP. These were of 90 in. (2,286 mm) diameter and all cylinders had a 62 in. (1,575 mm) stroke. This arrangement was longer than a two-crank form but, in order to reduce overall length, piston valves for each cylinder were placed at the back of the engine and operated from eccentrics by means of levers.

Cunard's answer to competition from other lines was cautious but innovative. Built by J. & G. Thomson of Clydebank, later to be John Brown & Co, "Servia" (1881) was not designed as a record breaker in terms of speed but she did show the way to future developments. She was the first large Atlantic liner constructed of steel, which was a major advance as this material was stronger than iron and allowed thinner plates to be used. That in turn resulted in a smaller displacement and so increased carrying capacity. At 7,400-gross-tons she was a large ship and to maintain a service speed of 16 knots would burn 190 tons of coal each day. Cylinders were arranged in a similar manner to those of "Arizona", with steam supply coming from six double-ended and one single-ended cylindrical boilers operating at 90 psi (621 kN/sq m). These were of the form subsequently known as "Scotch" boilers but were provided with steam drums, acting as superheaters, in the uptakes. Furnaces were of the recently introduced Fox corrugated form, which was designed to allow for higher steam pressure and increased heating surface area with thinner plates. Steel was used for boiler construction as it had been for a number of years previously. In order to reduce the risk of corrosion, the prime cause of which was then understood to be the presence of oxygen, a patent de-aerator was fitted in the feed line.

The auxiliary plant was extensive and included a Bell-Coleman dry-air refrigerating plant for preserving fresh meat. The traditional ice house was still provided, probable as a safeguard, but fitting a mechanical refrigeration plant showed a way to the future in storing provisions for the 1,300 passengers and 200 crew she could carry. Her twelve lifeboats had space for 720 people at most.

"ARIZONA"

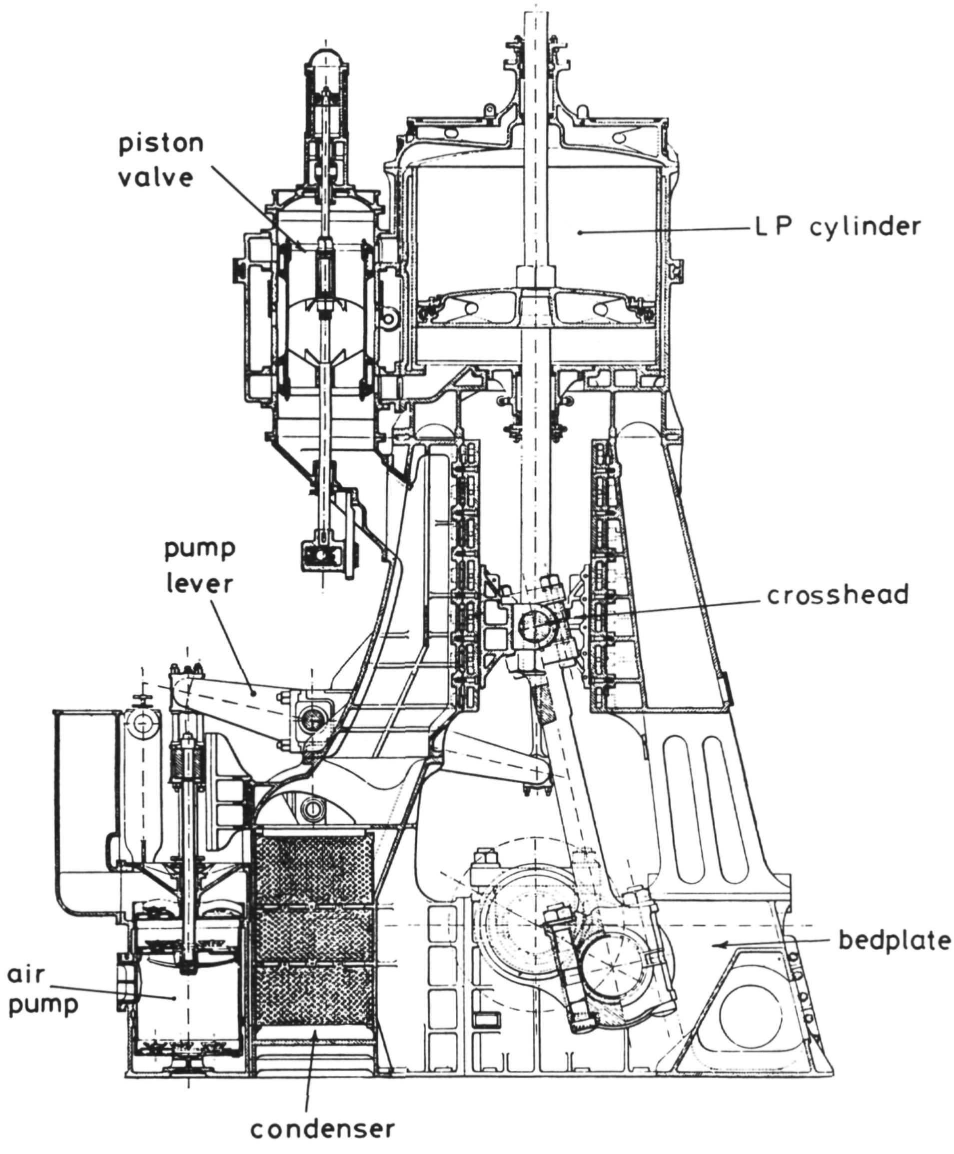

Fig. 13. – Section through engine of "Arizona".

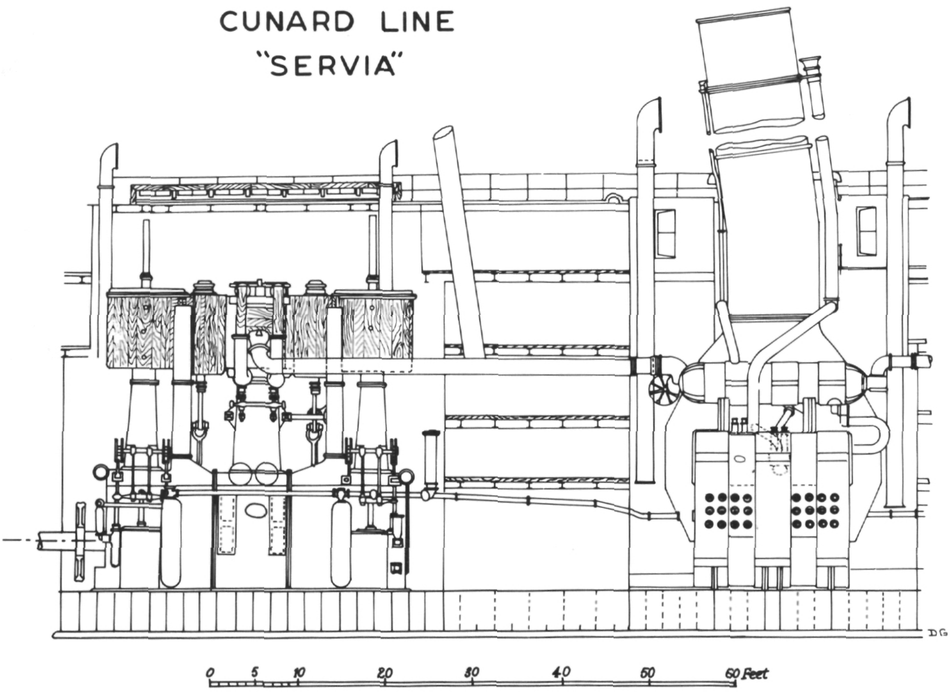

Fig. 14. – Section through machinery space of "Servia".

Construction and watertight subdivision of the ship was so good that she rated high on the Admiralty list of auxiliary cruisers. Her usefulness in any potential conflict was emphasised in publicity by the fact that, if cargo spaces were used for bunkers, "Servia" could steam 16,400 miles (26,400 km) at full speed, 27,300 miles (43,925 km) at 14 knots and 35,700 miles (57,440 km) at 12 knots [10].

A notable failure of the period which illustrates the advantages of steel ship construction was the Inman liner "City of Rome". A steel shortage would have delayed completion and so the decision was made to build her from iron. That resulted in a heavier vessel with reduced carrying capacity and service speed below contract. After five voyages she was returned to her builders as unsuitable and Inman Line was short of a ship. After modifications, "City of Rome" entered Atlantic service under Anchor Line management but was not the hig-speed ship she was intended to be.

From what has been mentioned above it might be supposed that only the British had an interest in Atlantic liners, but that was not the case. The Compagnie Générale Transatlantique (French Line), Norddeutscher Lloyd (NDL) and Hamburg-Amerikanische Packetfahrt Aktien-Gesellschaft (HAPAG) were all engaged in the opera-

[10] *The Engineer*, 7 April 1882, pp. 349-352.

tion of liners between Europe and New York but, in general, their ships were of British construction, mainly from the Clyde. The 1880s did see a change, however, and it was the French Line which took the lead. Six ships were ordered to replace an ageing fleet, with the first, "La Normandie", coming from the Barrow Shipbuilding Company, the others of similar design being ordered from French yards.

The three-crank tandem compound engine as fitted in "La Normandie" was similar in form to that provided by the same builder for the unfortunate "City of Rome". Dimensions were specified in metric units rather than the conventional imperial units then used by all British engine builders. For the later French-built ships, engines of slightly larger dimensions were constructed under licence in France by the shipbuilders. Dimensions of the French-built engines are as follows (with those relating to "City of Rome"'s engines in brackets for comparison) : HP 1,007 mm (1,029 mm), LP 2,003 mm (2,184 mm), stroke 1,776 mm (1,828 mm), indicated power 7,310 kW (7,470 kW) [12].

Steel crankshafts of the hollow built-up type were employed as they were lighter than the equivalent iron types and were notably stronger. Shortages of good quality steel limited its applications for engine parts but the critical crankshaft was one of those parts requiring attention. Defects in the steel could result in fracture, and manufacturers adopted different methods to eliminate gas inclusion. Whitworth compressed steel was subjected to heavy hydraulic pressure whilst still in the molten state in order to exclude such gases, and that was the process adopted for crankshafts fitted to engines supplied by the Barrow Shipbuilding Company.

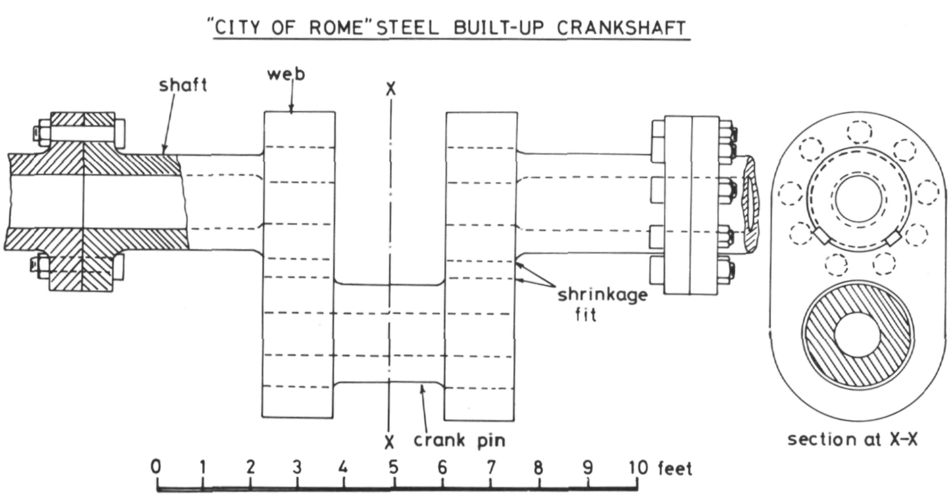

Fig. 15. — Steel crankshaft for "City of Rome" 's engines.

[11] *Marine Engineer & Motorship Builder*, October 1921, p. 421.
[12] *The Marine Engineer*, September 1880, pp. 127-131.

With the delivery of "La Normandie" the French shipbuilding and engine building industries developed their own styles and few orders for ships then went outside France. One of the main reasons for this action was the insistence of the French Government that subsidised mail steamers should be constructed in French yards. In later years similar restrictions applied to vessels of the German fleet but a number of high-class vessels were still to be constructed on the Clyde and Mersey before that happened.

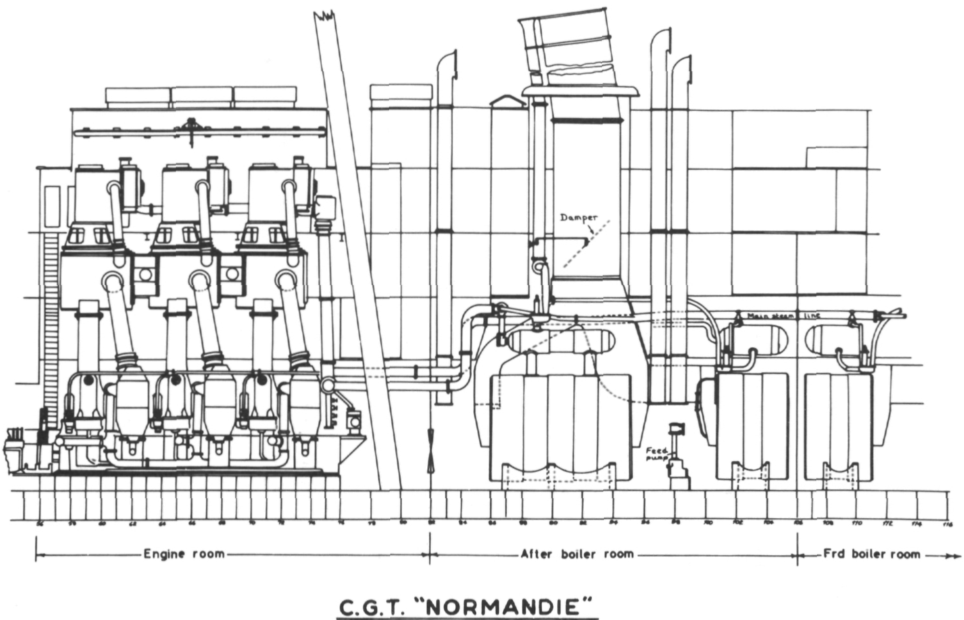

Fig. 16. – Tandem engines built by Barrow Shipbuilding Co.

Typical of vessels built for German owners during the early 1880s were the "River" class ships constructed for NDL by John Elder & Co. Eight ships of the class, of which the 4,900-gross-ton "Elbe" was the first, were built over a seven-year period and all had three-cylinder compound engines similar to, but less powerful than, that fitted in "Arizona". Elders built many fine and fast vessels during that decade and notable amongst them was the Guion Line's "Blue Riband" holder "Oregon" of 1893. Her three-cylinder compound engine, of typical Elder design, developed 12,000 ihp (8,950 kW) using steam at 110 psi (769 kN/sq m) supplied by nine double-ended Scotch boilers with Fox's corrugated flues. These boilers were made from steel as was the built-up crankshaft but, strange for that time, the hull was constructed from iron. Reasoning for that is difficult to determine, but steel was still relatively expensive compared with iron and shortages in supply did occur [13].

[13] *Engineering*, 29 June 1883, p. 602.

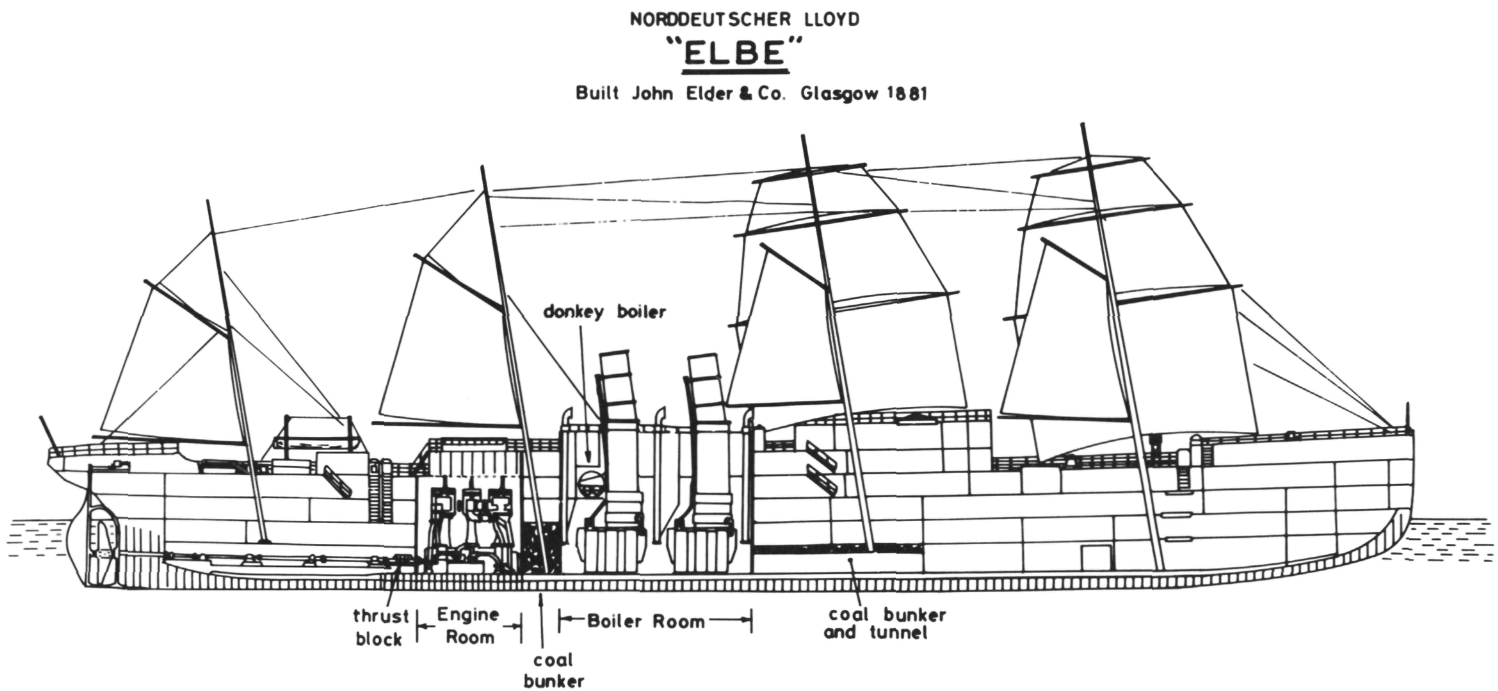

Fig. 17. – Section through NDL steamer "Elbe".

"Oregon" was fast, 18.05 knots for her record crossing, but speed cost money in the form of coal consumption. At that speed she would burn 300 tons per day. Some of that went in generating electricity, the ship having two generators, each of which was capable of suppyling the entire load of the 460 lamps installed.

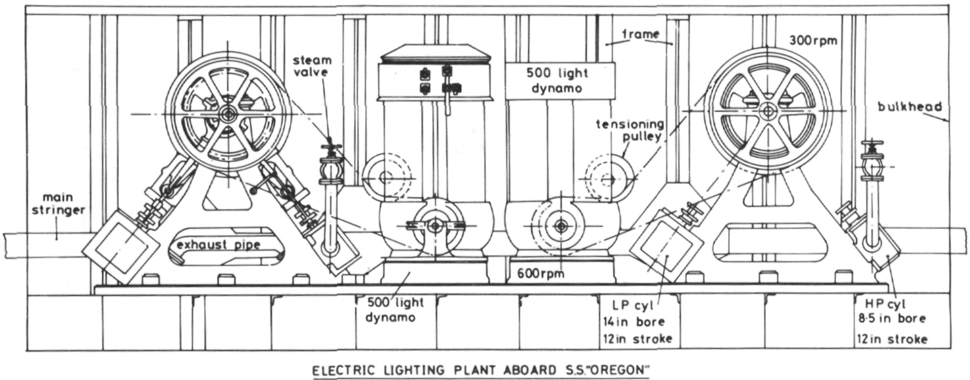

Fig. 18. – Electric plant as fitted in "Oregon".

Cunard's reply to "Oregon" came in the form of "Umbria" and "Etruria" a year later. Steel built, they were large ships, 7,700-gross-tons, with a draught to the then limit of water at New York harbour. Engines consisted of the standard Elders' form of three-cylinder compound engine but with cylinders larger than any yet manufactured and capable of developing 15,000 ihp (11,190 kW). Coal consumption of 315 tons per day required 109 stokers and trimmers with 11 engineers and one electrician completing the engine room complement. The electrical plant was the most sophisticated put in any ship to that date. Four generators supplied the power, which was directed throughout the ship by means of six independent circuits, some with sub-circuits. A switchboard allowed any generator to supply any of the circuits. Electrical installation aboard ship were definitely coming of age [14].

Passenger comfort in terms of ventilation was not forgotten, with a forced system being provided for the lower decks. An arrangement using high-pressure air issuing through nozzles was used to draw fresh air into the lower sections of the ship. This system avoided use of the usual fan and large amounts of ducting. Stale air vented through casings which surrounded the twin funnels, thus avoiding a chilling effect on the funnel gases during Atlantic winters [15]. Passengers were becoming more selective, and only the most up-to-date and well-apportioned ships could charge the highest fares and attract the first-class passenger.

[14] *Engineering*, 19 June 1885, p. 674.

[15] *The Marine Engineer*, November 1884, p. 215.

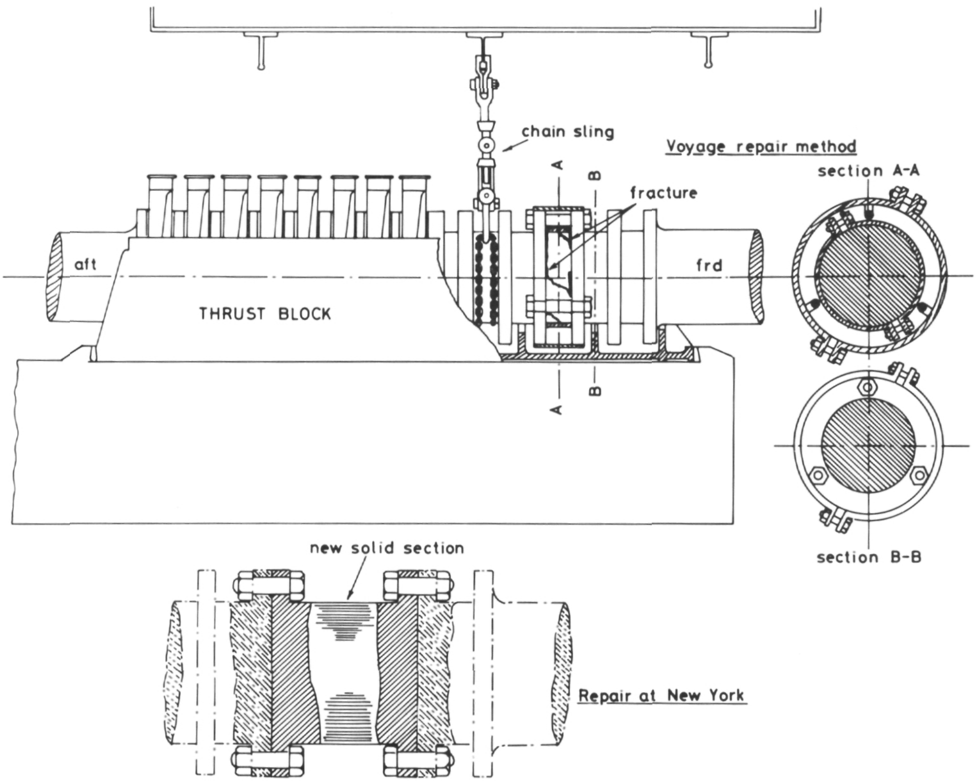

Fig. 19. – "Umbria" 's fractured shaft and repair method.

"Etruria" and "Umbria" were single-screw ships and, although constructed to the highest standards, were vulnerable to loss of propeller or shaft failure. During their operating lives both were subject to such incidents, which also afflicted a great many other liners. Before the days of radio any vessel losing its single screw would be at the mercy of the weather with only its basic sails to assist. There can be little doubt that some of those steamers lost without trace disappeared as a result of a failed propulsion system during severe weather.

During December 1892 "Umbria" suffered a fractured shaft whilst about 760 miles east of New York. The shaft fractured at the thrust block, but a repair was possible thanks to the ingenuity of the Chief Engineer and skill of his staff. With much hard work, drilling and cutting using hand tools, for no electrically powered tools were then available, two of the thrust block collars were converted into coupling flanges and the ship could proceed [16].

"Etruria"'s accident was much more spectacular and no amount of effort could rectify matters. During 1902 the propeller, a section of the shaft, rudder and a portion

[16] *Engineering*, 20 June 1893, p. 80.

of the stern frame were carried away whilst en route for Liverpool. The exact cause of the incident was never known but it would appear that the shaft failed and resulted in the propeller impacting with the stern frame, causing its destruction. Whatever the reason, "Etruria" was disabled and drifted helplessly until happened upon by another steamer which took her in tow [17].

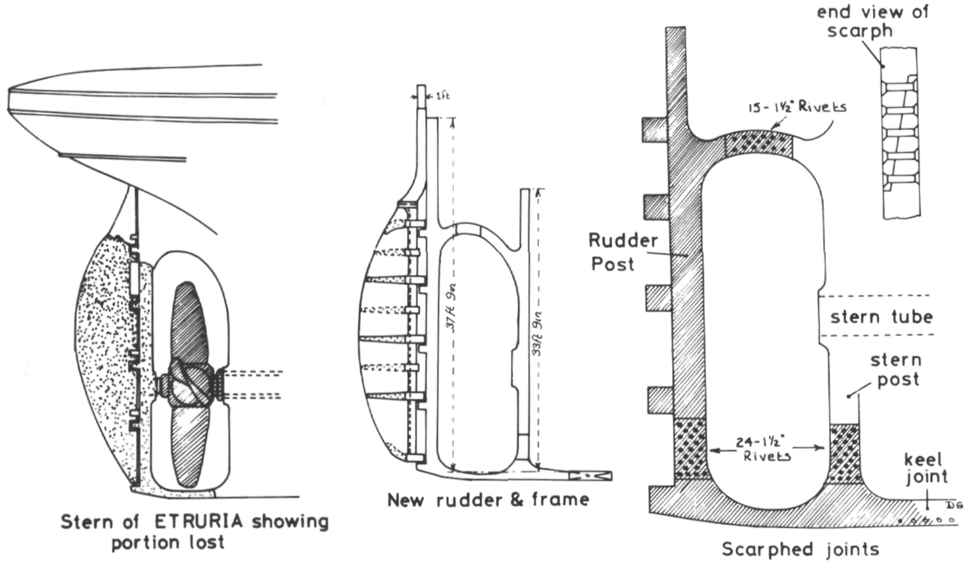

Fig. 20. – "Etruria"'s damaged stern section and repair.

Twin screw propulsion provided the answer to certain of these problems but there is never complete certainty as far as the sea is concerned. The Inman liner "City of Paris" (1889) proved this in 1892. She and her sister, "City of New York" (1888), were the most advanced ships of their day, being fitted with twin triple-expansion engines. Longitudinal bulkheads separated port and starboard engines whilst transverse bulkheads separated engine and boiler rooms. In effect each engine occupied its own watertight compartment, making it, so the designers considered, immune from problems afflicting the other engine.

At 5.20 pm on 23 March 1890, whilst the engines were apparently working well, the starboard engine suddenly raced for a short period then resumed normal speed. Within a minute the engine raced frantically then collapsed, the collapse being due to impact of reciprocating parts with the engine structure, owing to high speed during the period of racing. It subsequently turned out that the racing had been due to fracture of the propeller shaft, but loss of one engine should have enabled the ship to proceed on the other. However, in collapsing, parts of the starboard engine fractured sea-water pipes and ship-side connections, but more importantly they

[17] *The Engineer*, 6 June 1902, pp. 558-559.

punctured the longitudinal bulkhead. Pumps were not able to keep the port engine room dry, with the result that both engine rooms were soon out of action and the ship totally disabled. A tow was the only solution as sails had been reduced to such an extent as to be ineffective [18].

Such an incident illustrates the vulnerability of all ships, even those built and engineered to the highest standards. These new Inman Line ships were innovative. Triple-expansion engines had been introduced elsewhere a number of years earlier and their economic advantage over the compound was as marked as that of the compound over the simple engine. Triple expansion saved coal but the high-powered engines, 20,000 ihp (14,920 kW) total output, of "City of New York" and her sister demanded a plentiful steam supply. Three boiler rooms, each with three double-ended Scotch boilers, supplied that steam at 150 psi (1,035 kN/sq m). With natural draught there is a limit to how much coal can be burnt on a grate and hence to the steam generating rate. Higher steam output would require more boilers but that would take up more space. In order to obtain higher steam output from the same sized boiler, forced draught was developed. These "City" ships were provided with closed stokehold forced draught, the first on the Atlantic. This arrangement required air locks for entry into the stokehold and, when "City of Paris" was repaired following the accident, Howden forced-draught arrangement was fitted.

With each new large passenger ship built for Atlantic service the electrical installation increased in total power and complexity. Shipboard systems were more extensive than many shore installations and the systems fitted aboard "City of New York" and "City of Paris" were by far the most advanced afloat. For the first time electric lighting was applied to passenger and crew accomodation, as well as to working spaces, there being in excess of 1,000 lamps. The 100-volt electric system also powered electric motors which, again for the first time afloat, were used for ventilation purposes. By this time refrigeration plant for provisions had become standard and each ship was fitted with an ammonia plant to keep fresh provisions for the 2,000 people on board.

A further innovation was the anti-rolling tank. No matter what comforts were provided, a trip across the Atlantic could be very unpleasant in bad weather and little could be done to improve matters. Up to that time a number of warships had been fitted with anti-rolling tanks but they were not common in merchant vessels and had never before been installed in an Atlantic steamer. The system was a primitive form of the Frahm tank, later to become popular especially for German-built liners, and had been fitted following model tests by the builders J. & G. Thomson of Clydebank.

The twin-screw arrangement allowed for a novel design of semi-balanced rudder which was totally below the water surface. A hydraulic ram arrangement was employed for turning the rudder, devised by the Edinburgh firm of Brown Brothers, who subsequently fitted steering gear in most of the world's shipping. Hydraulic

[18] *The Engineer*, 18 April 1890, pp. 314-316.

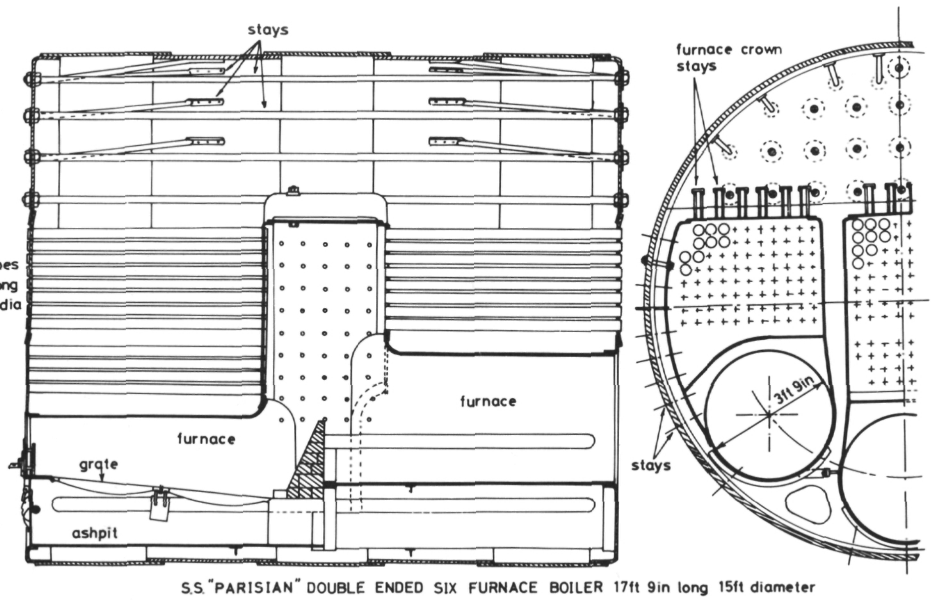

Fig. 21. – Typical Scotch boiler

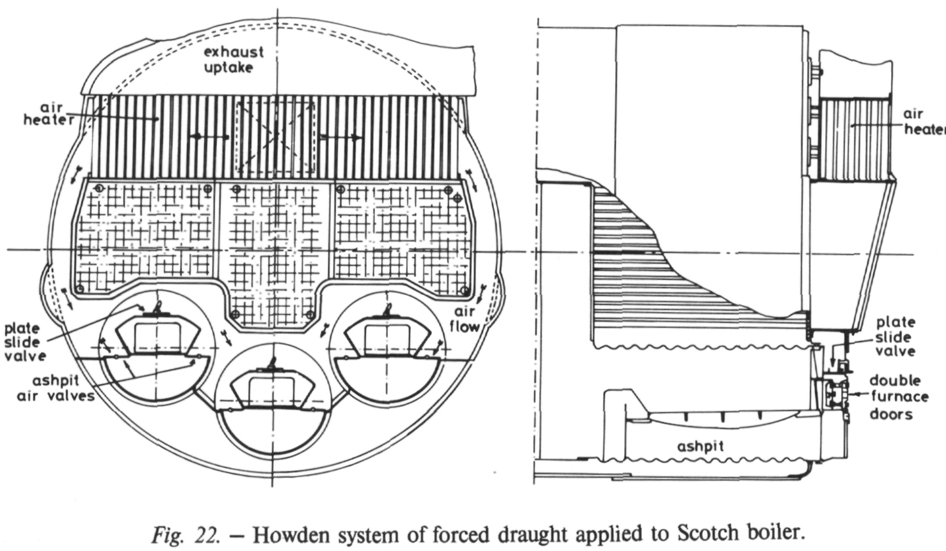

Fig. 22. – Howden system of forced draught applied to Scotch boiler.

power was also employed for the operation of deck machinery and hoists throughout the ship.

Construction of large triple-expansion engines presented problems in manufacture, especially in relation to the low-pressure cylinder. Engines for the "Cities" were of the following dimensions : HP 45 in. (1,143 mm) diameter, IP 71 in. (1,803 mm) diameter, LP 113 in. (2,870 mm) diameter and stroke 60 in. (1,524 mm). With these large dimensions the control gear was obviously also large and had to be powered by a small steam engine rather than hand operated. With such an extensive array of engineering plant it follows that a great deal of manpower was required for its operation. Under the control of a Chief Engineer were 18 assistant engineers, 3 electricians, 3 refrigerating engineers, 3 donkeymen, 3 storekeepers, 33 greasers, 54 fireman and 57 trimmers, plus one clerk. Carrying these people necessitated providing accommodation and food, but could not be avoided as they were essential to the operation of a large express liner. Coal firing was labour-intensive and large reciprocating engines needed constant oiling and greasing [19].

Any shipping company wishing to compete had to follow Inman's example and it was known that the pace of development in marine machinery would soon result in these two fine vessels being outdated. In praising the introduction of "City of Paris" the respected journal *The Engineer* commented : "The startling feature about the practice of Atlantic steam navigation is that it is perfectly well understood that the City of Paris will probably be obsolete in five years."

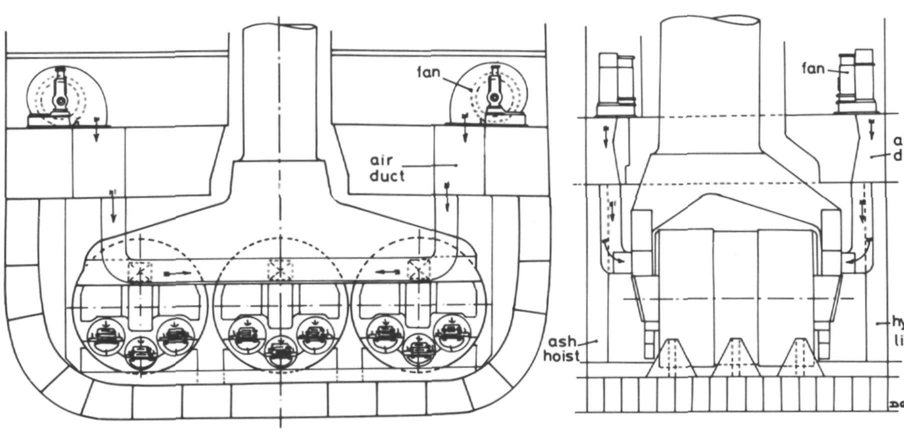

Fig. 23. — Arrangement of Howden forced draught for "City of Paris".

White Star Line responded with two 9,950-gross-ton 20-knot ships, "Teutonic" and "Majestic". Triple-expansion engines and Scotch boilers were fitted and, although cylinder dimensions were smaller than those for the "Cities", the steam pressure was

[19] *The Marine Engineer*, July 1890, pp.140-148.

higher at 180 psi (1,242 kN/sq m), allowing for greater power development. Large LP pistons as used with triple-expansion engines were beginning to cause problems of vibration, the three-crank arrangement being difficult to balance effectively. This fact and the development of higher powers in later vessels resulted in the introduction of four-crank arrangements which could be balanced on the Yarrow-Schlick-Tweedy system. These ships suffered from vibration problems especially when the LP pistons of both engines were moving up and down in unison, an effect which periodically occurred because regulating the steam supply to the engines in order to obtain exactly the same speeds was difficult. The advantage of triple expansion and twin screws can be seen from the fact that these high-speed ships would burn only 320 tons of coal per day. The smaller and slower "Oregon", built only 6 years earlier, consumed 300 tons per day [20].

A further advantage of twin screws was illustrated by the Fairfields-built HAPAG liner "Normannia" during her maiden voyage in June 1890. At full speed the ship came upon a large iceberg and had to take quick evading action. By putting the helm hard over and stopping then reversing the starboard engine with the port one kept full ahead, the ship was turned. An impact collision with the iceberg was avoided but the ship was struck a glancing blow and some 20 tons of ice fell on the deck, though no structural damage was sustained [21]. Twenty-two years later "Titanic" was not so lucky.

"Normannia" proved to be the final British-built vessel for the two major German lines, her Stettin-built sister "Furst Bismarck" was slightly larger. Both ships were fitted with twin 8,000 ihp (5,969 kW) triple-expansion engines and their auxiliary machinery plant followed similar installations already afloat.

Eastbound Atlantic passages generally offered less cargo than those westbound but there was cargo to be exploited in the form of meat. Live cattle had been transported aboard cargo ships but such would have caused problems with passenger vessels. In order to take advantage of the meat traffic available, a number of owners provided refrigerated holds as well as refrigerated provision rooms. This was no real innovation as far as maritime transportation in general was concerned but it did prove to be an advance for express Atlantic liners. Few items of cargo, apart from people and mail, required fast passage and so freight rates were not high. Perishable foodstuffs could be made to pay higher rates and fill otherwise unused space aboard the express liners.

White Star provided its two fast steamers, "Teutonic" and "Majestic", with two refrigerated holds each of 40,000 cu ft (345 cu m) capacity. Each hold had its own ammonia refrigerating plant, either of which could be made to cool both holds. So successful was the arrangement that the earlier built "Britannic" and "Germanic" were taken out of service in 1892 for conversion of hold space to refrigerated space. Instead

[20] *The Engineer*, 19 December 1890, pp. 489-503.

[21] *Engineering*, 29 August 1890, p. 247.

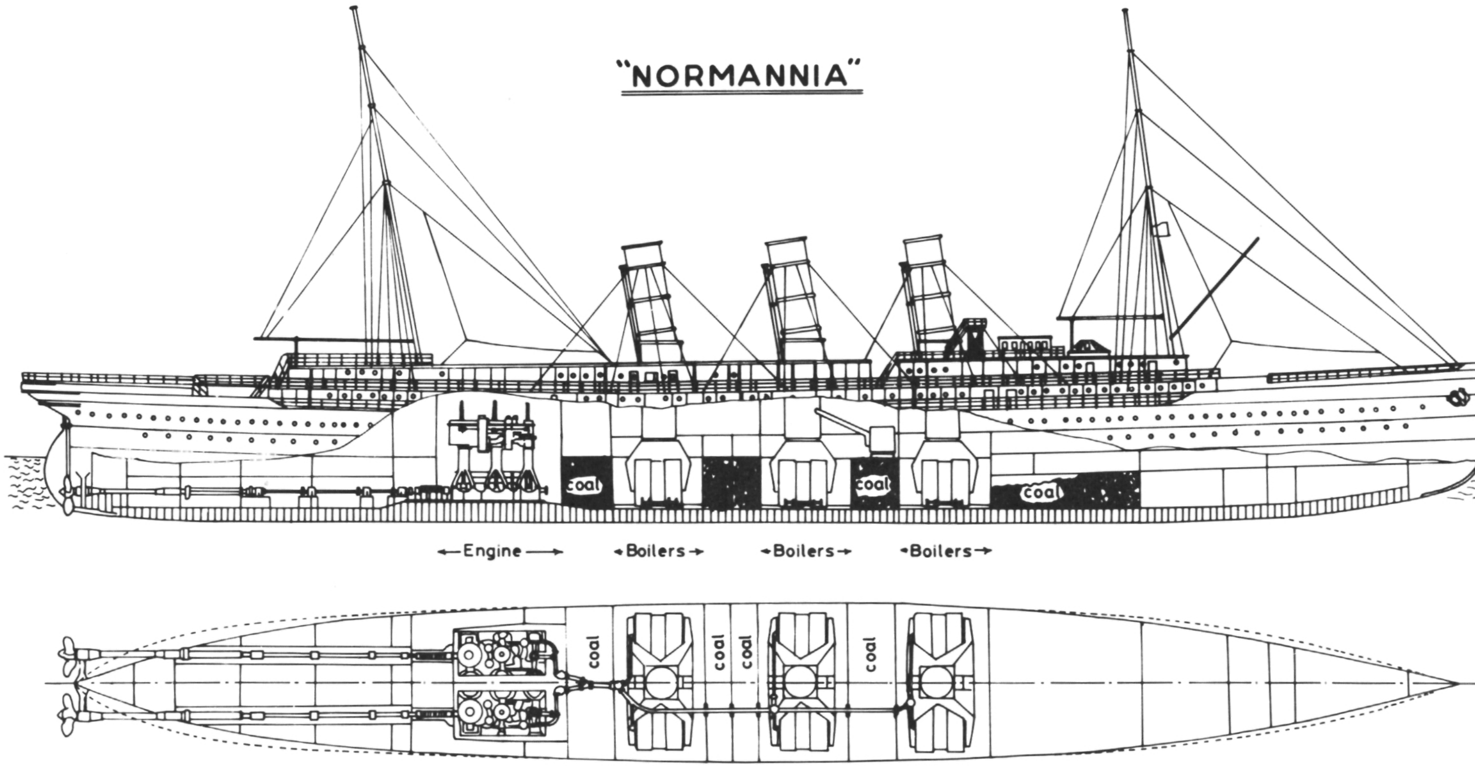

Fig. 24. – Twin screw German steamer "Normannia".

of an air-circulating ammonia plant these ships were provided with carbon dioxide systems employing brine circulation around the hold. Brine circulation made for easier conversion work, but ammonia attacked the copper pipes which would be used for brine circulation and so the carbon dioxide system had to be employed. The basic refrigerating principle remained the same as for ammonia but higher pressures were required because of the use of carbon dioxide gas [22].

High speed and larger ships demanded an increase in power and that in turn required larger engines. The triple-expansion engine had practically reached the end of its development by the early 1890s and the engines fitted in the twin-screw Cunarders "Campania" and "Lucania" (1893) were amongst the largest and most powerful ever made. They were certainly exceptional pieces of engineering but were still three-crank triple-expansion engines of the basic arrangement introduced years before. That statement is not in any way intended to detract from the design and constructional skill which went into their production ; it merely serves to illustrate the rapid developments taking place in the marine field. The Atlantic was a testing ground for some of the most powerful machinery afloat and manufacture of such taxed the skills of the marine engineering industry.

Each engine had five cylinders, tandem HP and LP cylinder arrangements being positioned each side of the single IP. All pistons had the same stroke, 69 in. (1,733 mm), with cylinder diameters as follows : HP 37 in. (940 mm), IP 79 in. (2,007 mm) and LP 98 in. (2,490 mm). The twin engine installations could develop 30,000 ihp (2,238 kW) and that would drive these 12,950-gross-ton ships at speeds in the region of 22 knots. The large reciprocating masses of these engines caused vibrations at some speeds, illustrating the problems of balancing a three-crank engine.

Further problems with such large engines involved regulation of speed or, more accurately, governing speed when the propeller was partially uncovered during rough weather. Traditionally it had simply been a case of reducing steam supply to the engine, but with a large triple-expansion engine closing the steam inlet valve was not enough. Even though steam would not be passing to the engine, there was a considerable quantity of steam passing between HP and IP as well as between IP and LP cylinders. That produced power which caused the main engine to race. A solution was to fit a steam engine which would move the engine's expansion link to mid-position ; thus all cylinder valves would cease to operate and no steam would flow between any of the cylinders. That engine consisted of a steam cylinder to which steam was directed whenever the governor cut in. So large were the linkages that manual control of the engine was not possible and small steam cylinders were required to move the linkages when manœuvring.

Steam at 165 psi (1,138 kN/sq m) was supplied by twelve double-ended Scotch boilers, which operated on a closed pressurised stokehold arrangement rather than that of forced draught. Coal bunkers occupied space foreward, aft and above each of

[22] *Engineering*, 19 December 1890, pp. 722-723.

the two boiler rooms, with coal being fed by chutes from bunkers to stokeholds. With a daily fuel consumption of 550 tons it was obviously essential that supplies to the boiler were maintained and an army of 84 firemen and 57 trimmers had to be employed to ensure that steam pressure did not fall.

A large cargo and provision refrigerating capability was provided together with an extensive electrical plant. With each successive express liner the amount and quality of the technology increased [23].

America re-entered the fray as an Atlantic liner builder and operator with "St Louis" and "St Paul" (1895). Built by William Cramp & Sons of Philadelphia, these 10,250-gross-ton ships were not as fast as the Cunard pair but could maintain a comfortable 20 knots. Their machinery attracted attention owng to their use of twin quadruple-expansion engines. Six double-ended and four single-ended Scotch boilers using Howden forced draught supplied steam at 200 psi (1,380 kN/sq m), the higher pressure being ideally suited to quadruple expansion. A four-crank arrangement was employed, tandem HP and LP cylinders driving the forward pair of cranks, first IP the third crank and second IP the fourth. Dimensions were modest compared with the engines of "Campania" : HP 28.5 in. (724 mm), 1st IP 55 in. (1,397 mm), 2nd IP 77 in. (1,956 mm) and LP 77 in. (1,956 mm), all with strokes of 60 in. (1,524 mm). Total power was a modest 16,000 ihp (11,936 kW), but the ships burnt only about 300 tons of coal per day. Surprisingly, they had bunker space for only 2,500 tons of coal, sufficient for eight days' steaming at full power. American coal was not of such high quality as that which could be obtained in Europe but, being American, these ships were likely to have been pressured into taking on maximum bunkers of American coal. By having small bunkers the owners need not take too much of that coal. Bunker space also reduced cargo capacity.

Final Atlantic marine engineering development of the century lay in German hands. "Kaiser Wilhelm der Grosse" (1897) was the first non-British holder of the "Blue Riband" since the 1850s and at 14,350-gross-tons she was the largest ship in the world. Her twin main engines were triple-expansion but employed four cranks, which allowed for more effective balancing. The cylinder arrangement working from the foreward end of the engine was HP 51.875 in. (1,320 mm), IP 89.75 in. (2,280 mm) and then two 96.5 in. (2,450 mm) diameter LP cylinders, all with a 68.875 in. (1,750 mm) stroke. Natural-draught Scotch boilers supplied steam at a rather modest 175 psi (1,208 kN/sq m). In order that the large quantities of coal required to feed the boilers might be brought to them quickly, a little railway system was arranged between the bunkers and stokeholds. Rapid disposal of ash from each stokehold was provided for by means of water-powered ash ejectors [24].

Safety was not neglected and an elaborate system of watertight doors was provided, with an arrangement of discs on the bridge to indicate when doors were open or closed. As ships became larger such features became essential.

23 *The Engineer*, 13 October 1893, pp. 345-358.

24 *Engineering*, 23 March 1894, p. 364 ; 8 April 1898, pp. 429-431.

HAPAG's answer to the NDL ship came by way of the "Deutschland" (1900). A larger ship of some 18,000-gross-tons, she was also faster and hence more powerful. A change came about in that quadruple-expansion engines were chosen, these being of six cylinders on four cranks and balanced on the Yarrow-Schlick-Tweedy system. Two 36.6 in. (930 mm) HP cylinders were mounted in tandem above two 106.3 in. (2,700 mm) LP cylinders, these combinations occupying the central crank positions. The 1st IP cylinder, 73.6 in. (1,870 mm), was placed forward and the 2nd IP, 103.9 in. (2,640 mm), on the aftermost crank. All had strokes of 72.8 in. (1,850 mm).

Each engine had been designed to produce 16,500 ihp (12,310 kW) but in service they could develop a combined total of 37,000 ihp (27,700 kW). Crossing at an average speed of 23.36 knots "Deutschland" captured the "Blue Riband" but the ship vibrated from stem to stern when pushed hard. It soon became evident that there was no solution except to operate at lower speeds. Even during later years a number of express liners suffered from severe vibration, which was never effectively overcome despite stiffening of the structure and a change in propellers.

In contrast to the earlier German record holder, "Deutschland" was provided with Howden forced draught on her Scotch boilers and these provided steam at 220 psi (1,528 kN/sq m), a pressure which could be efficiently used with quadruple expansion. As might be expected aboard such a ship, extensive use was made of electricity. As well as the usual lighting circuits, electricity powered the galley, forced draught fans, ventilation fans, water heaters and curling irons. Electric motors also

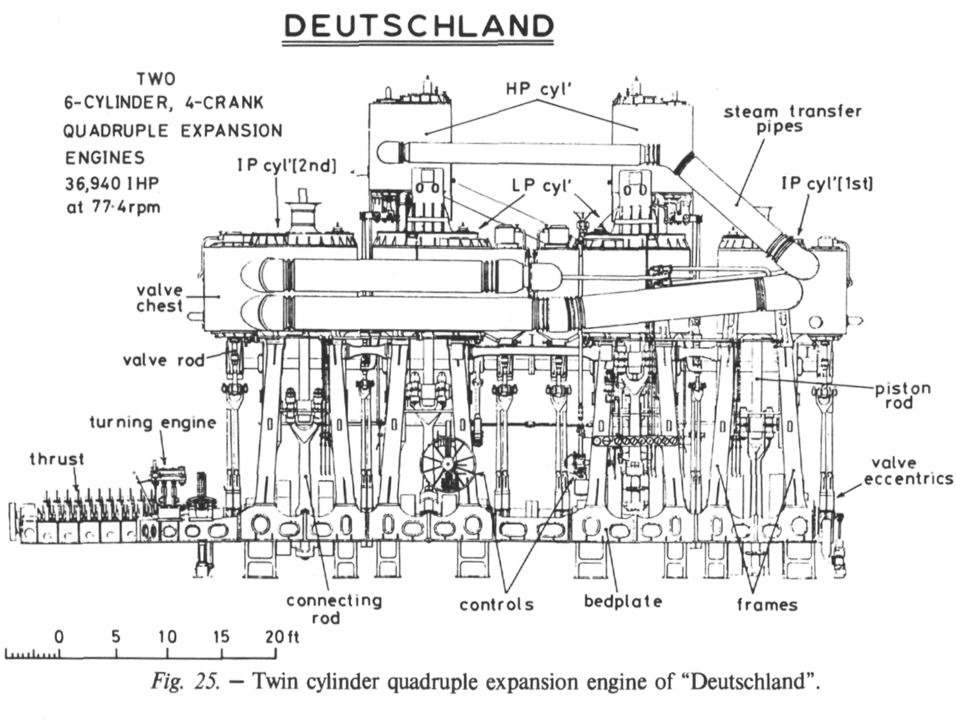

Fig. 25. — Twin cylinder quadruple expansion engine of "Deutschland".

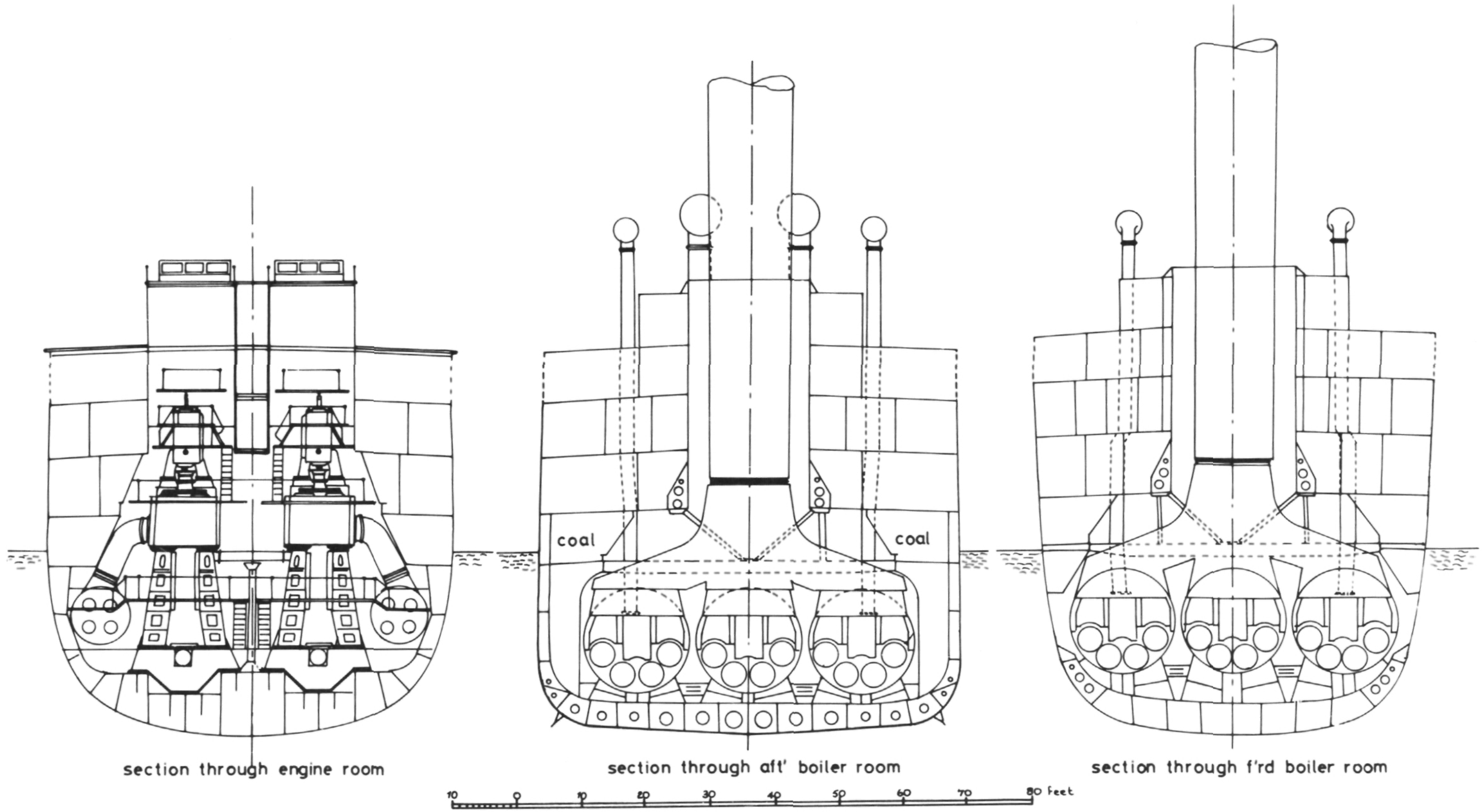

Fig. 26. – Section through machinery space of "Deutschland".

operated mail and provision hoists although no similar system of elevators was provided for passenger use. That came with later ships and was an essential feature as the number of decks increased [25].

This concludes the study of 19th-century Atlantic marine engineering and also the effective development of the steam reciprocating engine as a high-power generator. With the new century would come the turbine, gearing, water-tube boilers, oil firing and the internal combustion engine. All these in turn revolutionised travel on that waterway and caused changes in manufacture ashore as well as operation afloat. Eventually the jet aircraft demoted the Atlantic liner to history.

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Conclusion

Only infrequently did the Atlantic liner bring about a change in marine technology, usually innovations were tried on other waters before being introduced to the western ocean. However, because of the nature of operations on the Atlantic, with its demand for high speeds and engine powers, the Atlantic liner was always to the fore. Marine supply industries grew on the basis of support for a vast fleet of liners. With large numbers of people regularly crossing that waterway, owners had to ensure that their vessels were always well equipped, otherwise passengers would drift to the more modern and better appointed ships. The introduction of electricity was an immediate success and soon all ships wishing to attract the better paying passengers had to be so provided. In matters such as this developments for shipping use were often faster than those for shore applications.

Marine engines of the 19th century were larger than those used for any other purposes and the same was true for boiler plant. Because of the marine industry, and that serving the high-powered Atlantic liners in particular, development of large engineering manufactories progressed more rapidly than it would otherwise have done. These ships enjoyed the benefit of changes in technology but they also promoted changes and resulted in better manufacturing.

Acknowledgement

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A more detailed and complete history of the machinery of Atlantic liners during the 19th and 20th centuries will be available towards the end of 1990 with the publication of my book *Power of the Great Liners* by Patrick Stephens Ltd, Wellingborough, England.

[25] *Engineering*, 20 December 1900, p. 724.