British Marine Industry and the Diesel Engine

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Introduction

In 1892 Rudolf Diesel lodged a patent for an internal combustion engine with the German Patent Office. From this beginning grew an industry which, a century later, provided power for the majority of the world's merchant ships. Several inventors, including Akroyd Stuart and Emil Capitaine, had prior claims to internal combustion engines but Diesel's version employed compression ignition. He argued that compression to a sufficiently high pressure of the air charge in a cylinder would increase the air temperature to a point that would lead to spontaneous combustion of fuel subsequently injected into the cylinder. In these early engines fuel oil was forced into the cylinder by means of an air blast, the high pressure air atomising liquid fuel during injection. The engines of Stuart, Capitaine and others offered internal combustion but did not rely solely upon compression of the air charge to bring about ignition.

Several companies took an immediate interest in Diesel's engine, including Maschinenfabrik-Augsburg AG (later Maschinenfabrik-Augsburg-Numberg [MAN]) and Sulzer Brothers of Switzerland. Several others quickly followed, including Mirrlees, Watson and Yaryan of Glasgow in 1897.[1] When Diesel's patent expired during the early years of the twentieth century, many other engine builders became interested and a wide range of engines operating on the Diesel cycle were developed. Diesel's patent covered the means of obtaining fuel ignition but there were two different methods by which cylinders could be recharged with air, the four-stroke and the two-stroke cycles. There were, and still are, advantages and disadvantages to both, but the two-stroke has found favour for slow speed, direct-drive, crosshead engines while the four-stroke engine is confined to the higher speed, trunk-piston type.

The main problem as far as marine application was concerned lay in reversing the engine in order to go astern; electrical systems were tried but Sulzer introduced a directly reversing engine in 1905 and other builders soon followed.[2] Several builders concentrated on submarine engines, including MAN; the French concern, Schneider and Co., and the Italian Fabbrica Italiana Automobili Torino (FIAT). Scott Shipbuilding and Engineering Company of Greenock took a licence for FIAT engines in 1912,[3] while Barclay Curie on the Clyde and Swan Hunter on the Tyne became interested in the engines developed by Burmeister and Wain (B&W) of Copenhagen. Subsequently, the association of these concerns was dissolved and a sole British licence to construct B&W engines was granted

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to Harland and Wolff.[4] The North Eastern Marine Engineering Company of Wallsend on Tyne approached Werkspoor of Amsterdam for a licence in 1912, but the war delayed construction work.[5] Beardmore took a licence for the Italian Tosi engine, while Richardsons Westgarth held a licence for the Belgian-designed Carels engine. A number of shipyards, including Dennys of Dumbarton, bought licences from Sulzer.

British Diesel Engines

Vickers of Barrow worked closely with the Admiralty in the development of marine diesel engines, primarily for submarine propulsion, but a crosshead four-stroke cycle engine was designed and fitted in a number of Admiralty-sponsored vessels, including the monitor *Marshall Soult* and the fleet replenishment tanker *Trefoil;* a slightly larger engine went into another fleet replenishment tanker which subsequently became the *Marinula* of the Anglo-Saxon Petroleum Company. After World War I a commercial engine was designed based upon that crosshead engine, but with modifications aimed at reducing initial cost and maintenance (see figure 1). Six pairs of engines were fitted in twin-screw tankers built by Vickers, two were exported for installation in ships built in Japan and two larger engines were constructed for passenger ships also built by Vickers. An innovation as far as the Vickers engines were concerned was the solid injection of fuel into the cylinders; almost all diesels at that time used a blast of compressed air to force fuel into the cylinders. The engine was not a success, with only eleven ships fitted with the design, a number of which suffered broken crankshafts and other serious failures (see appendix table 1). The large eight-cylinder engines could develop just over 2000 kW, which was insufficient to propel the bigger and faster ships then being demanded. The company realised that its four-stroke design had reached the limit of development. Rather than spend more money developing a new power plant, a licence was taken for the MAN double-acting engine.[6]

Swan Hunter obtained a licence from the Swedish engine designer AB Diesel Motorer of Stockholm that became the basis for two different designs of Neptune engines introduced during the early 1920s, the so-called "A" and "B." Both operated on the two-stroke cycle and used blast fuel injection. The essential difference between the two was that the "A" engine had scavenge air cylinders positioned below the main cylinders, with the scavenge piston directly driven by the main piston (see figure 2). This produced a very tall engine but simplified cylinder head construction, since the scavenge cylinders could be supplied with compressed air when starting, thus avoiding the need for starting air valves in the heads. The "B" engine had scavenge air pumps driven by levers from some of the main piston crossheads, thus reducing engine height; these levers were also used to actuate cooling water and lubricating oil pumps in a manner similar to the operation of pumps on most steam reciprocating engines. Only three ships were fitted with "A" engines and eight with "B" engines (see appendix table 2), two of which actually were built by Swan Hunter for its own account (a number of companies would build ships for their own account in the hope of selling them before construction was complete; this also kept skilled labour employed). All Neptune engines were installed during 1924 and 1925 and the income must have been marginal; no attempt appears to have been made to licence the design.[7]

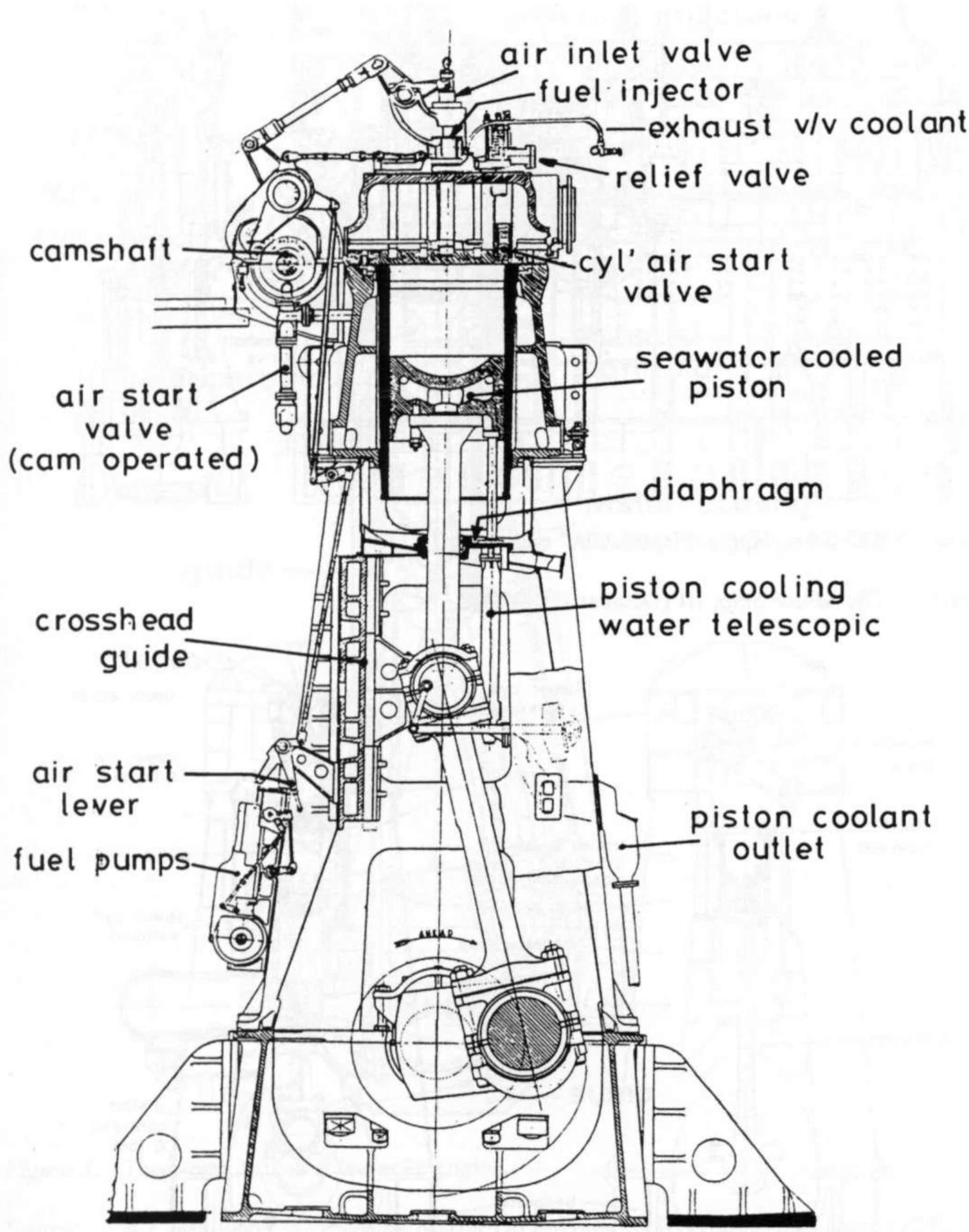

Figure 1: The Vickers four-stroke engine.

Source: *Engineering,* CXII (15 July 1921), 132.

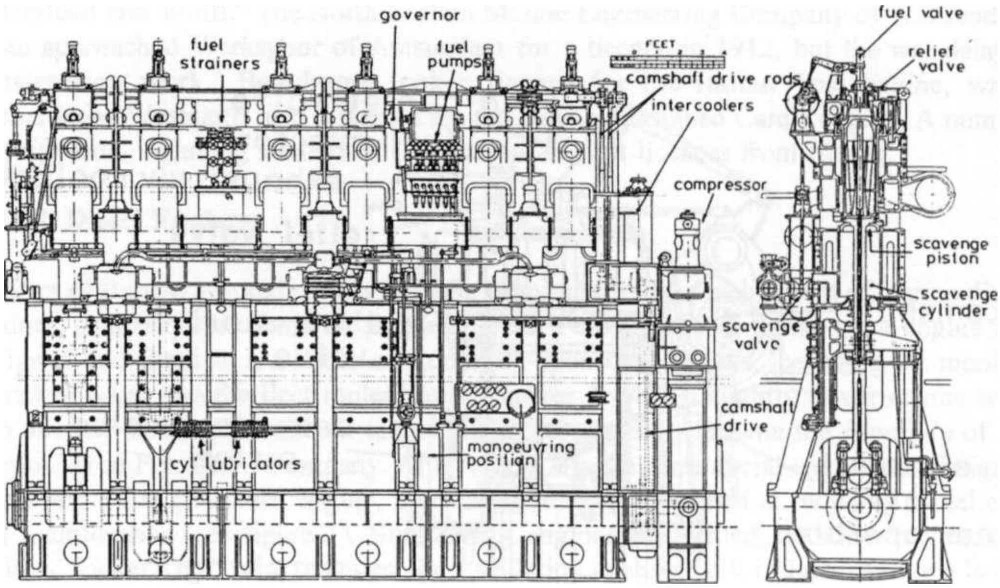

Figure 2: The Swan Hunter Neptune "A" engine.

Source: *The Motor Ship,* III (October 1922), 228.

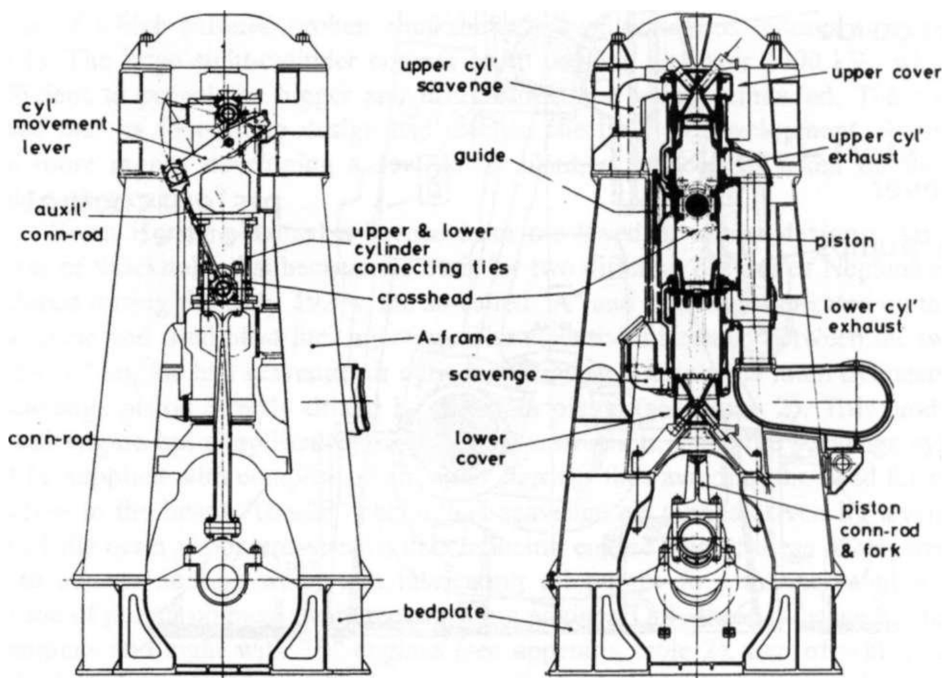

Figure 4: Cylinder arrangements of the NBDEW two-stroke sliding-cylinder engine.

Source: J.C.M. McLagan, "The Sliding Cylinder Double Acting Engine," Institute of Marine Engineers (IME), *Transactions,* XXXVI (1922-1923), 665.

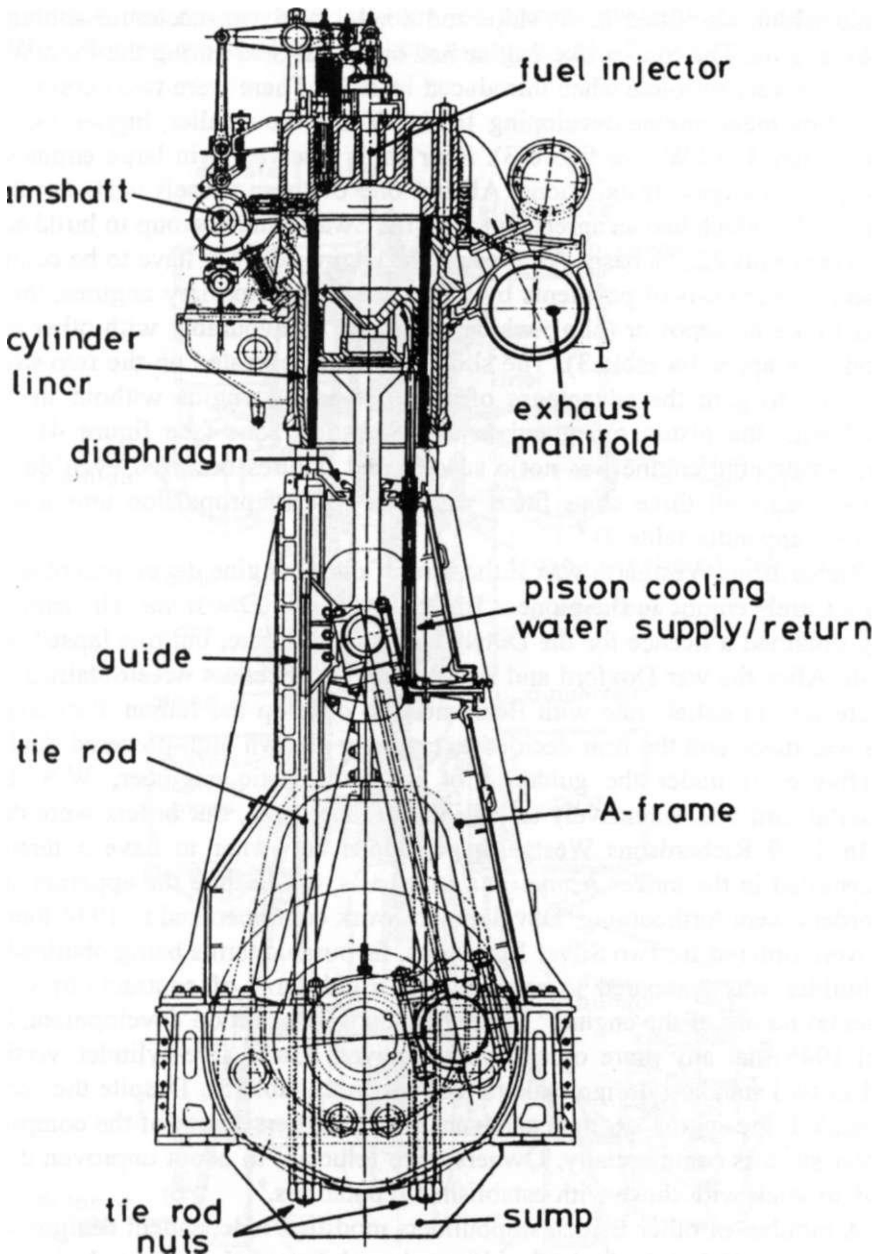

Figure 3: The North British four-stroke engine.

Source: A.L. Mellanby, "Clyde Built Marine Oil Engines," IME *Transactions* (June 1923), 714.

Swan Hunter was also instrumental in establishing the North British Diesel Engine Works at Whiteinch on the Clyde and effectively competed with itself for diesel engine orders during the difficult 1920s. North British designed two crosshead-type engines, a four-stroke which was fitted in six ships and a notoriously unsuccessful sliding cylinder two-stroke engine. The four-stroke engine had been designed during the First World War and was effectively obsolete when introduced in 1921. There were two versions, with the larger eight-cylinder engine developing 1675 kW and the smaller, higher-speed version developing only 373 kW (see figure 3). Four ships received twin large engines and two ships twin small engine installations. All but one of these vessels were for the British India Line (BI), which had an agreement with the Swan Hunter group to build and engine ships on a cost plus 22.5% basis. As a result, the engines did not have to be competitively priced, and on the basis of payments by BI for main and auxiliary engines, the cost was £37.7 per brake horsepower (bhp), which compared unfavourably with other engines of the period (see appendix table 3). The sliding cylinder operated on the two-stroke cycle in an attempt to gain the advantages of a double-acting engine without the problems associated with the piston rod gland in a combustion zone (see figure 4). For many technical reasons the engine was not a success and failures occurred even during trials. Within two years all three ships fitted with this type of propulsion unit had been re-engined (see appendix table 4).[8]

Richardsons Westgarth was at the fore of diesel engine development and in 1912 installed a Carels engine in the pioneer British motorship *Eavestone.* The same year, the company obtained a licence for the Dutch Werkspoor engine, but this lapsed before any were built. After the war Doxford and Beardmore-Tosi licences were obtained. Although plans were laid to collaborate with Beardmore to develop the Italian Tosi engine, little progress was made and the firm decided to engineer its own high-powered double-acting engine (figure 5) under the guidance of its enthusiastic engineer, W.S. Burn. An experimental unit was extensively tested in 1926 and 1927, but orders were difficult to obtain. In 1929 Richardsons Westgarth persuaded an owner to have a three-cylinder engine installed in the tanker *Irania* on a trial basis, but despite the apparent success no further orders were forthcoming. Development work continued and in 1934 four-cylinder engines were ordered for two Silver Line ships, favourable terms being obtained since the engine builder was "prepared to agree a very rigid form of contract...in view of the experimental nature of the engine." Further funds were spent on development, but it was not until 1945 that any more orders were received. Later, five-cylinder versions were installed in two standard design tankers (see appendix table 5). Despite the considerable sum expended, the engine's technical advances and the persistence of the company, it was not a great success commercially. Owners were reluctant to adopt unproven designs and preferred to stick with those with established reputations.[9]

A number of other British shipbuilders modified independent designs for marine purposes. Cammell Laird obtained sole marine rights to the opposed-piston Fullagar engine (see figure 6) and succeeded in attracting three sub-licensees, but the total number built was small. Technical problems plagued the design and at one stage Laird faced court action from the Still Engine Company over patent infringement with respect to cylinder liner construction. Only nine ships received Fullagar engines and all but two had been re-engined by 1930 (see appendix table 6). Unlike the majority of British engine designers, Cammell Laird attempted to develop a network of licensees but lacked the professional approach of its continental rivals. A North American agent was appointed on a commission basis, but as soon as a full-time job became available he departed, leaving the firm with poor prospects of finding licensees in the US.[10]

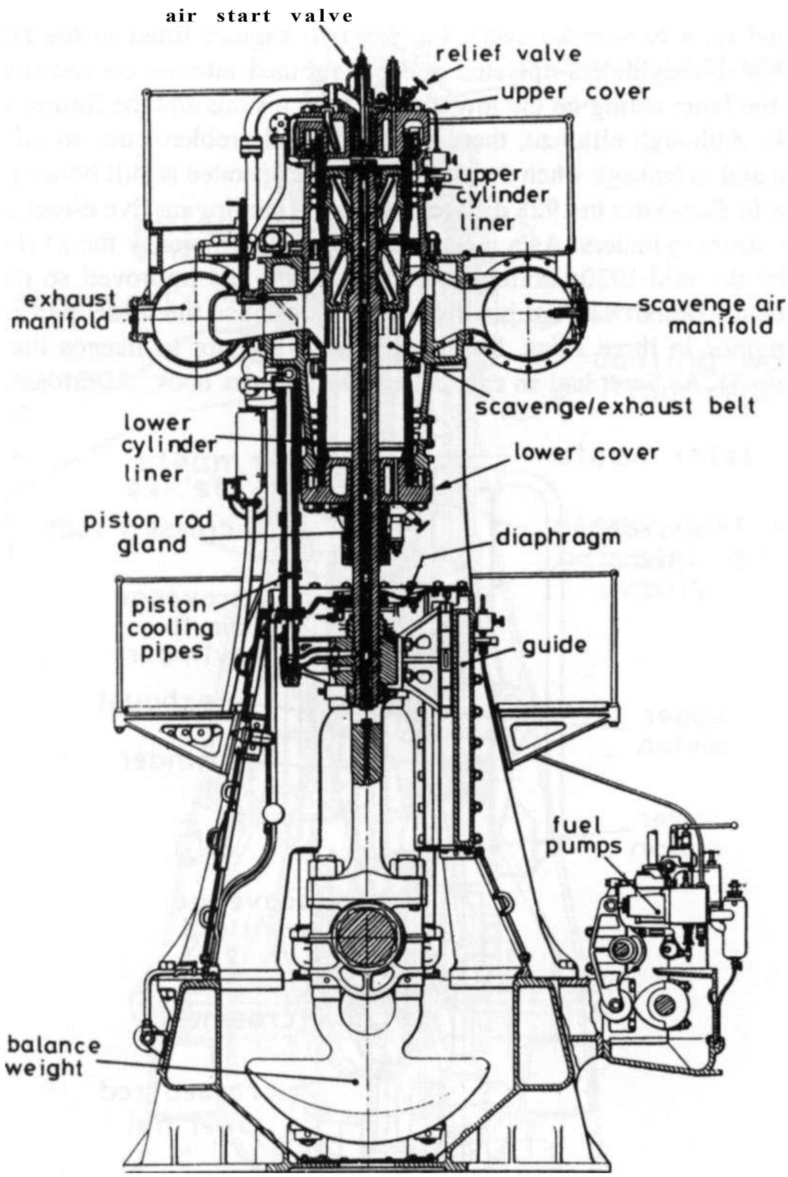

Figure 5: Richardsons Westgarth double-acting engine.

Source: W.S. Bun, "Double Activity Engineers," Institute of Mechanical Engineers (IMechE) *Transactions,* XXXVIII (1926), 281.

Scott of Greenock licensed the Still engine, which was more a concept for total energy recovery than an actual engine design (see figure 7). The basic principle was to recover as much waste heat as possible in the exhaust gases and engine cooling water by generating steam and using it to drive steam cylinders; the Still engine thus combined diesel and steam. Much of the design work was undertaken by Scott's engineers. The diesel operated on a two-stroke cycle. For the two engines fitted in the Blue Funnel's *Dolius* in 1924, the cylinders operated under combined internal combustion and steam power, with the latter acting on the lower part of the pistons and the former on the upper (see figure 8). Although efficient, there were technical problems due to oil entering the steam system and to leakage when the cooling system operated at full boiler pressure. The engines fitted in *Eurybates* in 1928 differed in design, employing five diesel cylinders and two separate steam cylinders. As a means of improving efficiency the Still concept was useful, but by the mid-1920s normal diesel efficiency had improved so much that the complexity of the design was not justified. Scott developed the diesel part of the engine and fitted engines in three ships, but there was no attempt to licence the design (see appendix table 7). As Scott had an extensive warship order book, no further diesels were built.[11]

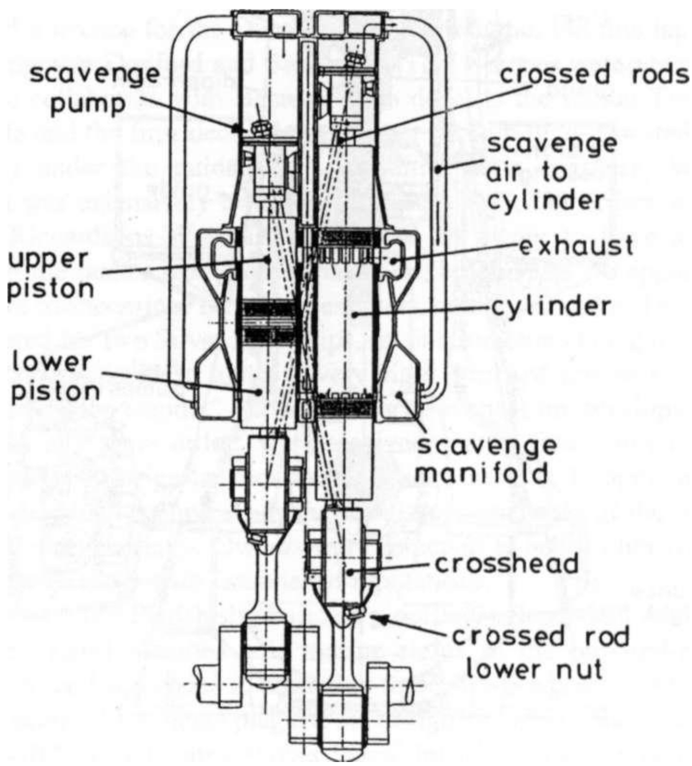

Figure 6: A four-cylinder Fullagar engine.

Source: W.K. Wilson, "The History of the Opposed Piston Marine Oil Engine — Part 2," IME *Transactions,* LXIII (1946), 180.

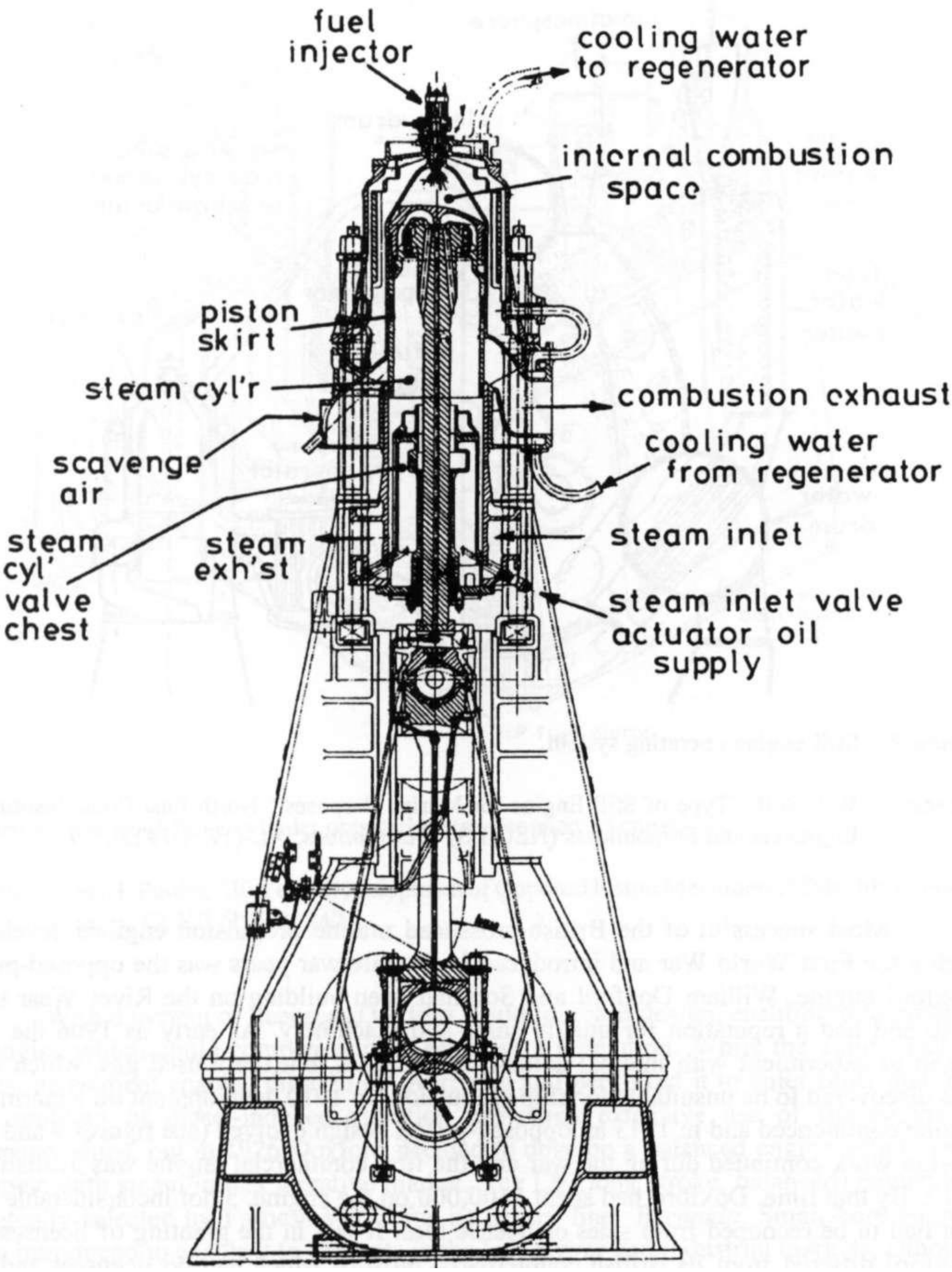

Figure 8: Section through Scott-Still engine fitted in *Dolius.*

Source: "Second Report of Marine Engine Trials Committee," IMechE *Proceedings,* I (1925), 439.

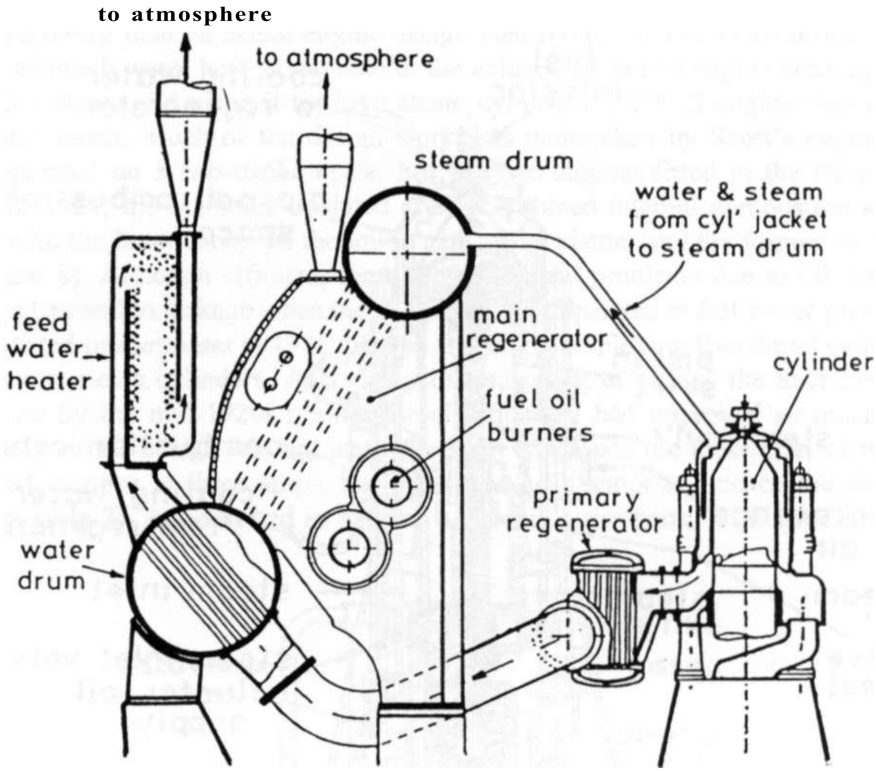

Figure 7: Still engine operating system.

Source: W.J. Still, "Type of Still Engine for Marine Purposes," North East Coast Institute of Engineers and Shipbuilders (NECIES) *Transactions,* XL (1924-1925), 393.

Most successful of the British crosshead marine propulsion engines developed during the First World War and introduced in the interwar years was the opposed-piston Doxford engine. William Doxford and Son had been building on the River Wear since 1840 and had a reputation for quality ships and machinery. As early as 1906 the firm began to experiment with internal combustion engines, but these used gas, which soon was discovered to be unsuitable for ship propulsion. In 1910 development on a marine oil engine commenced and in 1913 an opposed-piston design evolved (see figures 9 and 10). Design work continued during the war and the first commercial engine was available in 1919. By that time, Doxford had spent £100,000 on the engine, a not inconsiderable sum that had to be recouped from sales or license fees. It was in the granting of licenses that Doxford differed from its British counterparts, most of which had no licensees and had to recoup development costs from their own sales. Doxford did not actively seek licensees but was willing to grant this right on application, with no limit to the number of licenses. An initial payment of £10,000 plus a royalty of £1 per bhp was required; Vickers, which contemplated taking a licence in 1924, considered this too high. By the end of the 1920s Doxford had four British licensees and two from overseas.[12]

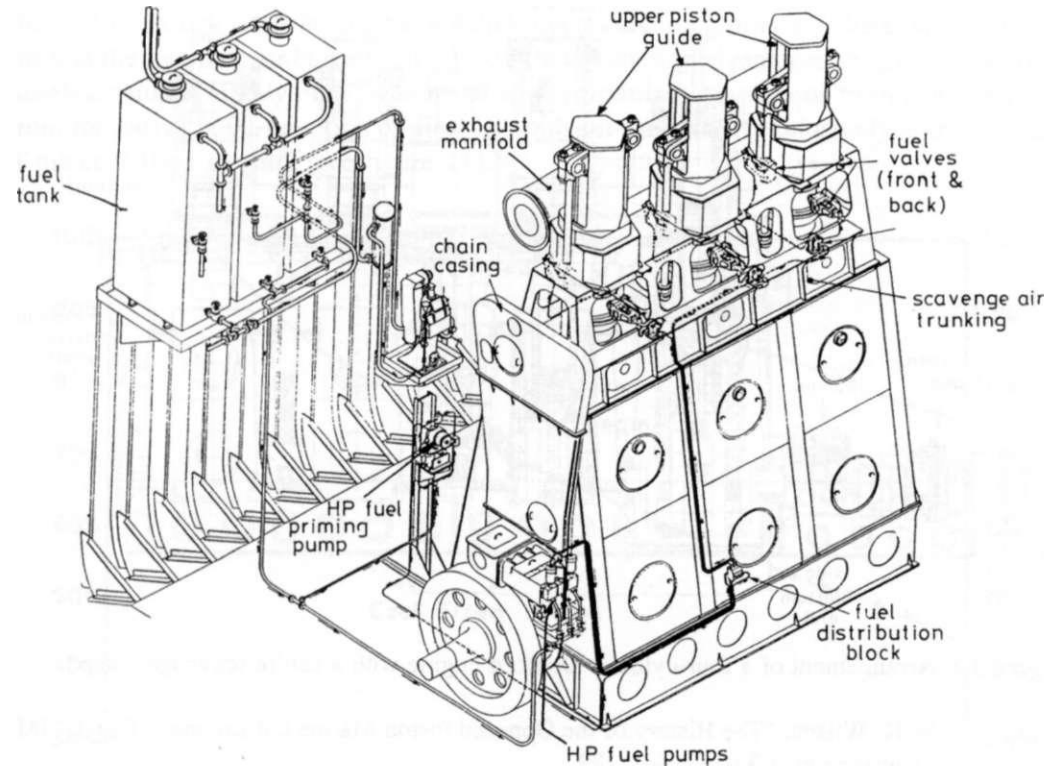

Figure 9: Doxford three-cylinder opposed-piston "economy" engine.

Source: W.H. Purdie, "30 Years Development of Opposed Piston Machinery," IMechE *Transactions,* CLXII (1950), 447.

With a system of licensees Doxford could invest in design, enabling it to produce an engine which could compete and so establish a reputation. While the engine had its faults, investment enabled these to be overcome and permitted it to enter other markets. The problem of diesel-induced vibration prevented extensive use of the engine in passenger ships, but in 1926 Doxford decided to develop a balanced engine which could compete with steam in that lucrative market. The LB (long stroke, balanced) engine was eventually selected by Furness Withy for its luxury liner *Bermuda.* Small-bore engines were introduced to enable it to compete in the low-power and industrial markets, although entry into the latter was unsuccessful. With improved trade following the depression of the early 1930s, four other British shipbuilders took licences, and by the end of the decade the number of engines built by licensees exceeded those constructed by Doxford itself (for a chronology of Doxford engine development, see appendix table 8).[13]

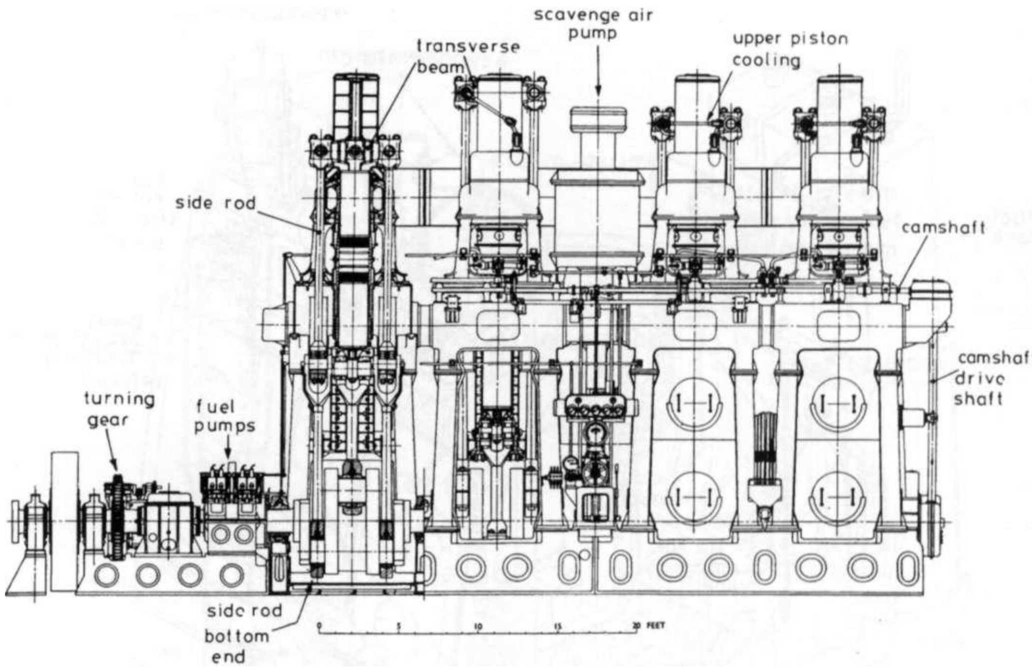

Figure 10: Arrangement of a four-cylinder Doxford engine with a centre scavenge pump.

Source: W.K. Wilson, "The History of the Opposed Piston Marine Oil Engine — Part 1," IME *Transactions,* LXIII (1946), 189.

The British Marine Industry

Internal combustion engines were of interest to the Admiralty for use in submarines and a number of designs were investigated. In March 1917 a two-cylinder experimental Fullagar oil engine failed to impress the Admiralty, but their Lordships indicated a willingness to order at least two of the 1270-kW version upon satisfactory testing. This was built by Laird and successfully tested, but when the war ended the Admiralty decided not to pursue the idea.[14] A considerable amount of investigative work was undertaken into internal combustion engines by the Admiralty Engineering Laboratory and a number of different engines were tried, including a single-cylinder Doxford opposed-piston engine procured shortly before the end of the war.[15] The idea of an opposed-piston submarine engine was abandoned in favour of a more conventional single-piston four-stroke design.

During World War I the needs of the nation were paramount and development on large British diesel engines had a low priority. But no such restrictions applied to major overseas competitors such as Sulzer, B&W or Werkspoor, all of which were able to improve their designs. With the coming of peace, there was an apparent need for merchant shipping that could not be met fully by tonnage released from wartime duties. British yards, in general, met the demand by building traditional ships with steam-reciprocating machinery and coal-fired boilers.[16] By the early 1920s, however, the boom had ended and the demand for tonnage plummeted. In the new climate shipowners wanted efficiency and low operating costs, which the large crosshead diesel engine could by then offer. Most British yards lagged behind their overseas competitors and there was antipathy towards the internal combustion engine despite its obvious advantages. Arguments against diesels emanated mainly from Britain and were particularly vociferous from coal interests. From the early 1920s, adoption of diesel propulsion was almost exclusively at the expense of the coal-fired steamer (see figure 11).

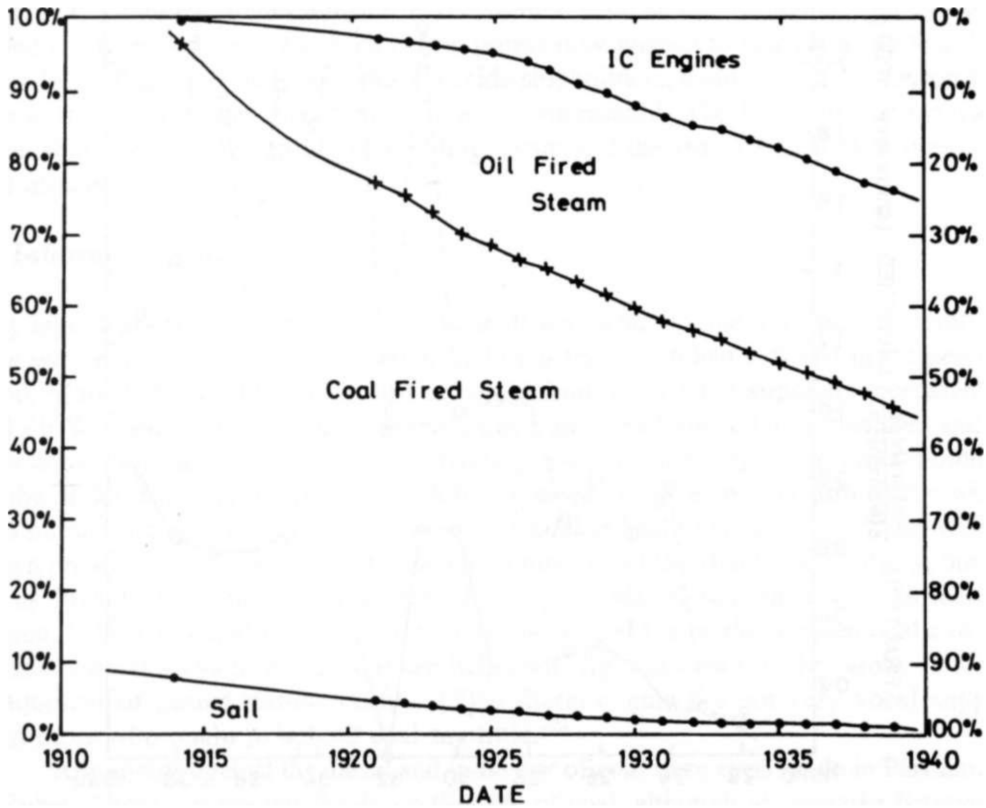

Figure 11: Change in marine propulsion during the interwar years.

Source: *Lloyd's Annual Review of Statistics,* various years.

The Case for Diesel Propulsion

Scandinavian owners adopted the diesel enthusiastically, in part because they had no fuel sources of their own; these owners wanted the most economical form of propulsion and quickly decided upon diesels. In 1923 Dan Brostrom, owner of the Swedish America Line, commented that "no leading Swedish, Danish or Norwegian shipowner thinks seriously of any other class of vessel than the motor ship."[17] Three years later, Gunnar Knudsen of A.B. Borgestad was able to say that "thanks to the motor ships owned by our company, we hope to be able to promise the shareholders a constant dividend of 10% in the coming years."[18]

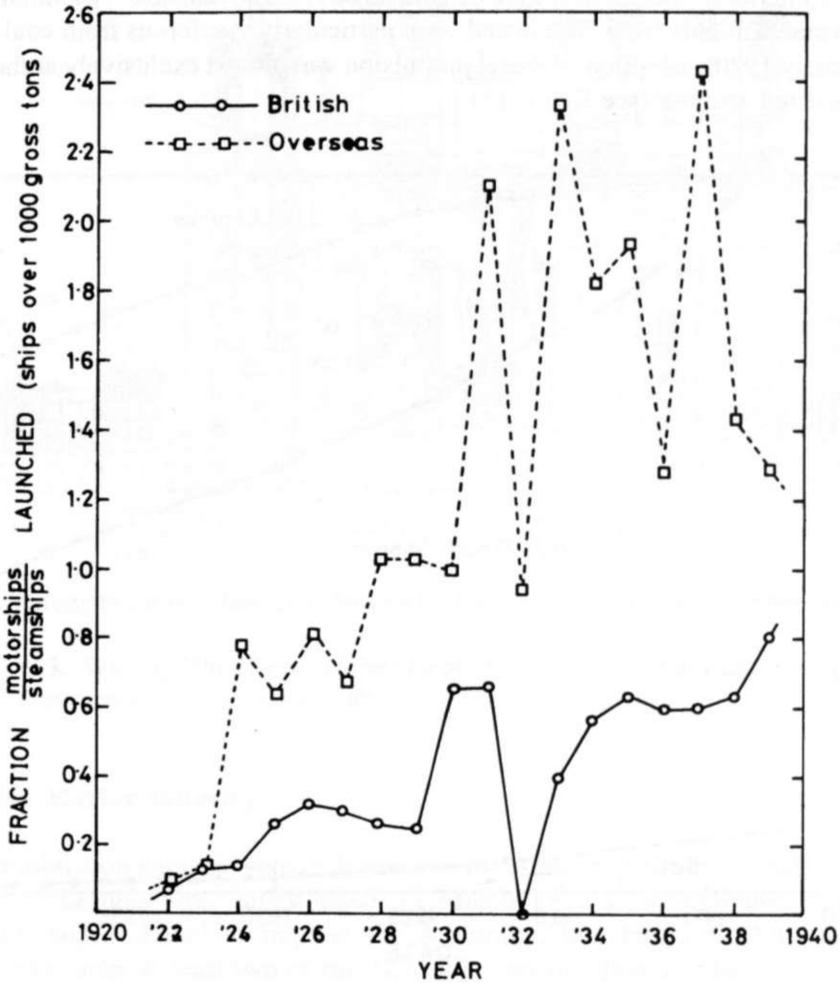

Figure 12: Proportion of motorships compared to steamships built, 1920-1940.

Source: Annual Statistics, *Lloyd's Register,* various years.

Diesel engines did make sense economically as far as many shipowners were concerned. In 1925 Furness Withy, a major British shipowner that favoured motorships, ordered five from Deutche Werft on the grounds of cost alone: the price of £150,000 per ship was £60,000 to £100,000 per vessel less than British tenders. Its Chairman, Sir Frederick Lewis, was willing to give the order to any British yard able to quote a price even £10,000 per ship more than the Germans, but there were no offers.[19] The ships thus had German rather than British diesel engines.

Overseas yards quickly adopted the diesel and were in a position to offer it to any owner who expressed an interest. Tonnage built in British yards tended to be steam-powered while the rest of the world increasingly favoured diesel (see figure 12). The complacency of shipbuilders on the northeast coast of England with respect to the diesel engine was attacked in a 1920 editorial in *The Motor Ship,* which opined that "they do not want the motor ship to progress because it would mean that they would be driven out of their complacency and [they would be] forced to deal with something new."[20] Although some shipbuilders argued that they held no brief for any particular engine, the magazine's editor, A.P. Chalkley, found himself barred from several shipyards and contractors were warned not to advertise in *The Motor Ship* unless they wished to risk future orders.[21] As late as 1924, Readhead and Sons, the Tyneside shipbuilders, claimed that the reason they did not offer diesels was that owners were not interested.[22] The fact is that Readhead's engine shops were only capable of building steam and the firm never took a licence to build diesels.

The Influence of Coal

Many arguments were put forward in favour of the steam engine, but the champions of steam were really battling for the British coal industry, which had suffered in the postwar period. Markets for coal had been lost as competition from other suppliers increased. In 1928 Sir William Noble, chairman of the Cairn Line, which owned nine steamers and no motorships, indicated his lack of understanding about engineering when he commented that the diesel was only a fashion, which he expected "to give another turn of the wheel and a normal increase in world consumption of bunker coal to be resumed."[23] As well as being a prominent shipowner, Noble was also a director of the Blackwell Colliery, but his role as President of the UK Chamber of Shipping placed him in a very influential position. C.W. Cairns, also of Cairn line, likewise joined the battle between coal and oil. "There are other ways in which coal can help in its fight against oil," he wrote, "such as the adoption of geared turbine outfits...[T]he diesel engine has got very vocal support whilst those who ought to uphold coal say little."[24]

Arguments against the diesel and in favour of coal were even made in Parliament. Sir Robert Thomas came out firmly on the side of coal, although his remarks betrayed a lack of understanding of marine engineering and shipping. "The internal combustion engine has had its day," he argued, adding that "he was sorry that so much British capital was sunk in it." Moreover, "he believed that the future of propelling power for ships would rest with pulverised coal. That would mean not only an enormous saving in the running of ships but also be of great help to our coal trade."[25] Another champion of steam, and hence coal, was the eminent naval architect Sir John Biles. In a 1925 paper to the Institute of Naval Architects (INA), Biles advocated steam for practically every type and size of ship; to advance his cause he used estimated costings for steam plants, which were then still at the development stage, and compared them with operational data from early diesels.[26] Throughout May, a rather heated debate was carried on over the diesel in *The Times* among Lord Bearsted, chairman of Shell Transport and Trading; Lord Invernairn, founder of the shipbuilders Beardmore; and Sir Fortescue Flannery, a respected naval architect.[27] A year later Biles presented a second paper to the same learned society in which he made some extravagant claims for steam at the expense of diesel.[28] A third paper followed in 1928, this time addressing the question of fuel.[29] Again absurd claims were made, and during discussion of the paper a number of people questioned the validity of the data. One individual commented that Biles' "diesel figures appear lacking in foundation."[30] Sir John admitted his real motives when he told an opponent that he might "monopolise all the prophesying he likes so long as he helps to increase the use of British coal in place of foreign oil."[31]

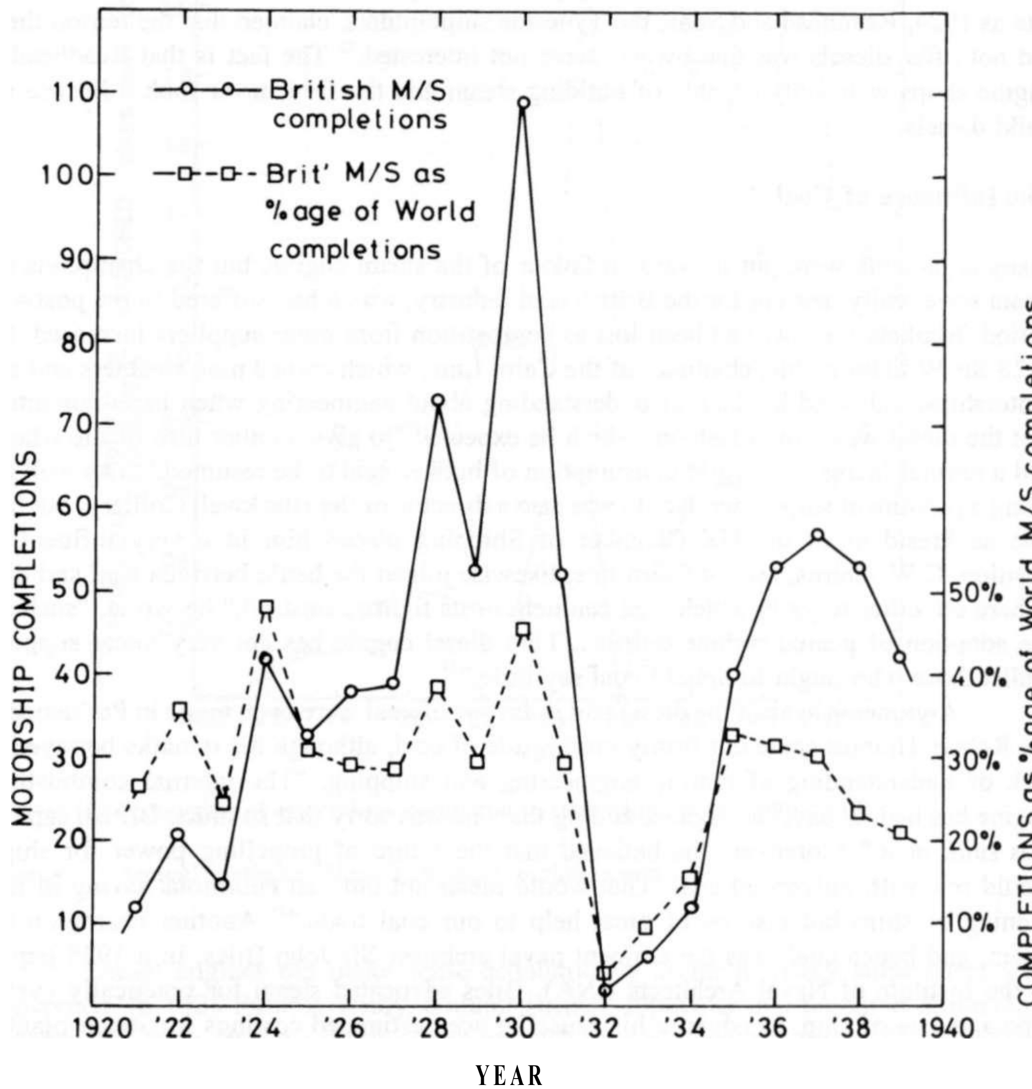

Figure 13: British motorship completions, 1920-1940.

Source: See figure 12.

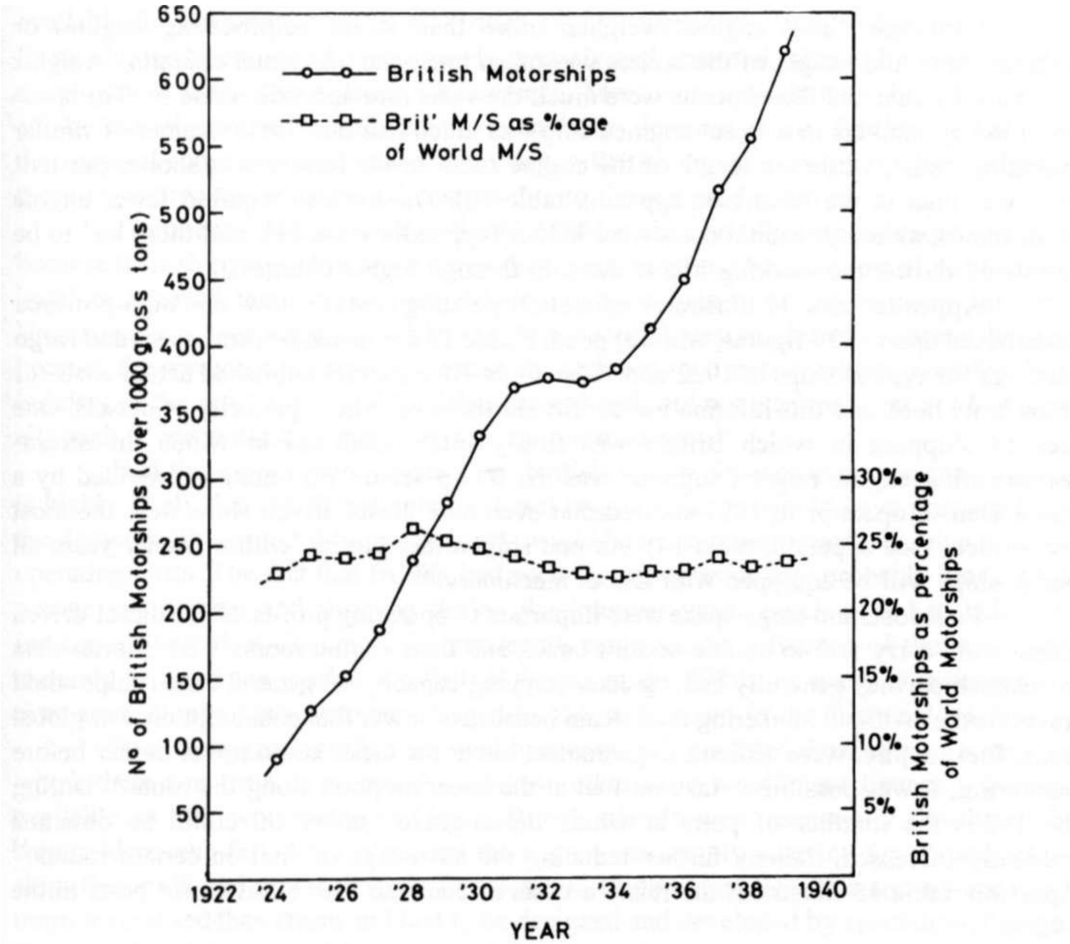

Figure 14: British-owned motorships, 1922-1940.

Source: See figure 12.

The general argument against marine diesels was that they burned imported oil rather than British coal. British shipbuilders were encouraged to stay with steam instead of diesel and they did so (figure 13). Despite being the world's major shipbuilding and shipowning nation, in the interwar era Britain's share of the world motorship fleet barely changed (see figure 14).

Economic Advantages of the Diesel Engine

There was no doubt that, except for express passenger liners, diesels offered greater fuel and space economy. Indeed, in 1924 no less a personage than the Chief Superintendent Engineer of Blue Funnel admitted that "oil for marine purposes has come to stay."[32]

Although diesel engines weighed more than steam-reciprocating engines or turbines when the weight of the boilers was taken into account, actual operating weights for similar steam and diesel plants were much the same (see appendix table 9). The space occupied by bunkers in a diesel-engined ship was much less than for a steamer of similar operating range, while the length of the engine room in the former was shorter per unit of power than in the latter (see appendix table 10). Diesels also required fewer engine room hands, although capital costs were higher (appendix table 11), and these had to be recovered during the working life of the ship through higher charges.

Appendix table 12 illustrates estimated operating costs for low- and high-powered ships based upon 1920 figures, while appendix table 13 compares working costs and cargo earnings for typical ships in 1922 and 1926. Only Blue Funnel published actual costs for ships in its fleet, and this information confirmed the economic superiority of diesels. One area of shipping in which Britain was firmly established and in which the steam-reciprocating engine reigned supreme was the tramp sector. Information provided by a major Danish operator in 1921 showed that even here diesel-driven ships were the most economical (see appendix table 14). As one shipbuilder put it, "within twenty years all tramp ships will be equipped with Diesel machinery."[33]

Fuel costs and cargo space were important to operating profits. Since diesel-driven ships could carry fuel in double-bottom tanks, and their engine rooms were shorter than in steamships, they generally had a greater carrying capacity. In general diesel ships could travel further without bunkering than steam because of lower fuel consumption. For global trade, fuel supplies were difficult to guarantee, but as the diesel could travel farther before bunkering, it was possible to take on fuel at the cheapest ports along the route.[34] During the 1920s the number of ports at which diesel-grade bunker oil could be obtained gradually increased, thereby further reducing the advantage of coal on certain routes.[35] Appendix table 15 illustrates the relative costs of coal and fuel oil at world ports in the 1920s.

Many countries, including Norway with its expanding fleet, had no indigenous fuel supplies to protect. For these nations, self-interest lay only in making a profit from shipping. As a result, almost all Scandinavian tonnage built after 1918 was powered by internal combustion engines. Germany lost many of its coal-producing regions and much of its merchant tonnage as a result of the war; it, too, quickly adopted diesel propulsion. Some British owners also shifted to diesel, and the number of motorships in the British fleet increased. Yet it was not until close to the outbreak of World War II that British shipyards approached parity in terms of motor and steam construction (see figure 12). While the depression of the early 1930s restricted investment in new tonnage and induced owners to retain older and less efficient coal-fired steamers, by the time the economic downturn ended few British crosshead diesel engines were being produced.

Conclusions

During the 1920s a number of British crosshead diesel engine designs evolved but most failed to make an impact as many domestic owners were encouraged to stay with the coal-fired steamer. There were many reasons why these British engines failed to succeed, including technical faults and high initial cost, but the lack of orders limited the funds available for development. Not all British engines were technically inferior, either: the Swan Hunter Neptune and Scott diesels certainly had potential, although the shortage of development funds was a definite hinderance. Moreover, the relatively high initial cost of the diesel compared with steam must have deterred many British owners and discouraged some overseas owners from fitting British-designed engines which might be more expensive than continental designs due to limited production runs.

Continental designs such as B & W, M A N, Sulzer and Werkspoor received orders because their shipyards built more diesel than steamships and because some British engine builders licenced them rather than developing their own or taking licences for other British engines (see appendix table 16). Many British designs failed to attract licences because the owning concern did not actively seek out such opportunities; even Doxford, builders of the most successful British marine diesel, did not attempt to attract licensees, although it was willing to grant permits upon application.[36]

Had there been more orders from British owners for motorships in the 1920s, it is highly likely that the British marine diesel engine industry would have prospered and the domestically-owned shipping industry would have been more profitable due to lower operating costs. The fact that Britain had such vast reserves of coal probably hindered its marine engineering and shipping during the interwar years, much as it had helped to induce technological change in the nineteenth century. The influence of the coal lobby certainly reduced the market for British diesels in the 1920s, as many shipowners and even some shipbuilders were encouraged to stay with steam in the "national interest."

Poor management often resulted in money being wasted developing engines for which there was little or no market, while in other cases insufficient finance was made available to test worthwhile products. British diesels were essentially developed by shipbuilders who failed to realise that the engine was simply a device for propelling the ships they built and that their main function was shipbuilding. Diesel engines were much more specialised than steam and had to be designed and developed by specialists; this was the way that the successful continental firms, such as Sulzer and M A N, had done it. British shipbuilders wanted to design and build the entire product when they should have concentrated on shipbuilding and relied upon specialist designers for the propulsion. At a time when orders were limited by the postwar recession and the reluctance of many British shipowners to switch to diesels, it was folly to invest in engine development without attempting to create a market through a system of licensees. Yet only Doxford adopted this policy, and then in a half-hearted manner compared with the Europeans. Still, it was the Doxford engine that carried the torch for British diesels into the post-1945 era.

The failure of the British shipping industry to embrace diesel propulsion put domestic engine builders and shipbuilders at a comparative disadvantage. Had the nettle been grasped early enough, these industries might well have been in a stronger position to survive the upheavals of the 1970s and 1980s. The same can also be said of the British shipping industry.

Appendices

Table 1
Vickers Engines

Vessel	Year	Shipbuilder	Type	Cylinder Size (mm)	Power kW	RPM
*Trefoil**	1917	Vickers	4SSA (two)	8x432x686	560	150
*Marinula***	1916	Vickers	4SSA (two)	8x527x838	932	140
*Narragansett****	1920	Vickers	4SSA (two)	6x622x991	933	118
*Seminole*****	1921	Vickers	4SSA (two)	6x622x991	933	118
Scottish Minstrel	1922	Vickers	4SSA (two)	6x622x991	933	118
Scottish Standard	1922	Vickers	4SSA (two)	6x622x991	933	118
Scottish Maidens-	1922	Vickers	4SSA (two)	6x622x991	933	118
Scottish Musician	1922	Vickers	4SSA (two)	6x622x991	933	118
Moveria	1924	Vickers	4SSA (two)	8x762x1143	2014	110
Hayatomo Maru++	1925	Mitsub Zosen	4SSA	6x464x686	448	150
Modavia	1927	Vickers	4SSA	8x762x1143	2014	110

Notes: * Fitted with Admiralty sponsored crosshead engines. ** Fitted with Admiralty sponsored crosshead engine. Sold to Shell Tankers; broken up 1928. *** Broken up 1934. **** Broken up 1936. + Re-engined with Werkspoor engines, 1939. ++ Engine exported.

Source: Various editions of *Lloyd's RegisterofShipping*—particularly build date of ship, various editions of *The Motor Ship* for year of build.

Table 2
Swan Hunter Neptune Engines

Vessel	Year	Shipbuilder	Type	Cylinder Size (mm)	Power kW	RPM
*Arnus**	1922	SH&WR	2SSA (two)	6x432x889	783	124
*Kistna**	1924	SH&WR	2SSA	6x445x889	821	125
*Kola**	1924	SH&WR	2SSA	6x445x889	821	125
British Motorist	1924	SH&WR	2SSA (two)	-8x610x1270	2,387	93
lossifoglu	1924	SH&WR	2SSA	6x572x1143	1,641	100
Siherpine +	1924	SH&WR	2SSA	6x572x1143	1,641	100
Silverlarch +	1924	SH&WR	2SSA	6x572x1143	1,641	100
British Petrol ++	1925	SH&WR	2SSA (two)	8x610x1270	2,387	93
Lenfield	1924	SH&WR	2SSA	4x610x1270	1,120	
Neptunian	1925	SH&WR	2SSA	6x610x1270		
Athelking +++	1926	SH&WR	2SSA (two)	6x572x1143		

Notes: * 'A' type engines were fitted; + Re-engined with R-W double acting engine 1936. ++ Re-engined 1938 with Vickers-MAN Double-acting engine following crankshaft failure; new engine originally built in 1932 but not used. +++ Re-engined in 1934 with twin Kincaid/B&W engines.

Source: See table 1.

Table **3**
Comparative Costs of Marine Engines (1928)

	Engine Type	Cost per ship
1	Triple Expansion; Steam Pressure 180psi	£11.8
2	Single Reduction Geared Turbines	£17.5
3	Doxford with steam auxiliaries	£24.8
4	Doxford with Electrical auxiliaries	£27.2
5	R-W Double-Acting Diesel (steam auxiliaries)	£20.2
5	R-W Double-Acting Diesel (electric auxiliaries)	£22.4

Source: A.E. Seaton, *A Manual of Marine Engineering* (London, 1928).

Table 4
North British Diesel Engine Company

Vessel	Year	Shipbuilder	Type	Cylinder Size (mm)	Power kW	RPM
Domala	1921	Barclay, Curie	4SSA (two)	8x673x1194	1675	96
Hauraki	1922	Wm Denny & Co.	4SSA (two)	8x673x1194	1675	96
Durenda	1922	R. Duncan & Co.	4SSA (two)	8x673x1194	1675	96
Dumra	1922	C Hill & Sons	4SSA (two)	6x381x762	373	165
*Dwarka**	1922	C Hill & Sons	4SSA (two)	6x381x762	373	165
Dumana	1923	Barclay, Curie	4SSA (two)	8x673x1194	1675	96
*Swanley***	1924	Barclay, Curie	2SDA	3x622x1118	1492	100
*City of Stockholm****	1925	Barclay, Curie	2SDA	3x622x1118	1492	100
*Storsten*****	1926	Barclay, Curie	2SDA	3x622x1118	1492	100

Notes: * Broken up 1937 following grounding in 1935. ** Re-engined with a Barclay, Curie Doxford engine, 1927. *** Re-engined with SH&WR steam triple expansion, 1927. **** Re-engined with Barclay, Curie Doxford engine, 1928.

Source: See table 1.

Table 5
Richardsons Westgarth Engines

Vessel	Year	Shipbuilder	Type	Cylinder Size (mm)	Power kW	RPM
Irania	1929	Blythswood S.B. Co	2SDA	3x546x965	933	90
Silverpine	1924	re-engined 1935	2SDA	4x699x1200	2984	110
Silverlarch	1924	re-engined 1935	2SDA	4x699x1200	2984	110
Empire Chancellor	1945	J. Laing & Sons	2SDA	5x699x1200	3357	105
Empire Inventor	1944	J. Laing & Sons	2SDA	5x699x1200	3357	105

Source: See table 1.

Table 6
Fullagar Engines

Vessel	Year	Shipbuilder	Type	Cylinder Size (mm)	Power kW	RPM
Fullagar+	1920	Laird	2SOP	4x356x508	375	125
Malia++	1921	Hamilton	2SOP (two)	4x470x1270	746	115
La Playa+++	1923	Laird	2SOP (four)	4x356x406	615	250
La Marea\ 1 **I** 1	1924	Laird	2SOP (four)	4x356x406	615	250
*Baron Dalmeny*****	1924	Hamilton	2SOP	6x470x1270		
*British Aviator**	1924	Palmer	2SOP	6x584x1829	2238	90
*British Chemist**	1925	Palmer	2SOP	6x584x1829	2238	90
*Florida Maru****	1925	Kawasaki	2SOP	6x559x1676	1865	
*Cuba Maru****	1926	Kawasaki	2SOP	6x559x1676	1865	

Notes: + Engine removed 1921; renamed *Caria.* ++ Former Fullagar engine installed together with another of same size; Larger engines as indicated installed May 1923. Renamed *Daga* 1928; re-engined with Denny Sulzers 1930. +++ Electric drive; re-engined with Fiat engines 1928. **I I I I** Electric drive; 1939 Renamed *Darien* and turbines fitted. * Engines built by Palmer; 1930, re-engined with Doxford. ** Engine built by Rowan; Re-engined with Doxford, 1929. *** Engine built by John Brown.

Source: See table 1.

Table 7
Scott Engines

Vessel	Year	Shipbuilder	Type	Cylinder Size (mm)	Power kW	RPM
Dolius	1924	Scott	Still (two)	4x559x914	933	120
*Eurybates**	1928	Scott	Still (two)	5x686x1143 2x610x1143	1865	105
*Anshun***	1930	Scott	2SSA	6x686x1118	2238	112
*Yochow****	1933	Scott	2SSA	5x559x914	932	116
*Yunnan*****	1934	Scott	2SSA	5x559x914	932	116

Notes: * Steam cylinders replaced by diesels, 1947. ** Sold by China Navigation Company, 1946; broken- up, 1966, after serious damage to ship. *** Sold by China Navigation Co. 1960; broken-up, 1972. **** Sold by China Navigation Co., 1959; broken-up, 1971.

Source: See table 1.

Table 8
Doxford Engine Development

Year	Cylinder Power (kW)	Bore (mm)	Stroke (mm)	No. cyls.	RPM	SFC kg/kW/hr	Comment
1919	504	580	1160+1160	4	77	0.268	Prototype engine
1924	541	580	1160+1160	4	87	0.250	Uprated prototype
1926	522	600	760+1040	4	110	0.232	Balanced engine
1928	200	400	540+760	3	145	0.216	Marine Industrial
	273	400	540+760	3	200	0.220	
1928	615	600	980+1340	4	98	0.237	
1931	881	700	880+1220	4	120	0.230	
1933	541	600	980+1340	4	92		Welded structure
1935	448	520	880+1200	3	115	0.212	Economy engine
1935	448	560	700+980	5	115	0.216	1st five-cylinder engine
1938	970	725	950+1300	5	123	0.219	*Dominion Monarch*
1939	1119	813	1016+1397	4	94	0.210*	*Sun Doxford*
1949	274	440	620+820	3	145	0.224	Trawler Engine
1951	1057	750	2500	6	110		
1952	933	600	2320	3	125	0.207	Exp. T/C engine
1959	1300	700	2320	6	120		No scavange pumps
1961	1243	670	720+1380	6	120		"P" type
1965	1865	760	520+1600	9	119	0.219	"J" type
1971	1865	580	420+880	4	300	0.201**	*Seahorse*
1978	1350	580	340+880	3	220	0.201	58JS3

Notes: * Consumption figure calculated using shaft output power and electrical power generated using waste heat. ** Projected consumption. SFC means Specific Fuel Consumption.

Source: *The Motor Ship,* various dates; Doxford publicity brochures.

Table 9
Comparison of Machinery Weights for 3500-SHP Installations

Engine Type (All have steam Auxiliaries)	Boilers	Machinery Weight
H&W 4-S, s-A	2 Scotch	635 tons
Doxford 2-S, O-P	2 Scotch	550 tons
Sulzer 2-S, S-A	2 Scotch	695 tons
D-R Geared Turbine	3 Scotch	698 tons
D-R Geared Turbine	2 Water Tube	515 tons
Quadruple Expansion	3 Scotch	730 tons
Triple Expansion	4 Scotch	660 tons

Source: L.J. Le Mesurier and H.S. Humphreys, "Fuel Consumption and Maintenance Costs for Steam and Diesel Engined Vessels," North East Coast Institute of Engineers Shipbuilders *Transactions,* LI (1934-1935).

Table 10
Comparision of Engine Room Lengths

Vessel	Date	Gross Tonnage	Type of Engine	SHP	ER Length (m)	Length per SHP (mm)
Nestor	1913	14,629	Steam Reciprocating	7500	30.175	4.02
Anterior	1925	11,174	Steam Turbine	7500	25.6	3.41
Ajax	1931	7,797	Diesel	8600	16.46	1.91
Glaucus	1921	7,582	Steam Turbine	6000	21.03	3.51
Orestes	1926	7,845	Diesel	6600	18.29	2.77
Anchises	1911	10,000	Steam Reciprocating	5000	20.12	4.02
Maron	1930	6,701	Diesel	5500	15.24	2.77
Machaon	1920	7,806	Steam Reciprocating	4400	21.03	4.78
Tantalus	1923	7,777	Diesel	4500	19.2	4.27
Asphalion	1924	6,274	Turbine	3700	19.8	5.35
Peisander	1925	6,224	Diesel	3700	17.53	4.74
Sultan Star	1930	12,326	Steam Turbine	9000	34.37	3.82
Tuscan Star	1930	11,449	Diesel	9000	22.6	2.5

Source: S.B. Freeman, "Modern Types of Propelling Machinery for Mercantile Use," Institution of Mechanical Engineers *Proceedings,* CXXII (1932); and *Lloyd's Register of Shipping^* 1930-1931).

Table 11
Cost of Steam and Diesel Plant (1926)

Cost (£000) Weight (Tons)		Steam Reciprocating		Turbine		Diesel
		Coal	Oil	Coal	Oil	Oil
2500 SHP Single Screw	Cost	38	39	45	46	68
	Weight	540	540	560	560	650
6000 SHP Twin Screw	Cost	85	86	95	96	120
	Weight	1300	1300	1200	1200	1100

Source: W.G. Cleghorn, "Steam Versus Diesel Machinery for Cargo Vessels," Institution of Engineers and Shipbuilders in Scotland *Transactions,* LXX, Part 1 (1926).

Table 12
Comparative Figures for the Operating Costs of Diesel and Steam-Powered Ships

	Ships of 1000 BHP					Ships of 2400 BHP				
	Diesel	Double-Reduction Geared Turbines		Steam Reciprocating		Diesel	Double-Reduction Geared Turbines		Steam Reciprocating	
		Coal	Oil	Coal	Oil		Coal	Oil	Coal	Oil
Fuel, lbs/HP. hr.	0.45	1.5	1.1	1.95	1.4	0.45	1.5	1.1	1.75	1.25
Fuel Consumption/ day	4.82	16.1	11.8	25	18	11.6	38.6	28.3	52.5	37.5
Price of fuel/ton	£11	£5	£10	£5	£10	£11	£5	£10	£5	£10
Fuel cost/30 days	£1595	£2415	£3540	£3750	£5400	£3828	£5790	£8490	£7875	£11250
Lubricating Oil Consumption/ Gals. per day	10	2	2	3	3	21	3	3	5	5
Lubricating Oil Consumption/30 days	£75	£15	£13	£22.5	£22.5	£157.5	£22.5	£22.5	£37.5	£37.5
Engineers and Electricians	4 + 1	3	3	3	3	7 + 1	4	4	4	4
Engine Room rat- ings	4	10	7	10	7	4	17	10	17	10
Total Engine Room Staff	9	13	10	13	10	12	21	14	21	14
Wages for 30 days	£191	£224.5	£195	£224.5	£195	£252.5	£380.5	£265	£380.5	£265
Subsistence for 30 days	£94.5	£136.5	£105	£136.5	£105	£126	£220.5	£147	£220.5	£147
Costs for 30 days	£1955.5	£2791	£3855	£4135.5	£5722.5	£4364	£6413.5	£8924.5	£8513.5	£11699
Cost Ratio	1	1.44	1.97	2.12	2.93	1	1.47	2.04	1.95	2.68
Saving per year, 200 days at sea, Diesel over steam		£5570	£12650	£14520	£25250		£13650	£30390	£27645	£48850

Source: James Richardson, "The Present Position of the Marine Diesel Engine," Institution of Engineers and Shipbuilders in Scotland *Transactions(1920).*

Table 13
Comparative Freight Costs for Diesel- and Steam-Powered Cargo Ships

	Type of Propelling Machinery	Single Screw 4-S, S-A with Electrical Auxiliary	Triple Expansion, Steam Reciprocating (50°F Superheated)		Geared Turbine (150°F Superheat) Oil-Fired
			Coal-Fired	Oil-Fired	
	Deadweight	10,050 tons	10,230 tons	10,235 tons	10,235 tons
	Cargo Capacity	9,357 tons	7,880 tons	8,555 tons	8,743 tons
	Power	2,500bhp	2,800ihp	2,800ihp	2,500shp
	Daily Fuel Consumption	12.1 tons	53.5 tons	37.5 tons	29.5 tons
	Comparative Working Costs				
1	Provisions/month	£201.25	£246.5	£208.5	£208.5
9	Wages/month	£505	£586	£510	£510
2	Fuel Cost/ton	£4.5	£1.75	£3.75	£3.75
2	Running cost per 288 days at sea	£24,195	£36,954	£49,122	£40,422
	Cargo carried on 9 round trips of 32 days at sea	168,426	141,480	153,990	157,274
	Cargo cost per ton per round trip	2s lOd	5s 2d	6s 5d	5s Id
1	Provisions/month	£151	£184.75	£156.5	£156.5
9	Wages/month	£404	£468	£408	£408
2	Fuel Cost/ton	£4	£1.25	£3	£3
6	Running cost per 288 days at sea	£20,628	£278,096	£39,168	£32,265
	Cargo carried on 9 round trips of 32 days at sea	168,426 tons	141,840 tons	153,990 tons	157,274 tons
	Cargo cost per ton per round trip	2s 5d	3s lOd	5s Id	4s Id

Source:* *Brassey's Naval and Shipping Annual **(1921-1922), 443; and (1926), 526.**

Table 14
Comparative Costs for Tramp Ships
(Voyage of 12,000 Nautical Miles, Time in Port 10 Days)

Type of Ship	Cargo (tons)	Total Fuel Cons (tons)	Hold Capacity (Cubic Ft. grain)	Power	Speed (knots)	Cost of Ship (Krone)	Operating Costs-H- (Krone)	Other Costs+ (Krone)	Cost per Ton	Cost ratio
Diesel	4000	245	220,000	1350 bhp	10	2.06M	62,500	83,700	36.5	1
Oil-fired steam with geared turbines	4000	780	254,000	1230 shp	10	2.25M	117,050	88,500	50.2	1.38
Coal-fired steam with triple expansion	4000	1140	238,000	1500 ihp	10	2.29M	95,950	89,700	46.5	1.27
Sailing ship with motor auxiliary power	4000	180	200,000	500 shp	6.5»	1.73M	72,900	116,800	47.5	1.3
Sailing ship	4000	-	230,000	-	4.5»»	1.4M	57,600	125,500	45.8	1.25

Notes: + Other costs include depreciation, insurance, maintenance and cargo. ++ Operating costs include fuel, water, wages and subsistence, stores, etc. * At this speed vessel would take sixty-two percent longer than the powered ships. ** At this speed sailing ship would take 118% longer than powered ships.

Source: E.L. Barfoed, "Motor Tramp Ships," *The Motor Ship,* II (July 1921), 134.

Table 15
Cost of Fuel Oil and Coal at Principal Ports, July 1920

Port	Fuel Oil per Ton	Coal per Ton
Adelaide	£9	£2
Bombay	£7.5	£2.25
Buenos Aires	£13.25	£8.5
California	£3.1 to £4.6	£3.45
Cape Town	£11	£2.3 (Transvaal)
Curacao	£4	£6.25
Hong Kong	£7.5	£5.76 (Welsh)
London/Liverpool	£12.5	£5.75
New York	£2.375	£2.75 to £3.4
Panama	£3.75	£6.25
Port Said	£12.5	£9.325
Rotterdam	£11	£8

Source: See table 12.

Table 16
List of Licences Granted by Major European Crosshead Engine Designers

Year	UK	Europe	Others	Total
		Sulzer (Switzerland)		
1924	7	19(1)	5	30
1926	7	14(1)	4	25
1930	7	20(1)	4	31
1934	7	21(1)	5	32
1939	6	19(1)	5	30
		B & W (Denmark)		
1924	1 + 1*	12(1)	1	15
1926	1 + 1*	10(1)	1	13
1930	1 + 1*	11(1)	2	15
1934	1 + 1*	11(1)	2	15
1939	1 + 1*	14(4)	2	18
		Werkspoor (Holland)		
1924	2	4(2)	3	9
1926	2	4(2)	3	9
1930	2	6(3)	3	11
1934	2	5(2)	3	10
1939	2	6(2)	0	8
		M A N (Germany)		
1924	0	11(6)	3	14
1926	1	11(6)	3	15
1930	1	13(6)	4	18
1934	1	15(6)	5	21
1939	2	14(6)	4	20

Notes: ( ) Licensees in Designer's Own country. * Sub-licence granted by UK sole licensee.

Source: *The Motor Ship Reference Books* (London, 1925, 1927, 1931, 1935 and 1939).

NOTES

* Denis Griffiths served at sea as a marine engineer before coming ashore to take a degree in Mechancial Engineering. He currently lectures in Mechanical and Marine Engineering at Liverpool John Moores University and has published many papers on the history of Marine Engineering. He is the author of eight books, the most recent being *Steam at Sea* (London, 1997).

1. The early years of Diesel engine development are discussed in B. Humm, "Rudolf Diesel and his Association with Sulzer Brothers," *Sulzer Technical* /?ev/ew, No. 1 (1958); and D.T. Brown, *A History of the Sulzer Low-speed Marine Diesel Engine* (Winterthur, Switzerland, n.d.), 5-7.

2. Brown, *History,* 9.

3. *Heavy Oil Engines for Marine Propulsion* (Greenock, 1913); and *Two-Hundred and Fifty Years of Shipbuilding* (Greenock, 1961), 193.

4. "The B&W Family, Part 1" (Unpublished mss., nd); and C.C. Pounder, "Milestones in Marine Diesel Engineering," *The Motor Ship,* LI (1970), 145-146.

5. The development of diesel engine-building by the North Eastern Marine Engineering Co. is discussed in G.L. Hunter and G. Yellowley, "Transition from Steam to Diesel by an Independent Engine Builder," *The Motor Ship,* LI (1970), 56-57.

6. D. Griffith. "The British Crosshead Marine Diesel Engine between the Wars," Institute of Marine Engineers (IME), *Transactions,* CVI, part 2 (1994), 105-107.

7. *Ibid.,* 111-113.

8. *Ibid.,* 107-111.

9. *Ibid,* 116-118.

10. *Ibid.,* 113-114.

11. Details of these early engines together with their problems may be found in *ibid.,* 105-129.

12. *Ibid.,* 114-115.

13. On the Doxford engine development, see D. Griffiths, "The Doxford Engine," Newcomen Society *Transactions,* LXVI (1994-1995), 27-51.

14. Details of correspondence between Cammell Laird and the Admiralty on this matter, together with details of the engine and its trials, is contained in various documents located in Cammell Laird Archives, file 017/0006/000.

15. See C.J. Hawkes, "Some Experimental Work in Connection with Diesel Engines," Institution of Naval Architects (INA) *Transactions,* EXII (1920), 266-285; and R. Beeman, "Further Experimental Work on Diesel Engines," *ibid.,* LXVI (1924), 114-140.

16. I.L. Buxton, "Development of the Merchant Ship 1880-1990," *Mariner s Mirror,* LXXIX (1993), 73.

17. Interview with Dan Brostrom reported in *The Motor Ship,* IV (1923), 17.

18. *The Motor Ship,* VII (1926), 199.

19. *Lloyds' List Weekly Shipping Summary,* 11 March 1925.

20. *The Motor Ship,* I (1920), 59.

21. *Ibid.,* I (1920), 128; and LI (1971), 1.

22. Comment by Sir James Readhead quoted in *ibid.,* V (1924), 3.

23. Quoted in *ibid.,* IX (1928), 2.

24. Comment during discussion of the paper W.J. Drummond "The Rational Utilization of Coal," North East Coast Institute of Engineers and Shipbuilders (NECIES), *Transactions,* XLV (1928-1929), 235.

25. Quoted in *The Motor Ship,* X (1929), 88.

26. Sir John Biles, "Relative Commercial Efficiency of Internal-Combustion and Steam Engines for High Speed Passenger Vessels," INA *Transactions,* LVII (1925), 1-26.

27. *The Times,* May 1925, various dates. *The Motor Ship,* VI (1925), 108, gives a summary of the correspondence.

28. Sir John Biles, "Relative Commercial Efficiency of Steam Turbine and Diesel Machinery for Cargo Ships," INA *Transactions,* LVIII (1926), 207-220.

29. Sir John Biles, "The Present Position of the Question of Fuel for Ships," INA *Transactions,* LXX (1928), 1-36.

30. *Ibid.,* 32.

31. *Ibid.,* 35.

32. S.B. Freeman, "Fuel Oil for Marine Internal Combustion and Steam Engines," NECIES *Transactions* (1924-1925), 106.

33. Comment by the shipbuilder Sir Alfred Yarrow in *The Motor Ship,* IV (1923), 226.

34. Comments by A. Campbell during discussion of W.G. Cleghorn, "Steam versus Diesel Machinery for *Cargo Ships," Institution of Engineers and* Shipbuilders in Scotland *Proceedings,* LXX, Part 1 (1926), 83.

35. A.C. Hardy, *Motorshipping* (London, 1928), 7-12.

36. A party from Vickers of Barrow visited Doxford in 1924 and reported that "as regards licences, Doxfords have not been seeking these but are willing to grant on application." Vickers Archive, Barrow-in-Furness, Report in Vickers Doxford Files, 1 February 1924.