The Doxford Engine: its Development and Decline

by

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INTRODUCTION

From a small Wearside yard at Cogxgreen in 1840 the firm started by William Doxford was destined to become Sunderland's biggest shipbuilder. Doxfords built naval and merchant ships, including the famous turret-deck steamers, but the firm also had a reputation for quality marine engineering. Experiments were carried out into oil burning with a high speed torpedo boat built in 1886: the new engine shop, built after a fire in 1901, was capable of turning out 30 marine propulsion sets a year. Even in 1906 Doxfords could see potential in the internal combustion engine propulsion of ships and years of detailed investigation and experimentation began.¹

Fig. 1. Sections through single-cylinder experimental opposed-piston engine.

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Initial thoughts were towards a gas engine but the project was abandoned in 1908 when it became evident that there would be considerable difficulty in constructing a gas producer to meet marine demands. Use of oil instead of gas was the next step and in 1910 a single-cylinder experimental engine was built. This operated on the two-stroke cycle with valve scavenging and air injection of fuel giving constant-pressure combustion. Compression and combustion pressures were 34.5 bar, output from the 495 mm bore by 940 mm stroke single-cylinder being 187 kW at 130 rpm.² The experimental engine represented a single-cylinder of an intended four-cylinder engine but trials carried out between 1910 and 1912 indicated problems related to cylinder cover, framing, main bearings, etc. Troubles encountered were common to all conventional engines of the period and a decision was made to
its way into the Swedish vessel Ygaren having originally been intended for a ship ordered by Grindon Steamship Company, in which Doxford held shares.\textsuperscript{11}

GROWTH IN THE 1920s

Five engines of the type fitted in Ygaren were built between 1919 and 1924, one being the subject of extensive trials during 1924–5. Carried out under the supervision of the Marine Oil-Engine Trials Committee appointed by the Institution of Mechanical Engineers and the Institution of Naval Architects these trials of the Furness Withy vessel Pacific Trader\textsuperscript{12} did much to establish the Doxford reputation. The relatively high output power on a single shaft, use of airless or solid fuel injection and reliability of these early engines attracted the interest of British shipbuilders. Several approached Doxford for licences and a number were granted. At that time Doxford did not seek licences but were quite willing to grant on application and no limit was put on the number which would be granted. Terms, however, were considered to be on the high side by at least one potential licensee, Vickers of Barrow: an initial payment of £10,000 plus a royalty of £1 per brake horse power.\textsuperscript{13}

Between 1924 and 1927 several new cylinder sizes were introduced and some modifications made, including the use of dished pistons to give a spherical combustion chamber. Designs on offer included a 540 mm bore three-cylinder engine developing 1313 kW and a four-cylinder engine developing 3730 kW. The oil engine still suffered criticism with respect to vibration and Doxford failed to win a passenger ship engine contract on those grounds. In 1926 a decision was taken to design a balanced engine which would avoid such criticism and allow entry into the developing passenger ship market. In order to balance primary inertia piston forces a differential stroke was introduced: up until that time top and bottom pistons had equal strokes. Other changes included adjustments in weights of
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reciprocating parts, boring of the centre crankpins to achieve balance of rotating masses and change in
the firing order to obtain secondary balance. Complex analysis was required but so successful was the
new design that it was immediately chosen for the quadruple screw luxury liner Bermuda. At this time
the designation LB (long stroke, balanced) was applied to the engines.

In 1928 torsional vibration problems became evident in two twin-screw ships fitted with large
balanced engines. All new designs were subject to detailed analysis so that critical speeds could be
avoided; however, torsional fatigue cracks were discovered in one of the crankshafts after only 2.5
round trips to Australia. No other engines had experienced such problems and analysis had indicated
that there should not have been a problem at the operating speed of 98 rpm. It was soon determined that
changing the firing order to produce the balanced engine had created a critical speed at the operating
speed. The solution involved removal of the heavy flywheel from the after end of the crankshaft and
fitting light flywheels to each end of the crankshaft. In later years the flywheel at the forward end
developed into the well known Doxford-Bibby detuner.†

Fig. 3. Mechanically operated fuel valve as used for the LB engine.
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During 1928 thought turned to the lower power market and a three-cylinder 400 mm bore engine was designed for both marine and land application. A lever-driven scavenge pump provided combustion air, the drive coming from the main crosshead of the centre cylinder. Cooling water and lubricating oil pumps were driven from a crosshead attached to the scavenge pump rod. One of these engines was exhibited at the North East Coast Exhibition during 1929 and was then used for experimental work before being fitted in the concrete vessel Lady Wolmer during 1942. The other engine was fitted in the small tanker Freshmoor in 1929. These were not the smallest engines built by Doxford as in 1921 a number of two-cylinder 70 kW generating sets running at 320 rpm were constructed. Upper and lower piston strokes actually differed, a novelty at the time, the upper being 220 mm and the lower 280 mm for a bore of 200 mm. Although initial results were promising the project was abandoned because of problems involved in manufacturing large propelling engines and small auxiliary engines with the same plant; there was also severe competition from four-stroke medium-speed engines.17

One factor mitigating against the oil engine was the type of fuel it burned. Boilers could burn heavy grade residual oil from the refinery process, commonly known as boiler oil, but the oil engine required refined lighter oil which involved higher cost. Doxfords carried out many trials in the burning of boiler oil in their engines and a number of shipping companies co-operated in these trials. Centrifugal separation of fuel was introduced and fuel sprays were modified in order to reduce the formation of carbon deposits on the sprays. In 1921 Furness Withy encouraged Doxford to undertake boiler oil tests with the engine to be installed in its ship Dominion Miller, it being the intention to run the ship on heavier grades of fuel.18 During the 1920s a number of Doxford-engined ships operated successfully on a mixture of diesel and boiler grade fuels but the price differential between grades became so small that the practice was abandoned.19

DOXFORD DEVELOPMENT IN THE 1930s

A number of British shipbuilders took licences from Doxfords during the 1920s but the only overseas interest came from the Sun Shipbuilding & Dry Dock Co. of Pennsylvania, USA and Lindholmen Motala A/B of Gothenburg, Sweden. British licensees were Barclay Curle, and Fairfields on the Clyde, Richardson's Westgarth of Hartlepool, and Workman Clark of Belfast. Barclay Curle built two engines to replace failed North British sliding cylinder engines but the only really active licensees during the 1920s was Sun, much of its output going to re-engine former steamships. The depression in shipbuilding during the early 1930s limited prospects but improved trading saw John Brown, David Rowan, Alexander Stephens and Swan Hunter take licences later that decade.

Doxfords the marine engine builders was owned by Doxfords the shipbuilders but the fact that practical engineers had control of engine matters enabled progress to be made independently of shipbuilding. The needs of Doxfords the shipbuilders were, naturally, important and the recession in shipping had an effect on both sides of the business. It became clear that a low-speed, low-powered and highly fuel-efficient ship could make inroads into the tramp shipping market which had previously been the domain of the steam reciprocating engine. The Doxford "Economy" ship was developed. Initially the three-cylinder 520 mm bore engine was fitted to this standard design ship but with the subsequent trend towards higher speeds the 560 mm bore engine was substituted. Later in the decade, and during WWII, three- and four-cylinder versions of the 600 mm bore engines were used. By employing a lever-driven scavenge pump at the back of the engine instead of a crankshaft-driven unit, the length of the 520-mm-bore three-cylinder engine was only 7.9 m. The lever also actuated cooling water and lubricating oil pumps thereby avoiding the need for other pumps to be operated at sea.

First of the 'Economy' ships was Sutherland in 1935. For a deadweight capacity of 9400 tonnes she could maintain a speed of 10.5 knots on less than 6.5 tonnes of fuel and 30 litres of lubricating oil per day. With a bunker capacity for 790 tonnes of fuel a Doxford "Economy" ship could travel 48,000 km without the need to take bunkers.20
Part of the programme which resulted in the ‘Economy’ ship was waste heat recovery by means of steam generation and in 1929 investigations commenced. The efficient uniflow scavenging of Doxford engines required a lower scavenge air supply than other types of engine, thus the exhaust temperature remained higher as it was not cooled by excess air. Experiments indicated that the excess air supply could be reduced from the 30% level (other engines used about 60% excess air) to around 20% or even 10%. A reduction in excess air supply to 20% of that required for cylinder combustion also allowed for a reduction in scavenge pump size. With the exhaust temperature raised to 375°C it was possible to generate 0.6 kg of steam per kW engine power at a pressure of about 10 bar.21

Upper and lower pistons were both cooled by water supplied to and taken from the pistons via swinging link arrangements. A simplified system using rubber hoses was introduced for upper pistons during the 1930s and that remained standard until development of the “P” type engine in the 1960s. Corrosion in the cooling water system with subsequent leakage at the swinging links had been a problem with the very first engines but the Doxford Works Chemist, Ernest Armstrong, devised a solution which alleviated the problem. Bichromate of potash in distilled water worked well provided that no seawater entered the cooling water system.22 Preventing leakage of seawater into the engine cooling system was always a problem and as late as 1952 questions were still being asked at Doxford licensees’ meetings on the matter.23

During the 1930s Doxfoths began to make use of electric welding for the construction of engine frames and bedplates thus reducing weight significantly. Initially only frames were of welded construction, a saving in weight of some 25% being claimed for the small three-cylinder engine.24 but the success achieved prompted Doxford designers to extend the process to bedplate construction. Specific weight for welded engines fell to 113 kg/kW for a single screw ship and 85 kg/kW for a twin screw installation; for engines having cast frames and bedplates specific weights per engine were around 155 kg/kW.25

Introduction of a five-cylinder engine during 1935 and proposed construction of a six-cylinder engine prompted further study on torsional vibration and it became evident that some form of vibration
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supressor would be required. In collaboration with James Bibby the Doxford-Bibby detuning wheel was developed\textsuperscript{20} and this became a standard feature on the forward end of Doxford engines until development of the 'J' range in the 1960s.

![Image of Doxford engine](image)

Fig. 5. Five-cylinder LBD engine with crank driven scavenge pump.

A major advance in engine power came with the enginign of the liner \textit{Dominion Monarch} with four five-cylinder engines during 1939. Two engines were built by Doxfords and the other pair by Swan, Hunter, & Wigham Richardson, who also built the ship. Each engine was rated 4850 kW at 123 rpm, the 725 mm diameter cylinder being the largest built to that time and the ship the highest-powered motorship in the British fleet.

WAR AND POSTWAR GLORY YEARS

The needs of war restricted development work at Sunderland but Doxford engines played an important part in the survival of Britain. Their high power-to-size ratio allowed for increased cargo space compared with steam powered ships, there was no tell-tale smoke cloud as the engine exhaust was clear, and engines could be built quickly by a large group of licensees to meet the demands of hull constructors. The three-cylinder engine proved to be very popular for driving standard ships as developed by Doxford and other shipbuilders.

In America the Sun Shipbuilding & Dry Dock Company continued to build Doxford engines but did not follow exactly the British pattern. In fact Doxford allowed its licensees a considerable degree of leeway in terms of engine construction as it did not object to design modifications being made. Drawings issued by Doxford were for guidance and not production; individual licensees prepared production drawings from these to suit their own manufacturing facilities. It was not until 1959 that strict conditions with respect to modifications were enforced as part of new licensing arrangements.\textsuperscript{27} In
1925 Sun constructed a pair of 560 kW engines on a common bedplate for Henry Ford's yacht Sialia. Each four-cylinder engine, 330 mm bore by 432 mm + 560 mm stroke, drove its own propeller but the form of construction allowed for a very compact design.28

![Image of a four-cylinder LBD Doxford showing transverse beams and upper piston cooling hoses.](image)

In 1939 Sun commenced production of the largest bore Doxford engines ever built. Engines of 813 mm bore were constructed in four- and five-cylinder versions. Canadian Vickers building three four-cylinder engines by special arrangement in 1946. These Canadian built Sun engines retained the older camshaft drive arrangement incorporating vertical shaft and bevel gear. British and American built engines employed a chain drive from the crankshaft; oil sumps of the Canadian engines also had straight sides and flat bottoms instead of sloping sides.29 A major Sun innovation was the use of the rotary scavenge blower instead of the reciprocating scavenge pump, drive being by means of a chain from the crankshaft. Two such blowers applied to the four-cylinder 813 mm bore engines of 1939,30 however, the arrangement proved unsatisfactory and later engines reverted to crank driven scavenge pumps.31 In 1941 Sun constructed geared installations for four C3 class standard passenger/cargo ships, there being two six-cylinder 3170 kW engines running at 180 rpm geared to a single propeller shaft. Cylinders were of 533 mm bore by 1524 mm combined stroke, air was supplied by separate electrically-driven blowers and facilities were provided for the burning of boiler grade oil.32,33

During the conflict additional licensees joined the fold, including Vickers-Armstrong in 1943. In 1945 an approach was made by two continental engine builders, Wilton-Fijenoord of Holland and Eriksbergs of Sweden, concerning the possibility of licencees and Doxford took the trouble to find the reactions of existing licencees to the granting of such. Opinion was that if a licence was refused these
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builders would seek one elsewhere but if one was granted it was likely to enhance British and Doxford prestige abroad.\textsuperscript{34} That attitude did not extend to German engine builders as a licensees’ meeting in May 1953 disapproved of granting a licence to a manufacturer from that country.\textsuperscript{35} During the 1953–4 period Dr. J. Ramsay Gebbie, Deputy Chairman and Managing Director, firmly refused licence applications from engine builders in Japan, Poland and Yugoslavia.\textsuperscript{36} At the time there may have been a desire to protect existing licensees but the engine was extremely popular, over 50% of British built large motorships were being fitted with Doxford engines during the 1950s, and overseas builders would have extended market share. In retrospect the attitude appears to have been very shortsighted as these countries were expanding their shipbuilding industries which could only have served to help Doxfords. Certainly the royalties would have assisted in financing future development work and it is highly likely that benefit would have derived from links with a Japanese engine builder. The attitude was parochial in the extreme.

Doxford engines were extremely popular and towards the end of the war problems existed as crankshaft production could not match the demand for engines. Crankshafts were built-up from separate main crankpins, main webs and forged “dog leg” pieces which formed main journals, side webs and side pins. These “dog leg” pieces were obtained from specialist forges and extensive discussions took place between Doxfords, their licensees and Forgemasters with respect to the bottleneck being caused by the failure of the forging industry to meet the engine builders’ requirements. Only when the needs of military production eased and rebuilding of damaged steelworks was in hand did the situation ease and sufficient crankshaft forgings become available to meet demand.\textsuperscript{37} That, however, was not expected to be before the second half of 1946.\textsuperscript{38}

Before WWII Doxfords had obtained crankshafts either complete or as rough forgings from European countries including Germany and Czechoslovakia\textsuperscript{39} but during the war and in the years that followed such sources were unavailable. Without doubt the problem concerning crankshaft production limited engine output but the same situation will have applied to the construction of all large diesel engines. During 1945 the Vickers’ engine works at Barrow was fully engaged in Doxford construction for vessels building in its own yards but the Scotswood works had spare capacity. This could not be effectively used, however, due to the bottleneck in crankshaft production.\textsuperscript{40}

With the coming of peace Doxfords decided that regular meetings of licensees would promote open discussion of problems and allow information to be disseminated. The first Technical Meeting of Licensees was held at the company’s offices in Sunderland on 11th & 12th May 1948, being attended by representatives from all British licensees, apart from Barclay, Curle, together with technical personnel from Wilton-Fijenoord of Holland and the Ordnance Factory of Melbourne, Australia.\textsuperscript{41} These meetings became regular events until the end of the 1950s. An early problem discussed was that of corrosion in engine crankcases especially when burning boiler grade fuels. Most licensees considered that a diaphragm was necessary to prevent combustion products scraped off the liner from entering the crankcase and one reported that two major customers were not prepared to place further orders unless diaphragms were fitted. Gebbie held the view that corrosion was due to water leakage from the lower piston cooling pipes and did not believe that a diaphragm was necessary.\textsuperscript{42} Adoption of oil cooling for lower pistons prevented any water contamination and a diaphragm arrangement was designed into new engines producing the designation LBD (D for diaphragm).

Problems still existed for older engines, particularly when burning boiler oils, and Doxfords designed a conversion system but it was expensive. One of the licensees, North Eastern Marine Engineering Co., developed an alternative conversion package which was simpler and cheaper, only requiring a smaller diameter piston skirt and new gland.\textsuperscript{43}

Two major changes of the late 1940s were the increasing tendency towards the use of lower grade boiler fuel with its higher viscosity and increased levels of sulphur, and supercharging as a means of increasing specific engine output. A great many fuel trials were carried out on test engines and the
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single-cylinder 670 mm bore experimental engine constructed in 1950. Shipping companies, particularly British Petroleum and Shell, encouraged the development of heavy oil systems but there were problems related to cylinder liner wear which could be two or three times that experienced with diesel oil. Doxfords decided that a new fuel system was required for use with boiler grade fuels and devised two different arrangements which were extensively tested. One arrangement employed individual cylinder pumps driven by compression of air in the particular cylinder but licensees preferred the arrangement based upon the former common-rail system. Heavy mechanically operated fuel valves were replaced by small hydraulically actuated CAV type injectors, fuel injection timing being regulated by cam operated timing blocks. Accumulator bottles in the fuel manifold at each cylinder maintained fuel pressure during injection, engine-driven fuel pumps supplying the common rail as in the earlier system. A major advantage of this system was that it made use of standard proprietary items which could be readily obtained. The system only required a single camshaft compared with the two needed to operate front and back fuel valves, fitted on earlier engines.

Fig. 7. Middle platform level of LBD Doxford showing front camshaft with fuel valve and air start valve arrangements.

Accompanying the new fuel system was a new and simplified air start and reversing system. Again camshaft-operated valves were replaced by much lighter components. Pilot air-operated starting valves required an air distributor and use of that device simplified the reversing system. The Doxford engine of the early 1950s was able to burn lower quality fuels and, in some areas, was easier to overhaul but in one respect it still lagged behind its major competitors—Doxfords were slow to adopt turbocharging.
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In 1949 people at Doxfoer's still held the view that supercharging was a long term proposition and that the immediate solution to higher powers was larger bores. Several licensees, including North Eastern Marine and Wilton-Fijenwoord, believed that the future lay in supercharging. A six-cylinder 750 mm bore engine was designed and put into service during 1951. The engine provided to be a success in that it could develop 6600 kW on a single shaft making it ideal for large tankers then being constructed; however, in 1955 disaster struck when crankshaft failure occurred in five engines over a short period of time. Doxfoer's acted with great urgency calling meetings of interested parties and having investigations carried out by Lloyds and other bodies. Reports were acted upon and recommendations issued to licensees concerning the modification of engines already in service or under construction. Axial vibration and incorrect crankshaft alignment were considered to be two of the main reasons for failure and in 1960 two of Doxfoer's senior personnel produced a paper detailing the problems and solutions. However, the damage was done with the result that certain shipowners and licensees turned their attention to other engines. One shipowner insisted that the crankshafts for two ships under construction be replaced by ones conforming to the new recommendations. As far as one leading Doxfoer engineer was concerned the limit of the normally aspirated Doxfoer engine appeared to have been reached in the 75LB6 engine.

In addition to the 670 mm bore single-cylinder engine Doxfoer's decided that a large bore (800 mm) experimental engine should be built in order to test the possibilities of high power development. By early 1949 drawings for the engine were well advanced but it was evident that the engine could not be operational for at least two years. By early 1950 it had been decided to hold the large experimental engine in abeyance and investigate the use of supercharging as a means of developing higher powers. A number of licensees were particularly keen on very high powers through the supercharging of the 725 mm and 750 mm bore engines then in production and approval was given for construction of an experimental three-cylinder 600 mm bore supercharged engine.

Brown-Boveri became involved in the investigations and anticipated a power increase of 40% to 50% compared with a normally-aspirated engine of the same size. The engine was operational by March 1952 when extensive testing commenced. Power increases of 50% were obtained and licensees requested that plans be made for turbo-charging other engines in the range, particularly the six-cylinder 700 mm bore engine, to give 7460 kW. Agreement was reached with British Petroleum for installation of the experimental engine in its motor tanker British Escort during 1954 and trials over the next year proved the installation to be a success, although the three-cylinder form was not particularly suited to turbo-charging. Turbo-charging required large exhaust and air inlet ports for maximum performance but enlarging the ports would have produced 'dead bands' in which starting air could not have been applied. In order to prevent the latter problem the engine had smaller ports than turbo-charging required and so operated below maximum rating. Doxfoer's quickly set about supercharging its range of engines with Brown-Boveri turbo-chargers and a new era for the Doxfoer engine began.

Initially Doxfoer turbo-charged engines retained their scavenge pumps, working in series with the turbo-chargers, in order to supply combustion air when starting or at low loads. They also offered a safeguard against turbocharger failure but were both costly and increased engine weight. Trials carried out in 1958 on the engine fitted in the Ropner tanker Thirlyb indicated that satisfactory operation could be obtained without scavenge pumps, combustion air when starting, at low loads and during emergencies being provided by electrically driven blowers. Retention of scavenge pumps for so long indicates a conservatism not shown by major competitors like Sulzer and Burmeister & Wain (B&W).

THE FINAL PHASE

In 1947 Doxfoer appointed Percy Jackson to set up and head a department devoted to research and development. Work on the burning of heavy oils and turbo-charging were carried out by Jackson's team but during the mid-1950s it became apparent that power potential limits of the LB engine had been reached, particularly with respect to the crankshaft. Plans for another single-cylinder experimental
engine were revived but with complete redesign of many features. In order to develop higher powers without risk of torsional vibrations a stiffer crankshaft was required. Reduction in upper piston stroke reduced side rod crank throw thereby allowing for overlap between side crankpins and main journals which in turn increased stiffness. The stiffer crankshaft enabled spherical bearings to be replaced by plain bearings, spherical bearings having been used on all Doxford opposed-piston engines from the first design in order to allow for crankshaft flexibility. A three piece cylinder liner was introduced and the upper piston guides eliminated because of the reduced upper piston stroke and increased rigidity of running gear connections. This single-cylinder engine survives at South Tyneside College of Technology.

Fig. 8. Section through the Doxford 'P' type engine.

Operation of the single-cylinder experimental engine proved satisfactory and a new engine developed, the 'P' type. The six-cylinder 670 mm bore prototype, designed to develop 7460 kW, was both shorter and lighter than an LBD engine of the same power. After extensive shop testing it was installed in the tanker Montana during 1961. Both turbo-charged and normally-aspirated 'P' type engines were offered but it was only the turbocharged version, operating on the pulse system, which attracted any interest. A considerable amount of design work went into the new engine which held Doxford's hopes for the future. In October 1960 it was announced that a further £333,000 would be spent from reserves in developing the 'P' engine, some £750,000 having been spent to that date on the project.

Publicity material issued at the time indicated that turbocharged versions would also be offered with bores of 560 mm and 850 mm but these were quickly cancelled. There was no demand for the smaller bore and within months of the proposal being made it was realised that a 770 mm diameter crankshaft would be required for the larger engine in order to avoid torsional vibration problems. This would have been prohibitively expensive and heavy. The new engine had reached the end of the road
as soon as it entered service. Problems in service did not encourage sales, high cylinder wear rates were experienced with the engine fitted in Montana whilst the second engine, fitted in Tudor Prince—experienced fractures in the side rod bottom end bearing caps. Only two licensees, Hawthorn, Leslie and Société des Chantiers et Ateliers de Provence, built any 'P' type engines.

![Diagram of the Doxford engine](image)

Fig. 9. Fullagar type arrangement proposed for Doxford engine in the 1960s.

The crankshaft was the problem but an opposed piston design presented difficulties in terms of crankshaft construction and a number of alternative methods of connecting the upper piston were considered. Lever systems and arrangements similar to that of the Fullagar engine were appraised and discounted as impractical. Increased crankshaft stiffness was obtained by adopting an idea proposed by K. O. Keller in 1931; machining side rod webs in circular form would allow them to act as main journals and would increase crankshaft stiffness with an accompanying reduction in engine length, weight and cost. The 'J' type engine was born.

Many standard Doxford features such as the fuel system and air start system found their way onto the 'J' engine; there was no point in changing systems which functioned effectively. Improvements were made to pistons, liners and their cooling, and to the cylinder lubrication arrangements but it was the crankshaft which was the major change. In order to allow side webs to act as main journals the stroke of the upper piston had to be reduced to about 30% of the lower piston stroke. The high stroke-to-bore ratio was a major advantage of the opposed piston design in terms of cylinder power production and this change diminished that advantage over single piston engines. Trends towards long strokes in single piston designs resulted in power per cylinder of the 'J' engine being little higher than that obtained from other contemporary slow speed designs. As with earlier opposed piston designs the 'J' engine still had the advantage of balance over its competitors. Doxford engines required more bearings than single piston designs and the use of thin shell bearings was aimed at easing maintenance workloads. Initially the centre connecting rod top end bearing employed two shells and a support pad.
but this was quickly changed to a continuous bearing. Engines were offered with 580 mm, 670 mm and 760 mm bores with between four and nine cylinders depending upon bore, power range being between 4476 kW and 18,650 kW.

No single-cylinder engine was built, Doxford going straight to construction of a nine-cylinder 760 mm bore engine which was installed in the tanker North Sands. Doxfoords had the ship built in order that the engine would be seen to work at sea; design and construction being well documented at the time. Performance in service was good and there was interest from shipowners, particularly those with Doxford engines already in their fleets, but only one licensee, Hawthorn. Leslie built ‘J’ type engines. Vickers did express an interest and sent people to Sunderland in order to investigate costs involved in manufacture. On the assumption that they would eventually be quoting for ‘J’ engines Vickers arranged to have price estimators visit Doxfoords; at least two other licensees, Fairfields and Wallsend Slipway had undertaken similar exercises. Licensees were, obviously, interested in the engine but there appears to have been a reluctance on the part of former shipowner clients to become involved again. Doxford engines were, or at least had been, profitable to the licensees; in the 1950s Hawthorn, Leslie (Engineers) Ltd. were making a profit of 25% on turnover, building, on average, one Doxford each month. Doxfoords continued development work on the ‘J’ engine and a major improvement came with adoption of constant pressure turbo-charging 1978, but again this was too late.
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Fig. 12. Section through “Seahorse” engine.

In 1969, at the instigation of Hawthorn, Leslie (Engineers) Ltd, who wished to have a more active role in the engine design process after having been licensees for many years, a research company was formed with the aim of developing an opposed piston engine which could be operated at higher speeds. Multiple geared or single electrical generating units could be devised making use of the inherent balance of the opposed piston engine. A four-cylinder prototype ‘Seahorse’ engine was built and commenced tests during 1971. There was great hope for this engine both in the marine field and for industrial applications but development costs were high and the initial breakthrough of a land or marine order never came. E. P. Crowdy, a director of Doxford Hawthorn Research Services Ltd, went on a world sales tour and believed that many orders would have been forthcoming had there been an engine in commercial service. There were internal shipyard pressures against the engine as more profit could be made from a vessel with a ‘J’ type engine than from a ship having a ‘Seahorse’ installation. One shipowner with a large Doxford engine fleet was willing to take two ‘Seahorse’ engines but the Doxford shipyard persuaded him to take a ‘J’ engine instead.
Eventually the project was abandoned and some of the knowledge gained used to develop the 58JS engine for the lower power market occupied by medium speed engines. Three-cylinder versions of this design were built to drive small container ships but by the time early problems had been solved B&W and Sulzer also had small engines available.
Fig. 14. Sectional drawing of 58JS3 engine.

Nationalisation saw Doxfords become part of British Shipbuilders and it was under that cloak that a final opposed-piston engine design was devised. In conjunction with International Power Engineering of Copenhagen project BS42:100 was started in 1982 with the intention of designing a 420 mm bore by 1000 mm combined stroke engine. Unfortunately with the departure of Robert Atkinson as Chairman of British Shipbuilders the project faded.76
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EPILOGUE

The Doxford opposed-piston engine was undoubtedly a major success particularly in the immediate post-war period. Its high power cylinder and high efficiency were important to shipowners whilst its availability in three- and four-cylinder versions made it popular with tramp ship owners. In the immediate post-war years Britain still had an extensive shipbuilding industry and any home grown engine had an advantage in attracting licensees from the ranks of these shipbuilders. The fact that shipbuilders often constructed their own engines was of benefit at that time but it became restrictive as far as Doxfores were concerned. When Gebbie, a Naval Architect, became Chairman of Doxford in 1957 he reduced funding for expansion of the engine works and it has been said that he was not interested in high powered engines as the Doxford shipyard could only build relatively small ships.

Doxford engines had three sets of top and bottom end bearings per cylinder, all of which required maintenance and routine survey. High costs of this work and the refusal of classification societies to ease survey requirements acted against the engine in its competition with single piston designs.

Factors influencing the decline of the Doxford engine include
1. Late adoption of turbocharging.
2. Engine problems, such as crankshaft failures on some 750 mm bore engines, resulting in loss of confidence.
3. Failure to grant and encourage more overseas licences, particularly in Germany and Japan.
4. Nationalisation and control of the engine department works by people with little engineering or shipping knowledge.
5. Decline of the British shipbuilding and shipowning industries.
6. Development of higher cylinder powers with single piston Sulzer and B&W designs.

Discussion of these factors would take a paper itself but there is little doubt that a good product and idea was not exploited as effectively as it should have been; no doubt the same can be said for many other areas of British industry.

Some have contended that the opposed piston concept had reached the end of its development but for others it still has potential.

The argument is now academic as there is no real British commercial shipbuilding industry for which engines could be built. Doxford's decline mirrored British shipbuilding decline because there was insufficient involvement with overseas engine builders. Without an extensive array of licensees insufficient royalties were earned to fund further development. Had a German or Japanese partner been sought in the early 1950s the story might have been different.

NOTES AND REFERENCES

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27. 17th Doxford Licensees' Technical Meeting. Licensees.

28. W. Ker Wilson, op cit (14), p. 84.


35. Minutes of First Doxford Special Policy Meeting, 26 May 1953: Licensees.


37. The problems concerning crankshaft production are illustrated by correspondence in the Vickers Ltd Doxford files for various dates between Nov. 1944 and October 1945: Vickers.


41. 1st Doxford Licensees Technical Meeting, 11th/12th May 1948: Licensees.


43. The Motorship, vol 44 (April 1963), p. 34.

44. 10th Doxford Licensees' Technical Meeting, 1 April 1952, Minute No 168; Licensees.

45. 9th Doxford Licensees' Technical Meeting, 30 Oct. 1951, Minute No 153; Licensees.

46. 4th Doxford Licensees' Technical Meeting, 14 June 1948, Minute No 94; Licensees.
54. 10th Doxford Licensees' Technical Meeting, 1 April 1952. Minute No 170. Licensees.
65. Doxford 'J' engine publicity brochure.
66. P. Jackson, op cit (59).
74. F. Orbeck, op cit (68), p. 41.
77. A. Storrey, op cit (36), p. 66.
81. F. Orbeck, op cit (68), p 51.
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### TABLE 1

**Doxford Engine Development**

<table>
<thead>
<tr>
<th>Year</th>
<th>Cylinder Power kW</th>
<th>Bore mm</th>
<th>Stroke mm</th>
<th>No. Cyls</th>
<th>RPM</th>
<th>S.F.C. kg/kW·hr</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>1919</td>
<td>504</td>
<td>580</td>
<td>1160+1160</td>
<td>4</td>
<td>77</td>
<td>0.268</td>
<td>Prototype</td>
</tr>
<tr>
<td>1924</td>
<td>541</td>
<td>580</td>
<td>1160+1160</td>
<td>4</td>
<td>87</td>
<td>0.250</td>
<td>Uprated prototype</td>
</tr>
<tr>
<td>1926</td>
<td>522</td>
<td>600</td>
<td>760+1040</td>
<td>4</td>
<td>110</td>
<td>0.232</td>
<td>Balanced engine</td>
</tr>
<tr>
<td>1928</td>
<td>200</td>
<td>400</td>
<td>540+760</td>
<td>3</td>
<td>145</td>
<td>0.216</td>
<td>Marine</td>
</tr>
<tr>
<td>1928</td>
<td>274</td>
<td>400</td>
<td>540+760</td>
<td>3</td>
<td>200</td>
<td>0.220</td>
<td>Industrial</td>
</tr>
<tr>
<td>1931</td>
<td>615</td>
<td>600</td>
<td>980+1340</td>
<td>4</td>
<td>98</td>
<td>0.237</td>
<td></td>
</tr>
<tr>
<td>1931</td>
<td>881</td>
<td>700</td>
<td>880+1220</td>
<td>4</td>
<td>120</td>
<td>0.230</td>
<td></td>
</tr>
<tr>
<td>1933</td>
<td>541</td>
<td>600</td>
<td>980+1340</td>
<td>4</td>
<td>92</td>
<td></td>
<td>Welded structure</td>
</tr>
<tr>
<td>1935</td>
<td>448</td>
<td>520</td>
<td>880+1200</td>
<td>3</td>
<td>115</td>
<td>0.212</td>
<td>Economy engine</td>
</tr>
<tr>
<td>1935</td>
<td>448</td>
<td>560</td>
<td>700+980</td>
<td>5</td>
<td>115</td>
<td>0.216</td>
<td>1st 5 cyl. engine</td>
</tr>
<tr>
<td>1938</td>
<td>970</td>
<td>725</td>
<td>950+1300</td>
<td>5</td>
<td>123</td>
<td>0.219</td>
<td>Dominion Monarch</td>
</tr>
<tr>
<td>1939</td>
<td>1119</td>
<td>813</td>
<td>1016+1397</td>
<td>4</td>
<td>94</td>
<td>0.210*</td>
<td>San Doxford</td>
</tr>
<tr>
<td>1949</td>
<td>247</td>
<td>440</td>
<td>620+820</td>
<td>3</td>
<td>145</td>
<td>0.224</td>
<td>Trawler Engine</td>
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<tr>
<td>1951</td>
<td>1057</td>
<td>750</td>
<td>2500</td>
<td>6</td>
<td>110</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1952</td>
<td>933</td>
<td>600</td>
<td>2220</td>
<td>3</td>
<td>125</td>
<td>0.207</td>
<td>Exp. T/C engine</td>
</tr>
<tr>
<td>1959</td>
<td>1300</td>
<td>700</td>
<td>2320</td>
<td>6</td>
<td>120</td>
<td></td>
<td>No scav. pumps</td>
</tr>
<tr>
<td>1961</td>
<td>1243</td>
<td>670</td>
<td>720+1380</td>
<td>6</td>
<td>120</td>
<td></td>
<td>'P' type</td>
</tr>
<tr>
<td>1965</td>
<td>1665</td>
<td>760</td>
<td>520+1660</td>
<td>9</td>
<td>119</td>
<td>0.219</td>
<td>'J' type</td>
</tr>
<tr>
<td>1971</td>
<td>1865</td>
<td>580</td>
<td>420+880</td>
<td>4</td>
<td>300</td>
<td>0.201**</td>
<td>Seahorse</td>
</tr>
<tr>
<td>1978</td>
<td>1350</td>
<td>580</td>
<td>340+880</td>
<td>3</td>
<td>220</td>
<td>0.201</td>
<td>58JS3</td>
</tr>
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</table>

* Consumption figure calculated using shaft output power and electrical power generated using waste heat.

** Projected consumption
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## Table 2

**Doxford Licensees**

(as at November 1936)

<table>
<thead>
<tr>
<th>Company</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ailsa Shipbuilding Co. Ltd.</td>
<td>Troon, Ayrshire</td>
</tr>
<tr>
<td>Barclay, Curle &amp; Co. Ltd.</td>
<td>Whiteinch, Glasgow</td>
</tr>
<tr>
<td>John Brown &amp; Co. (Clydebank) Ltd.</td>
<td>Clydebank, Scotland</td>
</tr>
<tr>
<td>Fairfield Shipbuilding &amp; Engineering Co. Ltd.</td>
<td>Govan, Glasgow</td>
</tr>
<tr>
<td>William Gray &amp; Co. Ltd.</td>
<td>West Hartlepool</td>
</tr>
<tr>
<td>Hawthorn, Leslie (Engineers) Ltd.</td>
<td>Newcastle-upon-Tyne</td>
</tr>
<tr>
<td>John Lewis &amp; Sons. Ltd.</td>
<td>Aberdeen</td>
</tr>
<tr>
<td>Richardsons, Westgarth &amp; Co. Ltd.</td>
<td>Wallsend-on-Tyne</td>
</tr>
<tr>
<td>David Rowan &amp; Co. Ltd.</td>
<td>Glasgow</td>
</tr>
<tr>
<td>Scotts’ Shipbuilding &amp; Engineering Co. Ltd.</td>
<td>Greenock, Scotland</td>
</tr>
<tr>
<td>Alexander Stephen &amp; Co. Ltd.</td>
<td>Linthouse, Glasgow</td>
</tr>
<tr>
<td>Vickers-Armstrongs Ltd.</td>
<td>Barrow-in-Furness</td>
</tr>
<tr>
<td>Wallsend Slipway &amp; Engineering Co. Ltd.</td>
<td>Wallsend-on-Tyne</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Company</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ansaldo S.A.</td>
<td>Genoa, Italy</td>
</tr>
<tr>
<td>Canadian Vickers Ltd.</td>
<td>Montreal, Canada</td>
</tr>
<tr>
<td>Commonwealth Government Engine Works</td>
<td>Melbourne, Australia</td>
</tr>
<tr>
<td>Eriksberg Mekaniska Verkstads A/B</td>
<td>Gothenburg, Sweden</td>
</tr>
<tr>
<td>Marinens Hovedverft</td>
<td>Horten, Norway</td>
</tr>
<tr>
<td>Nederlandsche Dok En</td>
<td>Amsterdam, Holland</td>
</tr>
<tr>
<td>Scheepsbouw Maatschappij</td>
<td></td>
</tr>
<tr>
<td>A/S Rosenberg Mekaniske Verksted</td>
<td>Stavanger, Norway</td>
</tr>
<tr>
<td>Societe des Chantiers et Ateliers de Provence</td>
<td>Marseilles, France</td>
</tr>
<tr>
<td>Sun Shipbuilding Co.</td>
<td>Chester, Pennsylvania, USA</td>
</tr>
<tr>
<td>Taikoo Dockyard &amp; Engineering Co.</td>
<td>Hong Kong</td>
</tr>
<tr>
<td>Wilton-Fijenoord N.V.</td>
<td>Schiedam, Holland</td>
</tr>
</tbody>
</table>
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TABLE 3

Doxford Installations
(to 1945)

No of Installations

Year

1920 1925 1930 1935 1940 1945

Licensee
Doxford

Post WWII years

Licensee
Doxford

Year


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DISCUSSION

Mr. Joe Roberts (Member), in connection with crankshaft failures, asked when the detuner on the forward end of the crankshaft came into use.

The Author replied that it came into being during the 1930s; however, it was not a detuner as such at first. When the engine was balanced the firing order was changed and this resulted in torsional vibration problems at speeds when no such trouble had been experienced previously; the problem was overcome by fitting small flywheels at the forward and after ends of the crankshaft. During the late 1930s the Doxford-Bibby detuner was developed and placed at the forward end of the crankshaft. This remained a feature of all Doxford engines until the 1960s when the J-type engine with its much stiffer crankshaft was developed.

Mr. Nicholas expressed surprise that the opposed-piston design was adopted ostensibly because of problems with cylinder heads and then that the opposed piston design, with all of its added complexity, was adhered to right to the bitter end. However, there has never been a single comment on the saleability of the Doxford engine although, presumably, it should run more smoothly than those of other companies.

The Author confirmed that the engine was saleable. He considered that Doxford engines "sold themselves" right up to the late 1950s because many British shipping companies already had Doxboards and once a company had a number of engines in its fleet it made sense to continue with that type as engineers would have been experienced with the design. The Doxford was a good engine and competitive in terms of fuel consumption and power output; specific fuel consumptions in the region of 0.22 kg/kWh during the 1950s were extremely attractive and compared favourably with Sulzer and Burmeister & Wain (B&W) engines which were the main competitors. It was only in the 1960s and 1970s that Sulzer and B&W overtook Doxford in terms of power output and specific fuel consumption; these engines had cylinder covers which had been something of a problem during the pre-war years but, with development of improved materials in the 1950s and later, troubles through damaged exhaust valves were reduced. Doxford opposed-piston engines had more bearings per cylinder than single piston designs and that resulted in greater maintenance costs as more people were needed on board ship. With the trend towards reduced manning levels in the 1960s the Doxford faced higher operating costs.

Mr. Nicholas asked whether, if one was on a ship with a Doxford engine as compared to a ship with another type of engine one would know the difference in terms of vibrations.

The Author could not make accurate comparisons with other makes but certainly Doxford engines did have good inherent balance and many passenger ships were built using them. Had the engines not been so good shipping companies would not have used them. During the period up until about 1960 they were certainly better than their competitors. The author recalls a Doxford advertisement of the early 1960s which showed a pencil balanced upon its end next to one of the moving side rods—the intention was, obviously, to show the absence of vibration.

Responding to the point that the shipping market was a restricted one the author replied that from the early 1960s Doxboards tended to be slipping whereas Sulzer and B&W looked for wider markets, particularly the far east, Switzerland has no coast line but Sulzer, a Swiss company, developed some very fine marine engines but did not confine their expertise to the marine market; Doxford engines were essentially marine engines.

Mr. Alan Noble (Member) asked how the power to weight ratio feature in comparison with other makes of engine.

The Author replied that he had no information then but figures would be presented when the paper was published. Doxford developed welding techniques for bedplate and crankcase construction during the 1930s and engine weights reduced at that time; for a cast bedplate and A-frame of the 1930s a specific weight of 155 kg/kW was typical but with welded construction the figure fell to 113 kg/kW. (A B&W engine of the late 1930s developing 3500 bhp weighed 320 tons giving about 125 kg/kW; figures for Sulzer and other engine builders were very similar giving the Doxford a distinct weight advantage). Doxboards were able to get away with certain features required of other engines, including the provision of tie rods, whilst the structure could be lighter due to the opposed-piston design; no combustion loads were applied to the bedplate as forces on upper and lower pistons cancelled each other out. Doxboards did have a better power to weight ratio than other engines but these engines progressed as improved materials were developed and they eventually overtook Doxboards as the opposed piston engine had more running gear per cylinder.

Mr. Marsden was interested in the use of heavy fuel oil. The author had suggested that Doxboards were one of the first to use this fuel.

The Author replied that it was in the 1920s with one owner carrying out a detailed investigation into the burning of boiler oil. (This was not the same as modern residual oil, however) It was a one off trial to investigate the
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cost differential between diesel oil and boiler oil use. In the 1920s residual fuel (boiler oil) was of much better quality than it is today as only certain of the lighter elements had been removed by refinery processing of crude oil and in general only preheating was needed to get it to burn properly in a diesel engine. Cost differentials were of major importance to the shipowner but the cost advantage of burning boiler oil was not significant at the time due to the small difference in price between diesel and boiler oils. Recent conversation with an employee of Sulzer has indicated that some shipping companies have been considering going back to diesel oil because of the atrocious quality of modern residual fuels with their implications on maintenance costs. As price differentials shrink once more there could be a cost advantage in burning diesel fuel as there would be less engine maintenance. There is going to be a problem with respect to exhaust emissions being the subject of legislation in the not to distant future and this will have an influence on the choice of fuel.

Mr. Paul Perch (Member) was interested to know, since other firms (in the 1960s anyway), sold marine diesels more or less in parts and made a living out of spares, what was the main demand for spares at Doxford.

The Author recalled that the ships on which he sailed used a lot of hoses for carrying cooling water to and from the upper pistons; demand for fuel injector nozzles was also fairly extensive. Piston rings and cylinder liners also wore a great deal more than they do today. These areas were all he could recall; in particular the Doxford had no exhaust valves which caused problems with other engines. He remembered sailing on a war-built Doxford which had swinging links for transmitting cooling water to and from the lower piston and these suffered leakage from pin holes. There must have been a good spares market; when Doxford ceased trading the one part of the company which survived was that dealing with spares.

Buying an engine was like buying a car; the purchase was the least expensive bit, keeping it going was costly. It would be interesting to see where the money was actually made and there must have been a fair business in supplying spares. The engineering superintendent of Andrew Weir Shipping, which still operated Doxford engines, has informed the author that obtaining spares today was not a particular problem as somebody would make the parts if the price was right.

Mr. E. F. Clark (President) asked about lubricating oil consumption.

The Author referred back to the 3-cylinder engine mentioned in the paper; in this case a 9000 ton ship doing 10.5 knots burned less than 6.5 tons of fuel per day and used only 30 litres of cylinder lubricating oil. Comparing Doxfords with B&W engines of the 1960s there was a higher cylinder lubricating oil consumption but he did not know to what extent.

Dr. Robert Carr (Member) asked whether opposed piston engines were now being made by anybody or were they totally obsolete.

The Author considered that they were obsolete; he felt that nobody would want to build them now, simply because there was no market. Sulzer, B&W and Mitsubishi now have the market for crosshead engines to themselves and in terms of land application only the Fullagar engine developed by English Electric for power station use ever found any favour. The large crosshead engine is, apart from a few applications in power stations, a marine engine.

Lord Carlton (Member) referred to the Fairbanks-Morse opposed piston Engine.

The Author said he has not yet investigated this engine as it was American and it did not find any real application in the marine world. He recalled that Fullagar and Doxford engines had been tried by the Admiralty at the end of World War I for use in submarines but with the end of that conflict development for submarine use ceased. Over the years many sorts of diesel engines, some very unusual, had been developed and at the time some of them were good. With the development of improved materials, better design and the reduction in fuel quality many went by the board.

Mr. J. A. Barnes then proposed a vote of thanks, which was carried with acclamation.