Motor Ship *Swanley* and its Double-acting Diesel Engine

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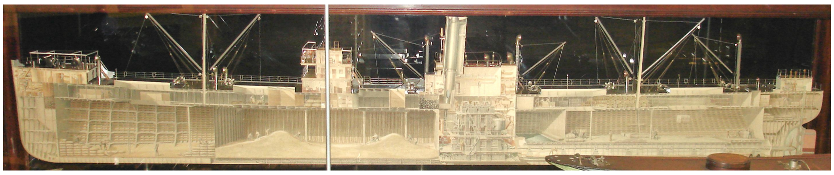
1.0 Introduction. The Glasgow Museums have an outstanding collection of almost 700 ship models. This Research Technical Note describes the engine of one of these models, a 1/48th scale half section model of the motor ship *Swanley* (I.D. No. T.1962.21.e), that is currently on display at Glasgow's Riverside Museum of Transport and Travel.

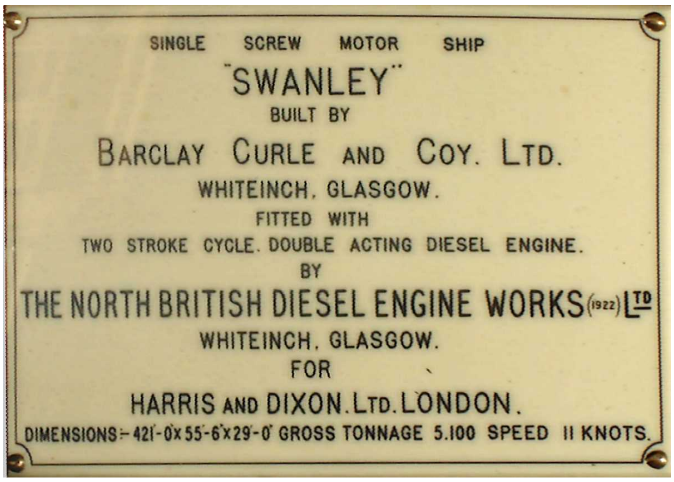


This model is unusual as it shows the internal layout and structure of the ship. Most ship models show the outside of the ship.

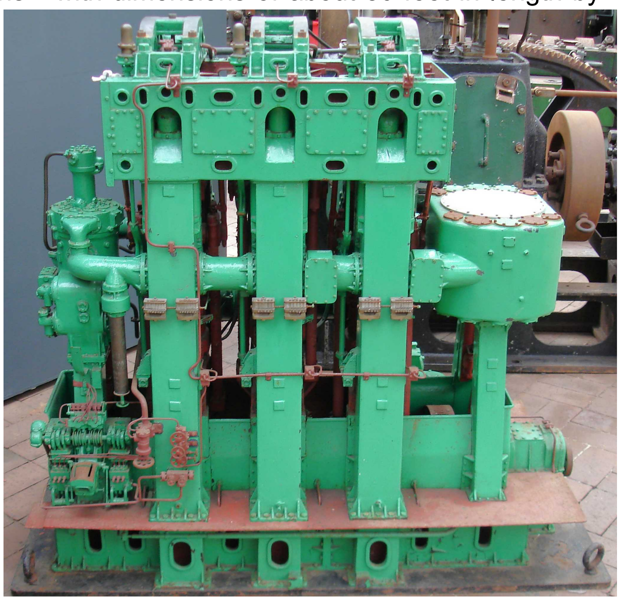
The *Swanley* was a typical tramp ship. i.e. a ship that 'tramps' the oceans carrying cargo to and from ports wherever the need arose. Tramp ships do not have a fixed schedule or an established port of call. Often she would be empty of cargo and would sail in ballast to get to a port where a cargo would be waiting for transportation. The model shows the distribution of the cargo holds and there is nothing unusual here. What is unusual is the engine room and the method of propulsion. The *Swanley* was the first British built ship with a double-acting diesel engine[1].

Although ultimately the engine was not a success, only three ships, *Swanley*, *City of Stockholm* and *Storsten*, were ever fitted with main engines of this type and all of these were eventually re-engined[1][3]. The engine had some unique features and was mechanically very interesting. If the engine had been built as a conventional diesel engine there would be nothing to write about. This note describes in some detail why the engine was built and why the unique features were incorporated into the design.

The *Swanley* was built by Barclay Curle & Company Limited, at their Clydeholm Whiteinch shipyard, and launched on the 22nd March 1924. She was a shelter deck vessel of 9,200 tons deadweight and registered to the Swanley Shipping Co. Ltd.[1]. She was powered by a 3-cylinder, 2-stroke cycle, double-acting, North British Sliding-Cylinder Engine built at Barclay Curle's adjacent North British Diesel Engine Works (1922) Ltd. These works, built in 1913, still exist today although no longer manufacturing diesel engines. The works building is historically important as the design was influenced by Peter Behrens AEG turbine factory in Berlin. A large Titan Crane, built by Sir William Arrol & Co. in 1920, stands in the yard and was capable of lifting the engines into ships berthed alongside[2]. The engine had a cylinder bore of 24.5" (622mm) a stroke of 44" (1118mm) and was designed to give 2000 b.h.p. at 100 r.p.m., sufficient to allow the *Swanley* to sail at 11 knots. The engine weight was around 220 tons[5] with dimensions of about 30 feet in length by about 29 feet in height and 15 feet in width.



Nameplate on the ship model.



1/8th Scale model of the sliding-cylinder engine.

2.0 Background. The diesel engine originated from the 1892 German patent by Dr Rudolf Diesel (1858 - 1913). By 1897 Diesel had a working engine. One of the first licensees was Mirrlees, Watson & Yaryan Co. Ltd., of Glasgow who built the first British diesel in 1897[8]. Right from the beginning Clydeside companies had an interest in the building and development of diesel engines.

Diesel recognised that there would be a market for marine engines as the higher thermal efficiency (compared to a steam engine) of the diesel engine would allow more cargo to be carried in place of fuel, or a greater range for the same amount of fuel. Diesel lived long enough to see his vision of marine engines become a reality. Shortly before his death, in 1913, some 300 diesel engined vessels of various sizes had been built[(12)].

The early diesel engines operated on the 4-stroke cycle (the Otto cycle) and were single-acting; i.e. there was a combustion space on one side of the piston only. This results in a power stroke, per cylinder, once every two revolutions of the crankshaft. In order to get more power out of the engine for much the same weight, 2-stroke cycle (the Clerk cycle) engines were developed. These engines had a power stroke, per cylinder, every revolution of the crankshaft. For the same size of engine as a 4-stroke the power output was effectively doubled. The difficulties for the 2-stroke were the need to scavenge the cylinder of exhaust gases in a short period of time and the more severe operating conditions associated with a power stroke every revolution.

To get even more power double-acting engines were developed. This was a logical development as steam reciprocating engines had been double-acting since the days of James Watt. Prior to the First World War several German companies including Maschinenfabrik, Augsburg - Nürnberg (M.A.N), Krupp, and Blohm & Voss attempted to build double-acting marine engines. Blohm & Voss succeeded in completed two engines that were installed in the motor ship '*Fritz*' launched in 1914. Due to the war there was limited scope for ocean operations. At the war end the '*Fritz*' was transferred to Britain as part of war reparations[(8)]. Renamed the *Assyrian* the diesels were replaced by steam engines in 1925[(11)].

After the First World War there was renewed interest in double-acting engines and a few companies took up the challenge including M.A.N., Burmeister & Wain (B&W) of Copenhagen, Sulzer of Switzerland [(9)], and Richardsons Westgarth[(10)]. All these double-acting engines used a conventional crosshead arrangement, i.e. there is a piston rod, passing through a sealing gland to the crosshead and a connecting rod from the crosshead to the crankshaft. Although this arrangement worked well on a steam engine on a diesel engine there were several difficulties:

(a) The piston rod reduced the power output of the bottom (lower) cylinder by about 10% compared to the top (upper) cylinder.
(b) The sealing gland (stuffing box) required to stop the products of combustion entering the crankcase had to seal against the full combustion pressure and was subjected to high temperature from the combustion process.
(c) The scavenging of 2-stroke engines have always presented a challenge for the engine designer. The double-acting engine added to the problem; the piston rod interfered with effective scavenging.
(d) There were access difficulties to service the sealing gland and on some designs the exhaust and scavenge valves.

3.0 The North British Sliding-Cylinder Engine. This engine was an attempt to eliminate the above difficulties by incorporating three innovations:

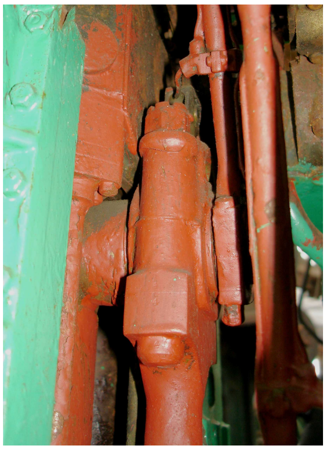
1. The sealing gland and piston rod, normally required on a double-acting engine, was eliminated.
2. The uniflow method of scavenging, by use of inlet and exhaust ports, was developed to operate with a single piston and a sliding-cylinder to obtain the desired scavenging.
3. The fuel valve camshaft and reversing gear were eliminated by operating the fuel valves by a combination of cylinder pressure and the sliding-cylinder.

A single cylinder experimental engine was built that incorporated the first two innovations. The trials of this experimental engine proved favourable and it was decided to proceed with the construction of a large three-cylinder engine of similar design[(13)]. The engine designer was Mr. J.C.M. MacLagan (1886 – 1962) of Drumchapel, hence the engines are sometimes referred to as MacLagan oil engines or MacLagan diesel engines. The concept of the engine was covered by several United States patents, and was widely reported in the technical press, e.g. 'The Motor Ship'[(5)]. A detailed description of the engine is given by MacLagan[(4)] and there is also a 1/8th scale model of the engine at the Scottish Maritime Museum at Irvine (Inventory No. 03413).

3.1 The Elimination of the Piston Rod. In the background discussion above, the engines were of the crosshead type. There was an alternative arrangement known as a trunk piston type where the piston rod, crosshead and guide was dispensed with and the piston was connected directly to the crankshaft via a connecting rod. The piston had a gudgeon pin and a skirt. The skirt acted as a guide within the cylinder. The trunk piston type of engine is popular today in both 4 and 2-stroke cycle engines especially for the smaller sizes of engine.

The trunk piston arrangement cannot be made double-acting as the connecting rod is in the way of the centre line of the piston. In order to obtain a double-acting engine, MacLagan arranged to extend the length of the gudgeon pin beyond the diameter of the piston and the cylinder. The piston was then connected to the crankshaft by means of two side connecting rods to a fork at the bottom end bearing (the big end). The top ends of the side rods connected to the extended gudgeon pin with bearings. The cylinder was in two parts, an upper and lower part, with a gap between so that the gudgeon pin could extend through and beyond the cylinder. The two parts of the cylinder were connected by tie rods to keep both cylinders reciprocating together. The whole cylinder assembly included cooling water jackets and the scavenge air and exhaust branches with sliding joints. The piston could now be made double-ended and hence a double-acting engine was achieved without having a piston rod, sealing gland and crosshead. A piston guide was directly attached to the piston to maintain alignment. The cylinders were closed by means of upper and lower cylinder heads in the form of stationary piston heads inside the cylinders. Sealing was by means of piston rings.

The disadvantage of the whole arrangement was that the pitch between each cylinder was wider than normal so as to accommodate the two side connecting rods. Hence there was an increase in the length of the engine but a double-acting engine had been achieved.



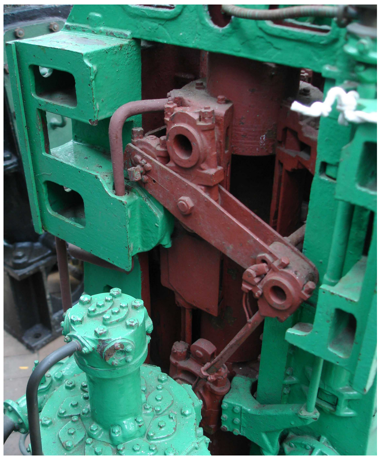
Left, one of the top end bearings to the extended gudgeon pin. Right, the side rods connect to the fork.

3.2 Scavenging and the Sliding-Cylinder. A two-stroke cycle engine requires the cylinder exhaust gases to be cleared away by fresh air supplied by a scavenge air pump. In the North British Sliding-Cylinder Engine the scavenge air pump was a double-acting reciprocating cylinder design driven from a crank on the aft end of the crankshaft. It supplied air to the cylinders at a pressure of 1.7 pounds per square inch. The drive to the scavenge pump was a conventional crosshead arrangement. A discharge pipe connected the pump to the front columns which acted as air reservoirs.

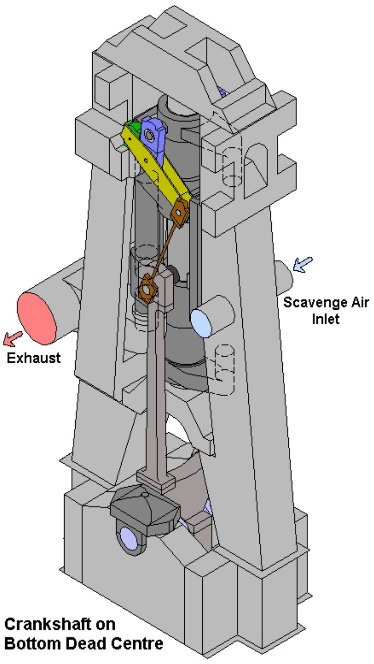
Several scavenging methods have been developed over the years. Each scavenging method has advantages and disadvantages but most marine engineers would agree that the uniflow system provides the most efficient system. In its simplest form the uniflow system uses ports at the ends of the cylinder thus eliminating valves. The elimination of valves was important to MacLagan, he wanted to produce a double-acting engine and the complication of valves and drive gear at the lower combustion area would present difficulties. Many engine manufacturers utilised the port scavenged uniflow system including Doxford, Junkers, Fairbanks Morse and Napier Deltic. All of these engines used opposed-pistons, i.e. there were two pistons per cylinder, one piston controlled the opening and closing of the exhaust ports while the other piston controlled the opening and closing of the scavenge air ports.

The problem for MacLagan was that his engine only had one piston per cylinder. In order to use a port scavenged uniflow system with one piston it was necessary to slide the cylinder to allow the opening and closing of a set of ports by means of the cylinder heads. In the MacLagan engine the control of the exhaust ports is achieved by the piston movement while the control of the scavenge air ports was by sliding the cylinder relative to the cylinder heads, which are of course stationary. The cylinder movement was synchronised, in phase with the piston, and was about 30% of the piston stroke. When the piston moves up so does the cylinder thus all the upper ports are closed and combustion can take place with the piston on top dead centre and the power stroke can commence. When the piston moves down so does the cylinder thus opening the upper scavenge ports and scavenging of the upper cylinder can take place as the decending piston uncovers the exhaust ports. The upper and lower cylinders are connected by tie rods so that the cylinders reciprocate together, hence the opposite effect is achieved with the lower cylinder. Thus the engine is double-acting with two power strokes every revolution of the crankshaft.

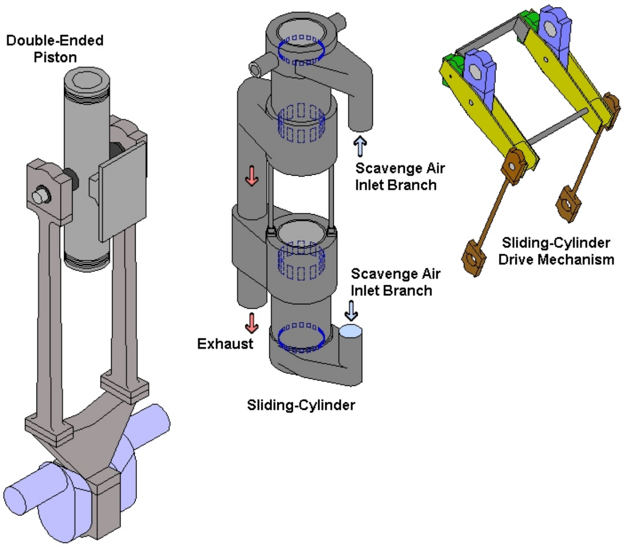
The cylinder movement is achieved by means of three members: a drive rod, a fulcrum lever, and a link. All these members are pin jointed by means of bearings and are driven from the extensions of the piston gudgeon pin. The need to accommodate the mechanism further increases the width between cylinders and adds to the overall length of the engine but an efficient method of scavenging had been achieved. An animation of the engine is at this link: 



One of the sliding-cylinder drive mechanisms.
View on the forward end
showing the drive rod, fulcrum lever,
fulcrum (pivot) and link.



One cylinder block assembly.



The main running components.

3.3 Fuel Injection Valves, the Elimination of the Camshaft. The engine was direct reversing and had a Michell type thrust bearing at the aft end of the crankshaft. The control position was on the forward port side. The fuel injection method was by blast air injection. This was a common method of fuel injection on the early diesel engines and it gave good combustion. The blast air was supplied at around 1000 pounds per square inch from a three-stage air compressor driven from a crank on the forward end of the crankshaft. The drive to the air compressor was a conventional crosshead arrangement.

It was normal (orthodox) practice to operate the fuel valves by a camshaft, together with a dog-clutch with lost motion, to allow forward and reverse running. However, MacLagan decided to eliminate the camshaft and dog-clutch altogether by operating the fuel valves by a combination of cylinder pressure and mechanically by the sliding-cylinder movement.

The fuel injection valves were on the port side, one each on the upper and lower cylinder heads. Within the fuel valve body there was a plunger spring loaded to about 450 pounds per square inch. There was a passage in the valve body between the plunger cylinder and the engine cylinder. Each fuel valve had a lever that was activated by a cam on the sliding-cylinder assembly. When the sliding-cylinder activated this lever it slightly opened the fuel valve. When the pressure in the engine cylinder exceeded 450 pounds per square inch the plunger movement allowed the fuel valve to completely open and compressed air carrying a metered quantity of fuel oil was injected into the engine cylinder. During injection the fuel would be atomised to a fine spray so that combustion would take place by compression ignition. As the sliding-cylinder recedes the fuel valve is allowed to close. The above sequence of events allowed the fuel valve to open just before dead centre and to close about 40 degrees after dead centre, regardless of the direction of rotation of the engine. Hence, as well as eliminating the camshaft the necessity for fuel valve reversing gear is also eliminated. MacLagan got this novel fuel injection system to work. Unfortunately the bottom fuel-valves were sometimes liable to be sluggish, and as the time available for experiment was limited, it was decided to adopt an orthodox cam-operated gear in the earlier engines[4]. The '*Swanley*' and the '*City of Stockholm*' were certainly fitted with orthodox camshafts.

The MacLagan fuel valve was operated by a combination of cylinder pressure and the sliding-cylinder.

4.0 The Maiden Voyage of the *Swanley*. After successful trials on the Clyde the *Swanley* sailed to Cardiff on the 30th June 1924 to load a cargo of coal for Colombo. MacLagan was on board for this maiden voyage to Colombo. Given the novelty of the engine, and it being a maiden voyage, no major problems seem to have been experienced[4]. The main difficulty appears to have been with the air compressor, and once the correct compound lubricating oil was obtained even that seems to have given no further trouble. In the longer term the alterations to the engine were: (a) the replacement of the flexible pipes, to the sliding-cylinder cooling water supply, with telescopic pipes, (b) additional closing plates to prevent lubricating oil leakage, and (c) deepening of the piston cooling pipe stuffing boxes. Although necessary, these do not seem to be major alterations. However, three years after the maiden voyage, the engine was replaced by a Doxford opposed-piston diesel engine.

The engines were not a success. The Motor Ship, in reference 7, only briefly comments that adverse reports on the general behaviour of the machinery were being circulated. Burrell explains in reference 1 that: "None of the three operators were happy with their vessels, complaining about the many engine breakdowns. In 1926 a committee briefed to examine the problem reported it was 'unwise to make further engines.' ---. It was agreed that all three ships be re-engined at builders' expense." The *Swanley* and *Storsten* were re-engined with Doxford opposed-piston diesel engines in 1927 and 1928 respectively. The *City of Stockholm* was re-engined in 1927 by conversion to a steam ship. All three ships were sunk, due to enemy action, during the Second World War. The North British Sliding-Cylinder Engines would have been scrapped at the time when the ships were re-engined but incredibly the model of the engine and the half-section model of the *Swanley* have survived. They could be the models referred to as being at the British Empire Exhibition held at Wembley in 1924[6].

5.0 Summary. The North British Sliding-Cylinder Engine was a brave attempt to get as much power out of a marine diesel engine while at the same time eliminate some of the shortcomings, perceived to be important, at that time (the 1920's). Looking back from this distance in time it is difficult to be sure what all the problems were with the engines. MacLagan, in reference 4, covers most aspects that designers of marine diesel engines would consider important but fatigue life was one area that he does not mention. Three other potentially contentious issues appear, to me, to be:

(1) The large number of bearings and sliding surfaces required for the sliding-cylinder, its driving mechanism and the scavenge and exhaust branches. Any lack of attention to the lubrication of these parts has the risk of seizure. There were 10 bearings in the driving mechanism alone i.e. 30 bearings on a three-cylinder engine. There is also the question of lubrication to the moving cylinder. MacLagan gives no details.
(2) The sliding-cylinder was more than just a sleeve. The mass of the sliding-cylinder, including its cooling water, water jacket and scavenge and exhaust branches, constitute a significant amount of reciprocating material and hence additional inertia forces would be experienced, although MacLagan does address this issue in reference 4.
(3) The amount of longitudinal width required for the side connecting rods and the sliding-cylinder mechanism. This amounted to about 40% of the cylinder pitch. The more space required for the

engine the less cargo can be carried. There would also be issues regarding the stiffness of the crankshaft design with increased number of cylinders.

Issue (1) would have a direct impact on the running and maintenance of the engine. Issues (2) and (3) would affect the potential for the development of the engine for larger sizes and powers.

With hindsight, the decision not to develop the engine further was the correct one. The future did not lie with double-acting engines. Successful developments in the large, slow speed, marine diesel engine market was achieved by single-acting 2-stroke cycle engines built by companies such as: B&W, M.A.N., Werkspoor of Holland and Sulzer. The Doxford type opposed-piston engine was also successful for many years. Today this market is now largely dominated by the single-acting, turbocharged, crosshead, 2-stroke cycle engines built by M.A.N-B&W and Wärtsilä-Sulzer. The largest engines designed by these companies today can have up to 14-cylinders and develop more that 100,000 b.h.p., i.e. 50 times the power of the MacLagan engine of 1924.

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