DIRECT DRIVE DIESEL MACHINERY (DOXFORD)

P. JACKSON, M.Sc., M.I.Mech.E. (Member)*

The revision of the International Tonnage Laws has brought to the fore the question of reduction in the space allotted to the machinery in order to improve the carrying capacity of cargo vessels. Previously, if the space occupied by the machinery was less than 13 per cent of the gross tonnage of the vessel, the nett registered tonnage was higher to the extent that, instead of a 32 per cent allowance for machinery space, the allowance was only one-and-three-quarter times the

TABLE IX.—DIRECT DRIVE PROPOSALS (DOXFORD MACHINERY) TWO-CYCLE OPPOSED PISTON CROSSHEAD SINGLE ACTING ENGINES

	1 Mr. W. H. Purdie's proposals, 1944	2 1946 re-design with lever-driven pumps	3 Supercharged engine 4 cylinder type
Engine distinguishing features	Central scavenge pump	2 lever-driven scavenge pumps	2 lever-driven scavenge pumps
Engine dimensions	4 cylinders 600×2,320	4 cylinders 600×2,320	4 cylinders 520×2,080
Engine speed r.p.m.	108	108	120
Ship's speed in service, port to port, knots	13	13	13
S.H.P.	3,300	3,300	3,300
M.I.P.	87	87	110
B.M.E.P.	76	76	99
Piston speed (mean), ft. per min.	820	820	825
Type of auxiliary machinery	Two Diesel electric and one steam electric set Electric steering and winches	Two Diesel electric and one steam electric set Electric steering and winches	Two Diesel electric and one steam electric set Electric steering and winches
Weights			
Main engines complete with thrust blocks and engine driven pumps, tons	245	230	190
Spare gear, including C.I. propeller and tail shaft, tons	21	21	19
160-ft. shafting and propeller, bearings and couplings, tons	65	65	60
Auxiliary machinery, including Diesel generators, boilers, funnel, silencers, gratings, ladders, switchboard, tons	120	122	124
Pipes with valves and fittings for bilge, ballast, steam, water and oil systems, tons	65	63	63
Water and oil in engines and boilers, tons	19	18	16
Total weight, tons	535	519	472
Dimensions			
Length of main engine	39 ft.	34 ft.	31 ft. 6 in.
Length of engine room required	47 ft. 3 in.	43 ft.	40 ft.
Casing required above upper deck level, feet	42×20	37×20	35×20
Height required for overhauling above tank top, to crane hook	36 ft. 3 in.	36 ft. 3 in.	32 ft. 6 in.
Fuel consumption per day at sea, tons	12½ (Diesel oil)	12½ (boiler oil)	12½ (boiler oil)
Auxiliaries per day at sea, tons	½ (Diesel oil)	½ (Diesel oil)	½ (Diesel oil)
Auxiliaries per day in port, including heating, etc., tons	1 (Diesel oil)	1 (Diesel oil)	1 (Diesel oil)
Annual consumption during 220 days at sea + 145 days in port, tons	3,000	3,000	3,000
Lubricating oil, annual consumption, tons	12	12	10
Weight of fuel to be carried for 60 days, tons	780	780	780
Weight of lubricating oil to be carried for 100 days, tons	4¾	4¾	4
Total weights of machinery, fuel and lubricating oil, tons	1,320	1,304	1,256
Tonnage of engine room spaces below upper deck, tons	627	570	530
Tonnage of total spaces framed in above the upper deck for propelling machinery and for light and air, tons	236	215	200

* Manager of Research and Development, William Doxford and Sons, Ltd.

TABLE X.—ENGINE ROOM AUXILIARIES

Item	1 Mr. W. H. Purdie's Proposal No. 2, 1944	2 Lever-driven scavenge pump engine, 1946	3 Supercharged engine, 4 cylinder type
Engine Service Auxiliaries			
Jacket water pumps	One engine driven pump of 150 tons per hr., plunger type	As 1	As 1 but of 120 tons per hr.
	One motor-driven standby pump 150 tons per hr., centrifugal type	As 1	As 1 but of 120 tons per hr.
Jacket water cooler	One tubular 150 tons per hr.	As 1	As 1 but of 120 tons per hr.
Sea water pump	One engine-driven, 200 tons per hr. plunger type: ballast pump as a standby	As 1	As 1
Forced lubricating oil pumps	One engine-driven 33 tons per hr. plunger type	As 1	As 1, but of 60 tons per hr. capacity
	One motor-driven standby pump		
Lubricating oil cooler	One tubular, 33 tons per hr.	As 1	One tubular 60 tons per hr. (for lubrication and lower piston cooling)
Valve cooling water pumps	Two steam-driven horizontal plunger pumps, 3 tons per hr.	As 1	As 1
Manœuvring air compressors	Two 100 cu. ft. per min.: three stage type: electric motor drive	As 1	As 1
Air storage tanks	Two 110 cu. ft. 600 lb. per sq. in. working pressure	As 1	As 1
Centrifuges: fuel oil	One 300 gals. per hr.	Two 300 gals per hr. (for boiler fuel)	Two 300 gals. per hr. (for boiler fuel)
lubricating oil	One 300 gals. per hr.	Two 300 gals. per hr.	One 300 gals. per hr.
Ship's Service Auxiliaries			
Ballast pump	One motor-driven 250 tons per hr., centrifugal type	As 1	As 1
General service pumps	One motor-driven 40 tons per hr., Duplex	As 1	As 1
Bilge pump	One motor-driven 40 tons per hr., Duplex	As 1	As 1
Oil fuel transfer pump	Two motor-driven 20 tons per hr. rotary displacement type	As 1	As 1
Electric generators	Two Diesel sets, 100 kW	As 1	As 1
	One steam-driven 40 kW	As 1	As 1
Boiler	One vertical oil fired or exhaust gas, 900 sq. ft., 120 lb. per sq. in.	As 1	As 1
Feed pump	One, 500 gals. per hr.	As 1	As 1
Condenser	One, 250 sq. ft.	As 1	As 1
Evaporator	One, 10 tons per day	As 1	As 1
Feed heater	One, 20 sq. ft.	As 1	As 1

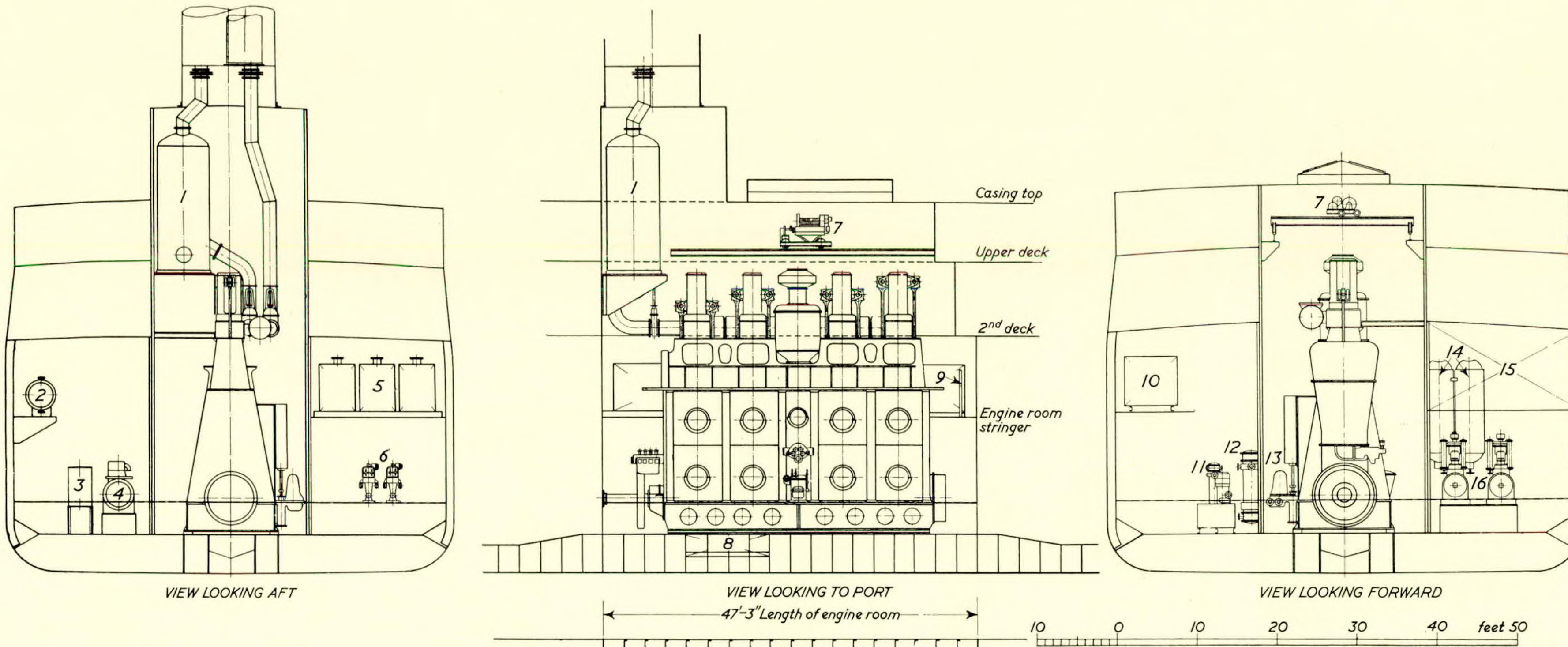
actual tonnage of this space, which resulted in a higher nett register tonnage and consequently in higher port and canal dues based on the nett tonnage. This penalty at 13 per cent has been eliminated, and the reduction in tonnage for small engine rooms is graduated so that if the machinery space be 10 per cent of the gross tonnage of the vessel then the allowance for nett tonnage is now ten-thirteenths of the 32 per cent reduction.

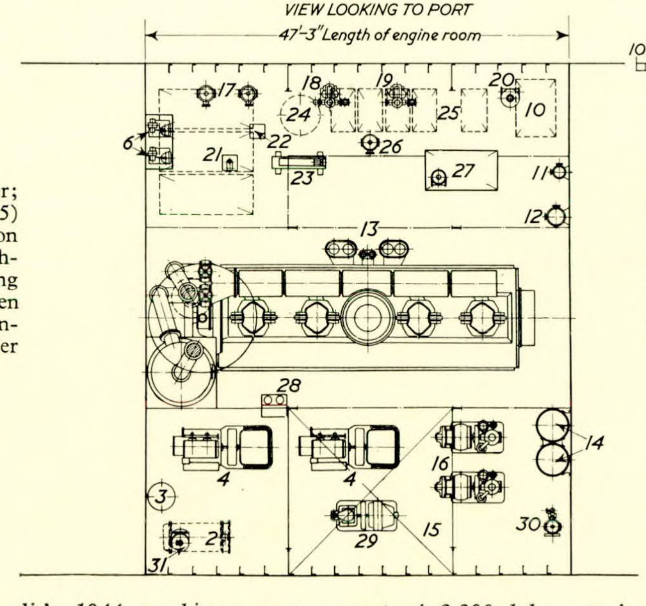
In view of this, the suggestion has been made that consideration should be given to reducing the space taken by the engine rooms of two types of vessel. Taking the smaller of these first:—

VESSEL A—8,000-TON CARGO VESSEL OF 12½ KNOTS

This vessel had a 3,340 h.p. engine installed running at 110 r.p.m. This power was on the basis of an all-riveted vessel and recent research and experience has shown that the power can be reduced for all-welded vessels. The engine room of the vessel when built was 51ft. 6in. long, but in a symposium to this Institute in June 1944, on "The Engining of Post-War Cargo Vessels of Low Power", Mr. W. H. Purdie showed three arrangements of engine rooms, each with a Doxford engine of 3,300 b.h.p. but varying auxiliary machinery, each engine room arrangement having a length of 47ft. 3in. The weight of the main engine was given as 245 tons and the total weight of machinery installed including spare gear and auxiliaries was 535 tons for the second proposal with two Diesel electric and one steam driven auxiliary. This will be used as a basis for consideration of the present vessel and the possibilities of reducing engine room length. Fig. 28 shows this machinery installation and Table IX, column 1, gives a summary of the weights, fuel consumptions and dimensions of this installation and Table X a summary of the engine and service auxiliaries proposed. No specification is given of the auxiliaries of Vessel A, nor is any weight given for the engine room machinery as fitted.

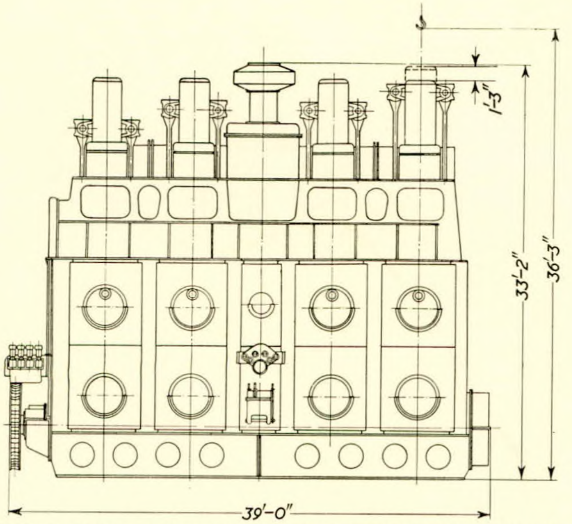
The engine shown by Mr. Purdie in 1944 was a four-cylinder Doxford engine of 600 mm. bore × 2,320 mm. combined stroke, having a central scavenging pump. Many installations of this type have been made in the intervening years but in general a somewhat increased engine room length has had to be allowed, since the shipowners required increased sizes of auxiliaries or additional auxiliaries or a different arrangement of machinery, so that the average length of the engine rooms of these installations has been about 51 feet. It would be interesting to have a list of the auxiliaries fitted in Vessel A,



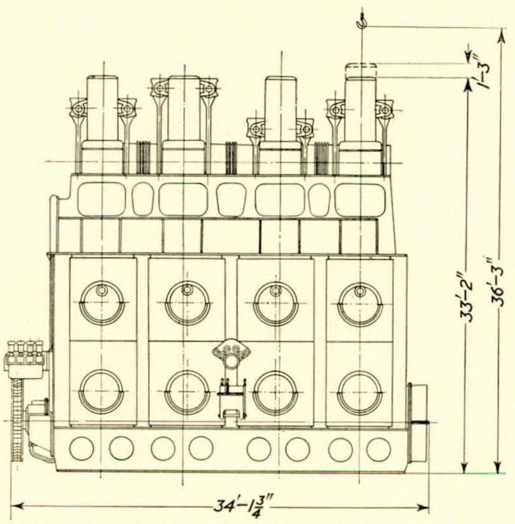


(1) Clarkson composite boiler; (2) Auxiliary condenser; (3) Float control drain tank; (4) 100-kW generator; (5) Fuel oil tanks; (6) Sharples centrifuges; (7) Six-ton electric crane; (8) Lubricating oil drain tank; (9) Switchboard; (10) Jacket water storage tank; (11) Lubricating oil cooler; (12) Jacket water cooler; (13) Engine driven pumps; (14) High pressure air storage tanks; (15) Engineers' store; (16) Starting air compressors; (17) Oil transfer pumps; (18) Bilge pump; (19) General service pump; (20) Ballast pump; (21) Drilling machine; (22) Grinder; (23) Lathe; (24) Lubricating oil cleaning tank; (25) Five lubricating oil storage tanks; (26) Standby lubricating oil pump; (27) Standby jacket water pump and suction tank; (28) Valve cooling water tank and pumps; (29) 40-kW steam-driven generator; (30) Steam-driven emergency air compressor; (31) Evaporator.

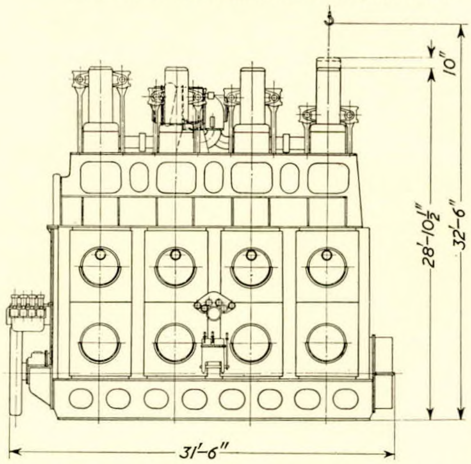
FIG. 28—*Mr. W. H. Purdie's 1944 machinery arrangement of 3,300 b.h.p. engine with Diesel and steam electric auxiliaries*



A. 4 CYLINDER 600 x 2,320 ENGINE WITH CENTRAL SCAVENGE PUMP. ENGINE WEIGHT, 245 TONS



B. 4 CYLINDER 600 x 2,320 ENGINE WITH LEVER DRIVEN SCAVENGE PUMPS. ENGINE WEIGHT, 230 TONS



C. 4 CYLINDER 520 x 2,080 ENGINE. ENGINE WEIGHT, 190 TONS

FIG. 29—*Doxford engines of 3,300 b.h.p.; (A) central scavenging pump; (B) two lever-driven pumps; and (C) supercharged engine*

since these must determine the length of 51½ feet. The length of the six-cylinder supercharged B. and W. engine of 3,340 b.h.p. was about 42 feet. The length of the four-cylinder Doxford engine was 39 feet.

In 1946, the 600-mm. bore Doxford engine was redesigned with reduced cylinder centres and with lever driven scavenging pumps instead of the central scavenging pump fitted to the engine shown in the machinery installation of Fig. 28. Fig. 29 shows a comparison of the lengths of these engines, from which it will be seen that the engine with lever pumps is 5 feet shorter and with this shorter engine it has been found that the length of the engine room has been determined by the auxiliary machinery.

Auxiliary Machinery (listed in Table X)

The power of the electric auxiliary machinery fitted in ships has been gradually increased over the past decade to provide better services for the crew and passengers, and an increased use of electrically driven pumps instead of engine driven pumps. On the other hand, the average speed of auxiliary Diesel generator sets has increased from about 400 r.p.m. to 600 r.p.m. and it is only by further increases in speed, or rating, or by more compact design that further reduction in the length of the electric generator sets can be achieved. In general a long stroke engine is the most suitable for Diesel auxiliary sets, since it will have a slower speed and be shorter in length than a squarer engine of larger bore. Similarly, engines of few cylinders are shorter in length, involve less maintenance, and operate at slower speeds with less noise. The average power of the auxiliary generator sets of modern cargo vessels of the type under consideration is between 100 and 150 kW and generally five- or six-cylinder engines are installed running at 500/600 r.p.m. High-speed engines are now available for this power, running up to 1,000 r.p.m. and even at 750 r.p.m. there is an appreciable saving in length. If instead of six-cylinder engines, three-cylinder engines be adopted running at 600 r.p.m., then the saving in length is appreciable. High-speed engines are more noisy than slow-speed engines, and they are not so reliable. The auxiliary engines are frequently the most noisy machinery on a ship. Fig. 30 shows a typical drawing of a war-time 120 kW set having five cylinders in line and for comparison a three-cylinder engine of modern rating showing a reduction in length of over 8 feet. These seem to be the only ways of reducing the length of the Diesel electric auxiliaries and with regard to other auxiliaries, vertical pumps occupy less space than horizontal pumps, and steam driven vertical tandem compressors occupy less space than motor driven two-cylinder types.

An alternative is to rearrange the engine room so that the electrical auxiliaries are placed on a flat at about camshaft platform level of the main engine and, while entailing rather more substantial construction of the upper floor of the engine room, such an arrangement does enable the length of the engine room to be reduced.

Supercharging

Although there has been considerable progress in the supercharging by exhaust gas turbo blower of the two-cycle engine in the past few years it is Doxford's opinion that the scope for the supercharged engine is in the higher powers. Should a shipowner really require to reduce the space and weight of machinery as much as possible, a supercharged engine could be installed in Vessel A to show a further reduction of nearly 3 feet in the length of the engine (Fig. 29). A standard Doxford engine having four cylinders of 520 mm. diameter × 2,080 mm. stroke, could be supercharged, showing a reduction in weight as in column 3, Table IX, of some 40 tons, and a further reduction in length of the engine room of 3 feet. A machinery installation showing this engine is outlined in Fig. 31, giving an overall machinery space of 40 feet.

Propeller Speed

It will have been appreciated that there is a tendency for propeller speeds to increase, owing to engine room machinery

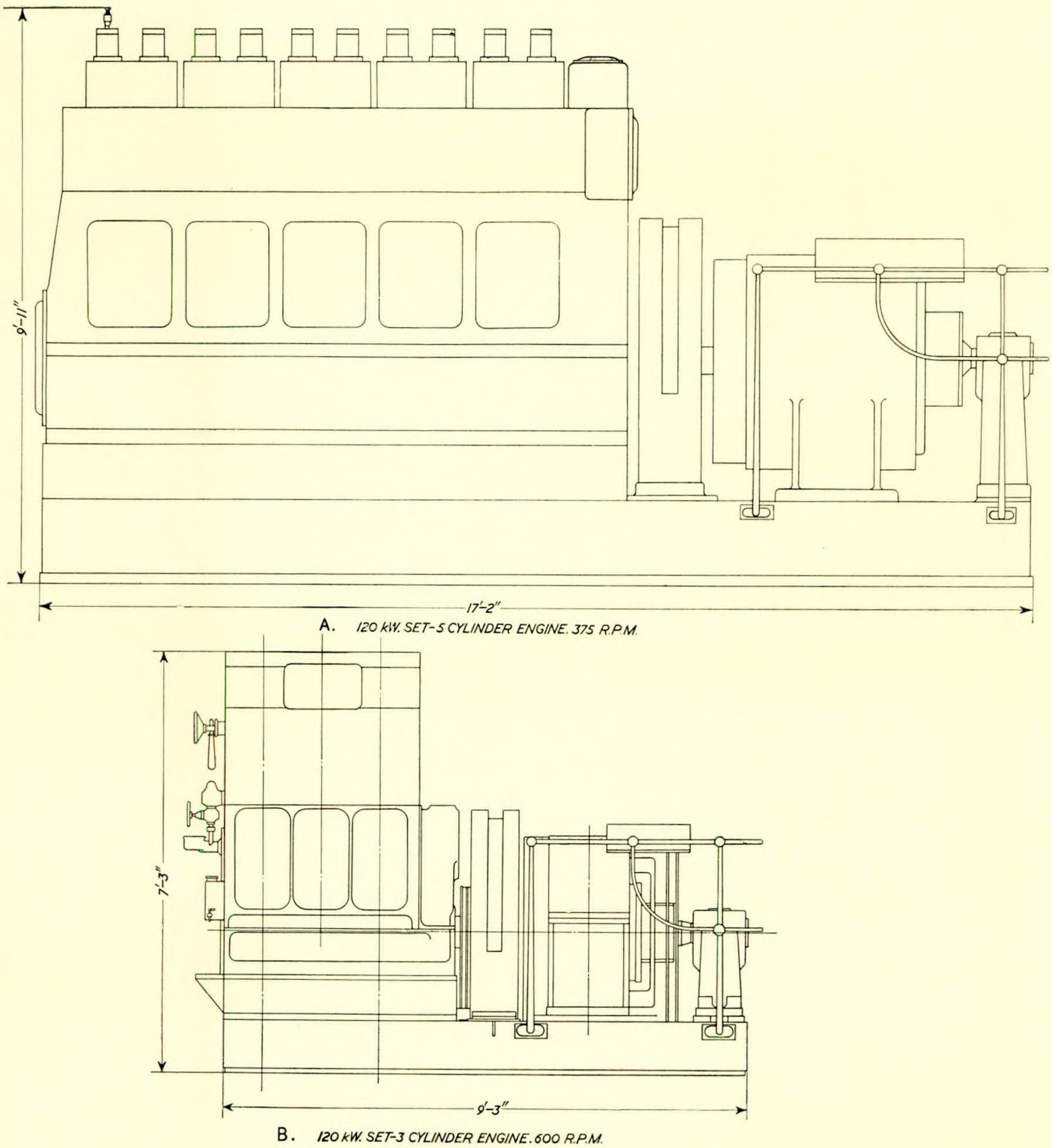


FIG. 30—*Diesel electric auxiliaries of 120 kW (A) 5-cylinder 375 r.p.m.; (B) 3-cylinder 600 r.p.m.*

being of lighter weight and occupying less space at higher revolutions. It is usually considered that about 90 r.p.m. is the most efficient speed for a propeller and that there is a drop in propeller efficiency of approximately 1 per cent for every five revolutions per minute over this most economical speed. A rough empirical rule occasionally applied is that the speed of the propeller in revolutions per minute should be ten times the speed of the ship in knots, so that with the increase in the speed of ships, there has been a tendency for propeller speeds also to increase. It is now almost universal practice for models of ships to be run in a model testing tank, and the most efficient propeller for a vessel of given speed to be determined. During recent years many vessels have been propelled by Doxford engines running at 116/118 r.p.m. and some three years ago a model was tested on the basis of the propeller running up to 130 r.p.m. and there was no more than a 0·1 knot drop in speed relative to a propeller running at 117 r.p.m. for the same vessel.

Economy of Operation

The fuel consumption of all the schemes of 3,300 s.h.p. put forward for Vessel A would be under 13 tons of boiler fuel oil per day for all purposes and 12 gallons of lubricating oil per day. With 220 days a year at sea, this gives an annual fuel consumption of 3,000 tons. Cargo vessels are usually fitted with bunkering capacity for eighty days of fuel, but if bunkers be carried for sixty days, the weight of the fuel is 780 tons. Large slow-speed direct propulsion engines can nowadays operate on boiler fuel at an average price of approximately 142 shillings per ton, and the cost of fuel per year, therefore, is some £21,000. Similarly, the annual consumption of lubricating oil of the Doxford direct drive machinery is about 12 tons of straight mineral oil of inexpensive non-detergent type.

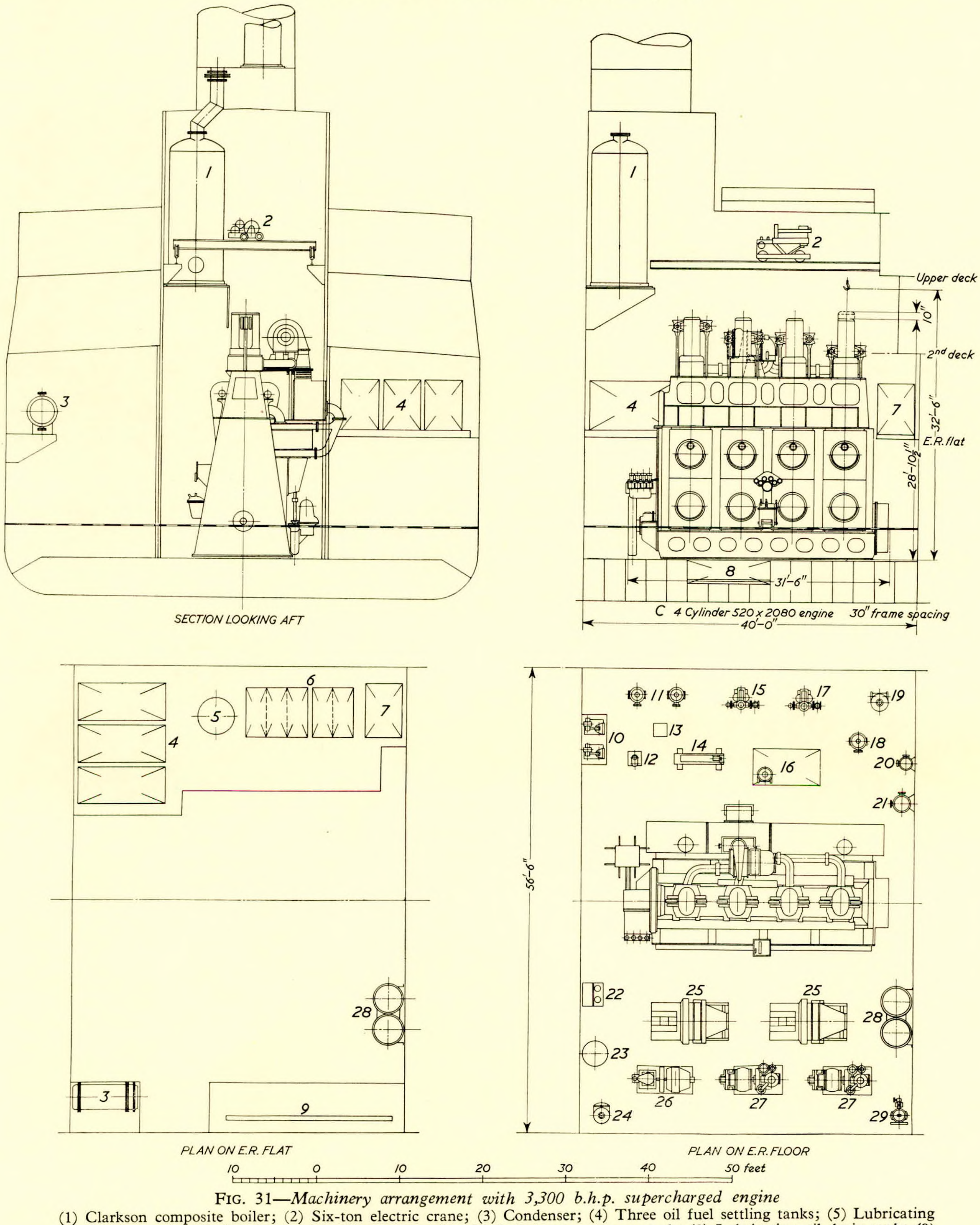
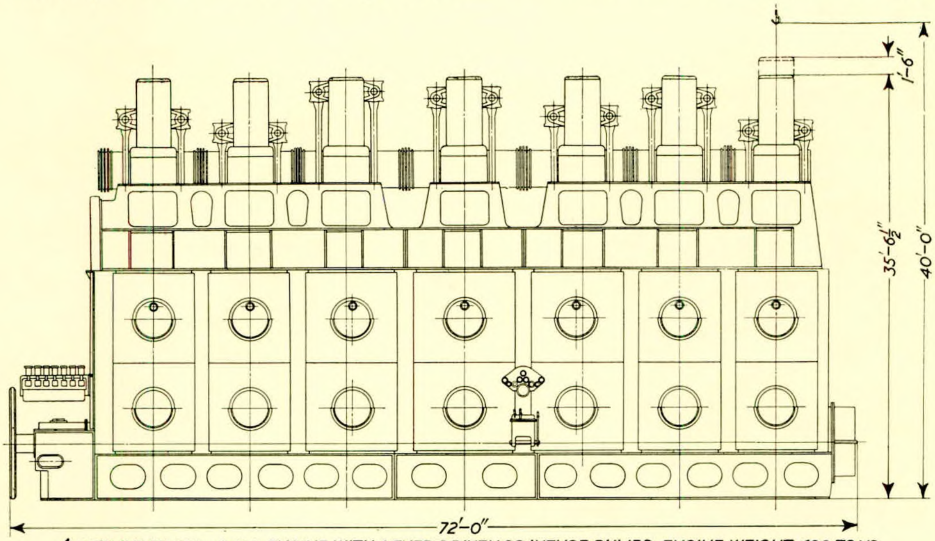
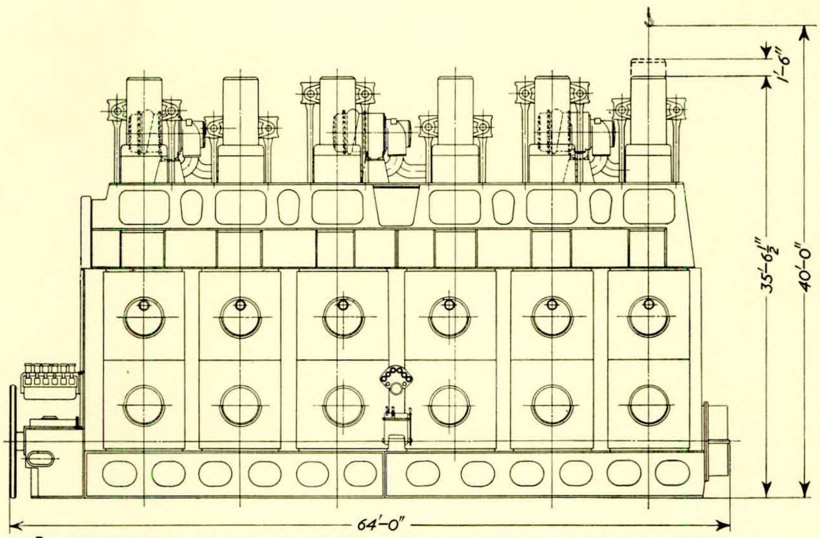


FIG. 31—*Machinery arrangement with 3,300 b.h.p. supercharged engine*

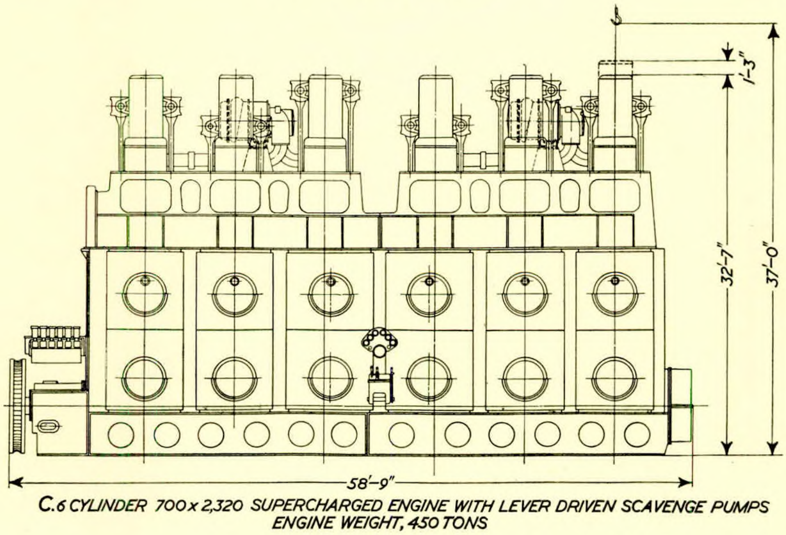
(1) Clarkson composite boiler; (2) Six-ton electric crane; (3) Condenser; (4) Three oil fuel settling tanks; (5) Lubricating oil cleaning tank; (6) Five lubricating oil storage tanks; (7) Jacket water storage tank; (8) Lubricating oil drain tank; (9) Switchboard; (10) Sharples centrifuges; (11) Oil fuel transfer pumps; (12) Driller; (13) Grinder; (14) Lathe; (15) Bilge pump; (16) Jacket water unit; (17) General service pump; (18) Lubricating oil pump; (19) Ballast pump; (20) Lubricating oil cooler; (21) Jacket water cooler; (22) V.C.W. unit; (23) Control drain tank; (24) Evaporator; (25) 120-kW generators; (26) Steam generator; (27) Two air compressors; (28) Air storage tanks; (29) Steam-driven emergency air compressor.



A. 7 CYLINDER 750 x 2,500 ENGINE WITH LEVER DRIVEN SCAVENGE PUMPS. ENGINE WEIGHT, 600 TONS



B. 6 CYLINDER 750 x 2,500 SUPERCHARGED ENGINE WITH LEVER DRIVEN SCAVENGE PUMPS.
ENGINE WEIGHT, 550 TONS



C. 6 CYLINDER 700 x 2,320 SUPERCHARGED ENGINE WITH LEVER DRIVEN SCAVENGE PUMPS
ENGINE WEIGHT, 450 TONS

FIG. 32—*Doxford engines of 10,500 b.h.p.*
(*A*) *7-cylinder engine 750 × 2,500*
(*B*) *6-cylinder engine supercharged 750 × 2,500*
(*C*) *6-cylinder engine supercharged 700 × 2,320*

VESSEL B—10,600-TON CARGO LINER OF 16½ KNOTS

Vessel B was powered by 10,500 s.h.p. machinery to give a loaded service speed of 16½ knots for an all-riveted vessel. For a welded vessel a service speed of 16½ knots would be given by a power of under 10,000 s.h.p. In the past, prior to supercharging, a power of 10,500 s.h.p. would not have been an easy proposition for a Doxford installation, although an offer might have been made of a seven-cylinder engine of 750 mm. bore × 2,500 mm. stroke at 110 r.p.m. Such an engine has never been built although proposals have been put forward. This engine would weigh 600 tons, and its length as shown in Fig. 32 would be 72 feet.

In view of the recent developments of supercharging the Doxford engine, a power of 10,500 h.p. does become a proposition, and an offer can be put forward with a six-cylinder 700 mm. bore × 2,320 mm. stroke engine, running with 33 per cent supercharge to give 10,000 h.p., which would give the required speed for this vessel with a welded hull. Alternatively, a six-cylinder engine of 750 mm. bore × 2,500 mm. stroke supercharged only 17 per cent could be put forward to give 10,500 b.h.p. with an engine weight of 550 tons and an engine length of 64 feet, as shown in Fig. 32. Tabulated particulars of these three engines are shown in Table XI. While at the present time the larger supercharged engine would probably be chosen; as experience with supercharged engines grows and greater confidence is given by satisfactory operation, the 700-mm. bore engine being lighter and more compact will be chosen. A machinery layout for the six-cylinder 700-mm. bore engine is shown in Fig. 33, showing an engine room length of 65 feet. Once more the auxiliaries determine the length of the engine room.

The author is of the opinion that the development of the slow-speed direct drive Diesel engine has not reached finality, and it is more than possible that within the next few years an engine of opposed-piston type will be developed which will have the effect of further reducing engine room length and weight of machinery. Shipowners tell us that it is necessary to reduce weight as well as space, since a vessel is frequently down to its marks before the holds are full, in view of the proportion of heavy machinery now being exported. It will

TABLE XI.—DIRECT DIESEL DRIVE PROPOSALS (DOXFORD MACHINERY) FOR TWO-CYCLE OPPOSED PISTON CROSSHEAD ENGINES FOR 10,600-TON CARGO LINER, 16½ KNOTS

	1 7 cylinder engine 750×2,500, unsupercharged	2 6 cylinder engine 750×2,500, supercharged	3 6 cylinder engine 700×2,320 supercharged
Engine distinguishing features			
Engine speed, r.p.m.	110	110	115
Ship's service speed, port to port, knots	16½	16½	16½
S.H.P.	10,500	10,500	10,000
M.I.P.	90	103	115
B.M.E.P.	79	93	104
Piston speed (mean), ft. per min.	900	900	875
Type of auxiliary machinery	Two Diesel electric and one steam set: electric steering and winches	As 1	As 1
Weights			
Main engines complete with thrust blocks, tons	600	550	450
Spare gear, including C.I. propeller and tail shaft, tons	35	34	32
160 feet of shafting and propeller, bearings and couplings, etc., tons	180	180	175
Auxiliary machinery, including Diesel generators, boilers, funnel, silencers, gratings, ladders and switchboard, tons	220	220	215
Tanks: pipes with valves and fittings for bilge, ballast, steam, water, and oil systems, tons	135	130	125
Water and oil in engine and boilers, tons	25	22	20
Total weight, tons	1,195	1,136	1,017
Dimensions			
Length of main engine	72 ft.	64 ft.	58 ft. 9 in.
Length of engine room required, feet	80	72	65
Casing required above upper deck, feet	76×20	68×20	62×20
Height required for overhauling above tank top, feet, to crane hook	40	40	37
Fuel consumption per day at sea, tons	41	39½	39½
Auxiliaries per day at sea, tons	1¼	1¼	1¼
Auxiliaries per day in port, tons, including heating from boiler heated by exhaust of auxiliary engines and immersion heater	2	2	2
Total annual consumption 220 days at sea +145 days in port, tons	9,600	9,300	9,300
Lubricating oil per day, gals.	32	32	27
Weight of fuel to be carried for 60 days, tons	2,540	2,450	2,450
Weight of lubricating oil to be carried for 100 days, tons	12¾	12¾	11½
Total weight of machinery, fuel and lubricating oil, tons	3,748	3,599	3,479
Tonnage of engine room spaces below upper deck	1,600	1,440	1,320
Tonnage of total spaces framed in above the upper deck for propelling machinery and for light and air, tons	400	360	330

have been appreciated that the greatest saving in length can usually be made by using an engine with the smallest number of cylinders.

Auxiliary Machinery (listed in Table XII)

The Diesel engine generator sets in this case are of larger size and engines of a different type are worthy of consideration. During recent years several engine manufacturers have developed more compact types of engines by adopting a V-type of construction and also have supercharged the engines to obtain a higher rating.

Such engines are manufactured by W. H. Allen and Co., Ltd., Mirrlees, Bickerton and Day, Ltd., The National Gas and Oil Engine Co., Ltd., Davy Paxman and Co., Ltd., and others, and if engines of this type be considered for the present proposition, there can be a saving in length on each generator set of over 6 feet (Fig. 34). Sets of supercharged type are shown in Fig. 33.

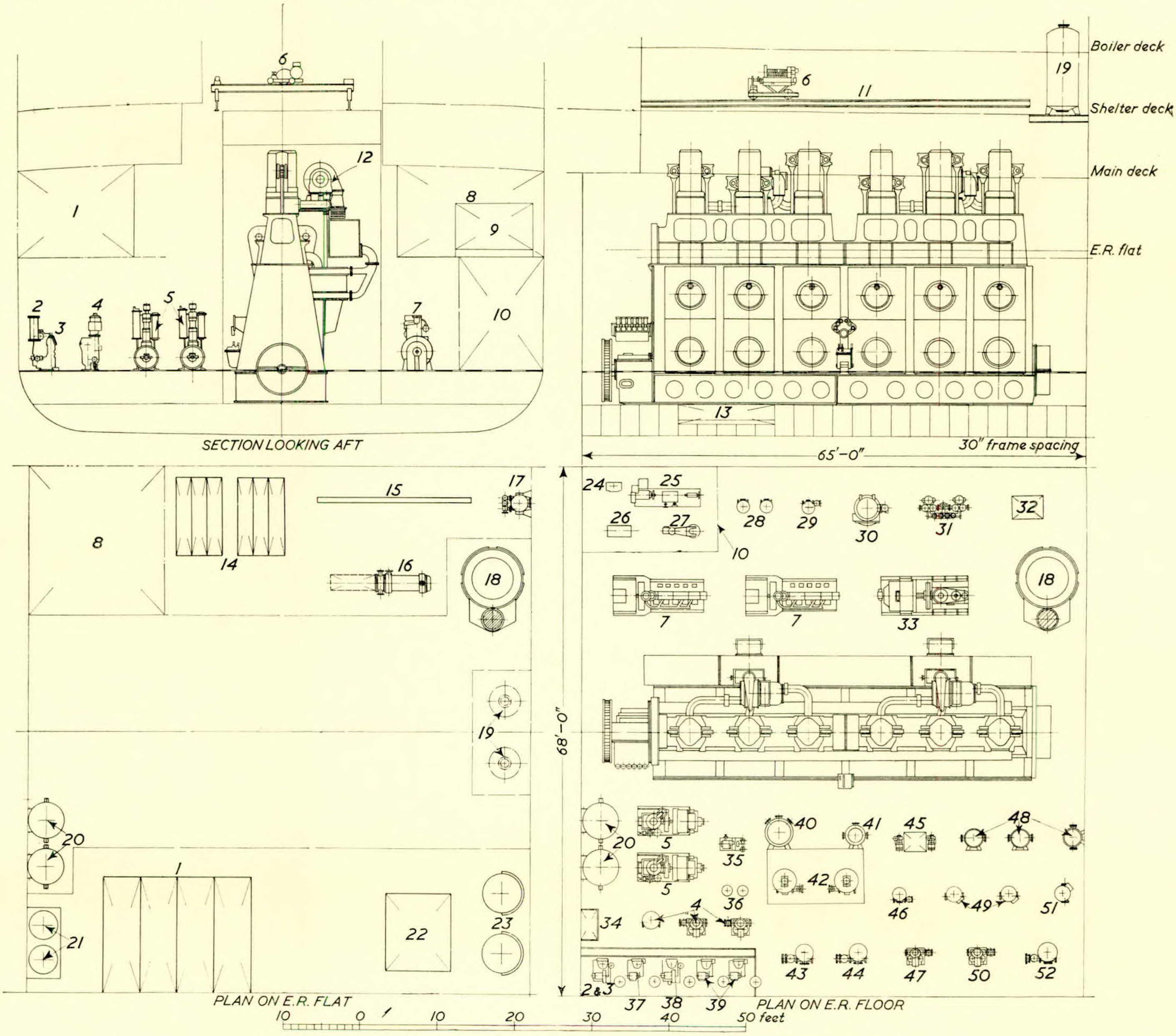
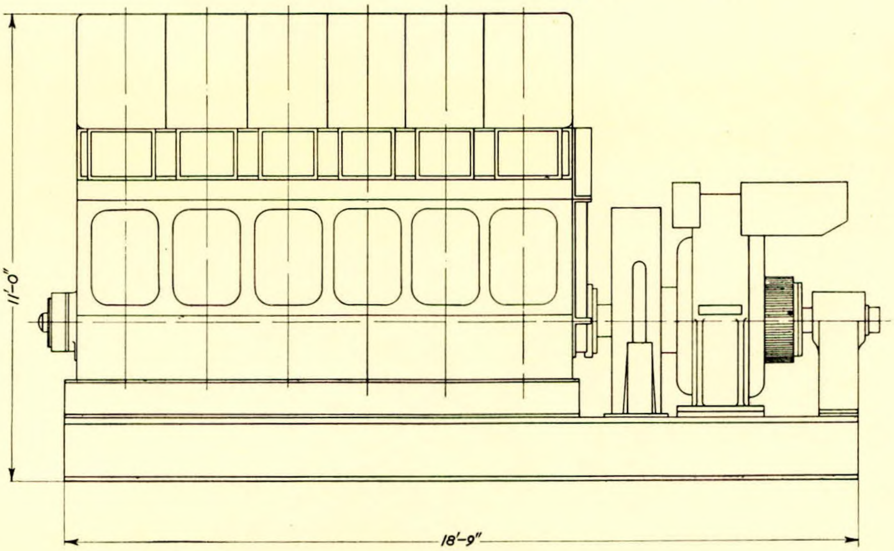
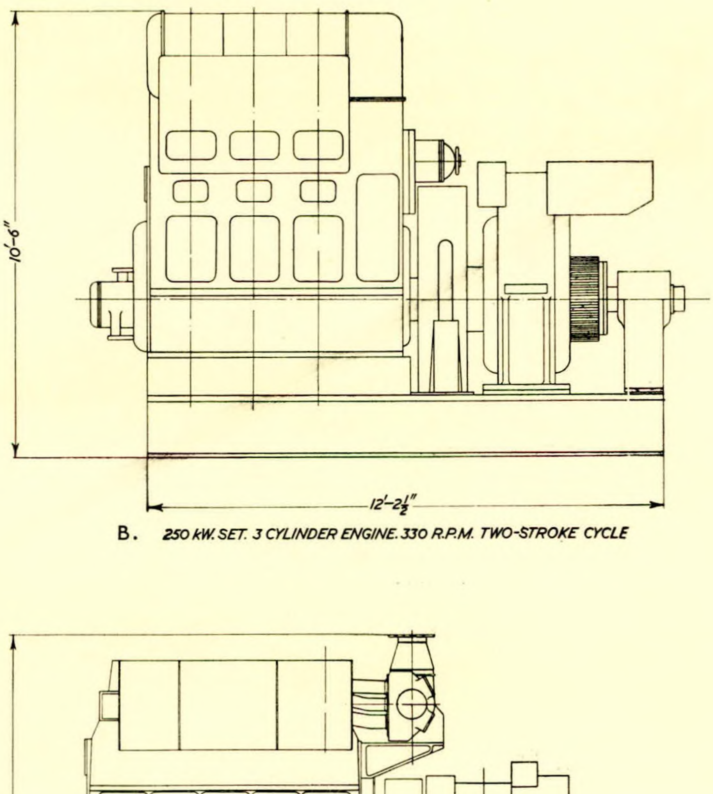


FIG. 33—*Machinery arrangement with 10,000 b.h.p. supercharged engine*

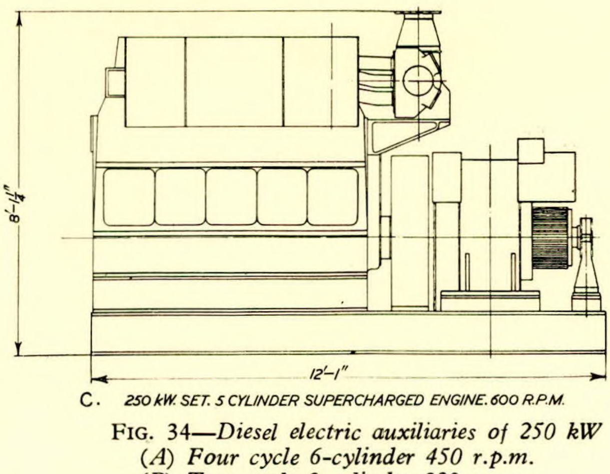
(1) Built-in fuel oil settling tanks; (2) Heaters; (3) H.O. purifiers; (4) Transfer pumps; (5) Air compressors; (6) Six-ton electric crane; (7) 250-kW generators; (8) Engineers' store; (9) Lubricating oil storage tanks; (10) Engineers' workshop; (11) Crane rail; (12) Superchargers; (13) Lubricating oil drain tank; (14) Six lubricating oil storage tanks; (15) Switchboard; (16) Condenser; (17) Feed heater; (18) Cochran composite boiler; (19) Two exhaust gas boilers at shelter deck height; (20) Air storage tanks; (21) F.W. system pressure tanks; (22) Jacket water storage tank; (23) Two lubricating oil cleaning tanks; (24) Grinder; (25) Lathe; (26) Shaper; (27) Drilling machine; (28) Domestic fresh water pumps; (29) S.W. circulating pump; (30) Evaporator; (31) Boiler feed pumps; (32) Feed filter and float tank; (33) 150-kW steam generator; (34) Maintenance bench with oiltight tray top for cleaning purifier bowls; (35) Emergency Diesel-driven air compressor; (36) Domestic fresh water pumps; (37) Heavy oil clarifier and heater; (38) Dual purpose purifier and heater; (39) Two lubricating oil purifiers and heaters; (40) Jacket water cooler; (41) Piston water cooler; (42) Jacket and piston water unit; (43) Standby S.W. circulating pump; (44) S.W. circulating pump; (45) V.C.W. unit; (46) Sanitary pump; (47) Bilge and fire pump; (48) Three lubricating oil coolers; (49) Two lower piston oil cooling pumps; (50) General service pump; (51) Lubricating oil pump; (52) Ballast pump.



A. 250 kW. SET. 6 CYLINDER ENGINE. 450 R.P.M. FOUR-STROKE CYCLE



B. 250 kW. SET. 3 CYLINDER ENGINE. 330 R.P.M. TWO-STROKE CYCLE



C. 250 kW. SET. 5 CYLINDER SUPERCHARGED ENGINE. 600 R.P.M.

FIG. 34—*Diesel electric auxiliaries of 250 kW*
(A) Four cycle 6-cylinder 450 r.p.m.
(B) Two cycle 3-cylinder 330 r.p.m.
(C) Four cycle 5-cylinder supercharged 600 r.p.m.

TABLE XII.—ENGINE ROOM AUXILIARIES FOR 10,600-TON CARGO LINER

Two Diesel generator sets of 250 kW.
One steam generator set of 150 kW.
One Cochran boiler composite type (exhaust gas heated and oil fired, 7,000 lb. steam per hr. at 120 lb. per sq. in.).
Two Clarkson or alternate fired exhaust gas boilers for auxiliaries (400 lb. steam per hr., each fitted with immersion heater unit).
One auxiliary condenser, 400 sq. ft.

Engine service auxiliaries
Thrust block, shaft, turning gear, included with main engine in Table XI.
Tunnel shafting, bearings, tailshaft, liner and stern tube and propeller included in Table XI.
Engine room floors, gratings, ladders, ventilators, exhaust pipes, funnel, tools, chocks, etc., included in Table XI.
One 6-ton electric crane.
Two air compressors, motor driven. 175 cu. ft. air per min. to 600 lb. per sq. in.
One auxiliary air compressor, Diesel driven: 20 cu. ft. air per min. to 350 lb. per sq. in.
Two starting air receivers: 150 cu. ft., 600 lb. per sq. in.
Two jacket cooling water and upper piston water pumps, motor driven: vertical centrifugal: double duty 300 tons per hr. and 100 tons per hr.
Two sea water pumps, motor driven: vertical centrifugal 600 tons per hr., one as standby.
{Forced lubricating oil pump: positive rotary displacement type.
Two lower piston cooling oil pumps: positive rotary displacement type. 75 tons per hr. (any two pumps to do these duties).}
One jacket water cooler, 300 tons per hr.
One upper piston water cooler, 100 tons per hr.
Three lubricating oil coolers, 75 tons per hr. (any two to serve lubricating oil and lower piston oil).
One h.p. fuel priming pump, C.A.V. 4 cylinder B.
Two fuel transfer pumps, 25 tons per hr.
One Diesel oil transfer pump, 15 tons per hr.
One auxiliary sea water circulating pump, 40 tons per hr.
Two fuel valve cooling pumps, 5 tons per hr.
One heavy fuel oil purifier }
One heavy fuel oil clarifier } 5 tons per hr. (one standby for either service).
One dual purpose }
Two fuel oil heaters.
Two lubricating oil purifiers, 3 tons per hr.
One lubricating oil heater.
Two boiler feed pumps, steam driven, 4 tons per hr.
One feed water heater, 4 tons per hr.
One evaporator, 10 tons per day.
One distiller, 3,000 gals. per day.
Fuel, lubricating oil and water tanks.
Switchboard, cables and wiring.
Lathe, driller, shaper, grinder—electric driven.

Ship's service auxiliaries
Ballast pump, motor driven, vertical centrifugal, 600 tons per hr.
One general service pump: motor-driven, 100 tons per hr.
One fire and bilge pump: motor-driven, 100 tons per hr.
One sanitary pump, 70 tons per hr.
Two domestic fresh water pumps, 10 tons per hr.
Fresh water tank, etc.

The daily fuel consumption of Vessel B with direct drive Diesel machinery would be under 40 tons per day, which on 220 days a year at sea is under 9,000 tons per year. The fuel consumption in port for two 250 kW Diesel sets during the day and one at night would not exceed 2 tons per day, including domestic heating and hot water from the exhaust of the auxiliaries aided by an immersion heater. With the main engine operating on boiler oil, the fuel bill per year would thus be some £66,000, and the weight of fuel to be carried for sixty days' bunkers would be 2,450 tons.

INFLUENCE OF THE MODIFIED TONNAGE LAWS

It will be seen from the figures given at the bottom of Tables IX and XI that the tonnage of the engine room spaces exceeds 13 per cent of the gross tonnage for both Vessels A and B for all proposals. The modified tonnage laws are of no benefit to direct slow-speed engine propulsion for cargo vessels of the types chosen.

CONCLUSION

It is claimed that for both low powered cargo vessels and for the higher powered cargo liner up to 13,000 s.h.p. the direct drive Diesel engine is the most economical proposition with regard to first cost and machinery weight, and certainly with regard to economy of operation, and the development of supercharging to the large two-cycle Diesel engine has introduced this type of machinery to the larger vessels.