THE UNIVERSITY OF MICHIGAN

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RECENT JAPANESE DEVELOPMENTS IN LARGE DIESELS FOR SHIP PROPULSION

By

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I. INTRODUCTION

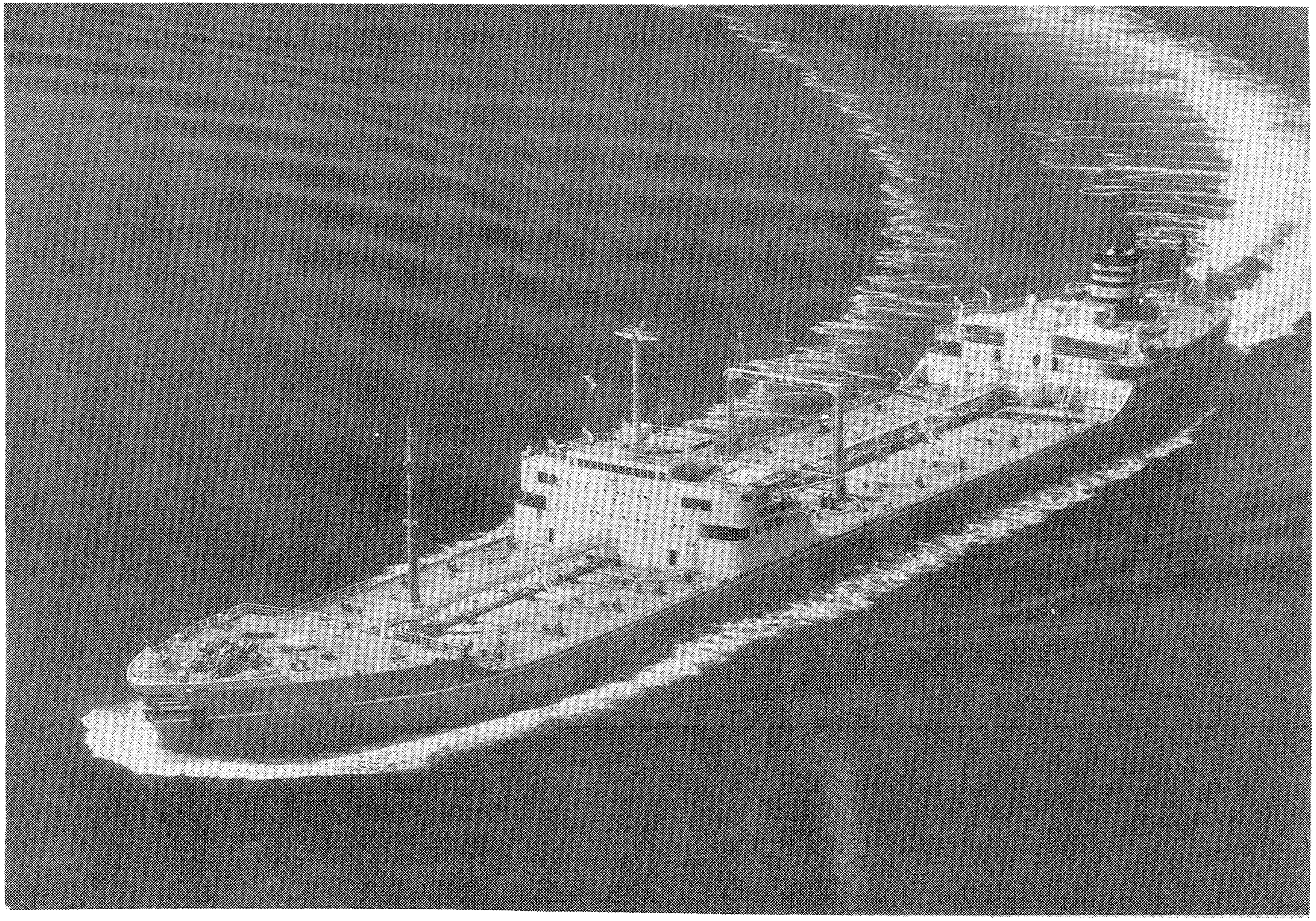
In recent years the large diesel engine has been the major power plant for ocean going ships built outside the United States. It is interesting to speculate on why the direct connected diesel has not gained popularity in this country. Since the author is not in a position to make any evaluation of the American attitude, this paper will describe a large diesel tanker installation and present its advantages as the author sees them.

The following quotation indicates the growing demand for ever increasing powers in merchant ships[1]:

"The accepted classes of large super-tankers (excluding the few of 85,000 and 100,000 DWT tons) now seem to be vessels of 33,000 DWT ton, 45,000 DWT ton and 65,000 DWT ton respectively. It still remains uncertain, in view of their special design characteristics, what power is required to give the larger of these large ships a speed of 14-1/2 to 16 knots, which, when all the technical and commercial considerations are satisfied, appears to be the most appropriate. Broadly speaking, however, apart from the case in which exceptional speed is demanded for special reasons, the power for the three types will be in the neighborhood of (1) 12,500-15,000 BHP (2) 15,000-20,000 BHP (3) 20,000-25,000 BHP respectively."

Because of the increase in available horsepower, savings are expected by employment of diesel propulsion. It has been increasingly demonstrated by the Japanese shipyards that the consumption of fuel oil used on a turbine tanker, over the ship's lifetime, becomes at least 50% greater than that of a corresponding diesel engine vessel using similar fuel.

With high rewards for efficiency in prospect, tanker owners must give the closest consideration to the employment of Diesel engines in the largest ships, provided reliable machinery of the requisite power is available.[1] Large numbers of diesel tankers are now on order in Japan, which, for the most part, are to be provided with turbochargers in order to raise charging pressures 30 to 50% with corresponding engine power increases of 40 to 50%. Plans are now being prepared in Japan for constructing a 840 MM (33") bore, 12-cylinder engine with a service output of 20,000 BHP. Also plans are in process for an 8-cylinder opposed-piston engine with a cylinder diameter of 880 MM (34.6"). Besides these, there are several tankers of between 40,000 and 50,000 DWT tons with twin-screw diesel machinery of 22,500 BHP (total).



15,000 BHP DIESEL TANKER "YUYO-MARU NO. 5" ON TRIALS

II. COMPARISON OF STEAM AND DIESEL FUEL OIL CONSUMPTION

In order to demonstrate some of the advantages of diesel machinery for high-powered vessels, there follows a comparison between a turbine and a diesel tanker, both of which were recently built by the author's company.

<u>Turbine</u>

Type	33,000 DWT tanker
Main engine	All impulse turbine and double reduction gear
Output, Continuous Maximum Service	15,000 SHP @ 108.5 RPM 12,750 SHP @ 102 RPM
Speed, Service	15-1/2 Knots
Steam conditions (superheater outlet)	454°C (848°F), 42 Kg/Cm^2 (596 Psig)
Boiler efficiency	88%
HP turbine revolution	6,474 RPM (at 15,000 SHP)
LP turbine revolution	4,257 RPM (at 15,000 SHP)
Turbine, condenser and boiler -- weight	410 Tons
Plant weight*	1,236 Tons
Fuel oil consumption at Service Output	243 g/SHP/Hr (0.535 lbs/SHP/Hr) 70.55 Ton/Day (155,000 lbs/Day) Low calorific value 10,000 Kcal/Kg (18,000 BTU/lb)

* Weights include hull engineering and electrical items.

Diesel

Type	33,000 DWT tanker
Main engine	HITACHI B&W (Buremeister & Wain) 1274VTBF-160 type 2-cycle airless injection diesel engine with turbochargers
Output, Continuous Maximum	15,000 BHP @ 115 RPM
Service	12,750 BHP @ 109 RPM
Speed, Service	15-1/2 Knots
Diesel weight (including thrust block)	565 Tons
Plant weight*	1,480 Tons
Fuel oil consumption at Service Output	
Main engine	160 g/BHP/Hr (0.352 lbs/BHP/Hr)
Diesel generator (at Service)	175 g/BHP/Hr (0.385 lbs/BHP/Hr)
49 Ton/Day, (108,000 lbs/Day)	1.0 Ton/Day respectively (2,200 lbs/Day)

*Weights include hull engineering and electrical items.

If it is assumed that both vessels are running from the Far East to Japan, carrying oil (an 18-day trip), a comparison of fuel oil consumption is as follows:

Turbine	Diesel
70.55 Tons (155,000 lbs) x 18 days --- 1,270 Tons (2,794,000 lbs)	Main engine -- 49 Tons (108,000 lbs) x 18 days -- 888 Tons (1,950,000 lbs)
	Diesel generator - 1.0 Ton (2,200 lbs) x 18 days - 18 Tons (39,000 lbs)
	Total 900 Tons (1,990,000 lbs)

Therefore, the grand total of plant weight, including fuel oil consumed, is:

Turbine		Diesel	
Plant weight --	1,236 Tons (2,720,000 lbs)	Plant weight --	1,480 Tons (3,260,000 lbs)
Fuel oil --	1,270 Tons (2,794,000 lbs)	Fuel oil --	900 Tons (1,990,000 lbs)
Total	2,506 Tons (5,500,000 lbs)	Total	2,380 Tons (5,250,000 lbs)

Accordingly the difference is:

	2,506 Tons	(5,500,000 lbs)
-	2,380 Tons	(5,250,000 lbs)
	126 Tons	(250,000 lbs)

This means that Diesel tanker has been able to accommodate 126 tons more cargo oil than turbine tanker. On longer runs, such as the 17,000 mile round trip voyage between the Persian Gulf and the east coast of the United States, the margin in favor of the diesel would be more pronounced.

The relative economic advantage of the diesel tanker, shown below, is based upon the conditions of the Fall of 1957 in Japan, for the Far East-to-Japan trade previously mentioned.

Supposing that the vessels are operated for an average of 9 trips annually, therefore, 18 days x 9 are 162 days at loaded condition, and 16 days x 9 are 144 days at ballast condition:

(1) Profit gained by the increase of 126 DWT, assuming $10.20/Ton for tanker freight at the time of Fall 1957 -- $11,566.

(2) Profit from decreased fuel oil consumption,

Turbine	Diesel
70.55 Tons x $16.20 x 306 days = $350.000.	49 Tons x $16.20 x 306 days = $242,000.

assuming $16.20/Ton of fuel oil at the time of Fall 1957, cruising days are 306.

Profit from decreased fuel oil consumption, assuming $26.00/Ton of diesel oil at the time of Fall 1957,

1.0 Ton x $26.00 x 306 days
= $7,950.

Thus,

$242,000
+ 7,950

Total $249,950

Therefore, the annual profit gained is:

$350,000 (Turbine)
− 249,950 (Diesel)

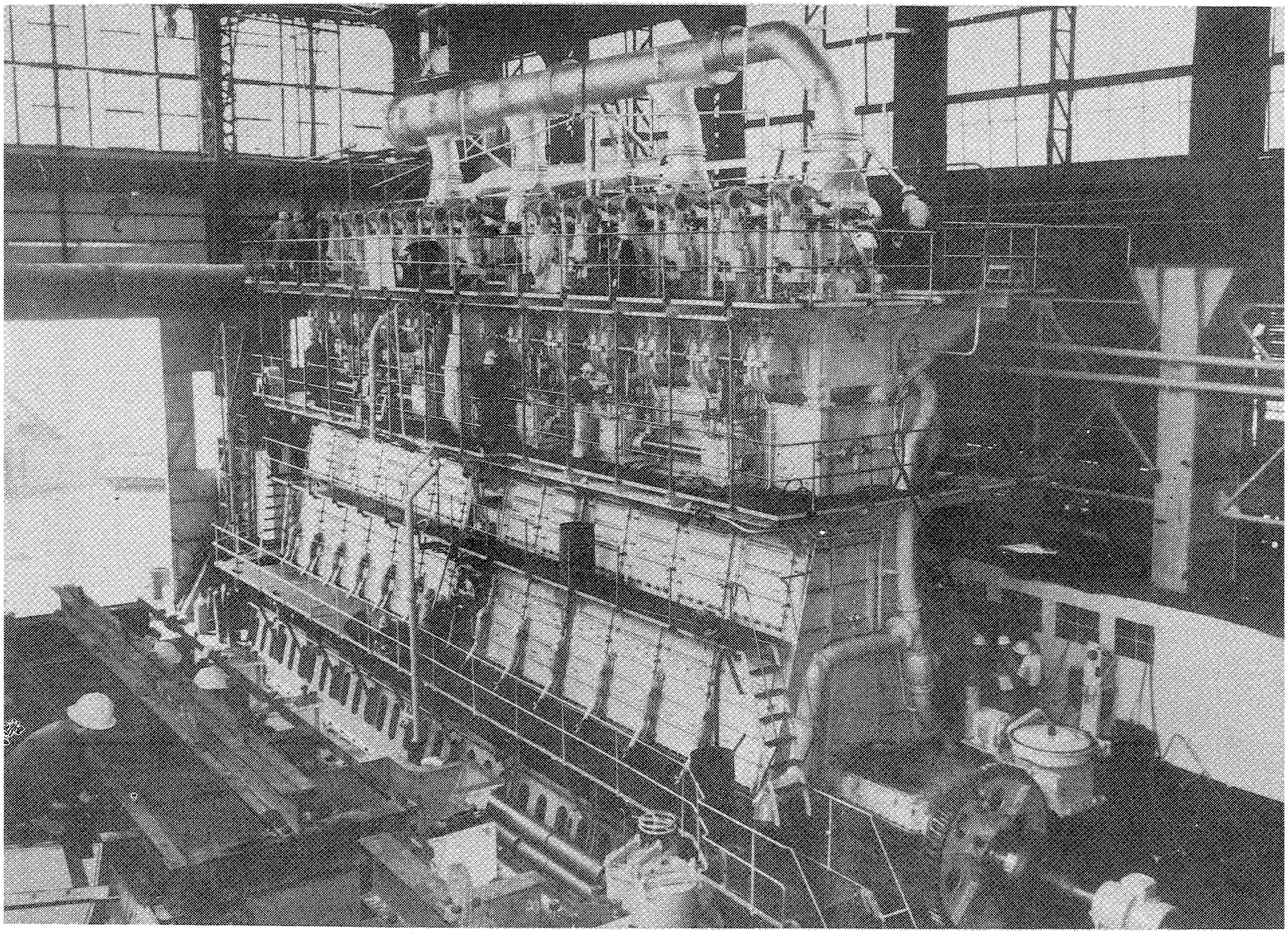
$100,050

Summing (1) and (2), this is a gain for the diesel tanker:

$ 11,566
100,050

$111,616

If the annual repair and maintenance costs are $13,900 and $6,950 respectively for the diesel tanker, based on Japanese standard costs for 1957, the net profit increase for the diesel tanker will be: $111,616 - ($13,900 + $6,950) = $80,766. Therefore, the diesel tanker has an annual profit of $80,766 over the turbine tanker of corresponding power.



15,000 BHP 12-CYLINDER DIESEL ENGINE READY FOR SHOP TEST

III. INVESTED COSTS

Following are some comparisons between the invested costs of a turbine and a diesel tanker, both of which are 33,000 DWT having 15,000 horsepower engines. Cost levels are taken for the Fall of 1957. In both instances, prices are appropriate for purchase of machinery from regular manufacturer rather than for their being manufactured in the shipyard.

Turbine		Diesel	
Turbine	- $457,500	Diesel	- $1,084,000
Boilers	- 417,000	Auxiliary Boiler	- 124,900
Condenser	- 55,500		
Total	$930,000	Total	$1,204,900

Therefore, balance is:

	Diesel Over Turbine	Turbine Over Diesel
Main engine & boilers	$278,900	
Auxiliaries		$ 69,500
Outfitting & others		83,400
Hull construction	22,200	
Electrical arrangement		33,350
Totals	$301,100	$186,250

Accordingly, $301,100 - $186,250 = $114,850 is an extra invested cost of diesel tanker regarding the engine room over turbine tanker.

Since it was earlier shown that the diesel ship would increase profits by $80,766 per year (exclusive of capital charges), it can be seen that the increased investment in the diesel ship would be paid off within two years.

IV. COMPARISON OF REQUIRED ENGINE ROOM SPACES

As illustrated in Figure 1, there is almost no difference between the space required for the diesel and steam installation. In comparing the engine room space, it is also important to take account of the required tank capacity.

	Fuel Oil Tank	Fresh Water Tank	Total
Turbine:	8,472 M^3 (300,000 Ft^3)	621 M^3 (22,000 Ft^3)	9,093 M^3 (322,000 Ft^3)
Diesel:	2,955 M^3 (104,300 Ft^3)	711 M^3 (25,180 Ft^3)	3,666 M^3 (129,409 Ft^3)

Accordingly, the total volume required for machinery plus fuel and water tanks is somewhat less in the case of the diesel plant.

V. DIESEL REPAIR AND MAINTENANCE

Recently, the period between changing main engine cylinder liners has been lengthened by the use of chrome-plated cylinder liners and other critical parts, and by the use of detergent lubricants. For the above reason, the cost of maintenance and repair has been considerably reduced.

VI. YUYO-MARU NO. 5

The Yuyo-Maru No. 5 is an example of the type of diesel tankers now being built in Japan. This vessel is a single screw tanker of 33,500 DWT and is the first in the world to be propelled by a 15,000 BHP diesel engine. The ship was delivered in August 1957. The principal dimensions are:

Length BP	643.34 Ft
Breadth molded	86.62 Ft
Depth molded	45.93 Ft
Loaded draft	34.61 Ft
Corresponding deadweight	33,500 Met. Ton (33,000 Long Ton)
Gross registered tonnage	21,000
Cargo oil capacity (100%)	1,596,310 Ft^3 (284,400 Barrels)

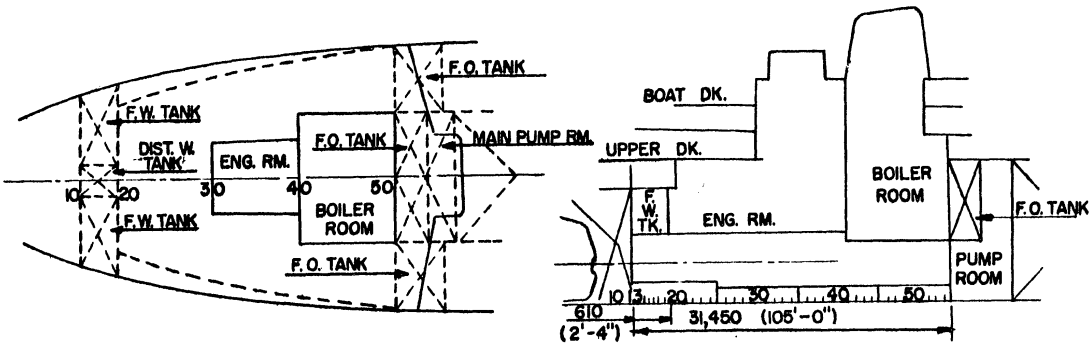
On the trial run, she attained a speed of 16.99 Knots, fully loaded, with the engine developing 14,610 BHP at 113.78 RPM. It was reported that at full speed there was less vibration than with a similar turbine vessel.

The Particulars of the Main Engine

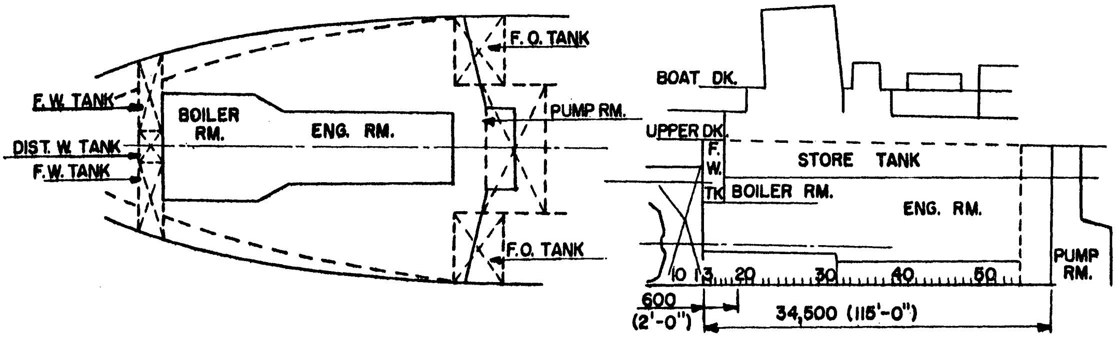
Type	HITACHI B&W 1274 VTBF-160* 2-cycle airless injection diesel engine with turbochargers
Output, Continuous Max.	15,000 BHP @ 115 RPM
Service	12,750 BHP @ 109 RPM (Approximately 305 BHP from the above BHP will be used for driving a lubricating oil pump.)
Size	12-cylinder x 740 MM (29.1") (bore) x 1,600 MM (63") (stroke)
Dimension	21,340 MM (69'-10") Length x 10,400 MM (34'-3") Height x 4,070 MM (13'-3") Breadth

* VTBF - Single acting 2-cycle cross-head type for propulsion with turbocharger.

By the adoption of turbocharging, it has been possible to raise the efficiency over the older non-turbocharged engine. The principal reason for this is that



33,000 DWT TURBINE TANKER



33,500 DWT DIESEL TANKER

FIGURE 1.

turbocharging raises the mean effective pressure without significantly raising the maximum cylinder pressure, and also provides more efficient scavenging. The net result is that the horsepower output per cylinder has been increased about 35% with a fuel rate reduction of about 5%. According to shop-test results, fuel consumption for 15,000 BHP was 159 gr/BHP/Hr (0.35 lbs/BHP/Hr); at three-quarter load it was 155.8 gr/BHP/Hr (0.34 lbs/BHP/Hr); and at half-load it was 161.3 gr/BHP/Hr (0.355 lbs/BHP/Hr), see Figure 2.

Besides the above-mentioned, the following test records were also obtained at the shop-test in June 1957.

Load percentage	100%
Revolution	115 RPM
Indicated mean pressure	7.94 Kg/Cm^2 (114 psi)
Maximum pressure	53.4 Kg/Cm^2 (766 psi)
IHP	16,800
BHP	15,000
Mechanical efficiency	89.5%
Pressure:	
Cooling water	1.75 Kg/Cm^2 (25.2 psi)
Lubricating oil	1.65 Kg/Cm^2 (23.8 psi)
Scavenging air	0.34 Kg/Cm^2 (4.9 psi)
Temperature:	
Exhaust gas, cylinder outlet	365°C (689°F)
Cooling oil, engine inlet	32°C (90°F)
Cooling oil, engine outlet	44°C(111.2°F)
Cooling water, engine inlet	59°C (138°F)
Cooling water, engine outlet	63°C (145°F)
Scavenging air, after air cooler	35°C (98°F)
Sea water	19°C (70°F)
Test room	22°C (76°F)
Fuel consumption	142.3 gr/IHP/Hr (0.314 lbs/IHP/Hr)
	159.0 gr/BHP/Hr (0.35 lbs/BHP/Hr)

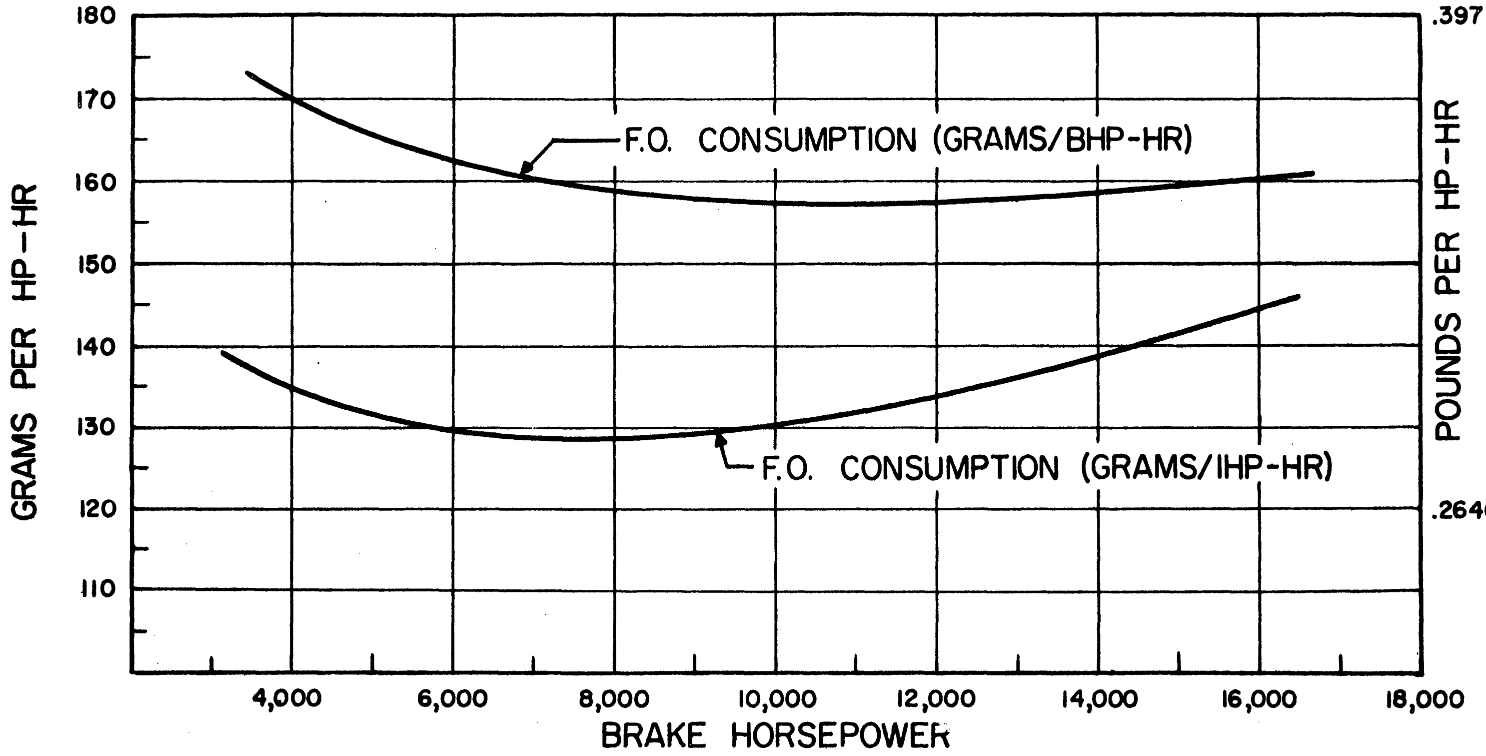


FIGURE 2.

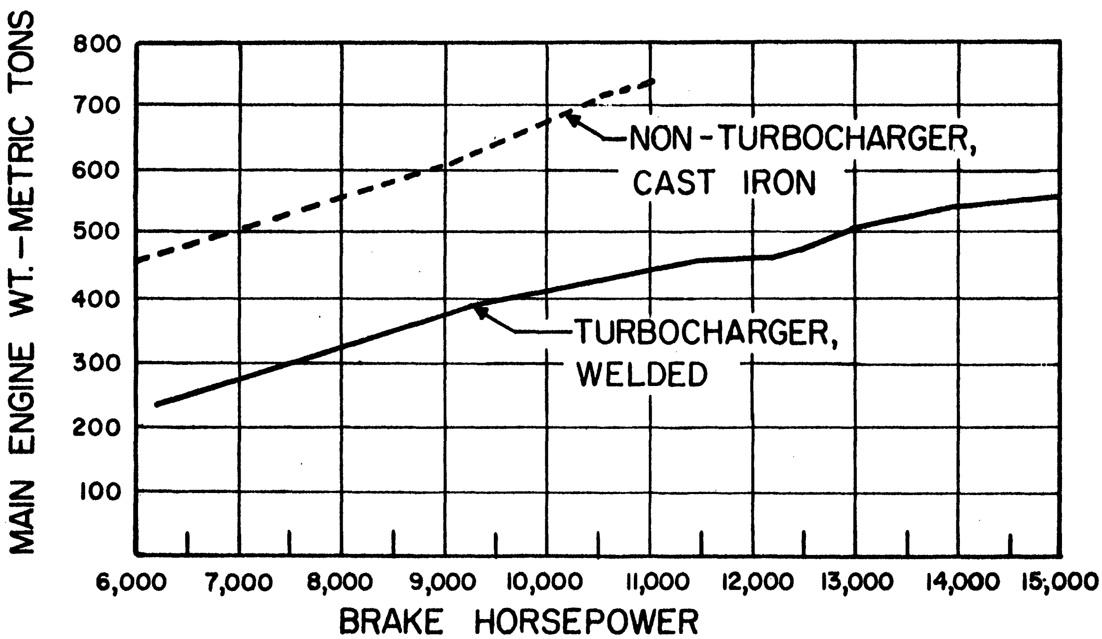


FIGURE 3.

Yuyo-Maru No. 5, First Trip Record

The author has recently been informed of the trip record of "Yuyo-Maru No. 5" as shown below.

	Westbound	Eastbound
	Departing from Japan, August 19, 1957. Arriving at Far East, Sept. 5, 1957.	Departing from Far East, Sept. 7, 1957. Arriving at Japan, September 26, 1957.
Cruising days	17 days, 16 hours	18 days, 16 hours, 18 minutes
Cruising mileage	6,496 miles	7,195 miles
Ship's condition	13,958-19,877 Tons (Ballast)	31,222 Tons (full loaded)
Main engine, RPM	(Mean) 105.2 RPM	(mean) 108.4 RPM
Main engine, BHP	(approx.) 11,100	(approx.) 12,860
Speed	(mean) 15.32 Knot	(mean) 16.05 Knot
Fuel oil consumption	41.92 Tons/Day (92,500 lbs/Day) 157.4 gr/BHP/Hr (0.348 lbs/BHP/Hr) 0.1142 Tons/Mile (253 lbs/Mile)	46.44 Tons/Day (102,000 lbs/Day) 150.5 gr/BHP/Hr (0.332 lbs/BHP/Hr) 0.1205 Tons/Mile (267 lbs/Mile)
Fuel oil used	Specific Weight - 0.8692	
Lubricating oil (internal) consumed	Approx. 100 liter/Day (26.42 gallons/Day)	

Fuel oil and lubricating oil were measured on the basis of the total consumption during round trip. However, lubricating oil was used somewhat generously on account of her maiden voyage.

It was also reported that although she had encountered typhoons No. 7 and No. 15 which were strong during these trips, there was no serious vibration. The entire operation was altogether satisfactory.

Comparison Between Turbocharger and Non-Turbocharger Engines

	Non-Turbocharged	Turbocharged
Output per cylinder (BHP)	920	1250
Mean pressure (Kg/Cm^2)	6.5 (92.5 psi)	8.0 (113.8 psi)
Engine weight (Kg/BHP)	69 (152 lbs) (cast)	40 (88.2 lbs) (welded)
Engine length (M/1000 BHP)	2.000 (78.8")	1.585 (62.5")

Because of a change from cast to welded construction, it has been possible to further materially reduce engine weight and size, see Figure 3.

There was a low noise level from the engine due to the adoption of a specially designed silencer, and to lagging of the turbocharger piping. The vessel is provided with four Rateau exhaust gas turbochargers. After the main tests were concluded, trials were performed with alternately three and two turbochargers in service, thus cutting off three and six cylinders respectively for emergency operation. Under these conditions, the engine was satisfactorily operated at 95 RPM and 70 RPM respectively, corresponding to an output of 8,450 BHP and 3,400 BHP. On the Yuyo-Maru No. 5, the engine was designed to enable boiler oil of viscosity not greater than 3,500 Second Redwood No. 1 at 100°F to be used. However, there is a system to facilitate a rapid change-over to diesel oil, if required.

Auxiliary Arrangement

Steam for cargo oil pumps [3 sets of horizontal turbocentrifugal type, 1,000 M^3/H (4,400 GPM) of sea water] and heating is supplied by 2 sets of "double evaporation" water drum boilers, each with a heating surface of 200 M^2 (2,160 Ft^2). Exhaust gas from the main engine is utilized in a forced circulating type steel-coil exhaust gas boiler (which is placed inside the stack), having a heating surface of 80 M^2 (860 Ft^2).

Electrical requirements are supplied by two sets of single-acting 4-cycle diesel generators rated at 225 KVA, 450-volt a.c.

Starting air for the main engine is stored in two 18 M^3 (635 Ft^3) reservoirs charged by two air compressors, one attached to each generator diesel and capable of delivering 52 M^3/Min (1,850 Ft^3/Min) at a discharge pressure of 25 Kg/Cm^2 (355 psi).

For engine circulating duties, there are two horizontal centrifugal pumps both driven by the oil pressure from a lubricating oil pump as illustrated in Figure 4. One pump is for sea water circulation to the main engine cooler, the other is for fresh water circulation to the main engine. The lubricating oil pump is driven from the main engine through a chain belt, and activates one oil motor to drive the two cooling pumps. When the engine speed is too low, steam turbine driven lubricating oil and fresh water cooling pumps are started. Both of these pumps are driven from a single turbine.

Other essential machinery items in the engine room and pump room are listed in the Appendix.

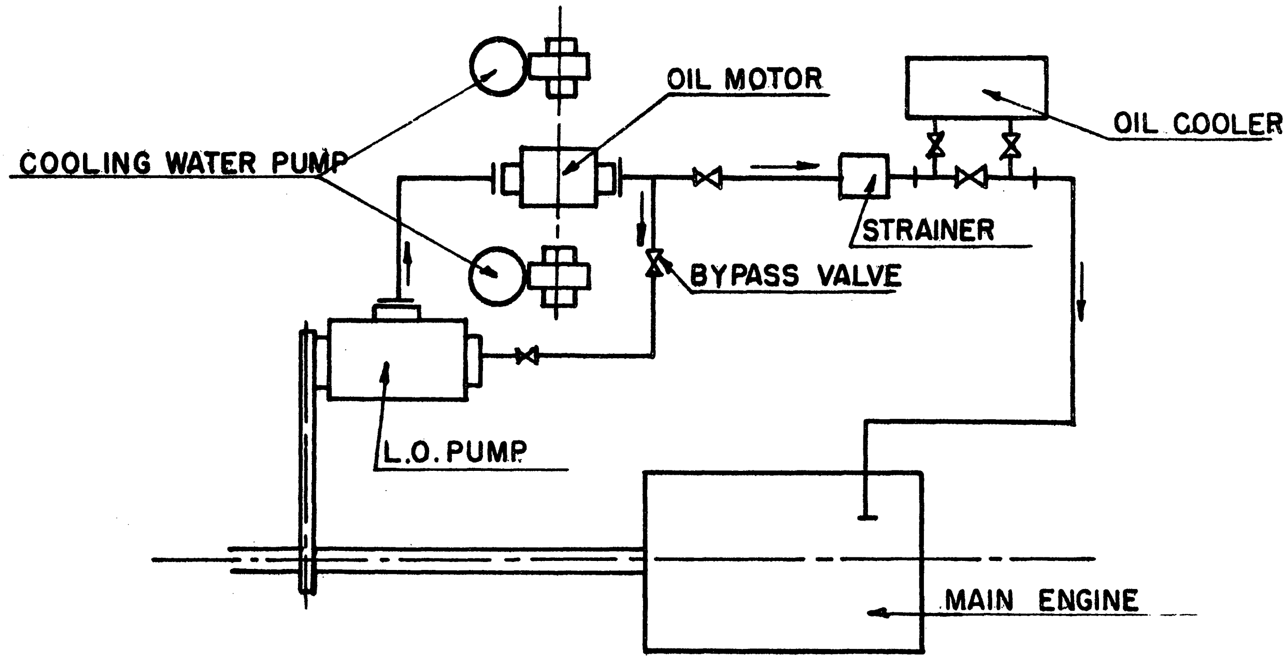

OIL MOTOR
OIL COOLER
COOLING WATER PUMP
STRAINER
BYPASS VALVE
L.O. PUMP
MAIN ENGINE

FIGURE 4.

VII. CONCLUSION

The production of diesel machinery for the past few years, indicated below, is taken from British Motor Ship, and relates to ships of over 2,000 DWT[4]. The great increase in motor ship production, especially in Japan, is notable and is explained by the greater efficiency of diesel plant as detailed in the paper.

	UK		GERMANY		JAPAN	
	M.S. DWT	Mch. BHP	M.S. DWT	Mch. BHP	M.S. DWT	Mch. BHP
1938	540,000	240,000	535,000	225,000	180,000	60,000
1953	1,009,000	465,000	720,000	365,000	346,000	198,000
1954	1,099,000	495,000	605,000	375,000	279,000	190,000
1955	1,020,000	477,000	700,000	468,000	379,000	240,000
1956	892,000	430,000	1,089,000	672,000	574,000	311,000
1957	1,019,000	510,000	1,225,000	652,000	1,253,000	613,000

M.S. - Motor Ship Deadweight Tons
Mch. - Machinery BHP

All of the shipyards and engine shops in Japan, as in other countries, have been fully occupied, and it is evident that there has been a large expansion and extension in building diesel tankers.

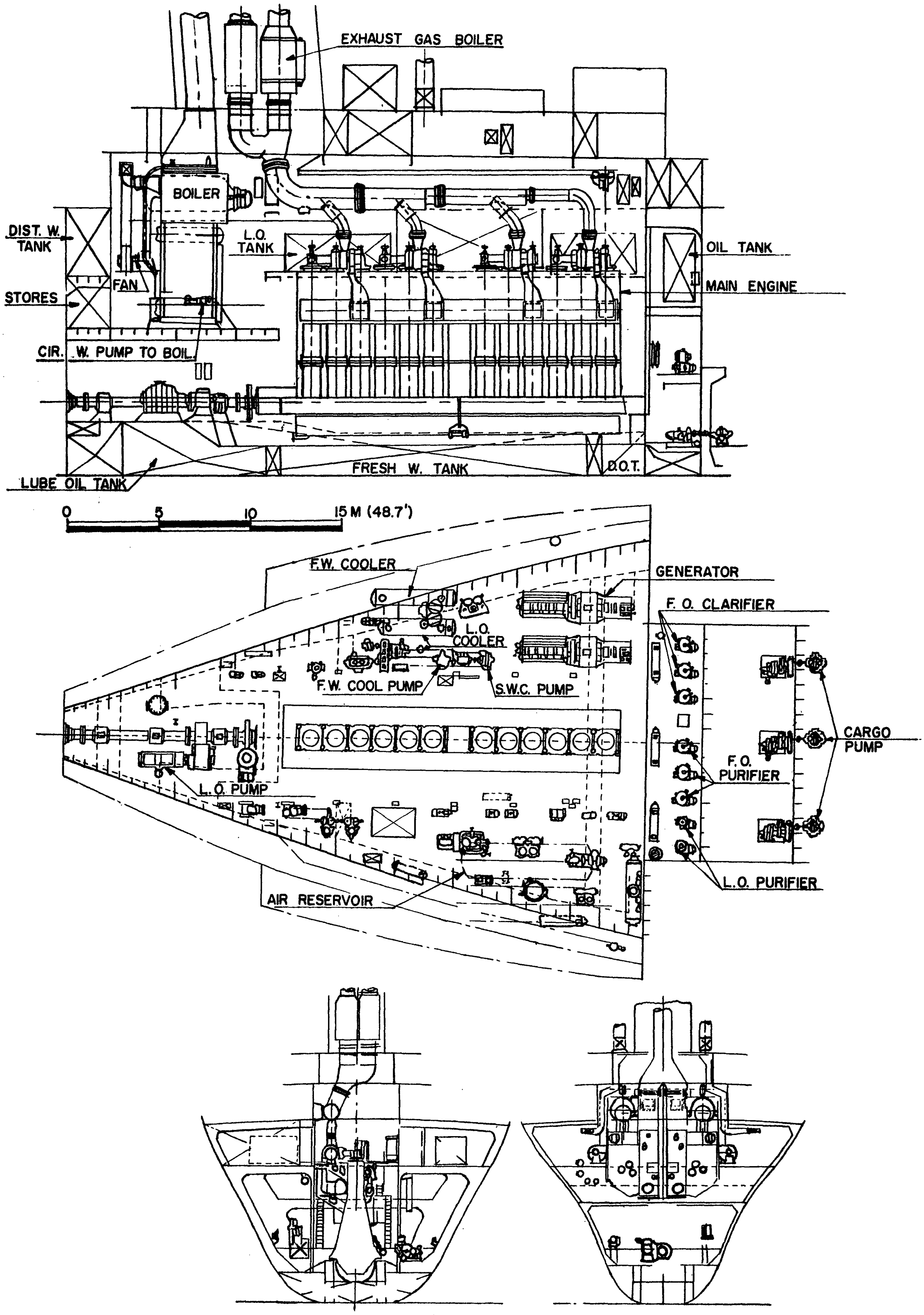

EXHAUST GAS BOILER
BOILER
DIST. W. TANK
L.O. TANK
OIL TANK
FAN
MAIN ENGINE
STORES
CIR. W. PUMP TO BOIL.
FRESH W. TANK
D.O.T.
LUBE OIL TANK
0
5
10
15 M (48.7')
F.W. COOLER
GENERATOR
F. O. CLARIFIER
L.O. COOLER
F.W. COOL PUMP
S.W.C. PUMP
CARGO PUMP
F.O. PURIFIER
L.O. PUMP
L.O. PURIFIER
AIR RESERVOIR

FIGURE 5.

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2. "Yuyo-Maru No. 5," SHIP, published by TEN-NEN-SHA, Tokyo, Japan, Oct., 1957.

3. "B&W 1274-VTBF-160 Type Shop-Trial Record," HITACHI Catalogue.

4. "Shipbuilding in 1957 and 1958," Brit. Motor Ship, Jan., 1958.

APPENDIX

List of Machinery

In Engine Room:

1 - Fresh water pump	elect. centrifugal	5 M^3/H(22 GPM)
1 - Sanitary pump	elect. centrifugal	15 M^3/H(66 GPM)
1 - Fire & General service pump (This pump can also be used as a stand-by sea water cooling pump for the main engine)	steam duplex	110 M^3H(485 GPM)
1 - Bilge & ballast pump	steam duplex	210 M^3/H(925 GPM)
1 - Butterworth pump	steam duplex	100 M^3/H(440 GPM)
1 - Bilge pump	elect. piston	15 M^3/H(66 GPM)
1 - Lub. oil shift pump	elect. gear	5 M^3/H(22 GPM)
1 - Stand-by fuel valve cooling and fuel oil supply pump	elect. gear	5 M^3/H(22 GPM)
1 - Fuel oil transfer pump	steam duplex	20 M^3/H(88 GPM)
1 - Fuel oil transfer & shift pump	elect. gear	20 M^3/H(88 GPM)
2 - Lub. oil purifiers	elect. De'Laval type	2,000 Lit/H (580 GPH)
3 - Fuel oil purifiers	elect. De'Laval type	3,000 Lit/H (870 GPH)
3 - Fuel oil clarifiers	elect. De'Laval type	3,000 Lit/H (870 GPH)
2 - Forced draft fans	elect. turbo	300 M^3/Min x 400 MM H_2O (10,600 Ft^3/Min x 15.7" H_2O)
4 - Ventilating fans	elect. axial	500 M^3/Min x 30 MM H_2O (17,600 Ft^3/Min x 1.18" H_2O)
2 - Circulating water pumps for exhaust gas boiler	elect. centrifugal	15 M^3/H(66 GPM)

APPENDIX (Cont'd)

List of Machinery

In Engine Room: (Cont'd)

2 - Feed water pumps	steam simplex 50 M^3/H x 230 M (220 GPM x 735 Ft)
2 - Burning pumps	elect. KIMO 4/2 M^3/H x 250 M (17.6/8.8 GPM x 800 Ft)
1 - Circulating pump for condenser	steam recipro. 900 M^3/H(3,950 GPM)
1 - Exhaust gas fan in E/R	elect. axial 60 M^3/Min x 30 MM H_2O (2,120 Ft^3/Min x 1.18" H_2O)
2 - Lub. oil pumps for turbocharger	elect. gear 6 M^3/H(26.4 GPM)
1 - Fresh water cooler	cooling surface 250 M^2(2,700 Ft^2)
2 - Lub. oil coolers	cooling surface 200 M^2(2,150 Ft^2)
1 - Fuel oil valve cooling oil cooler	cooling surface 6 M^2(64.5 Ft^2)
1 - Feed water heater for boiler	heating surface 25 M^2(270 Ft^2)
2 - Fuel oil heaters for boiler	heating surface 8 M^2(86 Ft^2)
1 - Fuel oil heater for main engine	heating surface 8 M^2(86 Ft^2)
2 - Fuel oil heaters for purifier	heating surface 8 M^2(86 Ft^2)
1 - Fuel oil heater for purifier (Boiler oil)	heating surface 2 M^2(21.5 Ft^2)
1 - Lub. oil heater for purifier	heating surface 1 M^2(10.7 Ft^2)
1 - Condenser for cargo oil pumps	cooling surface 150 M^2(1,610 Ft^2)
1 - Drain cooler	cooling surface 15 M^2(161 Ft^2)
1 - Evaporator	heating surface 5.22 M^2(56 Ft^2) 20 Ton/Day
1 - Distiller	cooling surface 5.8 M^2(62.5 Ft^2)

APPENDIX (Cont'd)

List of Machinery

In Engine Room: (Cont'd)

1 - Butterworth heater and drain cooler	heating surface 20 M^2(210 Ft^2) cooling surface 20 M^2(210 Ft^2)

In Pump Room:

3 - Cargo oil pumps	turbocentrifugal 1,000 M^3/H(4,400 GPM) sea water, 14 Kg/Cm^2(100 psig) steam
2 - Stripping pumps	steam duplex 150 M^3/H(660 GPM)
1 - Exhaust gas fan in P/R	elect. axial 260 M^3/Min x 33 MM H_2O (9,100 Ft^3/Min x 1.2" H_2O)
1 - Bilge & ballast pump	steam duplex 30 M^3/H(132 GPM)
1 - Fuel oil transfer pump	steam duplex 30 M^3/H(132 GPM)

The above-mentioned machinery has been worked efficiently, having no trouble at all since the vessel was completed in September, 1957.