Gas Turbine Propulsion Machinery for the MSTS Roll-On/Roll-Off Ship

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The history of the roll-on/roll-off type of cargo ship is reviewed to illustrate the development of the specific ship requirements for the Adm. Wm. M. Callaghan. The ship is unique in that it is the first large cargo ship to be built which has been initially designed to incorporate all advantages of gas turbine propulsion. The basic engineering problems and selections involved in the design of the machinery plant are briefly described. The service performance of this ship will have a significant influence on future applications of gas turbine machinery for commercial ships.

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Table 1 List of Ship Characteristics

<table>
<thead>
<tr>
<th></th>
<th>USNS COMET</th>
<th>USNS TAURUS</th>
<th>SS TRANSGLOBE</th>
<th>USNS SEA LIFT</th>
<th>GTS CALLAGHAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LENGTH, Overall</td>
<td>499'-0&quot;</td>
<td>4751.5m</td>
<td>520'-0&quot;</td>
<td>540'-0&quot;</td>
</tr>
<tr>
<td>2</td>
<td>LENGTH, Between Perpendiculars</td>
<td>465'-0&quot;</td>
<td>454'-0&quot;</td>
<td>496'-0&quot;</td>
<td>499'-6&quot;</td>
</tr>
<tr>
<td>3</td>
<td>BEAM, Extreme</td>
<td>82'-0&quot;</td>
<td>72'-2&quot;</td>
<td>71'-6&quot;</td>
<td>831'-0&quot;</td>
</tr>
<tr>
<td>4</td>
<td>DEPTH</td>
<td>48'-9&quot;</td>
<td>37'-0&quot;</td>
<td>43'-6&quot;</td>
<td>53'-0&quot;</td>
</tr>
<tr>
<td>5</td>
<td>DRAFT @ Full Load</td>
<td>27'-0&quot;</td>
<td>18'-10&quot;</td>
<td>23'-6&quot;</td>
<td>29'-0&quot;</td>
</tr>
<tr>
<td>6</td>
<td>PARKING AREA in Sq. Ft.</td>
<td>96,704</td>
<td>41,400</td>
<td>59,356</td>
<td>99,030</td>
</tr>
<tr>
<td>7</td>
<td>SPEED, Knots</td>
<td>18</td>
<td>15.7</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>8</td>
<td>TOTAL SHP</td>
<td>12,000</td>
<td>9,000</td>
<td>9,900</td>
<td>19,400</td>
</tr>
<tr>
<td>9</td>
<td>PROPELLIERS, Number</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Sea trials are scheduled for completion on the Adm. Wm. M. Callaghan, the first large commercial ship designed from inception for gas turbine propulsion. The power plant of this ship represents a reasonable and economic combination of existing, proven components, all designed for continuous, full-power operation of the engines. The purpose of this paper is to describe the application problems of the gas turbine engines and the contribution of the machinery design to the development of a ship for a specific set of transportation requirements.

The basic ship requirements are essentially military, being high sea speed, rapid port turn-around, and maximum cargo deck area. These requirements are the prime factors in achieving a high transport rate per ship-year. The conflicting requirements of deck area and sea speed have produced a long, fine-lined ship. The rapid port turn-around requirement has been satisfied by roll-on, roll-off capability for military vehicles from all cargo decks. In addition, all six hatches are served by booms and conventional cargo-handling gear. The validity of these requirements stems from a concept of transportation developed in recent years by the Military Sea Transport Service.

HISTORY OF THE RO/RO SHIP

Early appreciation of a "need for speed" in cargo discharge in the Military Sea Transport-
tion Service stemmed from the necessity for military ships to "get in, discharge, and get out" as rapidly as possible. In this day of missiles when air superiority over a harbor area is no assurance of freedom from attack, the luxury of four, five, or seven-day discharge periods is no longer available. This fact, coupled with the tremendous volume and variety of rolling stock required by a modern army, was the genesis of the first seagoing roll-on/rill-off vessel built in this country -- the USNS Comet. This ship, constructed for the Military Sea Transportation Service by the Sun Shipbuilding and Dry Dock Company, was delivered for service in 1957. Experience to date has proved the military advantages of a ship in which wheeled and tracked vehicles can be driven from shore side to a stowage space aboard ship and discharged in a like manner. The outstanding performance of the Comet in this service led to the conversion of the ex-LSD type ship, Carib Queen (now USNS Taurus) for roll-on/rill-off purposes in 1959, and also to the charter of a converted C-4, the SS Transglobe, in 1962.

These ships were joined in the winter of 1966 by the newly constructed USNS Sea Lift, a ship somewhat larger and faster than the Comet, but similarly configured. This ship was constructed for the Military Sea Transportation Service by the Lockheed Shipbuilding and Construction Company of Seattle, Wash. All four ships are currently operating in Southeast Asia and their performance has fully justified the military investment in roll-on/rill-off ships.

Table 1 lists the characteristics of the four roll-on/rill-off ships in service, for comparison with those of the Callaghan. It will be noted that in size, speed, and in carrying capacity, as reflected in the number of square feet of available deck area, the Callaghan is by far the largest and fastest ship. The profile views and two of the deck plans are shown in Figs.1 and 2.

PROCUREMENT PROCEDURE

With this background and knowledge of the ability of a roll-on/rill-off ship to combine...
effectively rapid loading and discharge with high speed, it was understandable when the Military Sea Transportation Service was directed by higher authority in 1965 to "immediately and actively" charter a roll-on/roll-off ship "of such design and with a hull of such size and potential speed as may be determined by the Secretary of the Navy to be required to provide operating experience in the design of Navy ships powered by gas turbines."

These directives initiated a unique procurement from the standpoint of the Government. Traditional Government practice has been a procedure in distinct steps:

1. Development of detailed contract plans and specifications.
2. Distribution of plans and specifications to interested shipyards.
3. Receipt and analysis of bids.
4. Award of the contract to the lowest responsive bidder.

The Callaghan procurement was quite different. Offerors were permitted to develop their own concept of the ship, circumscribed only by the requirement that the ship be gas turbine powered, that it have a speed in excess of 23 knots, and that it comply with a five-page statement of technical requirements developed by the Military Sea Transportation Service on the basis of their experience with roll-on/roll-off ships. Additionally, upon completion the ship was not to be the property of the Government, but rather was to be operated by its owner under a time charter agreement with the Military Sea Transportation Service. Financing was an offeror requirement, to be paid out by the charterer over the term of the charter.

The formal request for proposals was issued on March 16, 1965, and actual proposals were received on June 22, 1965. Of the six interesting and responsive offers received, three proposed a gas turbine electric drive, one proposed either a reversible-pitch propeller or alternatively an electric drive, and two proposed a reduction reversing drive of the type which was finally selected. The evaluation of the offers received was, in itself, a difficult task inasmuch as each offeror was quoting on a different proposal. The selection was made after weighing three criteria:

1. Cargo transport ability of the ship, assessed as its revenue-generating ability, versus its cost to the Government: 60 percent significant.
2. Ability to handle roll-on/roll-off cargo in a rapid and effective manner: 30 percent significant.
3. Ability to handle general cargo in an expeditious manner: 10 percent significant.

As offers were being reviewed, concurrent negotiations with offerors clarified proposals and on October 29, 1965, the award was made to Sunexport, a joint venture of Sun Shipbuilding and Dry Dock Company and the American Export Isbrandtsen Lines. The Sunexport offer, as evaluated by the Government, was determined to have the best potential.

In the seven months from March to October there were compressed those functions of contract plan development, Invitations to Bid, receipt and analysis of bids, and award of contract, which can take anywhere from 18 months to two years in a conventional procurement. This is a major reduction in the time needed to get underway in the construction of a modern ship, and could result in decreasing the total procurement and building time from an average of 47 months to only 33.

SHIP SPEED

Speed in the GTS Adm. Wm. M. Callaghan is a valuable characteristic. On the other hand, it is an expensive one since the required power varies as the cube of the ship speed. For example, a speed of 20 knots on the Callaghan requires 16,500 shp; doubling the shaft horsepower increases the ship speed by only 4.9 knots. The additional cost of providing a 25-knot and better speed for a ship of this type must be carefully balanced against the actual need for such speed and the benefits to be gained thereby.

The value of ship sea speed can be fully realized only when it is accompanied by other characteristics which reduce the in-port time of the ship to an absolute minimum. The significance of this in-port time may be recognized by reference to Fig.3, which plots the days in port against the number of round trips per working year (assumed as 350 days) that can be made by ships of 15, 20, 25 and 30-knot speed on a voyage of 3500 nautical miles between ports. With reference to Fig.3, a ship with a sea speed of 25 knots has a transport capability of 155 percent of a 15-knot ship for a total in-port time of two days per round trip. However, if the in-port time of the 25-knot ship were increased to ten days, its transport capability would be no greater than the 15 knot ship with the two-day port time.

On trips shorter than 3500 nautical miles, the effect of high speed would be less pronounced than that shown in Fig.3 and, conversely, on trips longer than 3500 nautical miles, the effect of speed would be more pronounced.

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PORT TURN-AROUND

In the dry-cargo service, port time is generally defined by the requirements of loading or discharging of cargo. In the bulk trades and in the tanker trade, where cargo can be readily handled by pumps, grabs, conveyors, or such other means, rapid turnaround and short in-port periods of less than a day are the rule rather than the exception. On the other hand, in the dry-cargo service it has been quite conventional for some ships to take as much as 12 to 14 days of total port time during a complete round trip where there is one port load and one port discharge.

Since all cost aspects of the ship operation, except fuel, are just about constant whether in port or at sea, ship operators are reaching for all methods which will measurable reduce the in-port time of the ship. The overwhelming acceptance by commercial operators of the containerization philosophy of cargo handling illustrates this point. Such containerization permits the cargo to be assembled in uniform-sized pieces, which, in turn, permits rapid loading and unloading. This gives better usage of the ship’s full potential, but requires a correspondingly larger investment by the owners to achieve the benefits of a superior system.

The USNS Comet, the SS Transglobe, and the USNS Sea Lift are all fitted with conventional cargo-handling gear of the boom and winch type, and in view of the advantages of the RO/RO method of loading, the question may be logically asked as to the need for the alternate type of cargo gear. This is primarily because a military vessel must be designed to meet all eventualities, and it was decided in the design of these ships that, notwithstanding their ability to load by the RO/RO method, they should also be provided with means to handle either vehicles or general cargo in the usual manner.

This same requirement existed in the design of the OTS Callaghan. The extent, or number of cargo gear units, has been reduced but the capability has been increased, particularly for heavy lifts. On the Callaghan two 120-ton booms, each serving two hatches, will be installed. These two booms in unison can handle weights up to 240 tons which will be of particular advantage in the transportation of some outsized pieces of military equipment, such as 135-ft landing craft, the shipment of which has continuously posed problems to the Military Sea Transportation Service. The variety of vehicles to be handled is indicated in Table 2.

As previously indicated, minimum port time for cargo handling is essential for realizing the full benefits of the high ship speed. Since the speed of the Callaghan is expected to be better than 25 knots, it is mandatory that the ship utilize the inherent capability of the roll-on/roll-off principle to accept and discharge cargo at high rates of speed. In 1963, under the supervision of the Maritime Cargo Transportation Conference of the National Academy of Sciences, tests were conducted under carefully supervised conditions relating to the loading capabilities of the Comet. In the first of these tests, the Comet loaded in Norfolk, Va., 298 vehicles representing 7971 measurement tons (one measurement ton equals 40 cu ft) in 4 hr and 55 min. This same cargo was discharged at pierside in Bremerhaven in 3 hr and 8 min. During the second voyage under this testing the Comet loaded 336 vehicles of 7772 measurement tons in 5 hr and 8 min and discharged this cargo into lighters while anchored in Bremerhaven in 3 hr and 8 min.

A representative mix of vehicles was used in both tests, consisting of Mark 60 tanks; 155-mm howitzers; personnel carriers; 1/4 ton, 3/4 ton,
Table 2 Tabulation of Vehicles

<table>
<thead>
<tr>
<th>TYPE</th>
<th>DIMENSIONS &amp; WEIGHT</th>
<th>PARKING, LOCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>LCU - 1610</td>
<td>135' x 39' x 448,000</td>
</tr>
<tr>
<td>(2)</td>
<td>LCU - 1466</td>
<td>115' x 34' x 436,000</td>
</tr>
<tr>
<td>(3)</td>
<td>LC119</td>
<td>74' x 21' x 15' x 140,000</td>
</tr>
<tr>
<td>(4)</td>
<td>Tanks, M-103</td>
<td>37' x 12' x 125,000</td>
</tr>
<tr>
<td></td>
<td>120 MM Gun</td>
<td></td>
</tr>
<tr>
<td>(5)</td>
<td>Tanks, M-60</td>
<td>27' x 11' x 11' x 95,300</td>
</tr>
<tr>
<td>(6)</td>
<td>Trucks, M-125</td>
<td>28' x 10' x 9' x 65,000</td>
</tr>
<tr>
<td>(7)</td>
<td>Trucks, m. 34</td>
<td>23' x 7' x 9' x 22,500</td>
</tr>
<tr>
<td>(8)</td>
<td>Semi-Trailers</td>
<td>29' x 9' x 50,200</td>
</tr>
<tr>
<td>(9)</td>
<td>Semi-Trailers</td>
<td>27' x 8' x 46,500</td>
</tr>
<tr>
<td>(10)</td>
<td>Semi-Trailers</td>
<td>31' x 8' x 9' x 50,000</td>
</tr>
<tr>
<td>(11)</td>
<td>Jeeps</td>
<td></td>
</tr>
<tr>
<td>(12)</td>
<td>Ambulances</td>
<td></td>
</tr>
</tbody>
</table>

and 2 1/2-ton trucks; ammunition trailers; and tank trucks.

In a subsequent exercise held in 1964 under full blackout conditions, the Comet loaded in Norfolk 297 pieces of equipment totaling 6761 measurement tons in 3 hr and 3 min. This cargo was discharged to a pier in Bremmerhaven again under blackout conditions in 1 hr and 21 min.

As a practical matter, cargo loading and discharge for ships of the Comet type may not be the time-limiting operation in port. Other functions, such as fueling, loading stores, providing leave for the crew, and obtaining repairs, have to be scheduled carefully to retain the time advantage gained by the cargo operation: With the ability to achieve rapid in-port turnaround periods, the high speed potential of the Callaghan can be utilized effectively and economically, and it is for this reason that the speed of this ship has been increased by at least five knots over that of its immediate predecessor, the Sea Lift, and over the speed of the first-generation roll-on/roll-off ship, the Comet, by 7 knots.

CARGO CAPACITY

The cargo capacity is the product of a basic compromise between hull form and possible ship speed with a given power-plant rating. In the case of a ship designed to carry military vehicles, the capacity can be increased further by some flare in the bow and stern sections above the waterline. Within the limitation of the hull form, the cargo capacity is finally defined by satisfying dual requirements of maximum deck area and ramp access into all cargo spaces. It is easily possible to design the machinery installation for maximum parking space without satisfying the traffic pattern and ramp access for all spaces. The vehicle access is illustrated by the exploded view of Fig.4.

Gas turbine propulsion machinery has the greatest advantage in satisfying cargo capacity requirements because of an inherently high ratio of engine power to engine-room volume; because the engines can be arranged in a low profile to fit the space least desirable for cargo; and be-
cause there is enough flexibility in the engine installation to suit the traffic pattern in cargo spaces above the engine room.

The advantages of gas turbine propulsion may be evaluated, in part, by comparison with a steam turbine propulsion plant within the same hull lines. The present deck area, or "parking area," of 165,000 sq ft would be reduced to about 150,000 sq ft, Fig.5. The advantage of a 10 percent increase in cubic cargo revenue can economically justify the additional fuel cost of a gas turbine plant in a full commercial trade where the annual revenue is in the order of eighteen times the fuel cost of a steam plant. This ratio of revenue to fuel cost does exist in some trades.

A more rigorous comparison may be made on the basis of a specific annual transport capability in tons per year. To match the transport capability of the Callaghan, a ship utilizing steam turbine propulsion machinery would have required either a larger hull or a higher sea speed. Either alternate would require a higher power rating, increased fuel consumption, and greater first cost. For example, with the same hull size, the sea speed would have to be increased at least 3 knots to give equivalent transport capability. The increased speed would increase the required power by 45 percent.
In the past, a major deterrent to an effective marine application of gas turbine engines has been the problem of reversing the output shaft for astern operation. A marine engine, intended for operation over the complete propeller speed range, must employ a free power turbine mechanically independent of the gas-generator section. In operation, the gas-generator section is cranked to self-sustaining speed and advanced to the rotor speed which produces the hot gas flow required by the power turbine. The power turbine is similar to a marine steam turbine in that the speed is controlled by the torque characteristic of the propeller. However, to date, a gas turbine engine with a practical reversing power turbine is not available, and the reversing feature must be provided by either the transmission or the propeller.

Several alternative transmission-propeller combinations were considered as solutions to the reversing problem:

(a) Electric generators with direct-drive propulsion motors and fixed-pitch propellers;
(b) Electric generators with geared propulsion motors and fixed-pitch propellers;
(c) Reversing reduction-gear drive with fixed-pitch propellers;
(d) Reduction gears with controllable-pitch propellers.

The reversing reduction gear was selected because it was fundamentally right in all important considerations:

(a) The reversing gear did not forfeit the great advantages of gas turbine propulsion with respect to space, initial cost, and simplicity.
(b) The transmission was essentially an extension of experience with existing machinery and involved the minimum development risk. In this regard, it is significant that the reduction-gear production drawings have been submitted for approval and released for manufacture before those of any other component.

(c) Maintenance of the reversing-clutch elements is consistent with the servicing concept of the gas turbine engines in that overhaul is accomplished by unit replacements within the period of port turn-around. The high ship availability gained by the use of gas turbine engines has not been compromised, therefore, by a transmission which would ultimately involve either the handling of heavy rotors within the machinery space or the dry-docking of the ship.

(d) The production of the reversing gears was compatible with the building schedule of the ship. The alternate propulsion drives involved longer engineering development and longer production time. These factors would delay both the orderly development of the ship design and the erection of the ship structure.

The main propulsion power of the Callaghan is provided by two Pratt & Whitney FT4A-2 gas turbine engines, each driving a Falk reverse reduction-gear unit, Fig. 6. The engines have been ably described at previous meetings.\(^1\)\(^2\) The shafting to the twin, four-bladed, fixed-pitch wheels has long sections outboard owing to the transom stern of the hull. Each shaft is sup-

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ported by a Vee strut at the propeller bearing. In order to place the lateral frequency of the shafting above the maximum propeller blade frequency without involving the hydrodynamic drag of a second set of shaft struts, the outboard shaft sections have been designed as torque tubes.3 These tubes have a high lateral stiffness and present a smooth flow surface from the hull to the propeller hub. Although this shaft design is not a direct consequence of gas turbine propulsion, it exemplifies a design innovation appropriate to high-speed ships where the gas turbine has the greatest potential advantage.

The reduction-gear units are of the divided-train type, similar to naval gears used for high power ratings, with the power from the high-speed gears divided by the use of quill shafts to the low-speed pinions. The reversing arrangement is of an existing concept wherein the input pinion, connected to the power turbine, rotates one set of clutch assemblies in the ahead direction and another set of clutch assemblies in the reverse direction. Output shaft rotation is provided depending on which set of clutch assemblies are engaged to drive the low-speed pinions which drive the output gear.

Referring to the gear diagram of the part unit, Fig.7, the input power is divided between the high-speed gears meshing with the engine pinion. When operating ahead, power is transmitted by the two quill shafts to the drums of the ahead clutches. By inflation, the clutch shoes are placed in contact with the clutch drum and thus transmit torque to the second reduction pinions. The outer set of high-speed gears are being driven unloaded in the reverse direction. The connected clutch drums also spin in reverse; however, with the reverse clutches disengaged the clutch shoes are spinning in the opposite direction, being driven by the pinions in mesh with the low-speed gear.

To reverse the rotation of the main shaft, the engine output power is reduced to the "idle" condition, the ahead clutches are disengaged, and the reverse clutches are pressurized. Initially, the reverse clutch drums are turning counter to the output glands and slipping occurs until the clutch torque dissipates the inertia of the system and the windmilling torque of the propeller.

When relative rotation in the clutch reaches zero, the shaft rotation has been reversed and engine power is increased to accelerate the ship astern. The proper sequence of engine throttle control and clutch control is performed automatically by a single throttle lever for each engine.

The clutches are of the Airflex pneumatic type with asbestos-faced shoes mounted on a torus gland, with a relatively flat oval radial section. A small cubic inflation of the gland moves the shoes radially inward to contact the clutch drum. The shoes are expected to last the life of the unit with normal, commercial ship operation. Each clutch assembly is made up of three glands, all supplied from a common air manifold. These gland assemblies have been proven with many years of heavy-duty service in other marine applications at comparable heat-absorption rates.

MAIN ENGINE INSTALLATION

Many possible configurations of the main unit and associated ducting are possible within the hull form. Generally, the objective of providing maximum cargo deck area was favored in the progression of design decisions on the machinery arrangement. Ideally, the main machinery should occupy that portion of the hull volume that is most difficult to utilize for cargo space. In this case, therefore, the main engines have been located as far aft and as low in the hull as possible. The main reduction-gear units are the critical items in defining the extent of the machinery space. These units are located about as far aft as the hull form will permit, allowing sufficient structure for the gear foundation and lubricating oil sump.

The extension of the machinery space forward into valuable cargo hold space has been minimized by locating the gas turbine engines aft of the
gears, above the main shaft, Fig. 6. This reverse arrangement is not usually possible with a steam turbine installation because of the main-condenser interference. The arrangement utilizes the hull form to the best advantage because the volume aft of the critical gear location is not suitable for vehicle cargo.

The main machinery space, defined in length by the main engines and gears, contains all of the propulsion auxiliary units which are suitable for remote operation, Fig. 8. The engine room, therefore, is nominally unmanned and subject only to routine inspection.

The auxiliary machinery space is aft of the main machinery space. Immediately aft of the bulkhead there is a control center with a centralized control console and electrical switchboard. An engineering watch stander can start and control the main engines and monitor plant operations from this location. Within the same water-tight enclosure there are located the auxiliary units subject to routine maintenance: The three diesel generators, the distilling plant, and the fuel-oil purifiers. Under normal conditions, all watch engineer's operations are accomplished in the control and auxiliary space without the need to go forward into the main engine room.

The location of the main engines cannot be disassociated from the problems of locating the large ducts required for combustion air and turbine exhaust. Because of the large cross-section area required for each duct, any configuration involving long horizontal runs or severe angles is not very practical. These ducts must rise almost vertically from each engine. Sufficient latitude does exist, however, to permit the duct configuration to be coordinated with the traffic pattern on the cargo decks above the engine room and with the quarters arrangement in the house.

Separate intake and exhaust ducts are provided for each engine to avoid induced circulation when one engine is secured. The intake and the exhaust duct for each engine is located within a structural casing that rises from the deck above the engine room to the top of the house. Combustion air is drawn through a weather screen facing aft on the boat deck, passed through a moisture separator, and accelerated down a vertical duct through two stages of silencers to a plenum chamber at the engine inlet, Fig. 9. The exhaust gas leaving the engine drives a cooling air eductor, passes through a single silencer, and exhausts from the stacks at a height and velocity sufficient to preclude recirculation to the air intake.

The danger of ingestion of salt-laden moisture is minimized by locating the weather inlet on the aft side of the house, 67ft above the water, by the weather screen which shields the weather plenum from blown spray and agglomerates the moisture particles, and by a low-velocity moisture separator using multiple moisture traps in each air channel. Prevention of icing at the weather
inlet is accomplished by mixing hot air bled from the main engine compressors with the free air upstream of the moisture separators.

Noise-control features have been provided to meet both the requirements of the U. S. Coast Guard in the engine room and the precedent sound levels achieved in living quarters of Maritime Administration vessels. The main engine room is protected from radiated noise by enclosures surrounding each engine. The quarters above are protected from inlet and exhaust noise by the silencers in the ducts, by the location of storage and utility spaces as "buffer zones" around the duct casings, and by the provision of double-wall construction for the exhaust ducts. Noise on the navigating bridge is minimized by the silencers in the ducts and by the directivity effect of the ducts, horizontally aft at the inlet and vertical at the exhausts.

The main engine installation has been designed for maximum ease in replacing the gas-generator section of each engine. A bolted access plate is provided in the deck of the cargo space directly above each gas generator. For major overhauls, the gas generator section will be disconnected from the power-turbine casing, all piping and electrical leads will be disconnected at the engine, and the section will be lifted in a horizontal position to the level of the cargo space and moved outboard to a handling crib. The lift is about 5000 lb and will be carried by two conventional chain falls without any special guides.

MAIN ENGINE SYSTEMS

The engine installation problems described above are all characterized by a degree of coordination with the basic ship design. The main engines also have critical requirements with respect to fuel, lubricating oil, cooling, and starting power. Generally, these requirements can be resolved independently of all the overall ship design. The associated systems are of a primary concern because a deficient design can lead to prohibitive maintenance. Because we are advancing into a new experience with propulsion engines, without full knowledge of minimum standards, every reasonable effort has been made to provide effective main engine service systems.

The fuel used initially for the gas turbine engines will be either jet fuel to ASTM Specification D1655-64T, Jet A or a light diesel fuel to the Specification MIL-F-16884F. The fuel system can handle a range of fuel characteristics encompassing the jet fuel, JP5, and jet and diesel fuels to Pratt & Whitney specifications PWA522-D and PWA527-A. The final selection of which of these fuels to use in service will probably depend on the price bids for bulk contracts. Another blend of jet fuel which promises a significant reduction in price is being currently tested in Pratt & Whitney laboratory engines. Research in this direction can be more significant than proposed cycle developments.

The fuel will be carried in a conventional arrangement of double-bottom tanks. These fuel tanks will not be used for salt-water ballast. Under emergency conditions, some of the salt-water ballast tanks can be used to carry fuel, if length of voyage dictates. All of the tank plates will be given a coat of aluminum primer before assembly of the double-bottom structure, resulting in much cleaner tank surfaces than usual practice. Fuel will be transferred in bulk from the double-bottom tanks, through strainers, to the reserve fuel tanks outboard of the auxiliary machinery space. Centrifugal
purifiers will draw from one of the reserve tanks and discharge purified fuel to a head tank located above the main engine room. Fuel will flow by gravity from the head tank to each main engine. The head tank, the valves, and the piping from the purifiers to the engines will be of stainless steel to preclude contamination of the purified fuel. The purposes of the head tank are to provide a steady flow of clean fuel to both engines, to maintain fuel flow in the event of a purifier failure, and to maintain fuel flow in the event of an electrical power failure.

The purifiers are sized to operate at a capacity above engine consumption. The resulting overflow from the head tank is piped to another set of reserve tanks designated for clean fuel. These tanks provide a second reserve of purified fuel in the event of a purifier failure.

Lubrication of the main gears and shafting follows conventional practice using a standard marine turbine oil, cooled by sea water. Each gas generator and power turbine section has separate lubricating oil systems using special, high temperature, synthetic oil. These systems utilize carbon steel or stainless steel in all components since the synthetic oil is not compatible with copper-bearing materials. The synthetic oil of each of the four engine systems is cooled by the 'main gear oil flow at 120 F. The oil-to-oil heat transfer results in coolers larger than would be required for sea water-to-oil. The principal reason for using main oil as coolant was to avoid any risk of salt-water contamination of the engine oil systems. Contamination of the engine systems could result in an unknown degree of damage to the engine bearings and control elements. It was desirable to avoid the necessity to disassemble an engine only for the purpose of inspecting for salt-water damage. The risks are different on the main gear system where damage by salt-water contamination of the lubricating oil may be quickly observed and assessed.

The main gear lubrication system is of the pressure type operating with two service pumps in use and one as a standby. In the event of electric power failure, a small emergency pump driven by an air turbine is automatically started by an oil-pressure signal. This pump maintains a reduced flow to the main gears during the period it takes to stop the shafts. Cooling flow for the lubricating oils is also lost during this period; however, there is enough cooling capacity in the system to preclude any bearing overtemperature before the shafts are stopped.

The required cooling of the engine casings is accomplished by circulating air through the enclosure around the engine and exhausting by the eductor at the engine exhaust flange. The cooling air is drawn directly from the weather on an upper deck level in the house and circulated to each enclosure by separate fans and supply ducts. These cooling supply systems are completely independent of both the engine combustion air intake ducts and also the general engine-room intake ventilation systems. Small silencers are provided in these supply ducts to prevent the noise within the engine enclosure from being transmitted to the quarters and deck spaces.

The starting power for the FT4 engines required a choice between air turbines and hydraulic motors. The hydraulic system was selected because of the advantage in this ship of the availability of two generator diesels which can be used to drive the two hydraulic pumps of the starter system. Two independent drivers are thereby provided, each at a low utility level at the time when cranking of the main engines is usually done.

The alternative air-turbine system would require a high-capacity air supply system which would be utilized only during engine starting. This system would be more attractive in a ship requiring low-pressure air for additional purposes.

**AUXILIARY SYSTEMS**

The selection of primary drive for ship service generators depends heavily upon the relative electrical loads at sea and in port. On the Callaghan, the sea load is relatively light owing to the reduction in propulsion auxiliaries required for gas turbine propulsion. The port load is high owing to cargo-hold ventilation and higher still when cargo gear is in operation. The electrical load summary is given in Table I. The usual mode of operation will use one generator at sea and two in port. Several combinations of number and size of generators were studied. The selection of three 500-kw units gives a satisfactory long-term power fraction on each unit, adequate standby protection, and low initial cost.

The method of heating the quarters has had an influence on the selection of generator drive. Early in the ship design, a decision was made to use electric heating throughout the quarters in order to avoid complication in the engine room. This selection adds to the electrical load but greatly simplifies the hotel service systems.

Utilizing the main-engine exhaust heat as an energy source for a generator drive is not attractive because the gain in fuel rate is very small and the high port load would require provision for an alternate type of generator of much larger capacity. This arrangement would result
Table 3 Electrical Loads for Various Operation Conditions Loads Represent Maximum Condition for Each Electrical Service

<table>
<thead>
<tr>
<th>ELECTRICAL SERVICE</th>
<th>PORT LOADS</th>
<th>SEA LOAD</th>
<th>ROLL-ON/ROLL-OFF USING CARGO GEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Propulsion and Ship Service Aux.</td>
<td>178</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>(2) Electric Heating, Winter</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>(3) Commissary Equipment, Including Refrigerated Stores</td>
<td>45</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>(4) Quarters Ventilation</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>(5) Hold Ventilation</td>
<td>50</td>
<td>450</td>
<td>450 *</td>
</tr>
<tr>
<td>(6) Cargo Gear</td>
<td>0</td>
<td>0</td>
<td>280</td>
</tr>
<tr>
<td>(7) Quarters Lighting</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>(8) Machinery Space Lighting</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>(9) Hold and Deck Lighting</td>
<td>30</td>
<td>290</td>
<td>290</td>
</tr>
<tr>
<td>(10) Navigation, Electronics, and IC</td>
<td>10</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>(11) Machinery Space Ventilation</td>
<td>62</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>(12) Total, Winter Load, KW</td>
<td>665</td>
<td>1165</td>
<td>1445</td>
</tr>
<tr>
<td>(13) Number Units Running, Winter</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>(14) Number Units Running, Summer</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Maximum Load, assuming some vehicles in every hold are driven to hatch opening

in a redundancy of generator capacity and additional heat-exchange equipment. By contrast, if the electrical load at sea were heavy and the port load very light, a waste-heat cycle would be attractive, including a small diesel generator for port load.

The selection narrowed to either diesel drive or auxiliary gas turbines with exhaust heat recovery. The potential of the auxiliary gas turbines could not be fully utilized, particularly in port, and the total energy concept of that alternative could be used only to provide distilled water. Initial costs favored the diesel drive. The two systems can be quite competitive and each gas turbine ship design has to be analyzed individually.

Having made the decision to use electric heating in the quarters, all other potential steam systems were eliminated. The additional expense of the auxiliary boiler, pumps, steam and drain piping would compromise the cost gain of the electric heating installation. All auxiliary heat loads in the engine room, therefore, are met electrically. Similarly, the distilling plant selected is a vapor compression unit. The distilled water requirement is relatively light since the usual needs for boiler feed water makeup and atomizing steam for boiler burners do not exist. Potable water for hotel purposes and sanitary use is the principal requirement.

A large-capacity ventilation system is provided for the cargo holds and is operated at full flow in the port condition. During unloading, some of the military vehicles are driving off and others are standing by with engines idling. Since coordination of the unloading sequence with the operation of selected ventilation will involve both a complication and a risk, all cargo holds are ventilated simultaneously. The fresh air supply insures at least 1 cu ft/min/sq ft of deck area to dispel gasoline fumes. The fresh air supply is also sufficient to reduce the concentration of carbon monoxide from idling vehicle engines to less than 100 ppm.

CONTROL

The development of the engine spaces of the Callaghan has verified preliminary opinions that gas turbine propulsion systems using aircraft-type units have serious virtues of compactness, simplicity, and ease of control. Remote opera-
tion is easily attainable, and the incorporation and attention of available concepts of control and system operation makes it amenable to a fresh approach on manning and surveillance.

As a minimum, the Callaghan incorporates bridge control of the speed and direction of propeller rotation. A simple engine station in the wheelhouse advises the officer in command that the system is functioning, that he has wheelhouse control, and that his two throttles control the main engines. Minimum alarm lights advise this man if an actual or potential malfunction threatens his plant availability, but the bridge is not otherwise given detail on the specific performance of any machine or system.

Details of component function or malfunction are available at the console-type machinery control center in the auxiliary machinery space. Main-engine performance is checked by observing only a half dozen temperatures and pressure ratios on each gas turbine engine, and these are monitored continuously, with alarms used to indicate system abnormalities, such as high bearing temperatures.

Auxiliary systems also are monitored at the main console, although in keeping with the basic plant simplicity, the actual number of instruments and controls are few. Lubricating-oil service and fuel-oil service both are indicated by pump running lights, with actual start-up of individual items to be local at the machine rather than remote at the console. Similarly, the diesel generators have local control, though the main switchboard is at the console location which is also right next to the diesel generators. The man on station can attend to synchronization, basic start and stop, and to monitoring of generator electrical performance. Except for indicator lights to indicate functioning pumps, and alarm indication of special malfunction, bilge and oil pumping is controlled from the individual manifolds, not the console.

Automatic data recording has been minimized, although logging of bells signaling change in speed or propeller rotation is maintained along with bar-chart records of basic engine performance.

Except for recurrent daily functions such as fuel-oil transfer, cleaning oil purifiers, and equipment switch-over on a planned basis, the plant requires little surveillance or adjustment. Maneuvering situations may require engineer action at the console if, for some reason, the bridge chooses to relinquish its ability to handle directly the speed and direction of propeller rotation. The supply of fuel to the engines is integrated with the engagement or release of clutches through a pneumatically actuated, sequenced system, so human requirements are very minor except in starting the plant or a generator.

Emergency situations, the customary automatic energizing of an emergency service bus permits the ship to operate at limited speed while proper corrective action is taken by the man in the engine room.

Serious consideration was given in the developmental stage of this vessel for augmented mechanization so as to permit unattended engine operation while at sea in nonmaneuvering situations. This would involve little augmenting of the plant since it already has shut-down capability if the main engine has a serious malfunction. Automatic start-up, sequencing, and load sharing of generators; automatic bilge-pump control in the engine spaces; more alarm and centralization of controls, rather than locally at the machine; and automatic power reduction in case of minor malfunctions were all considered. More extensive data logging was thought necessary to permit the engineer coming upon the scene after an alarm signal to be advised of plant and component performance for a time period prior to the actual alarming of a malfunction or, indeed, to show plant operation during the unattended hours.

A suitable engineering force would be available on board for emergencies, and would ordinarily perform day work involving routine vessel function and minimum maintenance. The overall philosophy of vessel operation assumes maximum dependence on shipyard performance of maintenance and includes the periodic replacement of the gas turbine gas-generator section. Spare generator sections are planned so that factory overhaul can be accomplished on used units, with the initial interval of use being about six months between overhauls.

At the time this is written, it appears that unattended engine-room operation would be unacceptable, without lengthy testing, owing primarily to legal restrictions imposed upon and interpreted by the U. S. Coast Guard. A minimum attendance on a watch basis is being developed and will be incorporated to the maximum extent possible. The present development of the control functions indicates that the operation of the plant actually requires no one in attendance, except for abnormal conditions. A one-officer watch appears to be the prudent way of meeting legal requirements, and also providing knowledgeable capability for emergency situations, without the cost of added automation which a full unattended service would demand.
SUMMARY

The Admiral Wm. M. Callaghan represents the most advanced application of the roll-on/roll-off concept of cargo handling as developed by the Military Sea Transport Service. The consequent rapid port turn-around is an economic advantage if combined with high sea speed. Gas turbine propulsion is attractive in this service because it provides the power needed for high speed and permits maximum cargo deck area for military vehicles within a given hull size. The detracting factor is the relative high price of fuel for the gas turbine engines. The ship is basically a high-utility carrier with high operating costs, but producing a very high rate of cargo transport revenue.

Gas turbine engines offer advantages to the ship with respect to arrangement of cargo spaces, minimum on-board maintenance, and simplicity of operation and control. The installation does impose special considerations for the removal of moisture from the engine intake air, purity of fuel, engine cooling, and noise control. The best reasonable solution at hand has been employed in each of these design areas. The service experience of this ship will be a source of cogent guidelines for the design, control, and operation of many future gas turbine installations. It will also provide merchant ship operators with a qualitative assessment of the gains and the risks of gas turbine propulsion.