Design and Powering of Cable Ship "Long Lines"

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The C.S. "Long Lines" was designed both to lay the new SD submarine cable system and to repair new and existing undersea cables. Within the limits imposed by this dual purpose, an entirely new cable ship design has been evolved which gives maximum working efficiency, maneuverability, and stability. While most of the special features of the ship — wide-range power plant, cable storage and handling facilities, etc. — are the result of its special function, a great deal of attention has been paid to providing optimum working conditions for, and safety of, the ship's complement.

I. INTRODUCTION

1.1 *Factors Affecting Ship Design*

The primary purpose of the new Cable Ship *Long Lines* was to lay a new type of cable system. Its secondary, but scarcely less important, purpose was to be capable of repairing all existing and new cable systems, both telephone and telegraph. The ship then, a tool in itself, had to carry other tools or hardware to do the job for which it was designed. First in importance were the cable tanks, the number and size depending on the amount and type of cable to be carried, then the means of payout for laying, and last the type of pickup for repair work.[1,2]

Speed and range were developed when the owner specified the extent of the ship's run, its longest service steaming time, and its time on the so-called "cable grounds."

Since the *Long Lines* was to be at sea for long periods of time and carry a multimillion-dollar cargo, great emphasis was put on the reliability of the ship and its component parts. All machinery and equipment used were designed to operate satisfactorily with a momentary roll of 30 degrees to either side or a pitch of 10 degrees, a permanent list of

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15 degrees to either side, and a permanent inclination of 5 degrees in either direction fore and aft.

Various agencies whose regulations had to be considered in the design, construction, and installation of all its parts, equipment, and outfit are listed in Appendix A. This listing shows that, in addition to the owner's specifications, regulations had to be followed with regard to the construction of the ship itself, the machinery, auxiliaries and outfit, the safety of the ship in the event of damage by flooding or fire, and the safety of the crew and those engaged in loading the ship.

1.2 *Contract Specifications and Plans*

When the cable and repeater laying techniques had been developed and test facilities and other requirements determined, authorization was given by the Long Lines Department of the American Telephone and Telegraph Company to proceed with the preparation of bidding data for a new cable ship. These data included the preparation of detailed ship specifications incorporating the requirements for the ship itself, its detailed characteristics, full machinery and electrical requirements, outfit, accommodations, messing, and decoration.

In addition to these specifications, approximately 30 contract plans and numerous other detail plans were prepared as further guidance to the prospective contractor. These included ship construction, ship arrangements, and plans peculiar to a cable ship, viz., bow sheaves, electronic spaces, jointing room, drum room, etc.

1.3 *Opening of Bids and Contract Award*

All of the foregoing bidding data were incorporated as a package unit and transmitted to shipyards in several countries who had expressed a desire to bid on the ship. A period of eight weeks was allowed for the preparation and submittal of the bids to the owner. The contract was awarded to Schlieker Werft of Hamburg, West Germany, who submitted the lowest bid.

Owing to the unfortunate circumstances of bankruptcy proceedings against Schlieker Werft when the ship was about ninety per cent completed, it was taken out of this yard and completed at Deutsche Werft, Hamburg, West Germany.

II. DESIGN

The design of a special-purpose ship such as a cable ship is complex and requires consideration of many factors not usually encountered in cargo ship design. The discussion that follows has been limited to areas of particular importance in cable operations.

2.1 *Selection of Hull Form*

A cable ship must be a stable working platform and have good seakeeping qualities. It must operate at a variety of speeds and with varying loads. Consequently, considerable attention must be paid to the hull form.

A ship that is to be operated at high speeds is designed with relatively fine lines, while a ship operated at lower speed can have much fuller lines. This is because at low speeds the frictional resistance, which depends on the area of the ship below the water line, is most important, but at higher speeds the wave-making resistance increases in importance; it is desirable to reduce this as much as possible by fining down the ends of the ship. The fineness of a ship is indicated by the block coefficient,[3] which is the volume up to the designed water line divided by the product of the length, beam and draft of the circumscribing block, thus:

$$C_b = \frac{V}{L \times B \times d}$$

where

V = volume of displacement in cubic feet
L = length of ship at load waterline in feet
B = extreme immersed breadth in feet
d = draft of water in feet
C_b = block coefficient (or coefficient of fineness).

The block coefficient is selected fine enough to give a reasonably low resistance when the ship is propelled at the design speed, but high enough to avoid an excessively large and costly ship. In selecting the block coefficient, the speed of the ship considered is not the actual speed but a speed in relation to the length of the ship, namely the design speed divided by the square root of the length. A longer ship can therefore be made fuller than a shorter ship for the same speed.

The heavy weights of the bow sheaves and the cable engines located at the ends of the vessel increase the moment of inertia and have a tendency to increase the pitching motion. This was considered in the development of the lines in order to reduce this adverse effect as much as possible.

2.2 *Displacement and Light Ship Weight*[3]

The displacement of a ship is the total weight of the water displaced by the ship, and is equal to the weight of the ship itself (light ship weight) and all weights carried on board. The full load displacement is the light ship weight plus the deadweight. The deadweight is the total of the variable weights on board.

The light ship weight can be divided up into the weight of the hull structure, equipment and outfit, and machinery. In the case of the *Long Lines*, these weights and the deadweight are subdivided as follows:

(1) hull structure, the weight of the steel in the hull;

(2) equipment and outfit, the weight of all joiner work and furniture, all machinery for handling the cable, steering gear, anchors and cable gear, boats and all other equipment needed for operating the ship, including the electric generating plants for the ship's use, and the approximately 62 miles of electric cable in the ship;

(3) machinery, the weight of all machinery and auxiliaries needed for the propulsion of the ship at the required speed; and

(4) deadweight, the weight of the cable, water in cable tanks, spare cable, cable gear (such as buoys, grapnel, rope, etc), crew, stores, fresh water for ship's use, reserve feed water for boilers, and fuel oil for the specified cruising range, part at full speed, part at cable laying speed.

With the exception of the first few items of deadweight that are the owner's requirements, all other weights are interrelated and depend on the size of the vessel. The procedure, therefore, is to select a family of ships of different displacements with proportions and coefficients based on data from other ships. Preliminary rough estimates of the weight of hull, equipment and outfit, horsepower required and weight of machinery and fuel oil for each of these ships are then made. Based on these estimates, dimensions of a hull able to carry the required payload are selected for further consideration. Arrangements are then drawn up to check that sufficient space is available for cable tanks, cable handling, machinery, crew accommodation, etc. Based on these arrangements, additional checks are made of the weight, and adjustments are then made of the dimensions.

2.3 *Stability*

In selecting the dimensions of the ship, the operational stability of the ship has to be considered. The stability depends on both the vertical location of the center of gravity of the loaded ship and the beam of the vessel. With a given center of gravity, the beam must be wide enough to avoid excessive heel due to high wind abeam or excessive angles of roll in a seaway. On the other hand the beam must not be too wide, since this may result in an excessively fast period of roll and violent motions when rolling, making it hazardous to move around on the deck.

When the ship is floating upright as shown in Fig. 1(a), the weight of the ship and its contents, W, acting downwards through its center of gravity, G, is opposed by an equal buoyance force acting upwards through the center of buoyancy, B, and the ship is in equilibrium. The buoyancy is the sum of the vertical components of the water pressure acting on the outside of the hull, and is equal to the weight of the water displaced by the ship. The center of buoyancy is the center of gravity of the underwater volume of the ship.

If the ship is heeled over by an external moment, the buoyancy provided by the wedge A in the upright position is replaced by the buoyancy provided by the wedge A_1. As a result the center of buoyancy moves from B to B_1 and the weight and the buoyancy are no longer in line but provide a couple, $W \cdot \overline{GZ}$, tending to bring the ship back to the upright position, as shown in Fig. 1(b).

The force acting through the center of buoyancy intersects the centerline of the ship at a point M. This point is called the metacenter. It is constant for moderate angles of heel at a particular water line.

The location of the metacenter for different drafts depends only on the width and properties of the water line and the displacement at that draft, and can readily be calculated.

Since the stability of the ship depends on the location of the center of gravity in the different loading conditions, careful calculations of the center of gravity of the light ship and all items of deadweight are made in

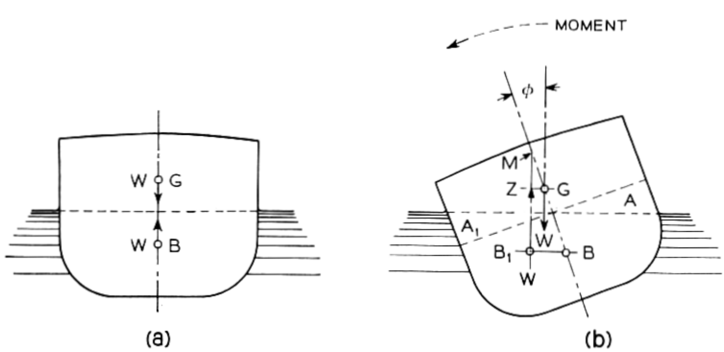

Fig. 1 — Factors affecting stability: (a) equilibrium state; (b) heeling.

order to be able to calculate the center of gravity and the stability for each loading condition.

The freeboard, or the distance between the water line and the deck at side, is also an important factor in the safety of the ship, since it determines the maximum angle of heel the ship can take without losing stability and increasing the chance of capsizing.

The righting moment is $W \cdot \overline{GZ}$ where $\overline{GZ} = \overline{GM} \sin \phi$. $\overline{GM}$ is referred to as the metacentric height, and is a measure of the stability of the ship.

2.4 *Model Testing*

When the dimensions and coefficients of the ship have been selected, a preliminary set of lines defining the shape of the hull is drawn, and a scale model of the ship's hull is built for testing.

This model is towed in a tank to determine the resistances of the hull at different speeds. The results of these tests are compared with the results of other model tests to determine that the resistance is reasonably low. Often several sets of lines are tested in order to obtain the best possible lines.

After completion of this towing test for bare hull resistance, the hull is tested with appendages added such as bilge keels* and rudders, and finally a self-propelled test is conducted to determine the interaction of the hull and propeller, the propulsion coefficient, and the actual horsepower required to drive the ship at different speeds.

In order to insure that the flow around the hull is as smooth as possible, especially near the propellers, where an unsatisfactory condition could lead to hull vibrations, the models are frequently tested in a circulating water tank. In this tank the water is moved in a uniform stream at different speeds by large pumps and the model remains stationary. Tufts are attached directly to the hull or to small pins a short distance from the hull. Windows are provided in the side and bottom of the tank, permitting observation of the direction and steadiness of the flow as indicated by the tufts. In addition, small quantities of dye are injected in the water at different points along the hull to indicate the flow. The model is observed both with and without the propeller running at the correct rpm for the relative speed of the ship and water, in order to observe the effect of the propeller on the flow around the model.

For *Long Lines*, preliminary tests for bare hull and appendaged hull

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* A bilge keel is a long fin running fore and aft and fitted to the hull, port and starboard sides at the turn of the bilge, to reduce rolling. In the case of the *Long Lines* these bilge keels were designed with a deeper than usual profile and a shorter longitudinal extent in order to minimize resistance and increase damping to effect a steady cable laying platform.

(with bilge keels attached to the hull, bossings and rudders) resistance were conducted at Stevens Institute of Technology using a scale model of wood, approximately five feet long.

In addition to these still water tests, the Stevens Institute Towing Tank conducted tests on the 5-foot model to evaluate the behavior of the ship in waves. Two types of long-crested irregular "seas" were chosen, a moderate sea with a significant height* of 19 feet generated by a 28-knot wind, and a steep sea with a significant height of 28 feet generated by a 33-knot wind. Test conditions were chosen to simulate full-scale operation when laying cable over the stern at slow speeds and repairing cable over the bow at zero speed. For each sea type, ship speeds were varied from zero to 14.6 knots for head seas, zero to 11.6 knots for following seas and zero speed for bow, beam and quartering seas. The model demonstrated superior seakeeping qualities under all conditions, and it was concluded that cable operations could be conducted under all conditions except steep head seas for ship speeds of about 10 knots and above.

On the basis of these test results, final ship lines were chosen for testing at the David Taylor Model Basin, Washington, D.C. Using a larger scale model, about twenty feet long, made of special wax, bare hull and appendaged hull resistance of the ship were tested. Then, with a suitably chosen set of stock propellers, the self-propelled tests were run. The deep water basin where these tests were conducted is 2775 feet long, 51 feet wide and 22 feet deep.

Lines of flow for bilge keel locations were also determined at the David Taylor Model Basin. After completion of the self-propelled test series, the fully appendaged model was checked in the circulating water channel at several displacements and under various operating conditions.

Final model tests were conducted by Schlieker Werft at the Hamburg Model Basin, Hamburg, Germany. These tests were all conducted at the full load displacement of the ship, and comprised an appendaged resistance test with several self-propelled tests. The self-propelled tests employed a series of propellers and formed the basis for the selection of important characteristics of the propellers designed for the ship.

2.5 *Inclining Experiment*

When the ship is essentially completed, the calculated light ship weight and the center of gravity of the ship are checked by the shipbuilder by means of an inclining experiment.

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* The significant height of a wave system is the average of the highest one-third of the waves which pass during an interval.

The ship is moored in such a way that it floats freely with minimum restraint. The draft of the ship at the draft marks is measured carefully from open boats simultaneously on both sides, forward, aft and midship, and the specific gravity of the water is obtained from samples at several locations along the ship. From this information and the shape of the hull the displacement of the ship in the inclined condition is very accurately determined.

The ship is inclined by moving one or more weights from a location on the centerline of the ship, Fig. 2(a).

The weights are moved to several positions away from the centerline of the ship, first on one side, then on the other, and finally on the centerline. The distance of the weights from the initial position is carefully measured after each movement and the resulting heeling moment $w \cdot x$ (a moment tending to incline the ship away from the upright position) is calculated.[3]

The angles of heel ϕ for each position of the weights are obtained by measuring the deviation of three long pendulums in different locations in the ship. The tangents of these angles are plotted against the corresponding heeling moments to keep a check on the consistency of the readings, since theoretically all observed points should fall in a straight line through the origin of coordinates.

If the displacement of the ship is W, and the heeling moment is $w \cdot x$, then, from Fig. 2(b)

$$\overline{GG_1} = \frac{wx}{W} = \overline{GM} \tan \phi$$

$$\overline{GM} = \left[W \left(\frac{\tan \phi}{wx} \right) \right]^{-1}$$

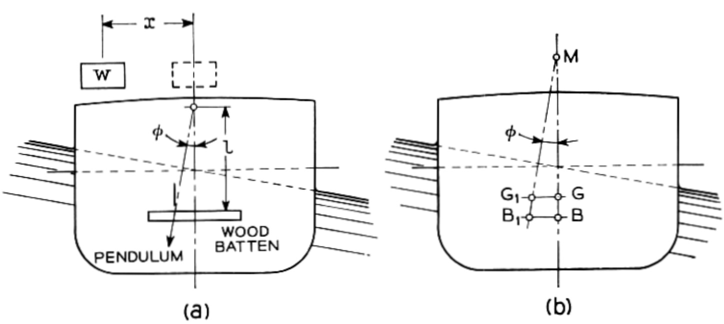

Fig. 2 — Inclining experiments: (a) placement of weights; (b) forces affecting height of center of gravity during heeling.

Taking the average value of ($\tan \phi / wx$) from the plot, the distance GM is calculated. Since the location of the metacenter M for the inclined condition is known, the location of the center of gravity of the ship in the inclined condition can be determined.

At the time of the inclining experiment the ship is completely surveyed, and the weight and location of all items needed to complete the ship is noted. All items aboard the ship not belonging to the light ship weight, such as inclining weights, liquids in tanks, tools, etc., are also recorded. By addition or deduction of the weight and moments of these items from the weight and moments of the ship as inclined, the light ship weight and center of gravity can be calculated.

Based on the inclining experiment, a stability book is prepared giving all information to the Master to enable him to load the ship to insure sufficient stability in all conditions of loading.

2.6 *Flooding and Damaged Stability*

The ship is divided into compartments by transverse watertight bulkheads spaced so that if any two adjacent compartments are flooded the ship will not sink. The ship loses stability when flooded, and it is possible that even if the ship would not sink, it could capsize due to insufficient stability or excessive heeling moments due to unsymmetrical flooding. The effect of the flooding of adjacent compartments on the stability of the ship is therefore calculated for different drafts, and the minimum initial stability that the ship requires before damage occurs is obtained. The stability required to prevent capsizing in case of damage of the most critical adjacent compartments for different drafts is tabulated in the stability book, and the ship must meet this requirement in all conditions of loading.

III. MANEUVERABILITY

Early in the conceptual period of *Long Lines* it was recognized that a high order of maneuverability and precise control of propulsion power were required to permit the full exploitation of the advanced cable handling techniques.

A cable ship should be capable of precise, rapid maneuvering at low speeds, such as is desirable in grappling and coming-up on a buoy, and should be able to maintain accurate station-keeping in adverse sea and weather conditions when standing on a cable. These requirements demand consideration of maneuverability aids and a propulsion system which is easily and rapidly controllable and can provide high propeller torques at low speeds for rapid accelerations. Further, it is desirable that the propulsion plant be readily adaptable to remote control, in order to permit maneuvering the ship for cable handling from the most advantageous position. This approach eliminates the time lag and opportunity for misunderstanding inherent in systems in which orders are communicated through several people to the engine room.

3.1 *Maneuverability Aids*

3.1.1 *Number of Screws*

Twin screws versus a single screw were considered and selection was made in favor of twin screws.

3.1.2 *Rudders*

Twin spade rudders were selected and are located in the propeller race. They have an area 50 per cent larger than normally used for merchant vessels, and rudder angles of 45 degrees instead of the usual 35 degrees, thus providing sharper turning angles.

3.1.3 *Bow Jet*

A propeller-driven bow jet was decided upon as an effective aid in maneuvering with the vessel operating at very low speed. The propeller, 5 feet in diameter, is mounted in an athwartship tunnel near the bow and is driven by a reversible dc electric motor through a reduction gear. It is controlled from the wheelhouse and from forward and aft control stations.

IV. PROPULSION STUDIES

Various propulsion schemes were studied in the light of the ship requirements, and it quickly became apparent that a variable-voltage direct current system provided precisely the requirements desired. Its primary advantages are as follows:

(1) Very large torques (limited by shaft strength to 175 per cent of full load torque) are available at any propeller speed from zero to full speed. This is essential to provide the rapid propeller accelerations and reversals demanded by the precise ship maneuvering requirements. Propeller reversals from full ahead can be accomplished in less than two seconds.

(2) Remote control is easily accomplished by the provision of a simple rheostat and appropriate instrumentation at the remote location.

(3) Propeller speed is smoothly and continuously variable from zero to full in either direction.

(4) The ship will spend a great deal of its life at reduced powers during cable operations; electric drive permits available propulsion prime mover power during these periods to be used for other purposes, such as supplying cable engines and some of the ship's service electric power.

(5) Electric propulsion is inherently flexible, permitting shutdown of unused units during periods of low demand and easy cross-connection in the event of a casualty.

The major disadvantages of dc electric propulsion are its relatively high weight and somewhat low efficiency. The high weight is acceptable in return for the desired operating characteristics. The low efficiency is not very significant in this ship because the low propulsion power of the ship, combined with the high hotel and auxiliary power demand created by the working nature of the vessel, results in the propulsion power being a much smaller percentage of the total ship's power requirements than in most conventional ships. A large portion of the ship's operating time will be at very low propulsion power for cable laying (about one-eighth power), decreasing the importance of high propulsion efficiency.

4.1 *Selection of Prime Mover*

Having selected dc electric drive, there remained the question of the type of prime mover to power the generators. After preliminary studies diesel engine and steam turbine prime movers were selected for further study. Their respective advantages are as follows:

(1) Advantages of the diesel engine
- (a) lower first cost,
- (b) lower weight of fuel required,
- (c) lower machinery weight,
- (d) lower amount of fresh water required, and
- (e) smaller machinery spaces.

(2) Advantages of the steam turbine:
- (a) lower operating fuel costs,
- (b) lower maintenance and repair costs,
- (c) increased reliability,
- (d) less noise and vibration, and
- (e) the large number of seagoing licensed marine steam engineers available.

4.2 *Final Selection of Propulsion Plant Drive*

After consideration of all the facts, such as the heavy work schedule for the new cable ship, limited availability of licensed marine diesel engineers, reliability and minimum time out for maintenance and repair, and the problem of noise and vibration in the engine room and crew quarters, it was concluded that the propulsion plant drive should be of the steam turbine type.

TABLE I — PRINCIPAL CHARACTERISTICS OF C.S. "LONG LINES"

Length over-all	511′-6″
Beam	69′-6″
Load draft	26′-9″
Horsepower normal, total	7700 shp
Sustained sea speed	15 knots
Cable capacity ($1\frac{1}{4}$″ dia. cable)	2000 nm

V. OVER-ALL DESCRIPTION OF SHIP

The principal characteristics of the *Long Lines* are given in Table I. The hull is all steel and is designed with transverse framing except for

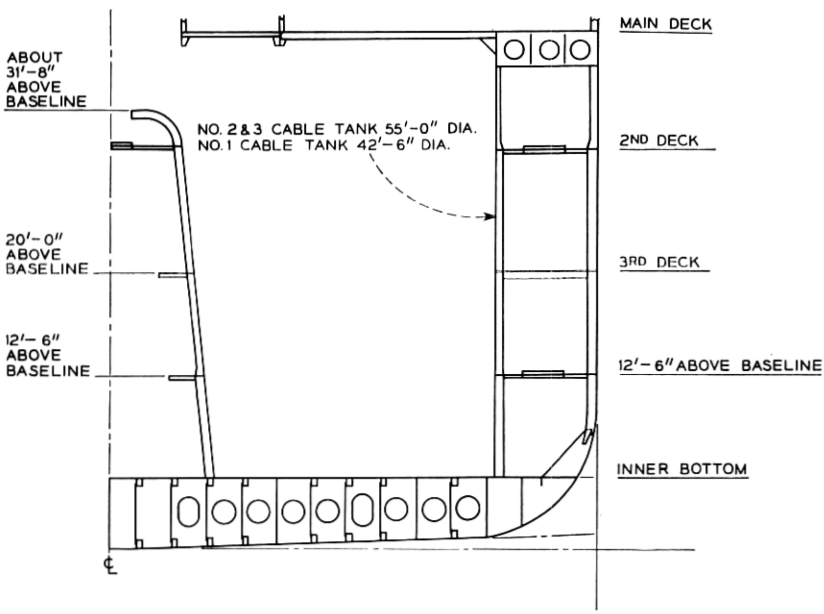

Fig. 3 — Typical cross section in way of cable tanks.

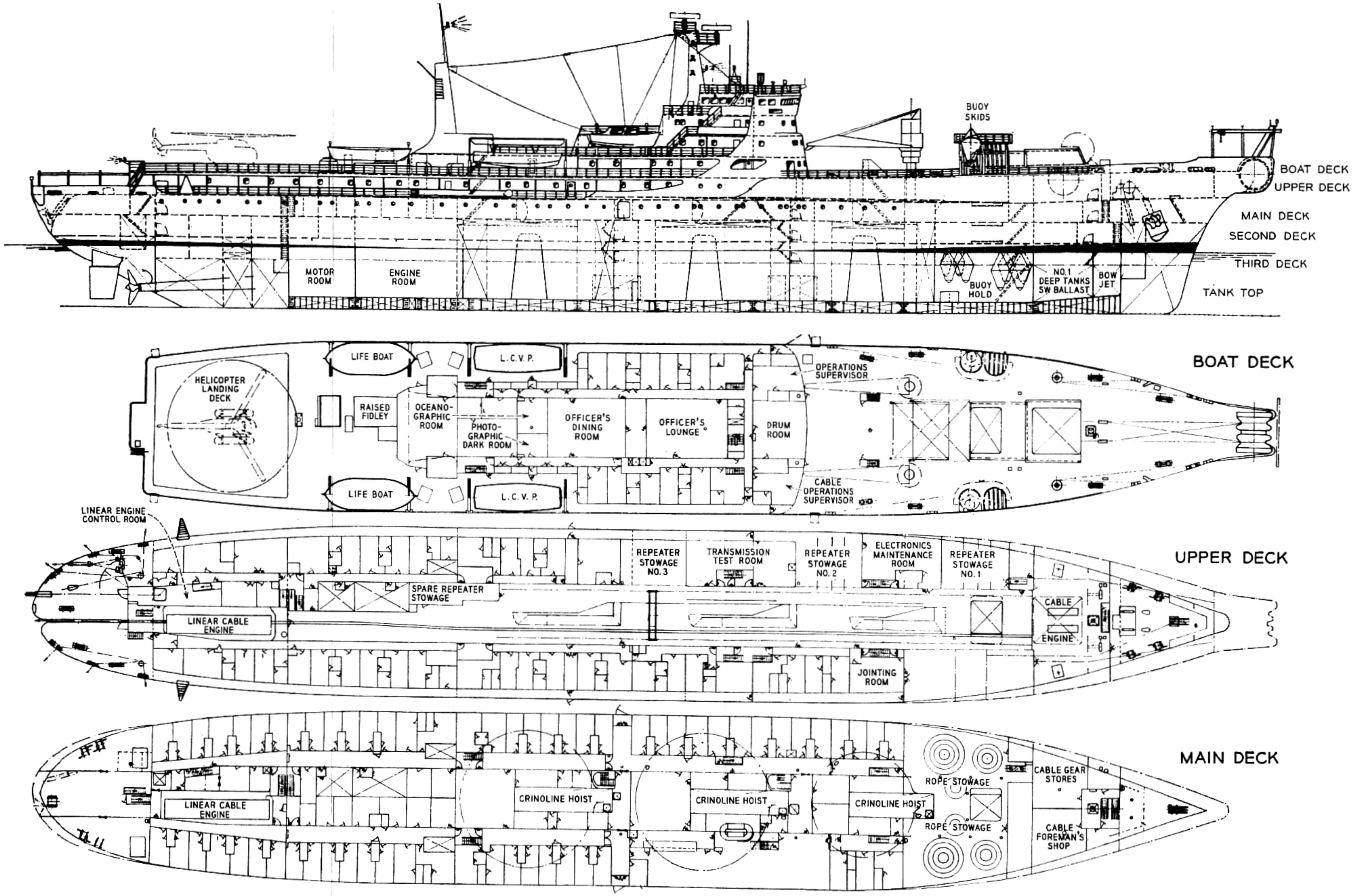

Fig. 4 — General arrangement of decks.

the inner bottom and bottom shell, which are framed longitudinally. It is of welded construction throughout except for certain shell seams and deck edge connections which are riveted. The shell is strengthened for navigation in ice. The propeller shafts also include an allowance for ice strengthening.

The three large-diameter cable tanks are located forward of the machinery spaces and provide approximately 138,500 cubic feet of space for cable storage. They are fitted with watertight cones and also with recesses for cable bights[1] at the forward end which extend for the full depth of the tanks. Fig. 3 shows the cable tank construction.

Ship service electric power and power for the linear cable engine are furnished by four ac generators, two driven by the propulsion turbines and two driven by independent steam turbines. Emergency service electric power is furnished by a diesel engine-driven ac generator set. Electric power for the bow cable engines is furnished by two dc generators driven by the propulsion turbines.

A helicopter deck, with its own lighting and with special safety rails around its periphery, is located at the aft end of the houses.

All joiner work throughout the ship, linings, bulkheads and ceilings, is of incombustible construction. Incombustible furniture and fire-resistant draperies, portieres, bedspreads, etc., are installed throughout as far as possible. All living accommodations, offices, lounges, wheelhouse, chartroom, radio room, and the principal working spaces are air-conditioned for personnel comfort and to provide a good environment for the large amount of electronic equipment.

A general arrangement of the decks is shown in Fig. 4.

VI. PROPULSION PLANT

The propulsion machinery is of the twin screw, steam turbine, direct current electric drive type.

6.1 *Design Conditions*

Design conditions for the propulsion plant are given in Table II. The layout of the main machinery spaces is shown in Fig. 5.

6.2 *Generator Train and Propulsion Motors*

Each generator train is driven through a single reduction gear by a 5000-hp steam turbine. Each train consists of the following, all driven in tandem at a constant 900 rpm by the propulsion turbine (see also Fig. 6):

TABLE II — PROPULSION MACHINERY DESIGN CONDITIONS

Shaft horsepower — normal, each shaft	3,850
Shaft horsepower — normal, total	7,700
Shaft horsepower — maximum, each shaft	4,250
Shaft horsepower — maximum, total	8,500
Sustained sea speed (at 80 per cent of normal power at full load draft)	15 knots
Steam conditions at boiler superheater outlet	600 psig — 850°F
Full fuel capacity (half cruising at full power 15 knots and half cruising 7.5 knots)	14,350 nm

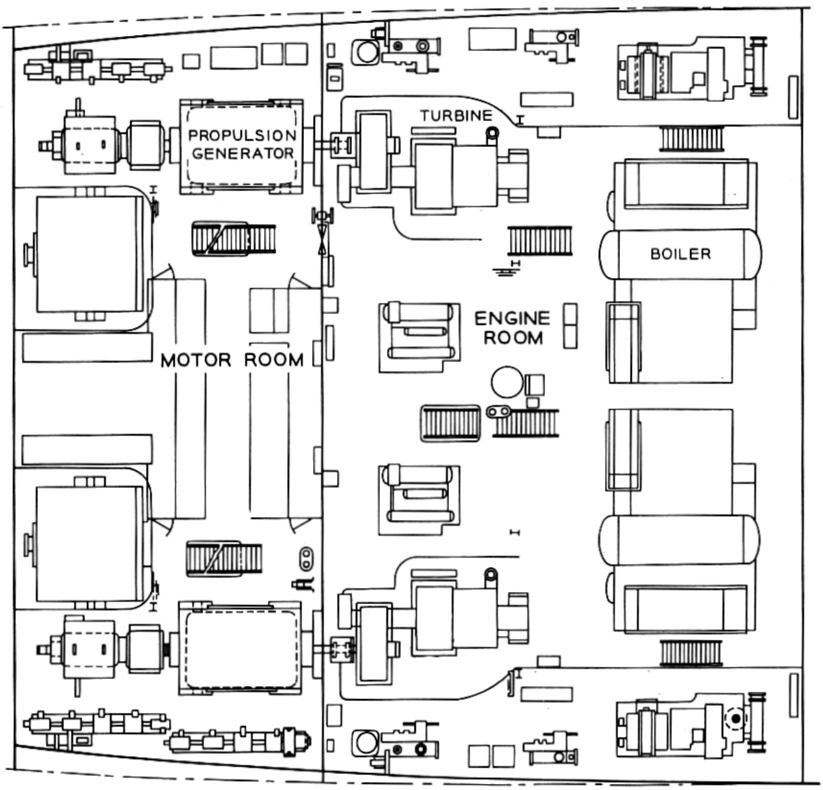

Fig. 5 — Layout of main machinery spaces.

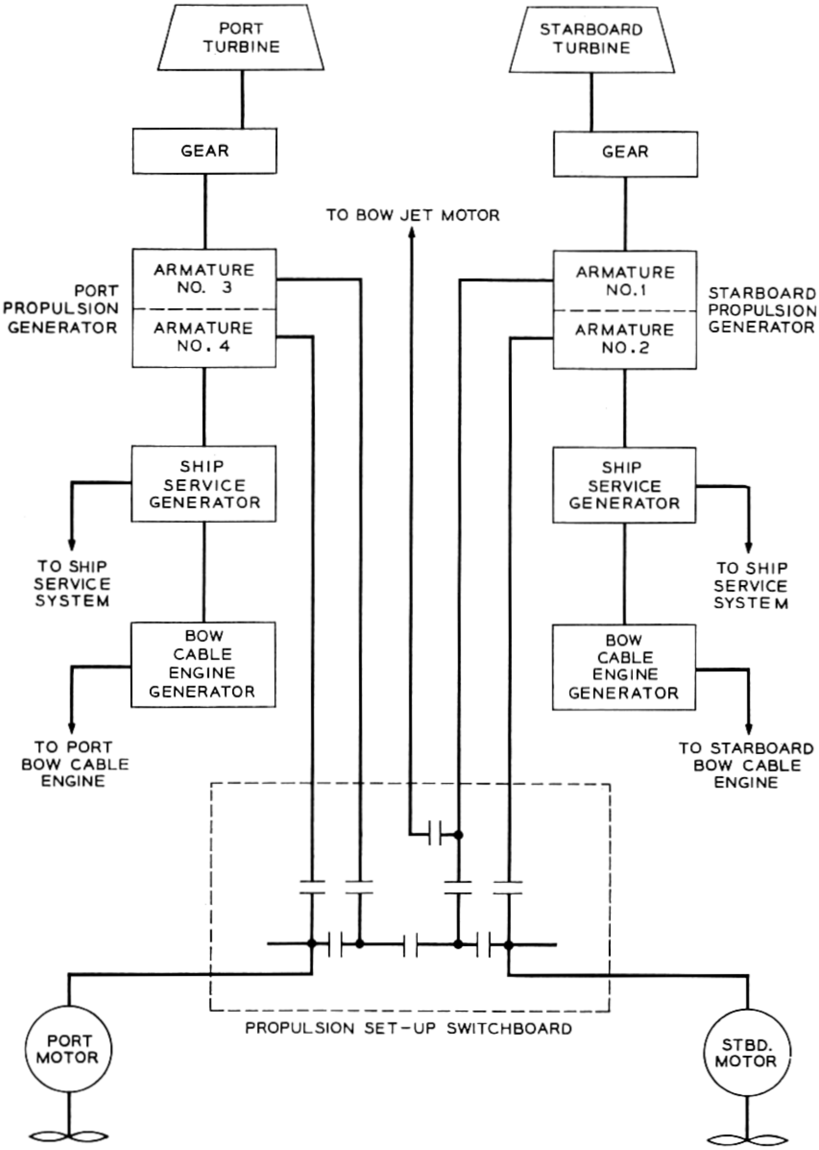

Fig. 6 — Generator train.

6.2.1 *DC Main Propulsion Generators*

The two armatures in each generator are completely independent electrically. The generator is totally enclosed, water cooled and force ventilated by a separately driven cooling blower.

6.2.2 *Ship Service Generators — 3-phase ac*

The machine is open and air cooled. This generator can be utilized to supply some of the ship's service power during periods when the ship is not operating at full propulsion power.

6.2.3 *Bow Cable Engine Generators*

This generator, rated 480 kw, 800 amperes at 600 volts, is totally enclosed, water cooled, and force ventilated by a separately powered 3-hp blower. Because of the infrequent service it is also provided with an externally operable brush-lifting device to lift the brushes off the commutator when the generator is not in use.

6.2.4 *Propulsion Motors*

Each propulsion motor is rated 4250 horsepower at 135 rpm. It is separately excited, with field weakening to reach 147 rpm in order to utilize full available power in the light ship condition. The motors are totally enclosed, water cooled and force ventilated by a separately powered 30-hp blower.

6.2.5 *Cooling of Units*

All propulsion motors and generators are kept slightly pressurized by means of a small make-up air fan. This fan supplies clean, electrostatically filtered air to the inside of the machines and maintains a slight positive pressure so that any leakage will be out of the machine. Thus the machine interiors are protected from engine room air contaminants.

6.2.6 *Control and Switching*

The basic principle of control is motor speed control by variable armature voltage with constant motor field. The manually operated speed control rheostat works in a control field of an amplidyne, the output of which supplies generator excitation. Since generator speed is held constant, this varies armature voltage, thus controlling motor speed. The system is speed regulated by means of generator output voltage feedback, and current and power limiting controls are incorporated to prevent overstressing or overloading the mechanical portions of the system. In addition, the necessary switching, interlocks and safety devices are incorporated in the control to take advantage of the flexibility available, yet prevent malfunction. One of the switching arrangements provides the ability to connect one of the propulsion armatures to the bow jet motor, thus providing 750 hp to the bow jet without the need for a separate generator. The control components and switchgear are contained in a propulsion set-up switchboard and a propulsion control console, both located in the motor room. In addition, there are propulsion control consoles in the bow of the ship, near the bow sheaves; in the wheelhouse, port, centerline and starboard; and in the stern of the ship, in view of the overboarding chute.

6.3 *Main Turbines*

The main turbines are of the high-speed, single-casing type and are connected to the main reduction gears through a flexible mechanical dental-type coupling. The port and starboard turbines are identical and have the same rotation. The turbines are designed to deliver the normal rated horsepower at the point of best economy with initial steam condition at the turbine throttle of 585 psig and 840°F total temperature and a vacuum of 28.5 inches Hg at the exhaust. The turbines are also designed for uncontrolled bleed steam for feedwater heating, boiler combustion air heating and other purposes.

6.4 *Reduction Gears*

The reduction gears are of the single-reduction, double-helical type, arranged to allow the main condensers to be mounted athwartship under the turbine.

6.5 *Shafting*

The shafts are solid forged steel, American Bureau of Shipping Grade No. 2 material.

VII. ENGINE AND MOTOR ROOM AUXILIARIES

7.1 *Distilling Plant*

Since the ship will be at sea for long periods of time, all the fresh water required on board is produced by two complete sea water distilling plants of the flash type. Each distilling plant is designed to meet the fresh water purity requirements of the United States Public Health Service, and each unit has a capacity of 12,000 gallons per day of fresh water of potable quality. One distilling plant can provide all the fresh water requirements for drinking water, hot and cold washing water, hot and cold fresh water for galley and pantry service (cooking and dishwashing), laundries, and make-up water for the boilers.

7.2 *Boilers*

Two natural circulation water tube boilers are installed, and each boiler is of the bent tube, oil-fired, single-furnace, single-uptake, air-encased type with water-walled furnaces. Each boiler is fitted with double-cavity, walk-in type superheaters, economizers, steam air heater and submerged internal type desuperheaters installed in the steam drum. These boilers produce superheated steam at 600 psig, 850°F at the superheater outlet.

The boilers are fitted with steam-mechanical atomizing fuel oil burners suitable for use with the automatic combustion control system. These burners combine the features of steam and mechanical fuel oil atomization. The system is unique in that the burners are used in two ways. They provide straight mechanical atomization (no steam assistance) of the fuel burned when the ship is operating at full power. In addition, they function as a steam atomizing burner (steam assisting in the atomization of the fuel oil) at low steaming rates, as during periods of reduced propulsion steam demands (cable laying and cable repair). This second function results in reduced fuel consumption when the straight mechanical atomizing efficiency falls. The primary advantage of the steam-mechanical atomizer is that good combustion efficiency over a wide range of operation is obtained with minimum steam consumption and a low fuel oil system operating pressure. The importance of wide-range burners may be appreciated when considering that the ship will operate for extended periods at light steaming loads, as during cable laying, cable repairing, maneuvering and in-port operation. These burners also have the advantage that the furnace can be kept clean under low steam demand operation of the vessel, because more efficient steam atomization of the oil results in more complete combustion.

The boilers are fitted with a pneumatic-type automatic combustion control system designed to maintain constant superheater outlet pressure. The combustion control system attains maximum fuel economy by maintaining the boiler steam pressure and temperature at the highest design conditions by controlling the quantity of oil and air being delivered to the boiler in the proper ratio to maintain maximum combustion efficiency. Maintaining the proper steam pressure and temperature insures maximum turbine performance. The control system will follow the fluctuations in the boiler loads due to changes in the ship's speed or electrical load changes, at the same time maintaining maximum fuel economy with a minimum of smoke.

VIII. SHIP'S SERVICE REFRIGERATION MACHINERY

A ship's service refrigeration system is provided and designed for the direct expansion of Freon 12 gas. Since the ship will be at sea for long periods of time, approximately 8000 cubic feet of refrigerated stores have been provided.

IX. PIPING

All piping installed in the ship was designed to meet the highest marine piping standards used in the U.S.A. Corrosion-resistant materials were used to reduce maintenance and repair costs and to obtain long life in service. All piping carrying sea water is of 90-10 copper-nickel alloy. This alloy is very resistant to the corrosion-erosion effect of sea water. Stainless steel has been used in many of the other piping systems. There are approximately 12 miles of piping installed in the *Long Lines*.

X. SAFETY AIDS

10.1 *Watertight Doors, Firescreen Doors*

Five watertight horizontal sliding doors have been installed at vantage points in some bulkheads to maintain the watertight integrity of the ship. These doors, normally open, are electrically operated and can be controlled collectively or individually from the wheelhouse. There are local door controls on both sides of each door.

Approximately 48 firescreen doors, normally held open by magnet control, can be operated from the wheelhouse and locally; about 30 more firescreen doors, normally closed, are operated locally. All of these are installed in the firescreen bulkheads for protection against fire.

10.2 *Fire Detection System*

A thermostatic detection system is provided to sound an alarm in the event of a fire. Detectors are installed in all public spaces, lockers, holds and similar unattended spaces. Manually operated alarm boxes are provided in all fire zones in readily accessible locations. An annunciator panel, which indicates the area originating an alarm, is installed in the wheelhouse, and alarm bells are provided in the wheelhouse, engine room and quarters of the firefighting crew.

10.3 *Firefighting Systems — General*

The vessel is equipped with the following firefighting systems:

(1) sea water extinguishing system for use in fighting fires in ordinary combustible materials, such as dunnage, canvas, wood, etc,

(2) carbon dioxide extinguishing systems and liquid foam extinguishing systems for use in fighting fires in substances such as gasoline, oils, etc., and fires in live electrical equipment, and

(3) steam smothering extinguishing system for limited use in fighting fires in substances such as fuel and diesel oil.

XI. BOW SHEAVES

An assembly of three roller-bearing bow sheaves is mounted in the overhang of the stem and enclosed within a supporting structure fairing into the forward body of the ship. The center sheave has a diameter of 11 feet, and the two outboard sheaves are each 10 feet in diameter at the root. The ring and hub of each sheave is of cast steel, and the sheave body is made up of steel weldments. The shafting is in three sections of different diameters to permit easy installation and removal. Automatic lubrication for the bearings has been provided.

For handling forward, a monorail and hoist have been provided extending over the bow sheaves. This is an impressive looking structure, since it includes a frame of heavy scantlings for overboarding repeaters at the bow. The frame can be fitted with a vinyl-coated nylon fabric covering for protection in severe weather.

XII. STERN CHUTE

Instead of a conventional sheave at the stern, a stern chute has been employed. This chute is located to starboard of the centerline of the ship and is formed by a 16-inch wide indent in the upper deck plating at the extreme aft end. This indent gradually falls away and fairs into the shell plating at the stern.

XIII. ALUMINUM ROLLING HATCH

A power operated aluminum rolling hatch about 50 feet long and constructed of two nesting sections is located over the bow cable engines. This construction coupled with rolling end flaps, also power operated, permits continuous bow cable operations in adverse weather.

XIV. SPECIAL STOWAGE

Stowages for various types of apparatus and equipment peculiar to the functions of cable laying have been provided and are located at vantage points throughout the ship.

Buoys are stowed in a large hold, two decks high, located forward of the cable tanks. This stowage is conveniently arranged so that the buoys can be transferred by a minimum amount of handling with a monorail and hoist device into the center of the hold; the hoist device picks up each buoy from its stowage position and, through a self-releasing hook, transfers the buoy to the deck crane hoist and from there to its "ready" stowage on the port or starboard buoy skids, or directly overboard. These buoy skids have been especially designed with overhead platforms to facilitate control in launching and positioning the buoys.

Stowages for grapnels, mushroom anchors and similar heavy equipment, together with chains and buoy rope, are located in the same hold as the buoys, but in the two tween decks directly above the buoy stowage. The chain is stowed in bins having a raised floor in portable sections, all to permit easy maintenance. Chain pipes are installed port and starboard, extending from the upper deck to the stowage on the third deck. By means of swiveling devices at the lower ends of these chain pipes, the chain can be run direct into each of the seven chain stowage compartments.

A total of four tanks, each 20 feet in diameter by 10.5 feet high, for the stowage of spare cable, are installed on the tank top level, port and starboard, between the main cable tanks. Twelve circular steel bins, all 4 feet high but of diameters varying from 4 to 16 feet, are provided for grapnel rope stowage. New rope is stowed on one side of the ship and used rope on the other side.

XV. NAVIGATION EQUIPMENT

In considering the nature of the mission of the *Long Lines*, it becomes apparent that it is of utmost importance that navigational facilities be provided that will determine the ship's location with the maximum possible accuracy at all times during cable laying or pick-up and repair operations.

Standard radio direction finding equipment, as required for certification by the United States Coast Guard, has been provided for taking fixes on land-based telegraph stations and beacons and on other ships at sea.

Loran equipment installed is of the latest type, known as Loran "C." This system provides greater range and greater accuracy than the standard Loran "A". It also has Loran "A" capabilities built-in for use in areas where Loran "C" signals are not available.

Decca Navigator equipment is installed in the chartroom. This equipment, operating in an area of Decca signal coverage, provides a continuous instantaneous indication that will give the ship's location by reference to Decca charts.

Two Decca true-motion radar sets are installed with indicators in the wheelhouse. True-motion presentation shows a fixed geographic area on the indicator with all moving objects, including own ship, moving across the displayed area, making it easier to plot vessel speeds, approach paths, etc., than is possible on the standard relative motion display. One radar, operating on a 10-cm wavelength, is superior at long range and in penetrating adverse weather conditions. The other radar is a 3-cm set that exhibits superior qualities in close navigation, as in rivers, harbors, buoyed channels and in close proximity to other vessels.

In order to provide correlation with charted depths and to furnish accurate depth information regarding a cable lay, two echo depth sounders are installed. Each sounder is provided with alternate transducers, one set forward and one aft. Kelvin-Hughes sounding equipment is provided in the chartroom for navigational purposes, and a duplicate indicator is installed in the drum room. The second echo sounder, located in the drum room, is an EDO instrument. In addition to the two echo depth sounders, there is a Westrex Model XV Precision Depth Recorder that is capable of extremely accurate depth recordings in conjunction with either the Kelvin-Hughes or EDO equipment in either the drum room or chartroom.

In addition to the foregoing, there is a standard Sperry Gyro Compass system. Steering control may be manual or by gyro pilot, using either of the dual controls in the wheelhouse, or manual from the bow or stern ship control console or, in emergency, from the trick wheels in the steering gear room.

A Pitometer Log is provided for showing the ship speed in the chartroom and wheelhouse and the draft of the vessel in the wheelhouse. A Chernikeeff Log System is provided to show ship speed in the drum room and to furnish input of ship speed to the true-motion radars.

XVI. EXTERIOR COMMUNICATION FACILITIES

A standard radiotelegraph installation has been installed for ship-to-shore and ship-to-ship communications, as is customary on all vessels of this size.

In addition, to provide optimum communications between the ship and the shore stations during her long periods at sea, a 5-kw single-sideband transmitter has been provided. As a back-up for this unit, and for use when maximum power is not required, a 1-kw single-sideband transmitter is provided. Compatible receiving equipment is installed, and interconnecting facilities are provided to permit use of the radiotelephone equipment from selected stations of the ship's automatic telephone system.

Low-power radiotelephone equipment is provided for use in harbor communications and VHF frequency-modulated units are provided for communication with the cable work boats or for communication with similarly equipped stations on other ships or on shore.

XVII. INTERIOR COMMUNICATION FACILITIES

Communication between key stations for ship operation is provided by sound-powered telephone, since the Coast Guard requires that such communication be independent of any other system on the ship. Normal communications facilities are provided by an automatic dial telephone system of latest design which incorporates private tie-lines between selected points in addition to dialing facilities.

Two public address systems are provided, one for general ship's use and the other for communication between functional stations of the cable operations system.

XVIII. SHIP'S ILLUMINATION

Conventional marine illumination standards, as set forth in the Illuminating Engineering Society's "Recommended Practice for Marine Lighting,"[4] were applied to all interior living spaces, work spaces, machinery compartments and exterior areas. The standards were modified to provide special illumination treatment to suit the function of each area, since it was important that good lighting always be available.

Recreation, berthing, messing and office spaces were illuminated to a standard employed for first-class passenger ships.

The floodlight installation on the forward open deck was designed to facilitate cable handling operations at night and includes special fixtures to illuminate the exposed cable from the deck to the water surface.

XIX. SEA TRIALS

On March 6, 1963, C.S. *Long Lines* sailed from Hamburg to the North Sea for sea trials, and returned on March 12, 1963.

These trials included the usual proving of all systems: speed and economy trials; the adequacy of the control system under all conditions of operation; steering and maneuvering tests, including ahead and astern steering, Z maneuvers and turning circles; and special steering trials to determine the maneuverability of the ship when laying and repairing cable.

All the trials and tests were successfully conducted and the ship was remarkably steady and free from vibration.

APPENDIX A

Various agencies whose regulations were required to be met in the construction and installation of all parts, equipment and outfit of C.S. *Long Lines*, include the following:

(1) American Bureau of Shipping to the highest class,
(2) United States Coast Guard,
(3) United States Public Health Service,
(4) Federal Communications Commission,
(5) United States Customs,
(6) Panama Canal Company,
(7) Suez Canal Authorities, and
(8) International Convention for the Safety of Life at Sea, London, 1948.

In addition to the foregoing, it was required that the recommended methods, materials and practices contained in the latest issue of the following published standards be followed in the construction of the ship:

(1) American Institute of Electrical Engineers, Standard No. 45,
(2) American Standard Safety Code for Elevators, Dumb-waiters and Escalators,
(3) American Bureau of Shipping recommendations for reducing stress concentration at keyways in propeller shafts,

(4) Code of Recommended Precautions Against Accidents connected with the loading and unloading of Merchant Vessels,

(5) American Society of Refrigerating Engineers Recommended Practice for Shipboard Installation, and

(6) Society of Naval Architects and Marine Engineers Ship Trials and Test Codes.

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2. Gretter, R. W., Cable Payout System, B.S.T.J., this issue, p. 1395.
3. *Principles of Naval Architecture*, **1**, The Society of Naval Architects and Marine Engineers.
4. *Recommended Practices for Marine Lighting*, AIA File No. 31.