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Patron : HIS MAJESTY THE KING. President: The RT. HON. LORD MOTTISTONE, P.C., C.B., C.M.G., D.S.O.

Cargo Ships and Propelling Machinery adapted to War Conditions

Read by W. S. BURN, M.Sc. (Member of Council).
On Tuesday, November 10th, 1942 at 5.30 p.m.

CHAIRMAN : H. J. WHEADON (Chairman of Council).

Synopsis.

Whilst the call for the production of more and more cargo ships, or more deadweight tons, is ever insistent, the author puts forward the urgent plea that such cargoship tonnage should be specifically designed to withstand war conditions as unconvoyed units without requiring a great naval "on-cost" in the shape of convoy escort protection.

The author demonstrates that not only shipbuilding capacity can be made more effective by increase in the ship's speed, thus increasing the amount of cargo carried with a given weight of steel, but that the loss by enemy action can be greatly reduced. The problem is then transferred to the engineering industry to supply more powerful engines of low weight and man power. This, it is claimed, is much easier of solution, in weight of material and in man power, than the actual building of hulls.

A carefully designed ship of 12,000 tons d.w. to run at 18 knots would require 12,500 b.h.p. The author propounds that such an engine could be designed to be only slightly heavier and to consume only 25 per cent. more weight of fuel than the Ocean class coal-burning steam engines of 2,200 b.h.p. No less than three times the amount of cargo could then be carried in the unconvoyed vessel at a comparatively modest increase in man power per vessel, such man power having the virtue of being chiefly of a non-shipbuilding character.

In addition proposals are made for the construction of a cargo vessel—termed a cargo warship—designed specifically to withstand war conditions. In addition to high speed, such a vessel would have low visibility from a submarine—all crew accommodation being below deck—but a good "eye" in the form of a ship based aircraft which can take-off or land on the deck with ease and safety.

Centralised ship and gun control will make for exceptional powers of defence. In addition the hull construction is constructed with side explosion chambers or internal "blisters" to withstand torpedo action.

Greater subdivision, especially horizontally, is provided to localise explosion effects and the combined carriage of liquid as well as solid cargo gives a large measure of control over the buoyancy in the event of underwater damage.

The crux of the problem is admittedly that of providing special high duty light weight oil engines, but it is submitted by the author that if this is tackled on a national basis to provide an engine for a specific war purpose, such an engine could be quickly designed and developed. The author has explored the possibilities of engine design and suggests that fundamentally the most suitable engine type is a moderate speed direct drive double acting two-stroke oil engine with two banks of cylinders in vee formation, giving exceptionally low weights and sizes.

Alternatively a high speed opposed piston engine of almost aeronautical type should be developed and used with electric reduction gear. Both of these types could with advantage, the author claims, be developed by a central national design and experimental department with a co-ordinated effort on the part of experienced oil engine designers, using to the full specialised design as well as manufacture.

Such engine types would be of great subsequent value to the entire marine engine industry as basis engines from which to develop after the war.

Whilst the need, of Britain, for marine transport in wartime is even greater than in peace time, the hazards of enemy action exceed a thousand-fold the worst marine risks possible from the elements. It is evident, therefore, that the basis of ship design must be adapted to war conditions.

The problem is essentially our own; no design lead can be expected from Germany as she has concentrated on the conquest of land accessible from Germany by land and river transport to solve her economic problems of raw material, food and production.

In this respect Germany has so far had time on her side, as while now she is able to live and carry on the war without reference to the outside world, we are still as dependent as ever on our supplies carried in ships from overseas. The past and present attempts of our enemy to sever our life lines, even while concentrating her attention on solving her own broad economic security, suggest that the campaign on our shipping may increase in intensity, radius and volume as time goes on. At the same time we must envisage the enemy building better and faster submarines on a mass production basis, simultaneously, attacks from the air can be expected to be renewed to an increasing extent as the sea raiding aircraft increase in range and carrying power, and special defensive measures to meet this menace will become increasingly evident.

For some two years the writer has interested himself in the possibilities of a specialised design of ship machinery and armament to meet this major menace, and the object of the present Paper is to give a brief outline of the problems involved and an indication of possible solutions.

New Types of Ships Required.

As the capacity to build new tonnage in this country is considerably less than the large amount of tonnage sunk or damaged, it is essential to economise in the amount of shipbuilding man hours per ton of cargo carried by improvement of the ship as a vehicle and by increasing its capacity to resist enemy action.

In order not to cause temporary inflation of the shipyards which will inevitably create labour difficulties after the war, it seems essential to increase the effectiveness of the present available manpower by standardised and fabricated designs.

It is submitted that there are already sufficient numbers of diverse specialised types and sizes of ships available, especially when considering the ships which will become available from the U.S.A.

It can be accepted that the nearer the approach to tanker construction, the less vulnerable is a ship to loss by torpedo or bomb action. This suggests, therefore, that as great a part of the ship as is practicably possible should be built to tanker design on the score of safety, but as large bulky cargo must be carried, a combination of tanker and cargo ship is necessary. In the proposed vessel out of a length of 525ft. no less than 275ft. is constructed on sub-divided tanker lines for oil, grain or bale cargoes, although out of 12,000 tons deadweight, the maximum tonnage so arranged is only 4,000 tons.

It is evident that the deck construction with loose hatches and the present method of sub-division and bulkhead arrangements of cargo ships is quite unsuitable. It is equally evident that even the bulkheads and sub-division of oil tankers can be improved upon. There is evidence to show that a measure of horizontal watertight sub-division is as necessary as vertical athwartship bulkhead sub-division and the provision of two watertight decks throughout the length of the ship, even above the oil tanks, is a basic feature of the proposed cargo ship adapted to war purposes.

By using these parts of the ship to carry oil that are unsuitable in shape for cargo, a most efficient design of vessel is obtained from a cargo disposal point of view, and a maximum of "efficient" cubic is obtained from the hull capacity, as well as a large measure of control of the buoyancy as and when required. A basic principle is that the holds of new ships should be designed to precise war transport requirements, regardless of peace requirements.

Furthermore there is doubtless an optimum cross section through typical cargo to give the greatest protection to the decks, the heavier cargo such as steel plates and bars being near the bottom and sides, whilst that at the centre and top in way of the hatches is of a wielding and compressible nature.

If necessary, a number of cargo warships could be converted to army transports for men and full equipment by fitting up part of the 'tween decks with suitable troop accommodation; full military equipment with even the heaviest tanks could be carried, and also a full complement of air co-operation planes, fuel and food supplies.

As an aeroplane carrier the proposed vessel would have certain advantages as the planes could be dismantled and stowed in the main holds, assembled on the after deck and flown off. For the transport of aeroplanes to the Middle or Far East, a vessel of this type would be invaluable.

Although the clear after deck is primarily for the use of aircraft, the deck space afforded could quite well do for the storage of invasion barges and T.L.C.'s, and special launching facilities could easily be arranged because of the initial low freeboard and the shape of the stern. The stern draught is also capable of adjustments to make direct launching practicable by alteration of the trim of the ship.

It is submitted that it is not economic in national man power to build or operate vessels of less than 12,000 tons deadweight, or for such vessels to travel at less than 18 knots. To give a vessel adequate protection, both the men and equipment required are too great to be wasted on anything but vessels of large carrying capacity such as the proposed vessel, which will carry at least three times the present standard convoyed cargo vessel in a given time. One result will, therefore, be a definite saving of armament per ton unit of cargo carried.

The present policy of producing adapted pre-war types of cargo vessels is inadequate for coping with a technically proficient and technically adventurous enemy who is building progressively better and faster submarines. Our vessels should incorporate the best efforts of all our technical specialists, and instead of vessels being largely the result of the local technique built with local manufacturing facilities, the design should be a national one, using the combined effort of the cream of technical specialists in each component part or section of design and afterwards being carefully co-ordinated. It should then be built as far as possible by manufacturing specialists to the best and most efficient standards, the less progressive firms being forced to the highest level of efficiency by external control.

The British shipbuilding and marine engine industry needs the application of similar principles that have made the American and to a less extent the British motor car industry efficient, that is, fewer designs are needed, but each design should be given more intense technical and scientific development to ensure functional suitability. Fewer and larger building establishments are then desired to give mass production of these more efficient and refined designs.

It is submitted that sufficient experience has been gained in naval requirements and great progress has been made in detail naval armament such as to warrant the complete co-ordination of the various devices in a special new type of vessel specially designed for the Battle of the Atlantic, which could be permanently retained as a naval type from which to develop in future wars.

A Special Cargo Vessel for War Sea Transport. The Cargo Warship.

Without disparaging for a moment the programme of shipping construction now being followed in this country and the United States, both shipping losses and the increasing demand made on shipping for operational purposes dictate ceaseless watch for opportunities to improve this programme.

There are broadly speaking two main drawbacks to building exclusively in war-time, cargo vessels suited to peaceful commerce:

(1) The ships are highly vulnerable to torpedo and to bomb.

(2) They require ceaseless and increasingly elaborate convoying, and therefore absorb in convoy work a very high proportion of Allied naval forces.

If, therefore, ships could be built fast enough to outdistance a submarine, so constructed as to have a good chance of surviving hits by torpedoes or bombs and of being less easily spotted, underwater detected, and ranged by submarines, and so armed as to be able to beat off on their own any but the heaviest attack either by submarine or aircraft, then such ships need not sail in convoy and could make more frequent voyages in a given time. They would be cargo warships.

There does not appear any reason why ships of this kind should not be designed and built. Even assuming that existing shipyards could not be turned over to building new types at this crisis in the Battle of the Atlantic, some new capacity could surely be devoted to that purpose on one side of the Atlantic if not on both. Existing British shipyard labour is undoubtedly capable of much greater dilution, and if this took place it would be possible to provide a substantial core of skilled workmen required to serve in new national prefabrication works laid out and equipped on the lines of the latest American practice to supply existing shipyards with prefabricated parts. If Kaiser's splendid ships can be built in U.S.A. with less than 5 per cent. of skilled shipyard workers when aided by a high degree of technical and production organisation, together with mechanical equipment to ease the need for personal skill and physical effort, then it seems very reasonable to assume that British unskilled labour will be equally competent to build at any rate the welded and prefabricated parts of ships. Kaiser himself was not originally a shipbuilder. He was in fact a production organiser—the very kind of man urgently required to ensure the production of cargo warships.

It is established that the shaped parts of the hull like the sides can be produced by our skilled British platers and rivetters with less man hours than even the American system, but flat surfaces like bulkheads, decks and bottoms adaptable to *machine welding* should be prefabricated on American lines for great reductions in man hours. It is a combination of the old and new technique that is wanted for the greatest immediate efficiency.

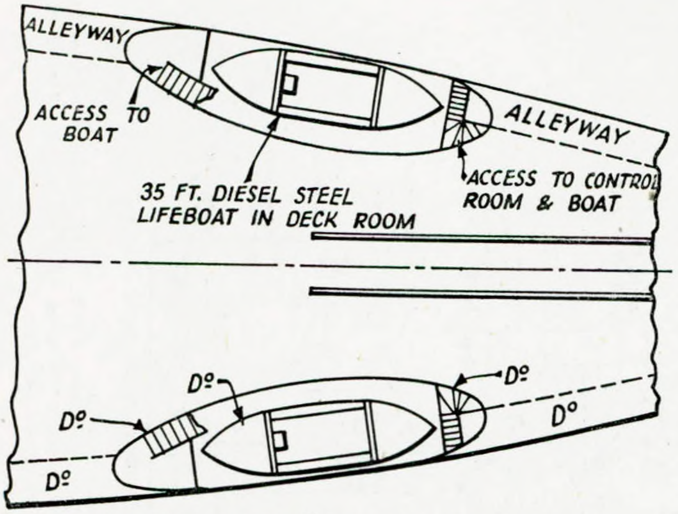
It is proved beyond question that the type of construction makes a lot of difference to the vulnerability of ships. For example, the tanker, owing to its construction, has proved much more difficult to sink than the merchant ship. Only recently, an official broadcast gave astounding details of the arrival of a tanker out of the big convoy that fought its way through to Malta. Any cargo ship which had received an equivalent number of hits and equivalent degree of damage would inevitably have sunk. The tanker did not sink. Moreover, it must not be thought that the convoy system is ideal. The British Admiralty in the last war and the American Navy Department in this were reluctant to adopt convoying not because they were conventionally minded, but because convoying reduces the effective use of tonnage. When (last March) the Americans enforced convoying for their coastal traffic it was frankly acknowledged that the system would reduce the number of voyages per ship by about half. Any ship therefore which does not need convoying is equal in carrying capacity to a ship of twice the size and of the same speed which does need convoying. The larger and faster ship of 18-19 knots proposed would have therefore nearly three times the carrying capacity as well as a much higher degree of immunity from enemy action.

Speed as a Measure of Defence.

The demand for more speed has been made from many quarters. Officers actually engaged on marine transport seem to be of one mind that higher speed is essential. Higher circles at the Admiralty, however, claim to have figures indicating that the losses with ships of 15 knots and over, out of convoy, are just as high as for 8 knot ships in convoy.

Now it would appear that the usual technique of the "U" boats is to have information of convoy movements and approximate routing by intelligence and aerial reconnaissance, to contact the convoy by hydrophone or ordinary vision in daylight, to track the convoy on the surface at a safe range of about 15 miles until nightfall, to make up to the convoy at leisure, pick out a suitable target, submerge and finally to deliver the torpedo attack, which is usually on the quarter or beam.

Provided the submarine has a sufficient excess of speed over



SECTION THRO' LIFEBOAT HOUSES

that of the convoy, it can always carry out this manœuvre. There appears to be ample evidence that the surface speed of the modern enemy submarine is now over 18 knots, and some appear to have a speed of even 21 knots.

Actual speed will depend greatly on the weather, but in average and bad weather the advantage will be greatly on the side of the larger ship of sufficient speed, and the chances of a submarine making up to an 18 knot ship are extremely remote and even to make up to a 15 knot convoy would be most improbable.

Chance encounters by lying in wait on known routes, especially where routes converge, as at a port—a method which can be augmented by using numbers of submarines to form a screen or filter—obviously cannot be combated by speed alone, although speed does reduce the all-important time element of attack and reduces the submarine's chance of success.

I believe that one of the chief virtues of the convoy system of the last war in which there was no aerial reconnaissance and indifferent hydrophones was in the increased difficulty the "U" boat had of contacting our ships—a very different condition from that appertaining to-day.

This suggests really high speed convoys to combine immunity with offensive action.

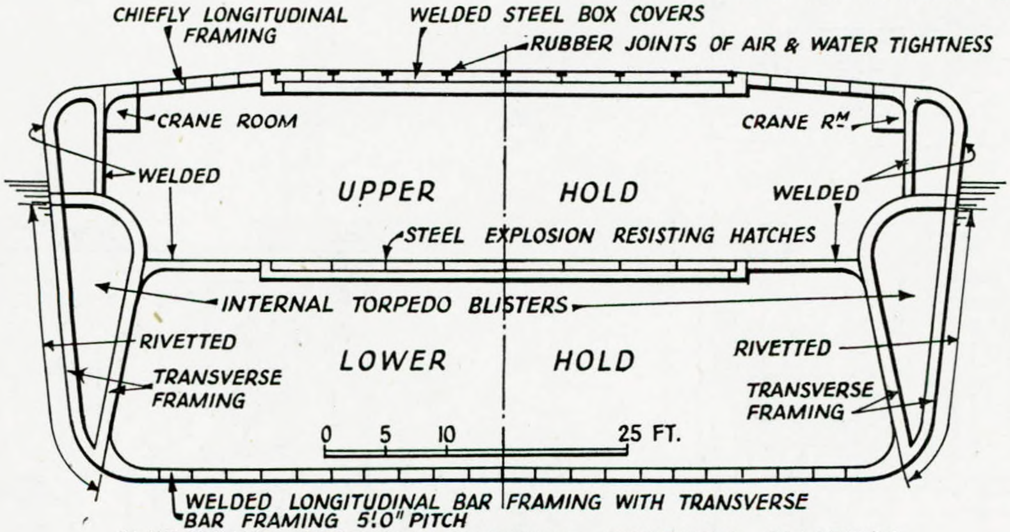
The need for large numbers of non-productive protecting escort vessels naturally reduces the effective cargo shipbuilding capacity and in addition immobilises a large part of our Navy from "offensive" action, which must have serious effect in diverting naval effort from offensive action to protective duties.

A Description of the Cargo Warship.

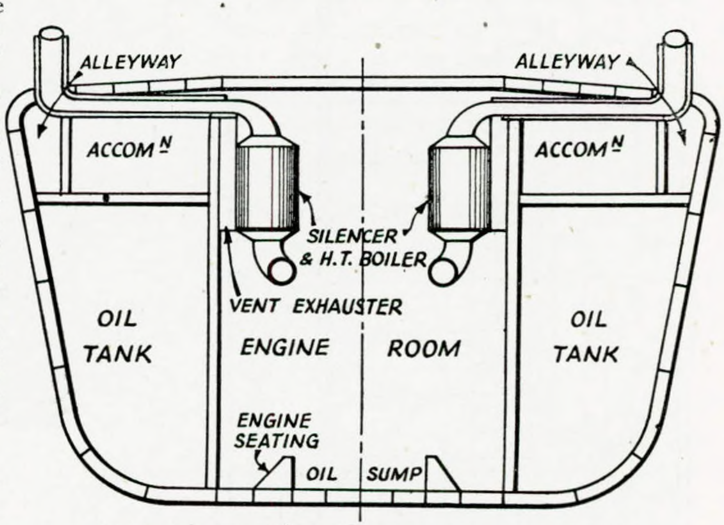
It would not be possible to give a complete specification of the cargo warship; but some of the principal details must be stated. The ship should be about 12,000 tons deadweight, because that is the most economical size to construct. The width should be exceptional at 80ft. and the draft normal at 26ft. Its speed should be at least 18 knots. There is no fundamental reason why all crew accommodation, saloon, galley, wireless room and the like should not be below deck at each end of the ship, with only the minimum requirements of control and lookout, air intakes and engine exhausts above deck. Specially designed cranes which lie flat on the deck when not in use, will be arranged down each side of the ship with all operating mechanism below deck so that a clear deck of some 70ft. wide is available for aircraft landing and all projections from the deck sides would be below wing level. Side alleyways below deck will entail the minimum use of the deck which would be streamlined to an unprecedented extent and capable of being safely awash in bad weather. Even the Diesel engined lifeboats would be accommodated in streamlined structures on gravity davits below the two forward control towers for protection against weather and enemy machine gun fire.

Propulsion.

As regards propulsion, the cargo warship should have two sets of engines, one at the bows of about 12 per cent. of the total



AMIDSHIPS SECTION SHOWING TORPEDO BLISTERS



SECTION THRO' FOR^D END OF ENGINE R^M

FIG. 1.

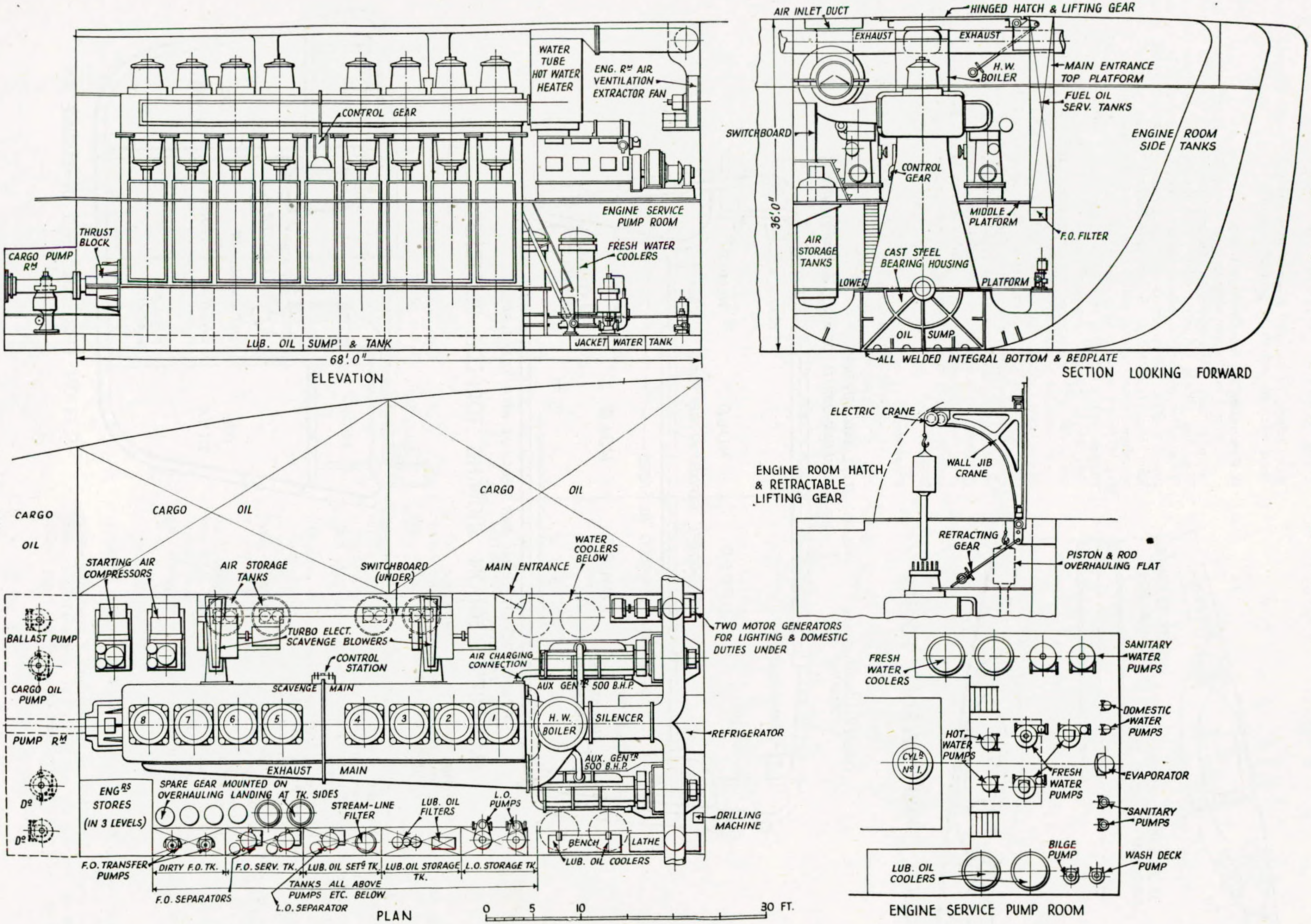


PLATE 2.

Machinery arrangement for Cargo-Warship, showing minimum engine room volume and weight for Slow Speed Direct Drive Engines. 8-cylr. light weight double-acting two-stroke oil engine. Cylrs. 28in. dia.—50in. stroke. 12,500 B.H.P. at 135 r.p.m. and 88lb. M.I.P. (max. power). Weight of main engine 400 tons (with all-welded entablatures, bedplate, etc.). 72lb. wt. per B.H.P. Total weight of complete engine room machinery ready for sea 675 tons.

power and the remaining 88 per cent. at the stern, two steering devices would also be required. The main purpose of this double ended construction is to prevent the ship from being disabled by a single torpedo or bomb. It was a near miss bomb that put the "Ohio's" single screw engines out of action. A bow "puller" propeller is only slightly less efficient than a stern "pusher" and these engines can be so designed that even the bow propeller will give over half the normal speed which can be achieved by both working together. The main engines should be heavy oil engines to ensure fuel economy, carefully designed to be free from vibration, and should possess high rotative speed to reduce weight. The transmission between engines and propellers could in some cases be electrical in order to obtain the highest degree of silence, speed control and reliability, and to utilise the highly efficient electrical industry. By these means, the weight of machinery in the cargo warship will be little more than in the Ocean type of cargo vessel; but the power will be six times as great. The fuel consumption due to the high efficiency of oil engines will be increased only by about 25 per cent. in weight, but this is a small matter to set against the other enormous advantages. By the careful selection of technological developments of internal combustion engines from all applications, engine types could be rapidly developed which would have all the necessary attributes. Underwater silence would be a prime consideration to prevent detection by German sonic hydrophones or the detonation of acoustic mines.

The control tower structure can be designed to house a sea Hurricane and provide a long after deck of nearly 400ft. for landing purposes; the hatches would be of flush deck design to permit of this. The take-off will be from a special forward catapult deck—a cleaned up version of the present system. The aircraft after landing will taxi to its catapulting carriage and track between the side control towers, the space between which serves as a hangar. There will be no need to ask pilots to take the fearful risk of being catapulted off without hope of landing unless, after fighting, they have still enough fuel to reach the shore. Protection against explosion from torpedoes and bombs will be made a fundamental consideration of the design and a much greater degree of compartmentation will be necessary than peace time practice would dictate. There will, in fact, be some twelve transverse holds, all in the body of the ship, instead of the usual five, each with double transverse bulkheads and a strong watertight and explosion resisting transversely arranged hatch with steel covers. Central longitudinal bulkheads in the main body of the ship below the waterline are undesirable as likely to affect the stability if one side is flooded—the disastrous effect of "heel over" was well demonstrated in both the "Ark Royal" and the "Eagle"—it is essential that damage should merely cause greater immersion and not affect the trim. The lower deck will constitute a horizontal bulkhead and will be strong enough with its hatches to break the brunt of any explosion within the hold so as to protect the all important air tightness of the main deck and hatches. Keep the deck and upper sides airtight and the bottom can be very badly damaged without causing a critical loss of buoyancy. Slight leakage can be corrected by introducing compressed air to the 'tween decks. Most important of all will be the protection afforded by special internal ships side explosion dispersion chambers. External torpedo "blisters" proved highly successful in the last war but interfered with the optimum shape of the hull for easy propulsion. In the proposed vessel the inner plating of the "double side skin" can be primarily designed to be immensely strong —which the use of welded joints will facilitate —whereas the ship's sides will be designed from hydrodynamic considerations but structurally much weaker, which incidentally, the riveted joint facilitates. It is useless to attempt to bottle up the vast torpedo explosion effects and the wide provision of organised weak areas is necessary; the rivet holes give a "perforated paper" effect ideally suitable for the purpose, provided the internal structure has sufficient independent longitudinal strength.

Naval architects do not have enough information about the behaviour of structures beneath the impact of explosion, but there is ample proof that an internal structure can be made fundamentally much more resistant than the normal flat bulkhead. We also know that the more cargo space 'tween decks, the less the effective force of an explosion on the vital decks. It is not generally realised that a ship fitted with strong watertight steel hatches is so much less liable to sink when torpedoed than a ship with loose or loosened hatches, because buoyancy can at least be maintained to the top of the hole in the vessel's side. In war-time a deck and topsides are more important than her bottom. A ship's sides are so vulnerable that the ship's strength must not depend on them to the same extent as a vessel designed to withstand marine risks only. A ship with a high freeboard and lofty superstructure is also an easier target for a submarine. The cargo warship must therefore have a low freeboard; to maintain this, however, it is desirable that a substantial part, say one-third, of the carrying capacity at both ends of the ship should be liquid, such as oil, which can be quickly discharged to give any desired extra buoyancy in the event of even two lower holds being flooded.

Welding saves steel and therefore weight, and allows heavier plates to be used. The cargo warship can thus be given thicker deck protection, especially over the accommodations and machinery—enough to resist all but the heaviest bombs and the low freeboard will to some extent make the ship a more difficult target for bombing attack. Many other constructional details conducing to greater invisibility and invulnerability could be listed, all of them simple and possible. But enough has been said to explain the general design and performance of the cargo warship illustrated on Plate 1.

It would combine the speed and much of the armament of a warship, with the carrying capacity of a highly efficient merchantman and almost the invisibility and underwater silence of a submarine. There is no reason why such ships should not be easily convertible to peace-time purposes. Any naval constructor or engineer will endorse the claim that such ships could be built. Nobody would ask that they should replace either the building of ordinary ships or the construction of the air freighters now approved in the United States. But the margin of safety in the Battle of the Atlantic and of the Mediterranean can never be too great, and it would surely be as worthwhile to build the first of these ships as an experiment as it was to build the first tanks.

Submarine and Torpedo Attack.

The problem of effective means of resisting submarine and torpedo attack has long engaged naval constructors and one highly successful design of the last war was the use of relatively light steel "bulges" or "blisters" on the ships' sides as designed by Sir Eustace Tennyson D'Eyncourt. During the last war no vessel with such blisters was sunk by torpedo attack; in one case, H.M.S. "Terror", a coastal Monitor, received no less than three torpedoes in one attack, without major damage.

The disadvantage of such blisters is the bad effect they have on propulsion, the speed being reduced as a result. The solution to this is to incorporate the "blister" within the ship's hull in the form of a double skin and indeed many and various constructions have been devised to do this with varying success.

It is now evident that Germany has highly successful designs, as evinced by the remarkable punishment the "Bismarck" and other German vessels have been able to withstand.

Whilst it is now established practice to incorporate anti-torpedo compartmentation in British warships of the larger type, such as capital ships and cruisers, it is remarkable that literally no attempt has been made with vessels specially designed to carry war cargoes, although the problem of adaptation of the hull structure is very much simpler in the latter vessels.

The French at one time carried out a great deal of experimental work on compartmentation and so-called elastic bulkheads which would resist the gas pressures by virtue of tension in the plating which were developed by torpedo action, and results in practice well established the possibilities of designing for explosion resisting apart from mere thickness of armour.

The first necessity is the greater transverse sub-division of the vessel from the usual six major compartments, i.e., five holds and one engine room, to twelve holds, two engine rooms and some twelve major oil cargo tank compartments as shown in Plate 1.

Instead of the usual single reinforced steel transverse bulkheads it is desirable that double transverse bulkheads should be adopted between the main holds which are quite separate in construction, so that the collapse of one bulkhead will not affect the other. Thus if an explosion penetrates the inner shell of a hold and the gas pressure rise causes the collapse of its bulkhead there is a pressure release via light hatch relief valves located in the cofferdam formed between the two bulkheads.

Apart from being a safety feature the double bulkheads are an important functional asset as they provide a space for hold ventilation ducts.

It would appear to be undesirable to subdivide into too small compartments, as a first essential is that there should be ample volume to prevent undue gas pressure rise, the holds are therefore 40ft. long, the horizontal sub-division makes in effect 12 holds as the chance of serious damage to the lower deck is remote.

In order to ensure stability under all conditions of side damage and consequent flooding no longitudinal bulkheads below the water line are desirable in the cargo carrying "beamy" part of the ship, but it is obvious that some longitudinal division is practically necessary in the oil cargo holds at the ends of ship. Undue compartmentation defeats its own end in restricting the explosive effect and increasing the tendency to bursting of the restraining walls. The size of compartment should be the maximum to enable two holds to be flooded without seriously affecting the buoyancy of the ship.

There can be no doubt regarding the necessity of some protective skin device to negative torpedo action once it occurs. External devices such as torpedo nets or blisters detract from the ship's speed which is so essential in war-time and therefore it is necessary that any protective constructions should be arranged within the "ship shape" hull proper and should not seriously detract from the carrying capacity of the vessel.

The need for economy of material prevents the use of abnormally thick plating and encourages the use of means to control and redirect explosive forces with non-rigid bulkheads, such as the curved portion of the "blister". A logical construction is to have a double skin or hull, the outer being made relatively weak and shaped to suit efficiency of propulsion, whilst the inner is relatively strong and shaped specifically to resist external explosion gas pressures and would therefore present a concave surface to such forces.

It is desirable that connections between the two hulls are reduced to the minimum and preferably limited to that at the transverse bulkheads. It is essential that the cellular space between the two hulls should be free of longitudinal framing, so that an explosion on one side of the space can be readily transmitted to the other side without obstructions which would be torn away.

Most important of all it is necessary that ample relief hatches or weak bursting plates should be provided at the top each side just below the water level.

It is known that the resistance to torpedo explosion effects in the oil cargo tanks of oil tankers is increased if the deck hatches are open to afford an immediate gas release. In the proposed vessel special light release hatches or safety valves are provided to each oil hold to give an almost instantaneous release to explosion gas pressures.

The inner hull must be responsible for the longitudinal strength of the vessel and be of such a shape and strength as to resist fracture at least twice as well as the outer hull.

The general structural principle on which the cargo warship should be based is the freedom from stress concentrations and the provision of an evenly proportioned elastic structure which will permit of considerable local distortion or damage of the outer shell without fracture of the main structure taking place. The use of welding for joining plates and structural parts not only makes possible a stronger joint—nearly twice that of a riveted joint—but makes possible simple structural design of much more even stress condition throughout.

The ideal amidship section of the new type of vessel would be a trapezoid with flat sloping sides. Primarily this will give the wide deck space needed, good "light" immersion and good sea riding properties, especially with the pronounced "counter" effect of the after landing deck. The ship's form would be very fine—a block coefficient of about ·6 being considered desirable. To avoid detection from the air the visible wake must be an absolute minimum. The bow must not have flare of a type to turn back the water, a "green" bow should be aimed at. The stern would be a fine "Tee" shape to accommodate the landing deck. A rounded gunwale is proposed to enable the structure to stand the severe whipping action after torpedo explosion and to remove an only too obvious stress concentration. It will also have beneficial effects in keeping the decks free from water.

Welded Construction.

Whilst in wartime the need for a welded ship's side is not so essential—in fact it may be a positive disadvantage for reasons previously stated—it will be absolutely essential that the entire internal structure, such as the inner bulge wall, bulkheads and the decks should be of efficient welded design, and executed by machine welding or at least efficient "down" hand welding. *This will necessitate all the internal parts of the ship being made in special prefabrication works* and therefore the proposed design is inseparable from a measure of shipyard reconstruction.

Propellers.

The introduction of a bow propeller, although common enough on American ferries, has certainly not been used for such a duty as the "Atlantic Ferry" and its presence is a pure war-time requirement; it is most interesting, however, to note that no less an authority than Lord Fisher advocated such a double-ended ship. According to a propeller expert, the efficiency of such a bow propeller would be 6-7 per cent. less than that of a stern propeller.

Normally the bow propeller only would be used when manœuvring or going astern and would here have great manœuvring advantages and would improve the handiness of a relatively large ship. The fact that a really fine lined ship only is under consideration facilitates the use of bow propulsion with efficiency.

Full speed astern under full ship control will enable the after deck to be used as an efficient take-off at reasonable speed and under full control into the wind for aircraft which may wish to use the vessel as a sea aerodrome.

A wide variety of relative powers of bow and stern have been considered and the present proposal is to use about 1,500 b.h.p., enough to propel the ship at 10 knots, which is equal to the likely maximum speed of a submarine submerged.

Steering.

It is considered essential to have an alternative rudder or steering mechanism in case of damage by torpedo or bomb of one gear, and as it is desirable to have them as far apart as possible a special double rudder is placed at the bow. It is realised that the steering from the bow rudder going ahead will be poor compared with the stern gear if the latter is put out of action, but when used in conjunction with the bow propeller will suffice to get the vessel out of the danger zone, after which the direction of the vessel would be reversed and the bow become in effect the stern.

To give the vessel exceptionally rapid turning capacity there must be a minimum of deadwood aft and in emergency both rudders would be used. Steering stability on a course would be aided by the pull of the forward propeller coupled with the use of a gyro compass.

The stern rudder is of the balanced type very similar to those used in warship practice; the two sides of the bow rudder can close the propeller aperture to give a normal bow form.

Ventilation.

The proposal is to cross ventilate the holds, *i.e.,* from port to starboard or vice versa, using the crane posts as inlets and outlets, each inlet and outlet having its own electrically driven forced draught or exhauster fan. All ducts will be of substantial design welded into the ship's structure, so that none of the usually weak ventilating shafts are required, and provision must be made to close off any ventilator to stop air getting into the holds in case of fire, or out of the hold in case of the holing or damage to the underwater hull.

The engine air supply is taken from the side alleyways and accommodation, a special built-in air inlet duct system being provided which can be heated as required electrically in each cabin and centrally from the ship's hot water system.

The engine room will have an exhaust fan with ducts leading air up the funnel casing.

Ballast and Cargo Oil Tanks.

To enable high speeds to be maintained when partially unloaded it is proposed to use the oil tanks, side blisters and if necessary even the double transverse bulkheads, making in all some 6,500 tons. The form of the ship will ensure an exceptionally good draft for a cargo boat with this tonnage. All tanks must be capable of alternative rapid evacuation for any adjustment of buoyancy, and hence two pump rooms are provided and also a compressed air supply for pressure evacuation.

It is proposed to use welded joints for all the tank portion of ship including the side plating of the forward and after portions.

Cargo Handling.

It would be wasteful of man power not to provide the most efficient known cargo handling plant. After investigation electric cranes instead of the derricks are proposed which are reminiscent of the well-known German type. There are two essential differences, first that all motors and winding gear are below deck protected from weather and indirect enemy action, and second, the central post is much shorter and fitted with a steady pintle well below deck. It is essential that all deck protuberances be reduced to the absolute minimum to avoid inducing eddy current which may affect the aircraft landing. The motto here is "Clear the decks".

The crane gear is located in each hold double bulkhead and is accessible from the side alleyways. Each crane will lift 25 tons and the intention is that two cranes would be used for lifts between 25 and 50 tons. The Ward Leonard principle would be used to give rapid light lifts and yet operate efficiently heavy and valuable lifts. The height of the crane posts is such that the uppermost portion will be below the under-wing height of most high wing aircraft.

Hold Hatches.

A distinctive feature is that the hatches—in fact the holds also—are arranged athwartships, thus to give size of hatch opening with a narrow hold (40ft.). The problem of designing a strong steel hatch which is both flush on the deck and can be easily made air- and water-tight is not easy, but the writer is satisfied it can be done. The first consideration is to provide the strong flush fitting box covers with strong attachments and the next is to make the joints air- and water-tight. The lower deck hatch covers need only be strong and explosion resisting and not air- or water-tight as the use of compressed air can check any water rise into the upper holds.

Wind Control.

A feature of the control structure is the possible use of a large door or screen between the control towers which can be raised or lowered to either allow free entry to the air flow, an increased nozzle action being obtained by raising it so that it concentrates more air at deck level, or it serves as a screen to convert the space between the two towers into an aircraft hangar to give proper protection to the aircraft and catapulting gear when the ship is battling with the elements.

Summary of Features.

In brief, the object of the proposed cargo warship, shown in Plate 1, is to provide:—

(1) The highest practical speed (18 knots) to assist cargo carrying capacity and to make the greatest possible use of the available shipbuilding effort and material and the available crews.

(2) A cargo vessel with such protective armament that convoying will be unnecessary and whose upper structure is arranged to give minimum visibility to enemy submarines, surface vessels or aeroplanes.

(3) The most complete co-ordination of the ship controls with regard to control of speed and direction, submarine and aeroplane detection and defensive armament to give rapidity of action.

(4) A cargo vessel that emits the minimum of vibration above and below water, and hence is difficult to detect or to activate acoustic mines.

(5) Protection from enemy aircraft by the carriage of an aeroplane which can both take-off and land on the vessel in a practical manner for reconnaissance as well as fighting enemy aeroplanes and bombing submarines.

(6) A type of cargo vessel with specially designed ship structure, holds and hatches to reduce the explosion effects from torpedo or mine and also with means to preserve buoyancy in the event of even serious underwater damage. The vessel, therefore, will be much more difficult to sink than present commercial type vessels, and so will invariably require repair rather than replacement, the special ship construction facilitating the rapid execution of such repairs.

(7) A hull design that is functionally highly efficient and having cargo carrying arrangements that are specifically designed to suit the carriage of war cargoes about the world, the size of the vessel being the greatest that can be conveniently manufactured in present shipyards, so as to reduce the amount of skilled labour per ship to the minimum.

(8) The co-ordinated use of all available technical skill to make the designs both highly efficient, of maximum simplicity, and suitable for mass production to facilitate the efficient absorption of diluted labour to ease the burden on skilled labour.

The illustration is largely self-explanatory; it will be agreed that the appearance of the vessel—the result of several preliminary designs—strikes a modern note. It is conceivable that although the type has been evolved purely for war purpose it may offer commercial possibilities. The clear decks and streamlined deck structures are surely more ship shape than the green house contraptions that should never be associated with ships any more than the early "birdcages" are associated with the modern smooth-formed aircraft.

Maintenance of Maximum Efficiency of the Crew.

The knowledge of the crew that they have the greatest possible protection from enemy action, with means for a large measure of offensive action will tend to the maintenance of the highest standard of efficiency.

Standardisation of equipment and machinery will eventually ease the difficulty in obtaining skilled crews, and will facilitate the relief of crews without disorganisation.

The thick deck plating over the centrally disposed accommodation gives a large measure of protection against the smaller type of aerial bomb, machine gun attack and light naval gun fire, as well as being well away from likely torpedo effects. The various compartments of the control towers are also afforded light armour plate protection.

Life-saving arrangements are given special attention. There are two large 40ft. steel lifeboats arranged forward at each side of the first deck of the control towers, with means for a large measure of protection from sea, wind and enemy action. The boats would have alternative Diesel engine and hand power co-axial propeller drives. The davits are of a most efficient rail gravity type which is especially suited to the ship's form and the position of the boats. The boats would be fitted with integral buoyancy tanks, long range fuel and water tanks, water distilling equipment and would be mostly covered in.

Efficient rafts are placed about the control towers and several down each side of the vessel about the deck cranes for emergency purposes.

The provision of much more spacious accommodation than is usual is made possible by the placing of the engines right forward and right aft, and the efficient use of space aft under the main deck not suited to cargo carrying, owing to the necessary fineness of the ship's lines aft, but which is eminently suited for accommodation purposes. In no case is crew accommodation immediately adjacent to the ship's side and all accommodation is above the water line with means for rapid egress, each member of the crew having, as far as possible, a separate cabin chiefly fitted with steel fittings of a fire-proof type. Air conditioning and h. and c. will be fitted, to each cabin. By using welded steel construction the partitioning of the accommodation is intended to reinforce the accommodation deck and give a strong structure with a minimum of framing, it must of course be of much greater strength than the oil tank sides below. Although not "above deck" the accommodation will be healthier than usual due to use of mechanical ventilation or air conditioning. Considerable spare accommodation is available for survivors from other vessels and for the carriage of a few passengers.

The smallest crew would be ensured by careful design of the vessel for the work she is meant for, and because of the fact that the absolute minimum of deck gear is exposed to the weather, thus removing hardship conditions. The provision of the special engine repair room will ease the burden on the watch-keeping engineers. It is the intention for most repairs and upkeep to be done ashore and in principle the intention is to follow automobile and aero practice and to replace defective parts with new rather than repair and overhaul worn or broken parts as in past marine practice.

Conversion to Post War Service.

Whilst the first consideration must be given to war requirements, care has been taken that the proposed vessel, although unconventional, should be well suited to world-wide cargo liner services and be able to compete effectively after the war, with all pre-war conceptions of ship design, as fundamentally the cargo can be effectively stowed, propelled with safety from marine hazards and unloaded.

If it is assumed that two million tons of such vessels (about 150 bottoms) could be produced, there is no doubt that all of them could be effectively used during and after the war and the chances are that most of them would survive the war. This tonnage would represent a carrying capacity much greater than the equivalent of present cargo vessel type tonnage. Cargo warships could be readily altered to individual requirements of the various cargo liner owners after the war.

The armament, of course, would be removed and one suggestion is that a well "bowed" deckhouse could be added between the control towers to house about 50 passengers, who would have their own promenade deck above. The moment of the armament and gun platform would balance the moment of the new deckhouse, thus maintaining a correct metacentre.

The upper part of the control tower would doubtless take the "house" colours like the present day funnel.

Instead of Hitler's "Strength Through Joy" ships, there would be exceptional opportunities for cheap travel on these vessels to all quarters of the world, and especially to the Colonies.

Present Building Capacity.

It is of interest to examine the present potential building capacity.

Without making wholesale changes in the methods of production in the British shipbuilding industry, which would take considerable time to accomplish and would entail great changes in the type and amount of man power available, it would appear that the past maximum output of about 1¾ million gross tons is not far from the maximum that can be produced. The real limitation is in the building of the hulls.

Increased cargo-carrying capacity with present shipbuilding methods can be obtained by building ships of the largest practical size. Whilst the present standard 10,000 d.w. tons vessel of 425ft.

length represents the economic size from the greatest number of British yards, a 14,000 d.w. tons vessel would result in probably 10-15 per cent. economy in shipbuilding man hours for a given cargo carried. Not more than 25 per cent. of our merchant shipbuilding yards could, however, build the larger ship without drastic reconstruction of the yards.

The greatest possible standardisation of details such as rudders, hatches, and ship's fittings generally, and the specialised manufacture of such parts in particular works—not necessarily shipyards—will undoubtedly save man hours. There seems no reason why, within given regions like the Clyde, Tyne or Wear the specialised manufacture of ships' fittings and the more complex parts which lend themselves to be prefabricated, should not be undertaken, to a much greater extent, the principle being that each yard should build more and more of less and less. The application of machine welding to all the flat constructions such as bulkheads will undoubtedly greatly increase the output with given man power. No doubt a further saving of man power to the extent of as much as 10-15 per cent. could be achieved by the reasonable extension of such means.

Bearing in mind the extra war-time welding and prefabrication equipment, it looks as if an output of two million gross tons is the maximum that could be expected if larger ships and greater standardisation, specialisation, and maximum prefabrication with present yards and available shipyard labour were all adopted. It is known that the building of a greater number of these improved ships has commenced and improved production methods are gradually being adopted. In these larger vessels the power has increased threefold and the possible service speed increased from 10½ to nearly 15 knots.

Most British shipyards are however fundamentally unsuited to immediate adaptation to the use of economic welded construction—which to-day implies machine welding and prefabrication of relatively large sections under ideal "factory" conditions and mere assembly on the shipyard berths—owing to the lack of space at the head of the slipways and shipyard transport facilities.

Extension to provide such space would invariably mean the demolition of workmen's dwellings, roads, railways or other works. The building of brand new shipyards on the American plan in steel producing areas is the ideal plan *per se,* but this would entail great social problems such as the provision of near accommodation for the workers.

A Solution to the Prefabrication Problem.

It is suggested that the practical solution is to provide new regional prefabrication works on each river or dock area engaged in shipbuilding with capacity to supply all the yards in the area with prefabricated parts or sections and to transport such parts by *water transport* in floating special self propelling pontoons from the riverside of the prefabrication works to the *river* end of each building berth and to provide cranage at each yard to transport sections *up* the yard. Such a system will make the best possible use of existing slips and equipment for plating and riveting and will cause the least social disturbance to the shipyard workers, whilst providing a means of employing modern welding construction to any desired extent.

Bearing in mind the availability of highly skilled shipyard workers used to building ships with conventional methods of riveted construction there are good reasons for the continuation of the riveted shell construction for most of the "ship shape" parts to be made at the existing yards. Flat parts like bulkheads, decks, and portions of the double bottom which are well adapted to the use of machine welding could, however, well be made at the new works and a great saving in man hours effected. As in America there is no reason why such prefabrication labour should not be well diluted—to the extent of say 75% (compared with 90 to 96% in U.S.A.).

As the tendency is to a great number of bulkheads, flat decks, stronger steel hatch covers and prefabricated fittings generally, the proportion of work done at the prefabrication works will tend to increase as time goes on. Marine engine builders would be able to obtain their bedplates and columns from the works and altogether a most efficient use could be made of available technique and skill which is in such short supply.

The Best Economic Use of Shipbuilding Man Hours.

There seems little doubt, however, that the overwhelmingly greatest saving that could be effected, from a shipbuilding point of view, would be by increasing the speed of the vessel, to make the present yard capacity more effective in producing ships of greater transporting capacity. The present Ocean or Liberty type of vessel, for example, is capable of maintaining a maximum service speed of about 10½ knots; it would be possible, however, without appreciably increasing the shipbuilding costs of the hull, to increase the speed to as much as 18-19 knots, which would give nearly twice the carrying capacity, assuming the speed of 10½ knots could be attained in convoy. The penalty would be almost entirely that incurred by the greatly increased engine power. Any increased cost of the hull due to change in form to suit the higher speeds could be offset by making the forward and aft lines more nearly identical and the use of symmetrical bar sections possible with welded construction, thus increasing the number of parts capable of being made off a given template or jig.

Now the average speed of the present 10-11 knot vessel operating in an eight-knot convoy between loading and unloading ports is not more than about 5½ knots, due partly to the time lost in convoy assembling and movements, and partly to the fact that the average speed of a so-called eight-knot convoy is always somewhat below this. Thus it will be seen that an 18-knot vessel of 10,000 tons d.w. capacity if it be made safe to operate unconvoyed, may have as much as *three times the carrying capacity* of the present standard 10,000 tons convoyed vessel, if one assumes rapid loading and discharge at ports.

By building ships of increased speed and perhaps slightly larger, the carrying *shipping capacity* would be then made to increase at a much greater rate than the carrying capacity of the sinkings, without vast changes to the labour diverted to ship construction.

It may be truly said that the problem is merely transferred to the marine engine industry, and obviously as the power required is increased from 2,200 shaft horse power for the 10½ knot vessel to about 12,500 horse power for the 18 knot vessel, the problem of engine production and fuel consumption would be correspondingly increased by about five to six times, if existing orthodox types of propelling machinery only are considered.

The whole British marine engine position as it is to-day is the crux of the problem and is well worth some detailed investigation.

The 2,200 horse power coal burning reciprocating steam engine installation of the "Ocean" class of vessel weighs about 570 tons ready for sea; the fuel consumption is about 1·7lb. of coal per shaft horse power per hour. Actually, the average coal consumption under convoy conditions appears to be about 32 tons a day. The American Liberty vessel of similar power i.e. 2,500 s.h.p. but with oil fired water tube boilers, burns about 21 tons per day in convoy but about 30 tons per day at full power. A standard vessel similar to the "Ocean" class, built in this country but with a Doxford oil engine of 2,500 s.h.p. power consumes only ·37lb. of oil per s.h.p. (in convoy 10½ tons of oil a day) and weighs only 500 tons. On the other hand, the 7,000 b.h.p. oil burning geared steam turbine installation built in this country for cargo liners weighs only 670 tons ready for sea, even when conservatively designed, and consumes only ·63lb. of oil per shaft horse power per hour. This amounts to 47 tons of fuel oil a day.

The best method of applying high speeds to steam engines to obtain reduced weights is by substitution of the steam turbine for the old-fashioned reciprocator. Great savings in material with some increase in efficiency is obtained by substituting modern water tube boilers for the old-fashioned Scotch cylindrical boiler. Manufacture of the latter to-day would appear to be too wasteful of steel. Fortunately turbines and water tube boilers can be most "happily married." Whilst for small powers of 2,200 horse power, there is a case for the present reciprocating steam engine, there is no case whatever for powers of 5,000 horse power and upwards, and only the latter are to-day required.

It is interesting to note that a modern unconvoyed cargo liner like the American C2 type of vessel with modern geared turbines of 6,000 s.h.p. will consume about the same weight of fuel as the Ocean type of convoyed vessel, and will make twice as many trips in a given time or carry more than twice the amount of goods. The construction of simplified C.2 vessels is being vastly increased, the tendency being to build more C.2 vessels at the expense of Liberty ships with reciprocating engines. It is significant to note that geared turbines of 6,000 s.h.p. are now being fitted to the E.C.2 Liberty ships and that the engine rooms were designed in such a manner that steam turbine machinery could replace the steam engines using the same water tube boilers with oil fuel. New gearing factories have been erected and are now in operation to eliminate the gear cutting "bottleneck".

A present day direct drive Diesel installation of the same power, i.e., 7,000 s.h.p., would weigh not less than 750 tons if run at speeds of 115 r.p.m. but would consume only ·38lb. of oil per horse power per hour, which amounts to 28·5 tons of fuel oil per day. When it comes to fuel consumption, it will be seen that the Diesel engine has great advantages and stands in a class by itself. The problem is to produce Diesel engines of large horse power with small man power. The large Diesel engine has the disadvantage of requiring greater skill to operate, is not as reliable as the steam turbine, and maintenance costs are invariably greater.

It can be seen therefore that there are wide differences in specific engine weight and performance. Assuming a trip across the Atlantic of 3,500 miles, the 10,000 ton coal burning vessel running in convoy at 8 knots and taking 17 days, would actually consume about 550 tons of coal, whilst the Diesel vessel of similar power would use only about 180 tons of Diesel oil for the same trip. *For the same weight of fuel the Diesel engine vessel could afford to have four times the power, i.e., as much as 9,000 horse power which would propel a vessel at 16 knots.*

There is little to choose in the man hours required to build the present modern slow speed single-screw direct drive Diesel machinery or geared turbine single-screw machinery up to 5,000 s.h.p., but as the power increases the advantage in man hours tends towards the steam turbine installation. The man hours for production of the main propelling engine of 7,000 s.h.p., whether Diesel or turbine, in numbers of 15 standard units a year from a normal marine works can be taken as being about the same.

If desired, the weight of turbine machinery of 9,000 shaft horse power, with gear reduction and modern water tube boilers, could be designed to be no greater than 570 tons, the running weight of the present old-fashioned steam reciprocating machinery of 2,200 horse power with Scotch boilers, but developing over four times the power from a given weight of material at only one and a half times the fuel consumption. There is no technical obstacle to obtaining high power with low weight from steam turbine machinery as this is commonplace in naval vessels. There is also no doubt that land electrical firms used to building high-powered machinery could produce as much as 12,500 s.h.p. for no more weight than the 600 odd tons—the weight of the standard reciprocator machinery. The man power per ton would be greater but it is doubtful if the total man hours would be basically any more than for the normal heavier commercial turbine machinery.

The penalty in man hours for the higher powered machinery could eventually only be solved by standardisation, specialisation and "tooling up". In all cases only so much saving can be made by efficient design, the remainder can only be effected by mass production methods. The small numbers involved would justify not more than one design and each firm could only specialise on the manufacture of certain portions of the work, the design being a joint effort of the principle firms.

In view of the preoccupation of marine firms used to turbine work with naval work, this suggests that the principal turbine installation producing firms should be of the land electrical type and furthermore that only one design of turbo electric unit should be considered.

At the present time the actual cost of fuel is immaterial, in fact it may be argued that for this country, it is better to save coal mining and transport man hours, and use only American fuel oil on Lend/Lease. A minor disadvantage of using machinery using oil fuel is that the bunkers carried from, say, America to this country must include the oil required for the return voyage, which in the case of steam turbine engines would be about 400 tons and in the case of the Diesel about 250 tons, which amounts would require reduction from the cargo carried.

The fuel advantage of the best oil engine compared with the best steam turbine is decisive and for a 12,500 s.h.p. vessel at 18 knots making a trip from New York to the United Kingdom would amount to 450-550 tons of fuel.

Coming to engine installation weight, whilst the probable figure of commercial turbo electric geared turbines would be about 900 tons for this power, the best well proven direct drive oil engine on orthodox lines would not be less than 1,100 tons, so that the total saving in weight of engines and boilers is still definitely on the side of the oil engine installation (250-350 tons). If, however, both turbine and oil engine of the smallest practical weight were considered, either system could be produced for no more than 600-700 tons weight, in which case the saving in fuel would become of increasing significance and the combined weight of oil engine plant and fuel would be as much as one-half of the turbine when setting off for long voyages.

Geared turbine installations at present in course of construction are running with a propeller speed of 120 r.p.m. This could easily be increased to 150 without serious loss in economy of fuel (2-3% reduction in propeller efficiency) but with considerable economy in material in the case of turbo electric machinery.

When the main engine is the major part of the total installation as in the direct drive Diesel, increase of speed has the greatest effect in reducing weights and costs. The effect is less but appreciable in the case of the turbo-electric, and still less in the case of the geared turbine installation.

At the same time it is obvious that the water tube boilers should be relatively highly rated, and should work at high pressures and temperatures; and naval rather than commercial outputs must be considered to economise in space and weight of material.

In a number of the larger and faster vessels under construction, the steam reciprocating engine, turbine and Scotch boilers (Bauer Wach type) are combined in a hybrid fashion to give powers of over 8,000 h.p., and the relatively good fuel consumption of 1·2lb. of coal per h.p. As the weight and fuel economy of such engines is much inferior to the geared turbine it seems difficult to justify the building of such a type.

It should also be compulsory for all wartime installations to have only electrical equipment of a.c. 400 volts, 50 cycles, as in normal industrial plant, as great savings in cost, weight and maintenance will thereby be effected compared with present standard marine direct current practice. The latest American oil tankers are being fitted with such a.c. electrical equipment. No British ships are being so fitted to the writer's knowledge.

As well as building geared turbines in land and marine engine shops it seems very desirable simultaneously to build turbo electric or electric reduction sets. It can be demonstrated that there is a negligible difference in weight and fuel consumption, and if sufficient numbers are ordered there will be only a small increase in man hours compared with double reduction geared turbines; these man hours are, however, from non-marine labour and to some extent will be women labour. There is an efficient electrical industry wishing to engage on this vital work which had been developed in a number of installations some years before the war.

The advantages of turbo electric propulsion in war-time are as follows:—

(1) It is possible to utilise the great potential output from the well-organised electrical industry and thus allow marine turbine manufacturers to concentrate to a greater extent on warship engines. It also eases the gear cutting "bottleneck" which imposes a definite limit to the number of geared turbine installations which can be built in this country.

(2) It is possible to place the propelling motors right aft and so dispense with a length of shafting and tunnel which is sensitive to torpedo action.

(3) Electric drive is the quietest form of drive, and this will tend to make it difficult for the German sonic underwater detectors to pick up sounds, and furthermore will be less likely to activate acoustic mines.

(4) The turbine generator and control gear can be placed higher up in the engine room above the motor and even in a separate compartment and thus be relatively free from torpedo action effects.

Once there is the need for using oil as fuel to conserve the "coal man power", the reciprocating steam engine can only have a minor place in a major shipbuilding programme to-day, and marine engine works accustomed to building steam engines could with advantage change over to the building of oil engines or the marine parts (i.e., shafting boilers and condensers) of turbo-electric units.

Generally speaking, steam reciprocating engines (the usual accompaniment being the Scotch boiler) are slow in speed, not suited to higher powers, heavy in weight, use conservative materials, have a large factor of safety, and are old-fashioned as regards general design. They are uneconomical in fuel but have major advantages in being reliable in service and requiring a minimum of technical skill to operate. In certain powers they are cheap to make, as relatively crude workmanship will suffice, in war-time however they are eventually a man power consuming doubtful luxury.

It is curious how it has survived longer as a major type in this country than any other and even the war has retarded its long overdue demise and there seem good reasons why the manufacture of low power—or any power—reciprocating steam engines should continue as the Liberty ships can supply all the numbers necessary of this type of ship. As an immediate source of engines, there was no doubt some justification in producing steam engines at the beginning of the war, but certainly not for the last two years. Marine engine works have been building inefficient steam engines of 2,200 h.p. which could equally well build efficient oil engines and an immediate change from steam to oil engines of moderate power could be made pending more radical developments required for high powers.

As far as main propelling direct drive Diesel engines are concerned, the building of types operating on obsolete cycles such as the four cycle should not be permitted in wartime, nor should the building of even Diesel engines of foreign designs be encouraged; only the British engines and the Doxford in particular should be standardised in this class and such engines should run at propeller speeds of not less than 125 r.p.m. and develop about 7,000 i.h.p. Not only is this type of engine the best from a fuel consumption, reliability and smoothness of operation point of view, but it is an almost entirely British development and has been already built by a considerable number of well-known British firms, such as Doxford's, Swan Hunter's, Barclay Curle's, Fairfield's, David Rowan and others.

Increasing the Power Output of an Approved Type.

Confirmation of the difficulty of obtaining the necessary engine power if the present conception of slow speed direct drive Diesel engines is retained, is given by Mr. Gebbie in a recent Presidential address in which he states that if 7,000 i.h.p. engines for 15 knot ships were built by a N.E. Coast firm instead of 2,900 i.h.p. engines for 11½ knot ships, only 10 engines per annum instead of 24 could be produced. Therefore if 14,000 i.h.p. were needed to give 12 knots presumably only five ships could be engined.

If one assumes a port to port speed of six knots for the convoyed ship against 18 knots for the unconvoyed and assuming the same deadweight capacity, the relative cargo carried would be roughly $6 \times 24 = 144$ against $18 \times 5 = 90$, a clear case supporting the present programme on the facts given.

There is, however, another important alternative for Doxford engined ships and that is to substitute the largest 725mm. bore three cylinder engine for the present smaller 520mm. bore three-cylinder engine, thus producing 5,500 i.h.p. at 135 r.p.m. instead of 2,900 i.h.p. at 108 r.p.m. still using the simplest form of Doxford engine. These engines could be installed in the present standard cargo vessels (not cargo liners) with a minimum of alteration and the smallest increase in weight and man hours, and would enable vessels to operate in the high speed (12-14 knots) convoy. This raises a vital issue as to the need for building any cargo liners during war time as surely only fast *cargo vessels* are needed of the simplest possible type regardless of any requirements of private builders. Such vessels would be much more serviceable for all war purposes than the present low powered type. It is submitted that all possible marine engineering firms capable of building complete oil engines or parts of oil engines should be engaged in building such engines.

Apart from the increased carrying capacity, the higher convoy speed will place much greater difficulties onto tracking submarines and therefore give much greater immunity from the underwater menace. This slightly higher speed will still enable present latest escort vessels to operate with efficiency.

It is difficult to conceive of any fundamental difficulties in such a scheme, which could not be overcome, to enable the same number of engines but of the larger size to be produced by the firm in question, if helped out by firms now building less efficient engine types. On the subject of crankshaft "bottlenecks" it appears to be entirely wrong to assume that victory is just "round the corner". We always had even a peace-time crankshaft problem (one of relatively high price) and it would be interesting to know the number of finished crankshafts or forgings of crankshafts ordered from abroad even in the "piping days of peace". The production of cheap large crankshafts will be necessary to win the peace. It is recommended that the American constructive policy of dealing with these bottlenecks should be well and truly digested.

One would imagine that it would be much more in the National interests to remove the crankshaft bottleneck than the gearing bottleneck for geared turbines as the electrical industry affords an immediate alternative to the latter.

The policy of adapting marine engine firms with experienced oil engine capacity to build the relatively inefficient steam turbine installations will be difficult to justify on a National basis. The American steam turbine policy can be well justified because, firstly, they are not normally builders of large marine oil engines, and secondly they are a major oil producing nation—which we are not. We have in this country the most economical and reliable oil engine developed and ready for real quantity production, and even if four times the present number were built this should not be considered excessive.

Simultaneously with this production further detail development should be undertaken with a Government financial grant to enable the engine in question to operate at even higher speeds and mean pressures for war purpose. The life of the engine as a whole is at present a minor consideration as long as weak points are avoided.

If the life of the engine were more than halved it would be fully justified as long as the generally reliability for a period of say five years could be maintained.

In order to improve the detail design of the engine, experimental work by the makers should be encouraged no less than in peace time, but in addition more "wholesale" means of increasing the specific output from a given engine by supercharging should be engaged upon.

The opposed piston engine of all engine types is the most readily adapted to supercharging—as exemplified by the recent Sulzer development, particularly when the basis engine is of a well developed and established practical type.

The suggestion now made is that experiments on supercharging on a National basis should be immediately undertaken, in conjunction with the previously mentioned large three-cylinder engine, in the following order:—

(1) The engine driven reciprocating blower should be replaced by a turbo blower driven by an a.c. motor and built by a well-known builder of turbines and electrical machinery, for *all* builders of such main machinery. This involves no experiment and will relieve marine engine builders of these parts and deflect work to non-marine builders. Installations can immediately be built to such a plan. Scavenge air quantities and pressures should be greater than with the normal engine pump to enable higher mean pressures and outputs to be obtained even at the slight reduction in fuel economy.

(2) All engine service pumps to be independently driven by a.c. motors and manufactured by a specialist pump and a.c. motor manufacturer, preferably one well used to industrial pump requirements on a production basis, but not already on marine work—such firms and very efficient ones at that, exist in this country. These service pumps and motors should be absolutely standard for *all* main propelling installations of this type.

(3) The development of an exhaust gas turbine to be immediately undertaken which should be coupled to an electric generator. The power that will be thus produced will not only be sufficient to supply power for scavenging purposes but also for all the engine and ship services. At first only light supercharging should be undertaken, followed by step by step developments in higher supercharging and corresponding engine outputs. By taking advantage of Swiss developments an immediate start could be made.

(4) The normal heavy exhaust boiler should be replaced by a light weight water tube water heater and circulating pump for all cargo and accommodation heating. The jacket water heat from the auxiliary engines should be also used for this purpose no alternative oil firing should be provided.

Such a programme will eventually solve the problem of increased power output without increase of weight, and with an actual reduction in man-hours from marine establishments. It is believed that the saving in scavenge and engine pump marine man hours will considerably offset the greater marine man hours required by the larger engine. It will also enable greater thermal efficiencies to be eventually obtained to maintain our lead in the Peace.

Separately driven pumps will allow a 6 per cent. increase in engine shaft horse power, thus bringing the power up to 5,820.

Elimination of the engine driven scavenge pump will give improved dynamic balance—an unbalanced double acting pump is surely an anathema to an opposed piston engine—and this in turn will give greater underwater silence. The opposed piston *side rod* engine is unique amongst all types in the freedom from transmission of ignition knocks or bearing knocking to the ship's hull—the double actor being the worst, and therefore the underwater vibrations will be much less than either a steam reciprocating engine and a geared turbine with its penetrating high pitched note.

Of all engine forms, the opposed piston can have the fewest number of cylinders, due to its inherent balance and this should be used to cancel out the natural complication of the cranks and connecting rods, three cylinders is therefore an optimum number.

On the question of speed of revolution, further development is needed to effect a reduction in the weight of the reciprocating parts. If these could be reduced some 15 per cent. this would enable a speed increase from a dynamic point of view up to 145 r.p.m., bringing the horse power figure up to 6,250.

By increasing the amount of scavenge air retained in the cylinder possible by the combined effect of increased amount of scavenge air and advanced relative timing of the exhaust cranks some 15-20° (such as is done in Burmeister opposed piston double-acting) there seems to be a reasonable expectation of quickly obtaining a further 12 per cent. increase in mean pressure without additional temperature effects. If flesh and blood must stand the greatest strains surely in war-time we can demand more from our engines.

This incidentally brings our horse power figure up to the 7,000 i.h.p. quoted by Mr. Gebbie. War requirements are really only commercial requirements multiplied, more power is wanted with less weight of engine and fuel and reduced man hours to do it. This can only be effected by some degree of change, by advances in design and advances in production methods. It is all a matter of regulated evolution to obtain power and revolutions.

The Fundamentals of Weight and Power.

As the major problem of producing a safe and efficient war-time cargo vessel is bound up with problem of producing a combination of engines having high power, low weight and high fuel economy it is worth surveying the position more fundamentally.

Generally speaking it seems more in line with modern tendencies to build more finer mechanisms and less sheer mass of steel; in other words putting in more engine power into a less number of ships seems to be a modern way of increasing carrying capacity.

Now the heavy oil or Diesel engine owes its existence to its quite exceptional thermal efficiency compared with any other prime mover. In marine form it consumes only 40 per cent. of the oil needed by a steam engine with oil fired boilers and even only 55 per cent. of that needed by steam turbines and water tube boilers. If, therefore, we are to compete in a world shipbuilding market it is absolutely essential that we should lead in the most economical use of fuel.

The Marine Diesel for Cargo Vessels.

In view of the German control of Scandinavia and the Continent and their access to the remaining neutral countries, the potential capacity of Diesel engine technique research and production of all types must now be definitely in excess of that of the British. Germany is, therefore, not only definitely ahead in engine design, but also in actual production.

Wherever, therefore, economical motive power is required, *i.e.,* tanks, war transport, submarines, or motor torpedo boats of various types, she will be in a particularly dangerous and dominant position and her past endeavours in fuel economy are now serving her well.

It is a curious but undoubted fact that the Diesel engine has had a difficult time in this country since its inception. It is informative to review each broad application of this most economical type of engine and the relation of the British Diesel industry in relation to other countries.

In the case of the largest of the oil engine types, the direct drive marine oil engine, the initial developments were mostly carried out abroad and most British marine engineering firms were initially content, and have remained content, to pay licence fees and royalties in payment for foreign designs and developments.

This is clearly demonstrated by the following examples of the largest British marine firms building large Diesel engines:—

	Type of Engine Built.	*Country of origin.*
Harland & Wolff	Burmeister & Wain	Denmark
Vickers Armstrong ...	M.A.N	Germany
Wallsend Slipway & Eng. Co.	Sulzer	Switzerland
Hawthorn Leslie	Werkspoor	Holland
Fairfield Ship & Eng. Co.	Sulzer	Switzerland
	Doxford	Britain (German origin)
Swan, Hunter, Wigham Richardson	Sulzer	Switzerland
	Polar	Sweden
	Doxford	Britain
Denny, Stephen	Sulzer	Switzerland
Kincaids	Burmeister & Wain	Denmark
Scotts	M.A.N.	Germany
David Rowan	Doxford	Britain
British Auxiliaries	Polar	Sweden
Cammell Laird	Sulzer	Switzerland
Doxford	Doxford	Britain
Richardson Westgarth ...	Richardson Westgarth	Britain
	Doxford	Britain

Germany to-day virtually controls all the engine types on the above list including the Swiss, the Swedish and the Danish.

The success of other nations with marine Diesels has caused an appreciable change in the orientation of the shipbuilding industry, to the serious detriment of this country, especially during bad times and slumps.

The reluctance of British firms to engage on research and development work has undoubtedly cost the nation dearly in the shipping and shipbuilding industry, and unless there is a change of heart towards new marine oil engine developments the position will tend to get worse. A solution might be to give special financial encouragement to firms developing their own types of engines instead of buying their "brains" abroad, or to impose a "technical tariff" on engines of foreign origin.

The tendency of British marine engine firms to be unprogressive in design has resulted in the lead in marine engine design being given to Germany, Switzerland and the Scandinavian countries. It is believed that the change in the centre of gravity of this important engine technique has all tended to feed the superiority complex of the German—and reasonably so. To win back the marine engine supremacy we once had will require an entirely new outlook, more technical courage, a greater financial support to new designs, a closer association with research and scientific bodies and a greater appreciation of the need for better workmanship and production methods which the Diesel engine demands.

Most of our large marine engine workshops are inadequately equipped for the superior manufacturing requirements of the modern oil engine.

As we have not led the way in design and specialised manufacture, there has been a great tendency for largely non-shipbuilding countries like Norway, Holland or Spain to buy less and less from this country and more and more from Germany and Scandinavian countries.

Whilst only one almost British engine—the Doxford—has been licensed abroad, German, Swiss, and Danish firms have, however, sold many licences all over the world.

By and large, it may be said that British technical prestige as regards large Diesels is definitely low.

When a British firm *has* tackled the Diesel problem thoroughly, it has been successful, e.g., the Doxford engine, which is perhaps the finest Diesel marine engine in the world (even though the success is primarily due to the eminent Swiss, Mr. Keller, and the initial patents and designs were Junkers).

There is no indication that leeway is being made up; on the contrary, we are lagging greatly behind Germany in the latest developments of Diesel electric and gear drives, using semi-mass-produced smaller size and higher speed engines. It is here that, in the future, we may take the lead if the writer's proposals are adopted, regarding the development of a series of new large and small marine engine types.

Why Not Evolve a Basis National Marine Oil Engine?

It will be noticed that oil engine design is controlled by only three main types, Doxfords, Sulzer and Burmeister & Wain.

No doubt the Doxford engine can be relied upon to develop on its own lines, but with regard to the other types it does appear that builders should rely no less on British technique and development. Now it is evident from the study of the history of the large marine oil engine that a single firm has a small chance of success of developing a design of its own, a fact tacitly admitted by the majority of builders in taking up the licence of a developed—usually foreign—type.

The task is enormous and the resources usually small; my own attempt at producing a large double acting two-stroke has been a good illustration—whatever the future developments.

Furthermore it must be admitted that at the moment no design exists which could satisfy power, weight and man power requirements for really fast cargo vessels. On the other hand we are in a very knowledgeable condition as to the suitability of detail constructions; problems once wrapped in mystery—those of air charging, fuel injection and combustion—are sufficiently known to warrant the immediate production of an engine to satisfy the precise latest requirements, always provided there is a pooling of knowledge and a co-ordinated effort made by all concerned. The time is ripe to produce a basis engine on National lines for the specific purpose of winning the Battle of the Seas.

Generally speaking, the availability of coal has tended to be a serious deterrent factor as far as the Diesel engine is concerned for all marine applications.

Fundamentally, as we are not an oil producing nation, whenever we use oil it should be used economically, whether in ships or on land or in the air. Engine power and all the vast implications in its uses and abuses to mankind has moved from coal to oil. We must be masters of the economic use of oil, if not of its production.

The world war demands the greatest economy of oil, for reasons of range of action, so will the Peace for economic reasons. It is vital, therefore, that this country of all countries should be the most expert in producing engine power with the least fuel. To-day this means the heavy oil engine in practically all applications.

U.S.A. is developing its factories to produce vast numbers of steam turbine ship installations using fuel oil at ·63lb. per horse power (or more). Our programme should be to produce vast numbers of oil engines using only ·38lb. of fuel per horse power (or less).

It will, however, be necessary to start afresh in our conceptions of both design and production as far as high powered cargo ship engines are concerned.

Investigation will show that the development of the internal combustion engine for the sea and for the air has gone along on widely diverging tracks. The marine oil engine has, especially in this country, kept to colossal slow speed engines, sometimes as much as 500-600 tons weight per engine. The propelling engine invariably works at the same speed as the propeller, i.e., about 100-125 revolutions per minute. It may be taken that the lowest possible weight in sight of a slow-speed direct drive engine of 12,500 horse power is 350 tons, using all improvements such as welded structure, two-stroke cycle, double action, and great refinement of design. The guiding principles of past British oil engine design have been long life, reliability and economy. To-day we cannot afford such luxuries. Conservatism in design and old-fashioned methods of manufacture are the rules rather than the exceptions. On the other hand, the aero engine has always been developed to be both light and economical, and truly magnificently produced. This must be translated somehow to marine establishments.

The Aero Engine and Its Relation to the Marine Engine.

The air propeller usually operates at more than ten times the ship propeller speed—1,500 r.p.m.—but even that is too slow for the aero engine, which operates, at full speed, at no less than 2,500-3,000 r.p.m. Even using a conservative cycle of operations, but using petrol as fuel, aero engines giving an aggregate of 6,000 rated horse power would weigh less than 3 tons. The optimum fuel consumption of the present aero engine is only about 25 per cent. greater than marine oil engines, using petrol instead of Diesel oil. *It is believed that the ultimate solution to the marine engine problem lies in harnessing the remarkable technical development of the aero engine and using the remarkable methods of research experiment and production to evolve a truly high speed marine oil engine,* probably three or four times as heavy as an aero engine, but having a much greater running life. Whereas the life of a slow-speed marine engine is about twenty-five years with a greater or less amount of repair work, the optimum life of the ideal marine engine is probably no more than five years with regular maintenance, overhauls and replacements at definite intervals as in aero engine practice. It would be possible to produce a suitable high speed marine oil engine without the use of any materials in short supply such as aluminium, as the greatest use would be made of steel pressings and steel welded construction without great increases in weight.

Above all it must be remembered that whilst mammoth marine installations are accepted practice in this country, there is no *fundamental justification* for them whatsoever, and only the restricted vision of a still steam engine minded industry justifies them. It should be noted that there are relatively few mammoth engines now built in the U.S.A. or in Germany.

Viewed in a broad field, vastly superior engine types can be seen to be physically possible to give great reductions in weight and man hours requirements.

If a judge of the High Court could investigate the true technical position of British marine engineering relative to continental marine engineering and our own aeronautical engineering, he would not find the position satisfactory to the former. In fact, no better recommendation could be made than to have a complete independent survey of the general internal combustion engine position *now* to ensure that we are making the best of our available resources *regardless of custom, usage or vested interests.*

Actually it is believed that it will be easier to design and develop a new and special high speed oil engine that can be made in our fine new aero engine shadow factories, than to attempt to modernise our relatively obsolete marine engine shops by supplying the expensive large type machine tools and equipment necessary. Nevertheless an attempt should be made to produce a suitable high duty direct drive design and modify the production facilities accordingly. Generally speaking, refined design for low weight means more man power, but given quantity production this is more than made up. The whole secret is in making enough of a given part and the lack of this quantity production has always been the perpetual deficiency of the marine engine industry.

In determining the size and weight and production costs of engines the fundamental factors are :—

(1) Speed of revolution.
(2) The cycle of operations, whether four or two stroke, and the type, whether single or double acting, or opposed piston supercharged or normal aspiration.
(3) Mechanical general and detail designs, i.e., in line, Vee or radial cylinders, trunk piston or crossheads.
(4) Suitability to high mean pressures and low maximum pressures.
(5) The type of the materials used, i.e., the use of welding; the factor of safety permitted.

The scope of the above factors varies according to the type of engine. In time of war it is essential to use the quintessence of all these factors in a new marine engine type.

A design has been developed for some time by the writer, initially for aircraft applications bearing in mind three preliminary considerations :—

(1) It makes use of a fundamentally light geometric form of engine—the horizontally opposed piston and cylinder.
(2) Because of the double acting crank design there will be an efficient crankshaft and crankcase material utilisation.
(3) After considerable design research it has been possible to ally the fundamentally correct side rod two-stroke opposed piston uniflow scavenging system to high speed trunk piston practice.

This new type will run at about 1,500 r.p.m., i.e., 12-15 times the speed of revolution of the present direct drive Diesel engine. It is thus a matter of wedding the most up-to-date cycle of operations and system of scavenging to aero engine technique. Such an engine will enable a double-acting effect to be obtained from each three-throw crankshaft and the crankshaft is of such a size that it can be stamped out in a single stamping. The fully forged construction will enable a much lighter and smaller crankshaft than conceptions based on Doxford designs. Advanced materials of the quality used in aero engine practice would be used with comparable factors of safety and general detail design technique, bearing in mind the longer life of engine required. A complete renewal of the engine is proposed every year, if worked under war conditions.

Particulars of a high speed oil engine suitable for Diesel electric drive would be as follows :—

Type: Horizontal opposed piston two-stroke.
7½″ dia.×18″ stroke (combined), 9″ actual.
6 cylinders (3 a side).
R.p.m. 1,500.
M.e.p.: 125lb. per sq. in.
Power: 2,250 per engine.
Weight: *5 tons* per engine; 30 tons for 12,500 s.h.p.
Fuel consumption: ·35lb. per b.h.p. per hour.

Two of such engines would be coupled to a 4,000 b.h.p. a.c. synchronous generator, three such generators would be electrically coupled to a propelling motor running at about 150 r.p.m. The generator and control gear would be almost identical to that proposed for use with steam turbine machinery, and development of the latter will serve the former.

In addition an engine of this type could be used for a wide range of naval craft including motor torpedo boats, submarines, corvettes, minelayers and all manner of fleet auxiliaries.

The basis cylinder could eventually be used in in-line forms in the larger war tanks and as either a horizontal, semiradial or radial engine would serve as a prototype for a Diesel aero engine to propel the larger bomber and transport airplanes.

It is believed that the amount of technical experience available to enable the rapid development of such an engine is enormous and by using *specialisation in design of details* to the maximum extent the amount of research and experimental work would be surprisingly small.

This new type when installed in conjunction with electric drive will not only be low in total weight—no more than 350 tons, i.e., half the geared turbine weight—but the production man hours will be low and the fuel consumption will not exceed ·39lb. per s.h.p. per hour at the propeller. All the generating machinery will be capable of being placed above the water line and only the aft propelling motor or motors will be liable to direct torpedo action.

The space required for such a type of machinery would be exceedingly small. Generally such a type of machinery is the logical development of the latest German Diesel a.c. electric system in which class of work we are now sadly behind.

Summarising, it is possible to build machinery which, compared with the Ocean class of vessel, would be six times the power, no greater fuel weight consumption, would take up one-third of the space and weigh no more, would be only a fraction as susceptible to torpedo action; and maintenance and overhaul would be simple and more like aero engine upkeep.

The scope is immense and only technical courage and encouragement to use available expert technical knowledge are needed.

It is highly desirable from a shipbuilding and shipping point of view to bring in any new type of engine or industry capable of making new propelling engine types—even if it does act as a temporary whip to existing builders—in the end this is better for the industry as a whole than internal agreements to prevent the admission of such external forces.

As well as high speed indirect engine types it is believed that the scope of the large direct drive oil engine is still enormous and therefore it is now proposed to examine various design aspects.

Crosshead versus Trunk Guides.

It is instructive to consider the means for taking up the lateral thrust arising from the angular movements of the connecting rod.

The obvious and most direct means is by an extension of the piston itself as in a trunk piston. The chief requirement is that the cylinder should be suitably lubricated, which it is in the case of the internal combustion engine.

The separate crosshead construction is really indigenous to double acting engines or to the steam engine where lubrication other than water must be excluded as far as possible, furthermore the piston is usually narrow in width as the piston seldom controls ports. Above all the steam engine is well adapted to the double acting principle which necessitates the use of a crosshead.

In the case of large single acting oil engines the use of crossheads was most probably due to the effect of conventional steam engine design following years of association with crossheaded steam engines rather than any fundamental mechanical necessity.

The simplest, lightest and fundamentally most correct construction for internal combustion engines is, I believe, the trunk rather than the crosshead construction for single acting engines and certainly in war-time only trunk pistons should be considered.

The Use of the Trunk Piston to permit Higher Rotational Speeds.

The application of high speed to the reciprocating engine lays bare the fundamental requirement of an engine mechanism having subject to the change of direction to be of the smallest possible weight; given this there is no dynamic objection to high speeds. This elemental fact must be kept clearly before us in all attempts to increase speed of rotation.

The force penalty involved is not merely proportional to the speed but as the speed squared.

A piston operating at 200 r.p.m. should therefore be one quarter of the weight of one operating at 100 r.p.m. for equal inertia forces. It can be established that the reciprocating weights of a single acting trunk piston two-stroke engine are just about one half of the weight of a double acting two-stroke engine with crosshead the same bore and stroke. Therefore dynamically there is nothing to choose between a double acting engine operating at 125 r.p.m. with a 4ft. stroke and 27½in. bore and a single acting engine of similar stroke and bore at $125 \times \sqrt{2} = 177$ r.p.m.

The reduction in propeller efficiency at the higher speed will not amount to more than about 5 per cent. for high speeds. It can be shown that there is much in favour of the higher speed single acting engine as a means of obtaining low weight.

As the speed of the propeller is limited there is no chance of taking full advantage of the rotational speed possibilities of the single acting engine when the direct drive is used and recourse must be made to its application in the indirect drive and really high speeds.

The light cylinder single actor is however in some respects the more straightforward proposition from a production point of view, it is fundamentally more silent due to the non reversal of the bearing loads, it requires no less than half the overhauling height —in war-time ships a most vital consideration as all overhauling should be done below deck level—and the fuel consumption would be lower on an i.h.p. basis.

The Vee Arrangement of Cylinders.

A well tried and successful method of reducing the crankshaft and crankcase weight in engines up to 10in. bore is to arrange pairs of cylinders in vee formation, each two cylinders using a common crank. Fundamentally there is no reason why such a system should not be used in quite large single acting trunk piston direct drive oil engines. The practical difficulty of slinging the covers and pistons into or out of position can be solved by scientifically arranged lifting points and specialised handling gear.

Such a system will increase the engine length of the single acting engine to only 25 per cent. longer than that of the double actor, and the cranks of an eight or twelve cylinder vee engine can be arranged to avoid all primary and secondary forces and couples just as in the case of certain arrangements of eight cylinder in line engines.

In the case of an engine of this size it will be preferable to have separate bottom end bearings—the cylinder centres of the two lines being staggered to allow this—as in the case of General Motors and Ford engines. A twelve cylinder engine will require only simple built up cranks made of plain forged steel pins and journals and cast steel webs. Such a single acting vee engine will be almost as double acting in effect as the conventional tandem double acting type and at a given speed will bring the weight down to that of the basic double actor without any reduction in thermal efficiency.

The vee shape will be found to suit the triangular end of a ship and will permit of a singularly compact engine room. A twelve cylinder arrangement is shown in Fig. 1 and could deliver the same power as the eight cylinder double actor.

The Double Acting Principle.

Careful investigation has shown that as far as the high power marine direct drive is concerned, the double acting two stroke, if carefully designed in detail, can be made the lowest in weight and man hours. As limitations of propeller revolutions prevent the full exploitation of the higher engine speeds possible with trunk piston designs. It is believed that for reasons of production and handling the maximum size of engine which can be made in most marine engine works is about 24in. bore and 42in. stroke. Such an engine could be designed to run at 165 r.p.m. and yet give refined performance. Ten cylinder Sulzer double acting engines of 30in. bore and 47¼in. stroke have operated at no less than 152 r.p.m. on trial, which is an adequate precedent.

Alternative Direct Drive Engines.

With a view to determining which type and arrangement of engine offered the best advantages for 12,500 s.h.p. the following were considered the most practical typical possibilities :—

(1) The *largest practical* size of direct drive double-acting two-stroke oil engine running at 135 r.p.m. with 8 cylrs. 28in. bore × 50in. stroke. M.i.p. 88lb. per sq. in. B.m.e.p. = 83lb./sq. in. Weight per b.h.p. 72lb.
   This is shown on Plate 2.

(2) The largest practical size of direct drive single acting two-stroke trunk piston vee oil engine running at 175 r.p.m. with two banks of 6 cylr. each 27in. bore and 48in. stroke. M.i.p. 92lb. per sq. in. B.m.e.p. = 86·5lb./sq. in.
   Weight per b.h.p. 85lb.
   This is indicated on Plate 1.

(3) The best practical size of direct drive double acting two-stroke oil engine running at 165 r.p.m. with 10 cyls. 24in. in. dia. × 44in. stroke.
   M.i.p. 90lb./sq. in. B.m..e.p. = 84·5lb./sq. in.
   Weight per b.h.p. 62·5lb.
   A cross section is shown on Fig. 4.

(4) The lightest, shortest and smallest possible oil engine to deliver the power required at 165 r.p.m. is a combination of vee and double acting two-stroke with two banks at 54° of 5 cylinder of above size and rating.
   Weight per b.h.p. 50lb.
   A cross section is shown on Fig. 6.

The last proposition is easily the best on all counts but silence, and has fundamentally exceptionally low weight and small size while still having only a moderate rating.

The broad column will make for stiffness and freedom from lateral movement. The turning moment will be much smoother than Fig. 2B and the balance can be made adequate. The bottom ends will be quite separate so that the crank pins will be twice the normal length.

The development of an engine of this vee double acting type appears to offer a complete solution to the propulsion of a cargo warship. There is really little that is new, it is rather a re-arrangement of known constructions.

As with the high speed engine with electric reduction gear the total weight of the propelling machinery will be less than that of the standard steam engine installation of 2,200 s.h.p., the total weight being 530 tons.

Torque From Multi-cylinder Two-stroke Oil Engines.

Figs. 2A and B have been included as showing the remarkable even torque possible from an eight-cylinder double actor. The actual torque at the propeller would be much better due to the flywheel effect of the engine rotating parts and the propeller and entrained water.

Modern developments in fuel ignition and combustion if applied would give even better diagrams and make the engine operation quite unobtrusive. The vee 10 double actor will have an almost completely smooth torque at the propeller; this is considered desirable to reduce any propeller vibrating forces and thus to give relative silence in operation. There must be no tendencies to propeller "singing" in a cargo warship.

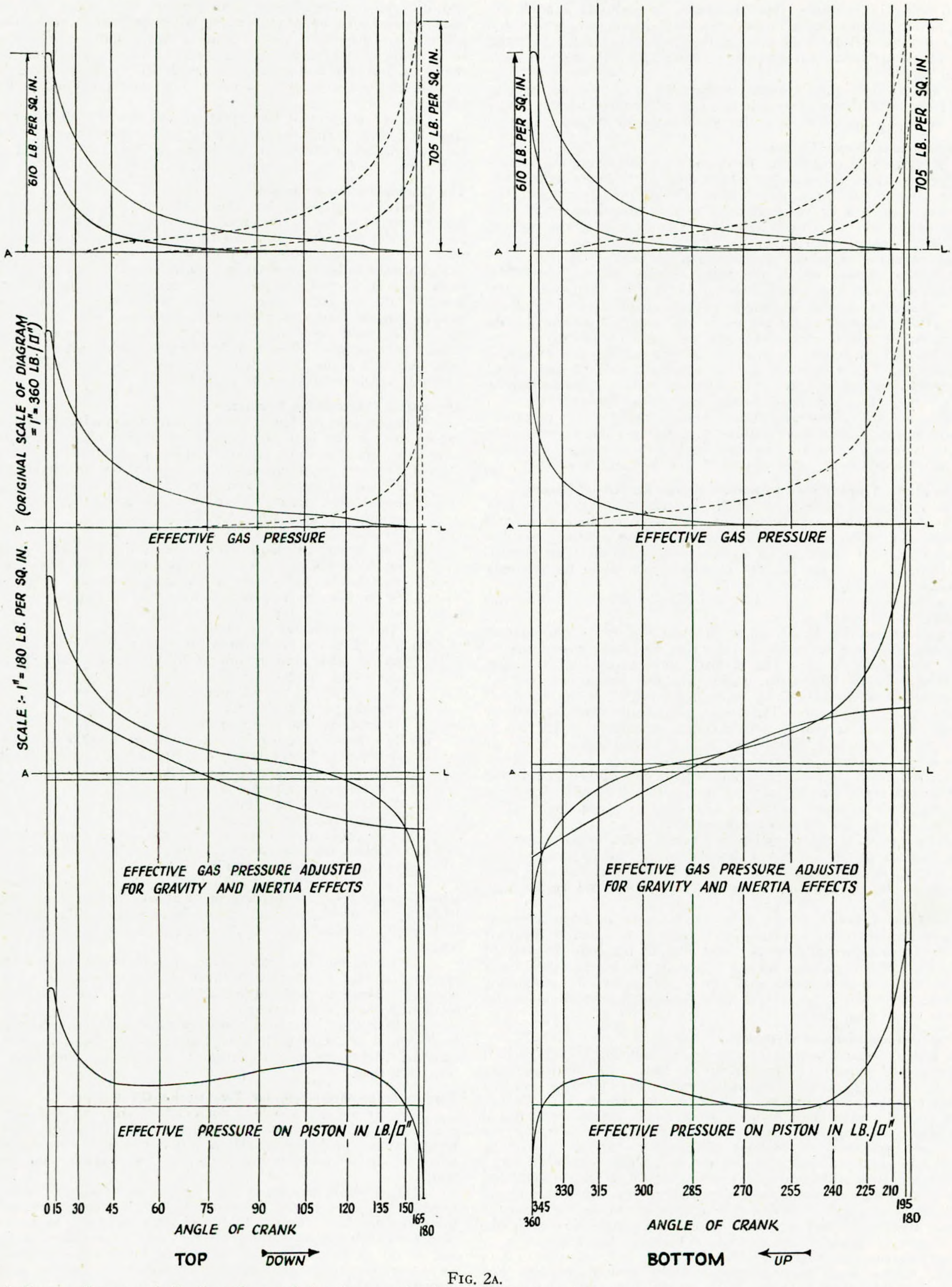


FIG. 2A.

Indicator diagrams indicating the need for low combustion and compression pressures to give smooth crank action.

CRANK EFFORT DIAGRAM FOR HEAVY WEIGHT EIGHT-CYLINDER DOUBLE-ACTING TWO-STROKE OIL ENGINE.

Cylinders, bore	27½in.
Stroke	47¼in.
Piston rod diameter	8¾in.
Revs. per minute	120
Mean indicated pressure at top side of pistons ("Silverlarch", trials, No. 1 cylinder)	79·5lb./sq. in.
Mean indicated pressure at bottom side of pistons ("Silverpine", trials, No. 2 cylinder)	84·6 ,, ,,
Average mean indicated pressure $=\frac{79{\cdot}5+{\cdot}89876\times84{\cdot}6}{1{\cdot}89876}$	= 81·91 ,, ,,
CONNECTING RODS FOUR CRANKS LONG.	
Mechanical efficiency	·908
WEIGHT OF RECIPROCATING PARTS :—	lb.
$\frac{\text{Connecting rod}}{2}$	3,969
Guide shoe	1,213
Piston rod complete	2,809
Crosshead	1,366
Piston cooling gear	270
Piston complete	2,716
Cooling oil, say	400
TOTAL	12,743 or 5·68 tons.

Number of cylinders		1	8
B.H.P.		1,200	9,600
I.H.P.		1,320	10,560
Indicated work per revolution	ft. lb.	363,000	2,904,000
Mean crank effort calculated from indicated work per revolution	lb.	29,366	234,928
Mean crank effort from crank effort diagrams		30,000	237,500
Excess error %		2·16	1·093
VALUES FROM CRANK EFFORT DIAGRAMS :—			
Number of cycles of angular velocity variation per revolution		1	8
Mean crank effort	lb.	30,000	237,500
Maximum crank effort	lb.	72,000	272,500
Minimum crank effort	lb.	12,200	198,000
$\frac{\text{Maximum crank effort}}{\text{Mean crank effort}}$		2·4	1·148
Total energy per revolution	ft. lb.	371,000	2,938,000
Maximum fluctuation of energy (loop on A-B)			
$\frac{\text{Maximum fluctuation of energy}}{\text{Energy per revolution}}=$	ft. lb.	100,804	15,710
=COEF. OF FLUCTUATION OF ENERGY		·2715	·00535

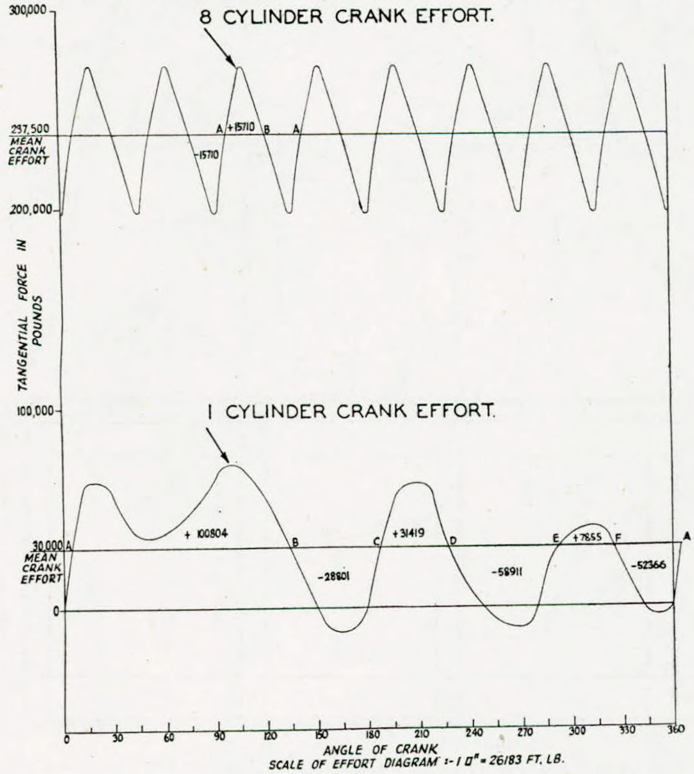


FIG. 2B.

Diagram showing the even turning moment possible from a heavy type 8-cylr. Double-acting Two-stroke Engine as shown in Fig. 3.

Cylinder Construction for Low Weight.

A prevailing fault of all double acting two-stroke oil engines is the excessive weight of the cylinders, exhaust pipes and scavenge mains. The great saving possible in weight has been demonstrated in the Doxford design of engine. In the latter case the air main is neatly formed in the main cylinder beam, and in the case of the double acting engine there is no reason why the cylinder beam, air and exhaust mains should not be incorporated as in the design shown in Fig. 4. Welded construction makes this possible and in addition it provides greatly increased strength and stiffness (which the double actor needs) with greatly reduced weight and giving definitely superior operational conditions. It can be seen that the air and exhaust flow can be simultaneously considerably improved and thus permit of higher mean pressures to be potentially available.

Elimination of the Bedplate.

The greatest saving in weight and man hours can be effected by the elimination of the normal bedplate and attachments to a heavy doubling plate on the tank top and by utilizing the actual ship's bottom as both bedplate and oil sump. This is fully justified by the use of welding and the additional stiffness given by the new steel cylinder beam. The intention is to weld cast steel main bearing housings to suitably arranged cross girders. The manufacture of this portion of the ship's bottom would be carried out in prefabrication shops and would be fully machined before leaving the works. If such a construction be adopted it will place the direct drive engine in an unassailable position as regards weight and man hours except for the really high speed oil engine with electric reduction gear.

The relative constructions of the orthodox construction and that proposed are well shown by comparing Figs. 3 and 4. More than 100 tons can be saved by this subterfuge.

Columns.

A considerable saving in man hours and weight can be effected by the elimination of column tie rods, which by proper welded plate construction can be avoided. Tie bolts would only connect the upper and lower cylinders as shown in Fig. 4.

Crankshaft.

There will be no crankshaft bottleneck as the shaft proposed is virtually a refined steam engine built-up crank built in two four-cylinder sections. No lubricating holes would be drilled as with the writer's usual practice. Very careful design is needed to give low weight. Cast steel pins and journals and webs would be acceptable to Lloyds. The turning moment from an eight-cylinder engine offers an exceptionally good crankshaft material utilization, as can be seen from Fig. 2B.

Piston.

The design suggested—which in an inferior form has been tried in service—represents in the writer's opinion the simplest in construction and is the lightest design possible. The latter is important at the higher speeds proposed. The lower end is of special cast steel and the upper of special cast iron.

Crosshead Guides.

The double guide on each end of the crosshead as used by Sulzers is much the more suitable construction for crosshead type oil engines. It gives greater accessibility, is lighter and permits a greater number of identical parts.

Piston cooling oil walking rod gear would oscillate from the bottom of each guide in a simple and accessible manner, and the piston rod internal pipe connections can be readily arranged without the usual special bracket.

Air Scavenging and Supercharging.

It is submitted that much higher mean pressures with economy and safety will be possible by separating the functions of scavenging and supercharging. The intention is to scavenge at 1½lb. per sq. in. and to supercharge at 3lb. per sq. in., the air supplied being taken from separate electrically driven turbo blowers. By means of a connection between the two air systems each blower will in emergency be able to serve both sets of ports.

The system proposed is like that evolved by the writer for a double acting engine, i.e., there are separate ports solely for the scavenging operation and the supercharging and air rotational movement. This system appears to have a fundamental advantage. A new design of cam-operated flap valve gives superior air flow to the supercharge ports.

Fuel Pump and Valves.

Experience seems to indicate the need for no less than four fuel nozzles per combustion space in engines of about 24in. bore, each nozzle spraying into and across the air stream. Efficient control of the fuel injection can best be obtained by elimination of the fuel pipe either by a constant pressure system and mechanically operated fuel valve or by a combined fuel pump and automatic injection valve with only a short interconnecting passage.

Low cost, reliability and efficiency can best be obtained by going to a specialist firm. A type of combined pump and atomiser has been developed by a prominent firm in connection with the writer and would be available. It is useless for small and moderate-sized marine firms at this date to manufacture their own injection equipment.

The new engine arrangement, although having four camshafts, is simple, accessible, low in cost and potentially offers the maximum efficiency and power output from a given cylinder.

Position of Machinery; Volume and Shape of Engine Room.

Once an engine is available which is very low in weight relative to the ship which it is to propel, it is possible to place it in the aftermost position and thus not only save the weight and cost of the tunnel shafting, bearings and tunnel, and the friction of the bearings, but above all it enables a much more economic utilization of available ship space for cargo carrying. The present wasteful method of reserving the best central portion of the ship, usually 20 per cent. of the length of ship, for the machinery should be altered once and for all.

The volume of the engine room should not exceed that which, if flooded with an adjacent compartment or hold, will prejudice the buoyancy or trim of the ship, and therefore it should not exceed 6-7 per cent. of the volume of the ship, the customary 13 per cent. being altogether excessive. In view of the large power required, this will necessitate great technical skill.

The shape should be narrow—not exceeding, say, 28ft.—to provide side spaces or tanks of sufficient volume to reduce explosion effects and thus preserve the engine room sides.

The vulnerability of the engines will be reduced as the length of the engine room is reduced, and therefore every practical expedient should be harnessed to this end. Therefore both double-acting two-stroke and vee type large in-line engines only should be considered for direct drives.

A suggested low volume arrangement of engine room using direct drive engines is shown in Plate 2. The basic principle has been to use vertical layers of machinery instead of the usual almost entirely single horizontal layer design.

The controls, switchboard, generators, air starting and blower equipment are all on the middle platform or above, and the main engines have almost no mechanism needing attention below this. The electrically driven service pumps can be controlled from the switchboard.

In the case of the cargo warship a problem of first magnitude was to enable the normal high engine room casing needed for double-acting engines and lifting gear to be dispensed with to keep the landing deck clear. This has been solved by the use of two hinged engine room hatches with attached jib cranes (normally hanging at the after end of engine room). Parts can be conveniently lifted onto the deck or transferred to the overhauling bay on the starboard top platform. The engine room for the vee double actor would be shorter than that in Plate 2 (40ft. would be ample), the headroom would be sufficient to allow the engines to be completely overhauled without opening deck hatches and the width would be the same. The turbo blowers would be mounted on the engine itself, about the centre line at each end of the engine. A single 1,500 b.h.p. vee six single acting two-stroke would serve as auxiliary generator, an engine which would be duplicated in the forward engine room. Single engines are preferred for low cost and ease in synchronising.

Auxiliary Oil Engines.

As greater power is required than can be economically provided by existing types and sizes of auxiliary oil engines there is a strong case for the development of a special auxiliary type—which incidentally can be used for coasters—of the vee two-stroke single-acting trunk piston port scavenging design of identical basic design to that of the main engines. Welded construction is essential and economy will be effected by mounting the engine on a common bedplate and oil sump, which in turn is integral with the engine room middle platform flat.

Each engine will develop 1,500 b.h.p. in six cylinders, 14in. bore by 24in. stroke at 325 r.p.m. and 90lb./sq. in. M.I.P., the overall length and height of each engine will only be about 10ft. and the weight will not exceed 30lb. per b.h.p.

There is much to recommend having the same basis design of engine from a maintenance point of view.

The manufacture of these engines could well be undertaken by the auxiliary engine makers to basic design supplied by the central design and development office.

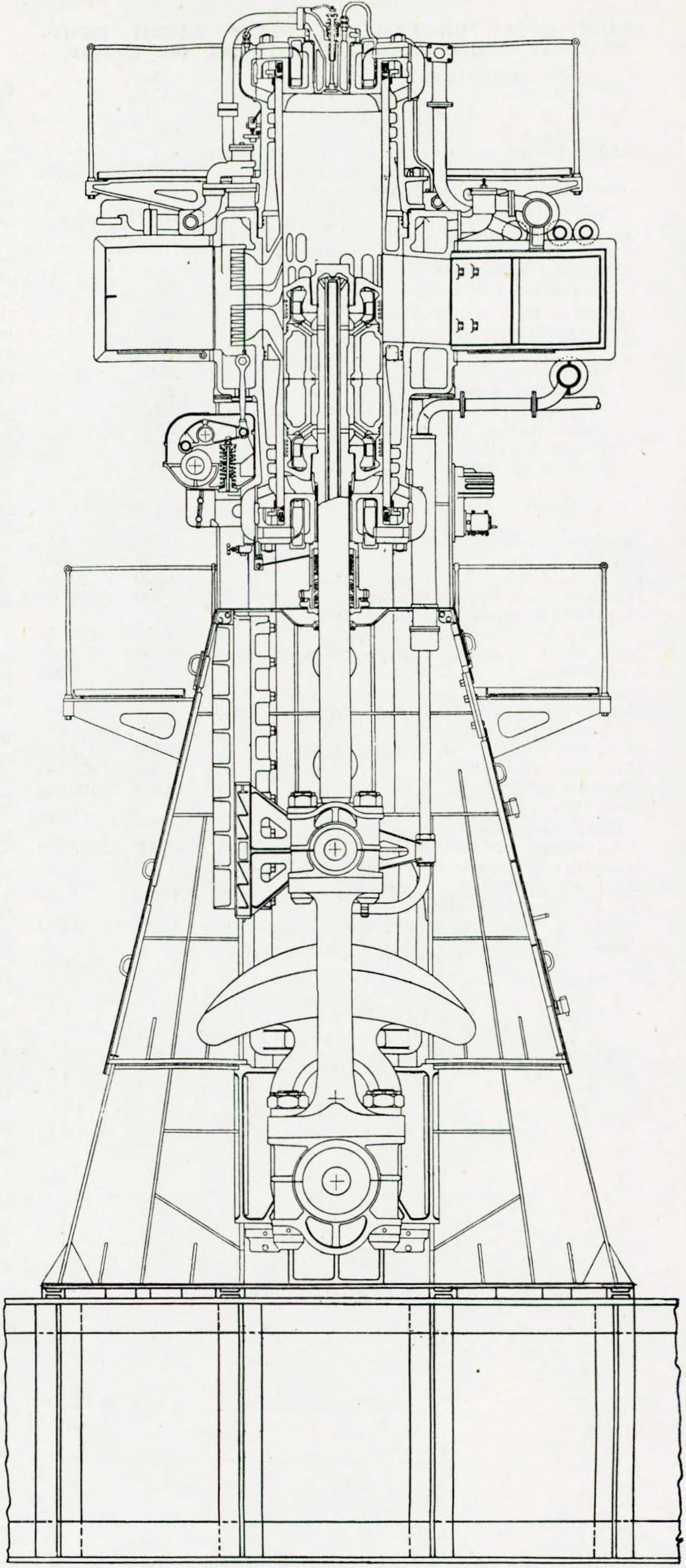


Fig. 3.

Typical modern Double-acting Two-stroke Engine, as designed by the author before the war, with separate bedplate bolted to tank top. In 8 cylinders would weigh 120lb. per B.H.P. and develop 9,600 B.H.P. at 120 r.p.m. and 82lb. per sq. in M.I.P.

As with the main engines, the cylinder entablature would form a main girder, but in this case the columns would be incorporated and the crankshaft hung from the crankcase as in automobile practice.

Cargo Warship Auxiliary Engines.

In normal operation at sea the intention is always to have the auxiliary generators running in the main engine room and also in the forward engine room in case either is put out of action.

In port the forward engine room will invariably be used and the main engine room closed down for maintenance.

The forward propelling motor will only be used when maximum speed is essential or when in danger zones. The forward propelling engines will provide all the heat necessary for the forward oil cargoes and accommodation heating either by hot jacket water or electrically.

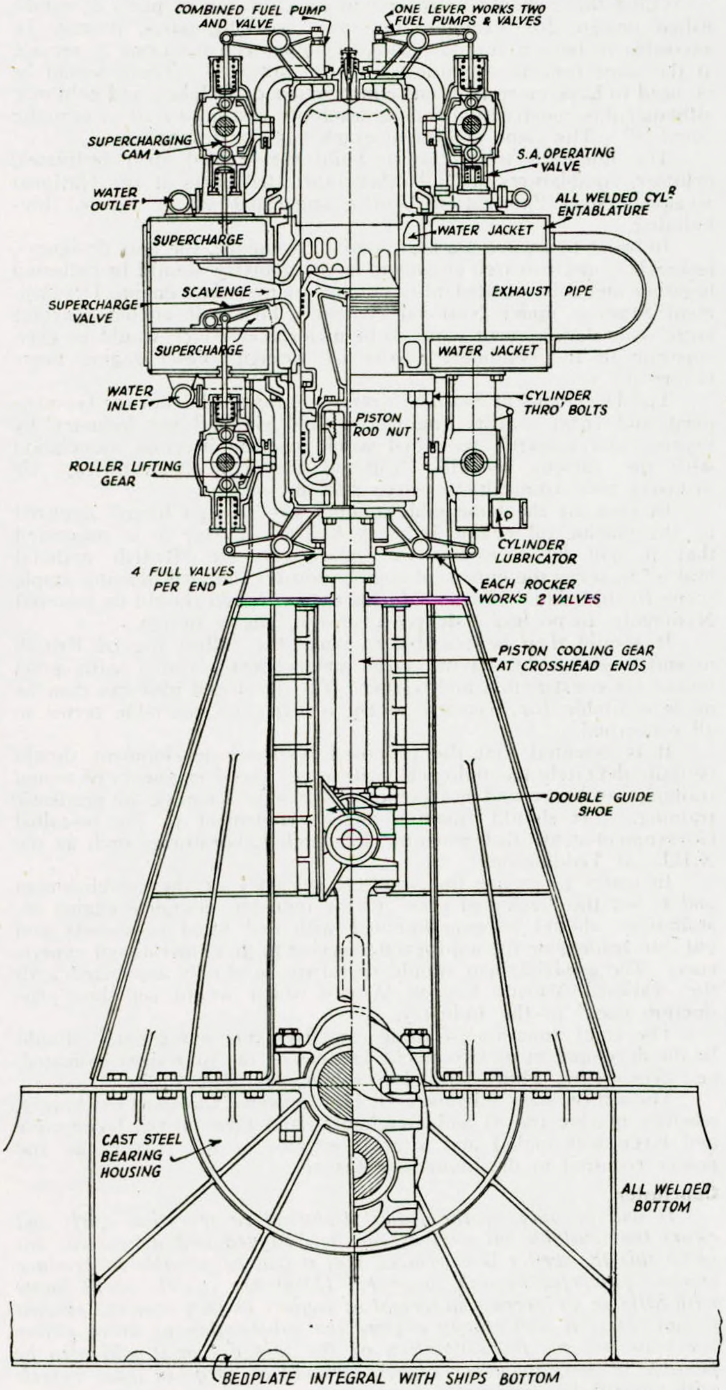


FIG. 4.

Suggested arrangement of High Efficiency Light-weight Direct-drive Double-acting Two-stroke Engine, to the same scale as Fig. 3. 10 cylrs. 24in. dia. × 42in. stroke at 165 r.p.m. and 100lb. per sq. in. M.I.P., developing 12,500 B.H.P. and weighing 62·5lb. per B.H.P. (350 tons total), having the greatest number of similar parts and using welded steel to the greatest extent.

Diesel Electric Drive.

Such an engine could be developed for use with the electric reduction gear for main propelling engines, but the total weight would then be no less than the medium speed double-acting direct drive engines and the total man hours would be considerably greater as no less than three 16-cylinder vee engines would be required or three 8-cylinder double actors. The fuel consumption would also be 8 per cent. poorer at similar propeller speeds. Fig. 5 gives an idea of the relative size of the double actor.

As, however, there is no suitable engine fully developed, it would appear to be more suitable to go to yet higher speeds right into the aircraft engine sphere and to use engine speeds of 1,200-1,500 r.p.m. with a size of engine which can be also used as an aero engine prototype. As the aero engine industry is now by far the largest and most modern industry producing engine power it is believed better to "hang one's hat" onto the technically most progressive industry for a quick return.

Standardised Ships' Service Room.

With the exception of the cargo pumps in oil tankers and refrigerating machinery in meat or fruit ships, the ships' pumping machinery is invariably distributed throughout the main engine room.

It is submitted that economy will be effected by concentrating all the ships' plant such as ballast, bilge, cargo oil, sanitary and fresh water pumps, ships' lighting sets and ship's compressed air pumps into special standard ships' pump or engine rooms so that no matter what type of main propelling machinery is used this equipment is standard. All these pumps, preferably of the silent high speed rotary type, should be electrically driven with a.c. motors, as in industrial practice, the power being provided from standardised auxiliary oil engines arranged above the pump room. The use of a.c. equipment will enable a reduction in man hours of nearly 40 per cent. compared with d.c. equipment and give greater reliability and less maintenance.

The auxiliary engines and pumps for providing the engine services should be separate from the above and arranged adjacent

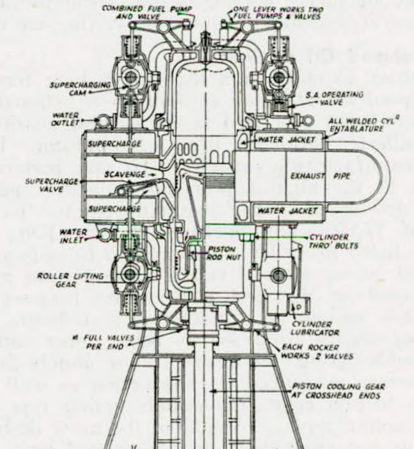


FIG. 5.

Relative size of 14in × 24in. Double-acting Engine of identical design to that of Fig. 4. Three 8-cylinder engines running at 300 r.p.m. would be required if used with gear or electric drive.

to the main engines in the main engine room. On the other hand, two ship's pump rooms should be arranged, one immediately below where control of ship is effected and one aft to deal with the after oil tanks.

One of the advantages of standardisation of electrically driven pumps and gear and the consequent reduction in costs is that the usual practice of elaborate pipe and valve connections to enable one pump to be used for many purposes becomes less necessary, and single-purpose pumps or mechanisms tend to become the order of the day. In other words, pipes and valves tend to become replaced by smaller pumps, wires and switches, which are easier to mass produce, lighter in weight and easier to fit on board. Remote control becomes possible with the more costly electric controls above water and relatively free from explosion effects.

As a war-time vessel is more dependent on bilge, ballast and cargo oil pumps to deal with water leakages or evacuation of liquid cargo to preserve buoyancy, the ship's pump rooms become a much more important part of the ship and should be centrally disposed and away from the ship's sides.

Generally speaking, the electrical and industrial pump industry can be of great use provided the fullest use is made of them, and even though it entails waiving peace-time commercial agreements as between land and marine work demarcations. The present marine pump suppliers could well be allowed to concentrate on purely naval work and the industrial firms co-opted to supply these special cargo warship requirements.

The entire fitting up of the ship's service room should be done by marine engineering firms, who would concentrate on this class of work as well as fitting propelling machinery equipment.

In the future the chief function of many marine engineering firms will be more and more that of erectors of bought-in machinery, pipes and fittings on shipboard rather than makers of the actual engines. This tendency has been noted for many years in connection with the extended use of auxiliary machinery; the use of electric drive will make this even more apparent.

Integral Construction of Machinery and Hull.

One of the advantages of having the bedplate integral with the ship's hull and also the oil sump and jacket water tank is that a large percentage of direct cooling action from the sea water will be obtained, thus appreciably economising in the size of the coolers.

Nationally Developed Oil Engines.

It is submitted in conclusion that for a long term programme new medium speed *direct drive engines* to a national basis design should be designed and produced at the earliest possible moment to make the fullest national use of present large marine engine works manufacturing capacity. To save material this engine should operate at the highest practical propeller speeds allowable for the power and speed of the required vessels. Even if a direct drive engine of 12,500 s.h.p. operates at 165 r.p.m., the propeller losses due to reduced propeller efficiency will be only about half that of the electrical losses with electrical transmission and this speed appears to give about the best compromise between efficiency of operation and low weight and production man hours.

The type of engine proposed as being most suitable for this speed is the double acting two-stroke of the double flow type. For reasons of economy in crankshaft production as well as in general weight and production costs, the double acting type of engine or vee type single acting type is considered the most desirable type for large engines, as the crankshaft and associated parts are simplest. The propeller shaft horse power of 12,500 s.h.p. which is required, can be developed in a ten cylinder double acting engine (requiring only five built-up cranks). A sound alternative is a 12 cylinder single acting vee engine having cylinders 27in. in diameter and 48in. stroke running at 175 r.p.m. and with six cranks.

A single acting engine for auxiliary purposes should be evolved of 14in. bore and 24in. stroke to develop 1,500 b.h.p. in 6 cylinders at 325 r.p.m. as a vee engine.

With regard to detail design such items as the fuel injection system should be of the C.A.V. or other well proved type.

A Diesel electric drive engine should be also developed with cylinders 7½in. × 18in. at 1,500 r.p.m., the control gear and air starting valves being of standard basis design. The scavenge air pumps, two in number, should be of the turbo blower type in all cases.

The cylinder design should be standardised on the result of experiments with variations carried out on two or three basis designs of :—

(1) A double flow port scavenging and exhausting system with mechanically operated scavenge port control valves for the larger single and double acting engine sizes.

(2) Uniflow scavenging with opposed piston for the high duty high speed single acting engine sizes.

The principle of both technique and production should be to control the designs from a central design office and experimental works, but using existing works for detail manufacture of the parts. The detail production should be specialised as far as possible, i.e., definite parts should be allocated to certain works in a region and production would be that required for the entire region of engine builders.

National marine engine production machine shops for producing extra quantities of all detail parts required will need to be erected and equipped to supply additional parts for any particular "bottleneck". Assembly will be effected at the various existing works, whether marine or aero engine according to the type.

Whilst there should be the minimum variation in parts of established design, for example, the main working parts, it may be advisable to have a few alternative cylinder constructions in service at the same time to encourage technical progress. There would be no need to have more than one construction of bedplate and columns although this construction can be developed and improved in periodic "models". The same applies to crankshafts and bearings.

The intention would be to build the welded steel bedplates, cylinder, entablatures and all other fabricated parts at the National Regional Steel Fabrication Works, suggested as an aid to shipbuilding.

In order to ensure the best possible technique, the best designers, technicians and research engineers in the industry should be collected together and concentrated into a number of first-class engine Development Stations under National control. This will enable constant large scale development work to be undertaken which would be even superior to the combined efforts of foreign Diesel engine firms before the war.

The Development Stations would be supported from the Government and from marine engineering and shipbuilding industry by licences and research fees, and would operate in close association with the various scientific National Physical Laboratories, Air Ministry and Admiralty research stations.

In view of the lamentable amount of "foreign brain" required by the marine oil engine industry before the war it is suggested that it will be necessary to replace this by "British national brains" to serve the entire oil engine industry, but still leaving ample scope for individual efforts. Marine engine design should be fostered Nationally, to no less a degree than aero engine design.

It should then be possible to make the fullest use of British inventive genius by having ideas independently tested with good means for construction and testing. The developed idea can then be made available for licensing to the industry on equitable terms to all concerned.

It is essential that the proposed National development should be quite definitely technological, with experienced engineers of sound training in charge and not persons of chiefly scientific or academic training. It should function as a complement to the so-called Government controlled Scientific Research Laboratories such as the N.P.L. at Teddington.

In order to ensure the practical efficiency of the establishment and to set the "technical pace" to the industry, complete engine installations should be experimented with and fitted to vessels and put into trading or the appropriate service to give operational experience. The establishment should therefore be closely associated with the National Marine Engine Works which would set the "production pace" to the Industry.

The chief function of these establishments immediately should be the development of two-stroke engines of the four sizes indicated, i.e., 27in. × 48in., 24in. × 42in., 14in. × 24in., and 7½in. × 18in.

These three sizes will cover all high powered transport machinery, whether marine (naval and merchant), land (generating, locomotive and large war tanks) and aircraft engines of the vast range and power required in the immediate future.

Conclusion.

It will be only by the fullest technical co-operative spirit and effort that suitable oil engines can be designed and developed, but given this the writer is convinced that it will be possible to produce engines powerful enough to propel 12,000 ton vessels at 18 knots with little or no increase in weight of engines or fuel over the present Ocean class; it will chiefly require the substitution of brain power for man power. By adaptation of the ship design it will also be possible to carry an unprecedented amount of cargo in these vessels with comparative immunity from enemy action.

DISCUSSION.

Contributions by correspondence, not exceeding 1,000 words in length, are invited to the discussion on this paper. Such contributions will be published, with the author's reply, in a subsequent issue of the TRANSACTIONS.