DIESEL ENGINES FOR SURFACE WARSHIP PROPULSION

BY

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Introduction

During the past decade there has been an increasing trend in the use of propulsion diesel engines in frigate size warships, particularly those constructed by the French, Italian and German navies. This trend may be influenced by political pressures to use indigenous diesel engines rather than British or American marine gas turbines but is mainly dominated by the advantages of improved fuel consumption and reduced intake and exhaust duct sizes. In the knowledge of such trends, the need for diesel alternatives to the all gas turbine configurations currently used in R.N. warships merits consideration. Although diesel propulsion can be considered across the whole spectrum of R.N. ships, this short article has been limited to those ships most likely to be required in relatively large numbers, namely:

(*a*) medium speed patrol craft of up to 1500 tons displacement;
(*b*) corvettes/light frigates of up to 2500 tons displacement;
(*c*) heavy frigates of up to 5000 tons displacement.

Ship Performance v. Basic Engine Type

To examine the suitability of engine types for specific ship applications it is necessary to define basic performance criteria. For the purposes of this article the following have been assumed for the three sample ship types:

(*a*) Medium speed patrol craft—maximum speed 25 knots
(*b*) Corvette/light frigates —maximum speed 30 knots
—cruise speed 20 knots
(*c*) Heavy frigates —maximum speed 30 knots
—cruise speed 20 knots.

As demonstrated by the European navies already using propulsion diesel engines in frigates, and through the recent construction of the Royal Navy's Hong Kong Patrol Craft, ships of this type require relatively compact lightweight engines due to constraints of space, stability, noise and shock. From the engines currently being used and those projected for future use, the most suitable types of propulsion diesel engine for new R.N. requirements can be characterized as follows:

(*a*) Maximum continuous power output greater than 3 MW.
(*b*) Maximum speed 1000 r.p.m. or above.
(*c*) Weight/power ratio less than 7 kg/kW.
(*d*) Volume/power ratio less than 7 m^3/MW.

Propulsion System Configurations

When using diesel engines for ship propulsion purposes the required operating characteristics can be affected by the overall transmission system design and configuration. For the purposes of general discussion it is therefore necessary to define a typical propulsion system configuration so that the desired engine operating envelope can be established. The aspects discussed below collectively define the propulsion system configuration used in this article:

(*a*) *Propeller Type*
The R.N. has utilized controllable pitch (CP) propellers in conjunction with the COGOG systems in current frigates, but for various reasons fixed pitch (FP) propellers are expected to be the future trend. When considering diesel engine operating envelopes FP propellers offer the most arduous requirements to meet and are taken here as the standard.

(*b*) *Gearbox*
Diesel engines of the type characterized above are normally unidirectional, and consequently the gearbox standard is taken to be of the reverse reduction type.

(*c*) *Shaft and Engine Combinations*
To simplify discussion it is assumed that future R.N. vessels will be fitted with two propeller shafts. Each shaft could be driven by two diesel engines or by one diesel engine either on its own or in combination with a gas turbine.

(*d*) *Engine Operating Characteristic Improvers*
It is possible to reduce the demands on engine operating characteristics by changing the normally fixed relationship between engine r.p.m. and shaft speed. This can be achieved by utilizing either CP propellers or other devices like slipping fluid couplings and two-speed gearboxes. FP propellers are assumed here and the other devices are ignored.

Engine Operating Characteristics

Engine operating characteristics are normally depicted as an envelope of power plotted against speed, within which the engine can be operated without exceeding thermal or mechanical limitations. The shape of the operating envelope can be changed to some degree to match particular requirements and it is therefore necessary for the end user to define the envelope shape for the applications in mind.

To construct an engine operating envelope suitable for general ship propulsion applications a number of aspects must first be defined:

(*a*) *Propulsion System Configuration*
As already discussed and defined.

(*b*) *Operating Configurations of Engines and Shafts*
In the case of twin shaft installations with one or two engines per shaft, it is expected that the following operating alternatives will apply:

- (*i*) With all engines in use.
- (*ii*) With one shaft trailing (in the case of single engine per shaft).
- (*iii*) With one engine in use per shaft (in the case of a two engines per shaft arrangement).

(*c*) *Engine Speed Turn-down Ratio*
This ratio is defined as the engine speed at maximum continuous power divided by the minimum engine speed at which power can be transmitted to the shaft line. It should be as large as possible in the interest of steady ship speed flexibility. However, for the engine type characterized above, engine speed turn-down ratios of more than 3 to 1 are exceptional and so this is taken as the minimum standard to be achieved.

(*d*) *Maximum Power*
Many engine manufacturers define maximum power as either intermittent or continuous. The former, which can be considerably higher than the latter, is restricted in terms of usage, normally in the form of 1 hour for every 12 operating hours or as a percentage of annual usage. For the purpose of engine operating envelope definition, maximum continuous power is used.

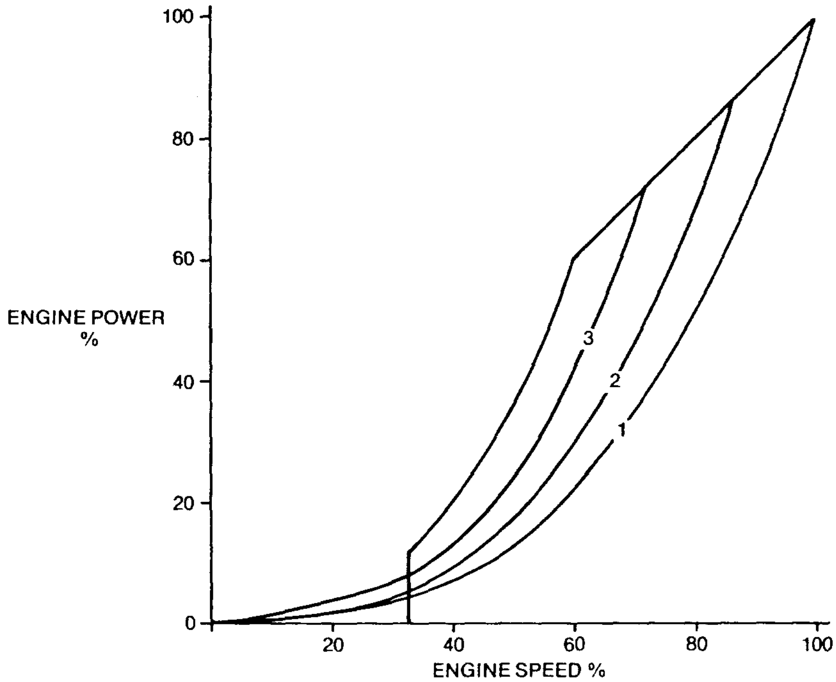

FIG. 1—PROPULSION ENGINE OPERATING ENVELOPE
1: NORMAL OPERATION
2: ONE SHAFT TRAILING (WITH SINGLE ENGINE PER SHAFT)
3: ONE ENGINE (OF TWO) DRIVING PER SHAFT

Taking these constraints into account the operating envelope required for future R.N. propulsion diesel engines is defined in FIG. 1. Engines with this envelope can be operated continuously at full power, and be capable of developing 70% full power and speed when operating singly in a two engine per shaft configuration, and 88% full power and speed when operating singly in a one engine per shaft configuration with one shaft trailing. The envelope provides good margins of excess power for dynamic manoeuvres when operated in the normal two-shaft configuration and provides adequate margins in the single engine modes.

To achieve the required envelope's minumum continuous power requirement of 5% of the maximum continuous power, the engine build standard will be different to the normal one optimized to achieve the highest possible power output. It can therefore be expected that

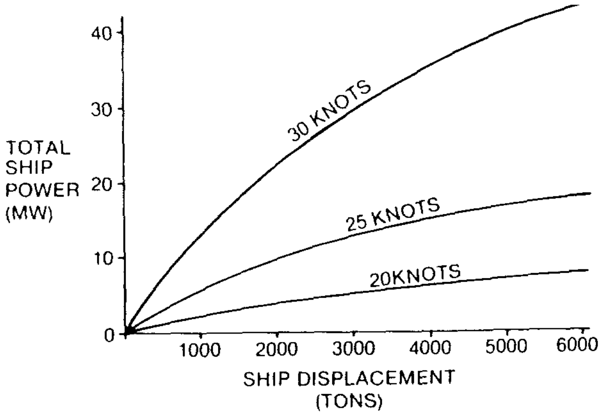

FIG. 2—POWER/DISPLACEMENT RELATIONSHIP FOR VARIOUS SHIP SPEEDS

engines optimized against the requirements of FIG. 1 will have a lower maximum continuous power than those produced against normal commercial requirements.

Maximum Required Ship Power

From the constant speed lines plotted against total ship power and displacement in FIG. 2, the individual engine power requirements for the two most likely propulsion plant configurations can be estimated:

(*a*) *Two shafts with two diesel engines per shaft*
In this case total ship propulsive power is provided by four diesel engines only. TABLE I below has been derived from FIG. 2 and shows the individual engine maximum continuous power required to achieve the desired maximum ship speeds for the three sample cases.

TABLE I—*Engine Powers for Different Ships*
(*two diesel engines per shaft*)

Ship Type	*Maximum Speed Required (rpm)*	*Total Ship Propulsive Power* (Shaft MW)	*Approx. Power per Engine* (Brake MW)
1500 T Patrol Craft	25 K	8·5	2·1
2500 T Light Frigate	30 K	26	6·9
5000 T Heavy Frigate	30 K	40	10·5

(*b*) *Two shafts with one diesel engine per shaft*
In this case two diesel engines provide the total propulsive power for patrol craft, but for frigates the two diesel engines are fitted for cruise purposes only. TABLE II below shows the individual maximum continuous engine powers necessary to meet these requirements.

TABLE II—*Engine Powers for Different Ships*
(*one diesel engine per shaft*)

Ship Type	*Maximum Speed Required (rpm)*	*Total Ship Propulsive Power* (Shaft MW)	*Approx. Power per Engine* (Brake MW)
1500 T Patrol Craft	25 K	8·0	4·2
2500 T Light Frigate	20 K	4·5	2·4
5000 T Heavy Frigate	20 K	7·0	3·7

From these tables it can be seen that the individual engine power requirements range from approximately 2·1 to 10·5 BMW depending upon application and ship displacement.

Engines Available

A comprehensive study of European diesel engines meeting the characteristics defined here and capable of complying closely with the power/speed envelope of FIG. 1 has shown that there are two distinct product groups:

(*a*) *Single Stage Turbo-charged Engines*
The engines in this group are basically conventional commercial designs aimed primarily at the rail traction market. They have high compression ratios to ensure good starting, and can be readily converted to marine configuration by the addition of appropriate ancillary equipments. Maximum power output, beyond that normally required for rail traction, can be achieved by increasing the number of cylinders up to about twenty. British and other European engines are available with power outputs up to about 4·5 to 5·0 BMW.

(*b*) *Two-Stage Turbo-charged Engines*
To increase the maximum power output of conventional engines and at the same time producing the correct operating profile for marine propulsion, some European engine manufacturers have developed special naval versions of their engines. Engines in this product group are characterized by:

- (*i*) Two-stage (series) turbo-charging.
- (*ii*) Low compression ratios.
- (*iii*) Provision of special starting arrangements in view of (*ii*).
- (*iv*) Other complexities to ensure satisfactory operation, e.g. turbo-charger air bypass systems, sequential turbo-charger operation and, in some cases, the use of auxiliary combustors.

The power outputs of these types of engines range from 6 to 8 BMW depending on bore size and number of cylinders.

Requirements for R.N. Future Warships

When assessing the relatively short-term future requirements for warship propulsion diesel engines, consideration must be given to the availability of British marine gas turbines. In this context there is sufficient flexibility to construct a range of propulsion systems using either type of engine or a combination of both.

Using the engine power requirements in TABLES I and II above, it is very evident that:

(*a*) Patrol craft applications can be met using conventional single stage turbo-charged diesel engines.

(*b*) Frigate cruise applications can also be met using conventional diesel engines.

(*c*) Light Frigate total propulsive power could be met using special two-stage turbo-charged diesels in CODAD or CODOG/CODAG arrangements.

(*d*) Heavy frigate total propulsive power is most likely to be met using COGOG, COGAG or CODAG arrangements.

The Way Ahead

Taking all aspects into consideration it seems almost certain that any future patrol craft will continue to use all diesel propulsion systems, and that cruise diesels will become the preferred solution for R.N. frigates in line with the trends already set by other European navies. In support of these considerations, action is in hand to identify a range of conventional diesel engines with the correct physical characteristics and an operating envelope at least sufficiently flexible for use in propulsion and cruise applications with one shaft trailing and with maximum power outputs spanning the 3 to 5 MW range.

The development of special foreign, higher power navalized diesel engines will continue to be monitored for the time being in order that these products can be properly assessed during feasibility studies for new ships.