The evolution of propulsion systems in French-designed frigates *by D Jacquinot**

During the past decade the CODAD propulsion concept has been developed and refined to address all of the requirements of French-designed frigates.

At the time of writing, propulsion equipment of the frigate 'La Fayette' is leaving ACB workshops in Nantes. *La Fayette* is the leadship of the latest class of frigates being built by France. She is due for sea trials in April 1993.

The propulsion system is of the CODAD configuration and it is noticeable that the last four types of frigate classes built by France all use this type of power plant. The classes concerned are:

- F.2000 ('Madina') 4 units built 1985 2750t multi-purpose frigate,
- FAA ('Cassard') 2 units built 1988 4200t anti-aircraft destroyer
- FS ('Floréal') 6 units ordered 1991 2600t patrol frigate
- FL ('La Fayette') 6 units scheduled 1994 3300t multi-purpose frigate

As far as propulsion systems are concerned the FS series may be discounted since they are largely built to commercial standards and may be compared to large OPVs, such as Norway's *Nordkapp*. Her propulsion system is not singular in any way, and, therefore, it will not be considered further in this paper.

Whereas the FAA class includes the implementation of a CODAD plant in the hull of a F70-ASW destroyer, designed in the '70s with a CODOG system, her propulsion system is basically an upwards extension of the plant produced for the F.2000 vessel. The two plants were designed within a very short timescale (approx 18 months) and no major innovation of the mechanical system applies to the FAA compared to the F.2000, except a 10% upgrading of the main diesel engine ratings. Major innovations were in the field of the propulsion control and monitoring system.

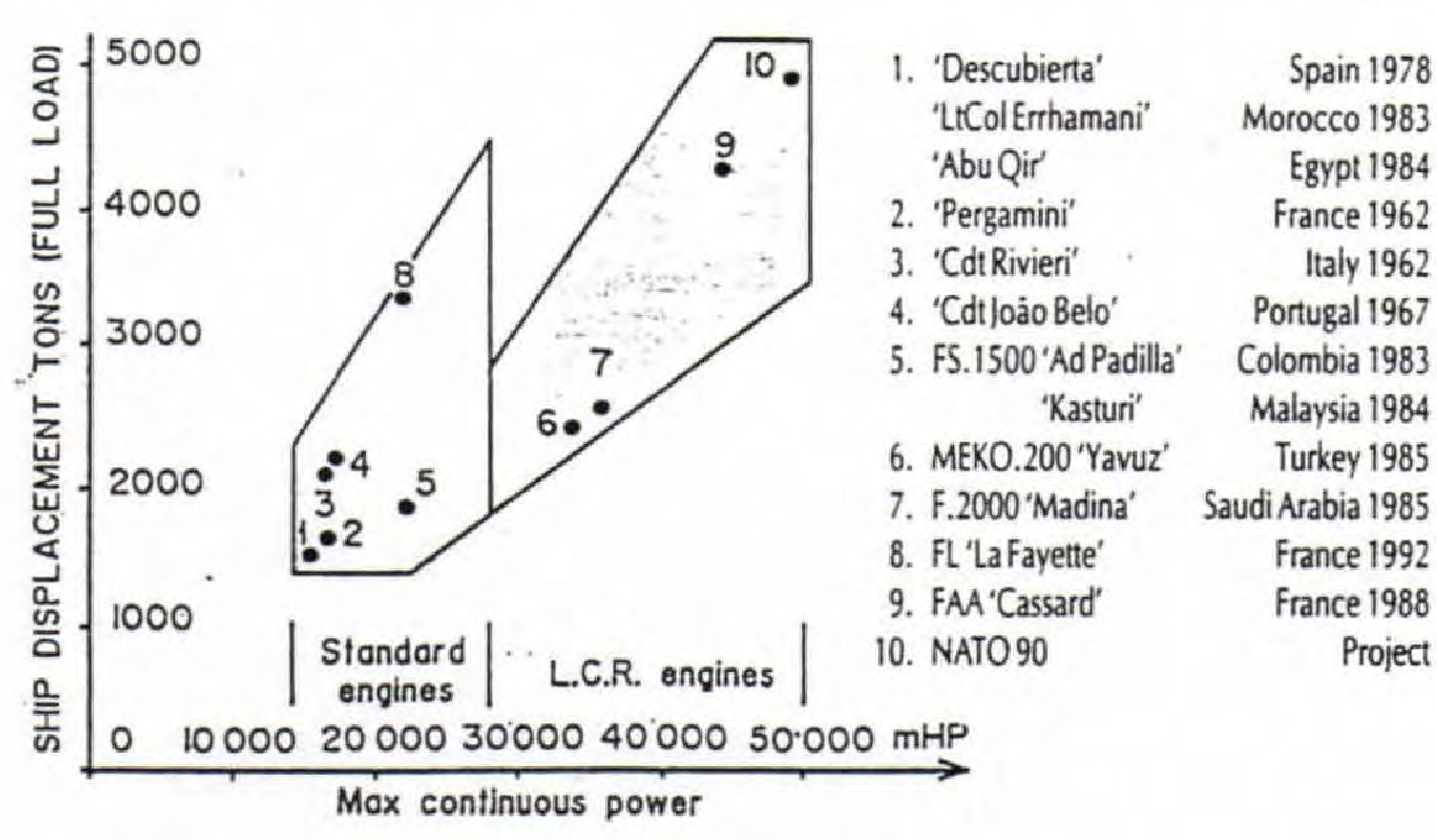


Fig1, examples of naval vessels with CODAD propulsion systems

In 1981, ACB was assigned the prime contractor for the design, production, erection and commissioning of the complete propulsion plant for first of class of the F.2000's. Today, ACB is contracted for the overall design and project management of the propulsion system and the production of gearboxes, shafting and propellers, control system and some auxiliary machinery modules for the 'La Fayette'-class.

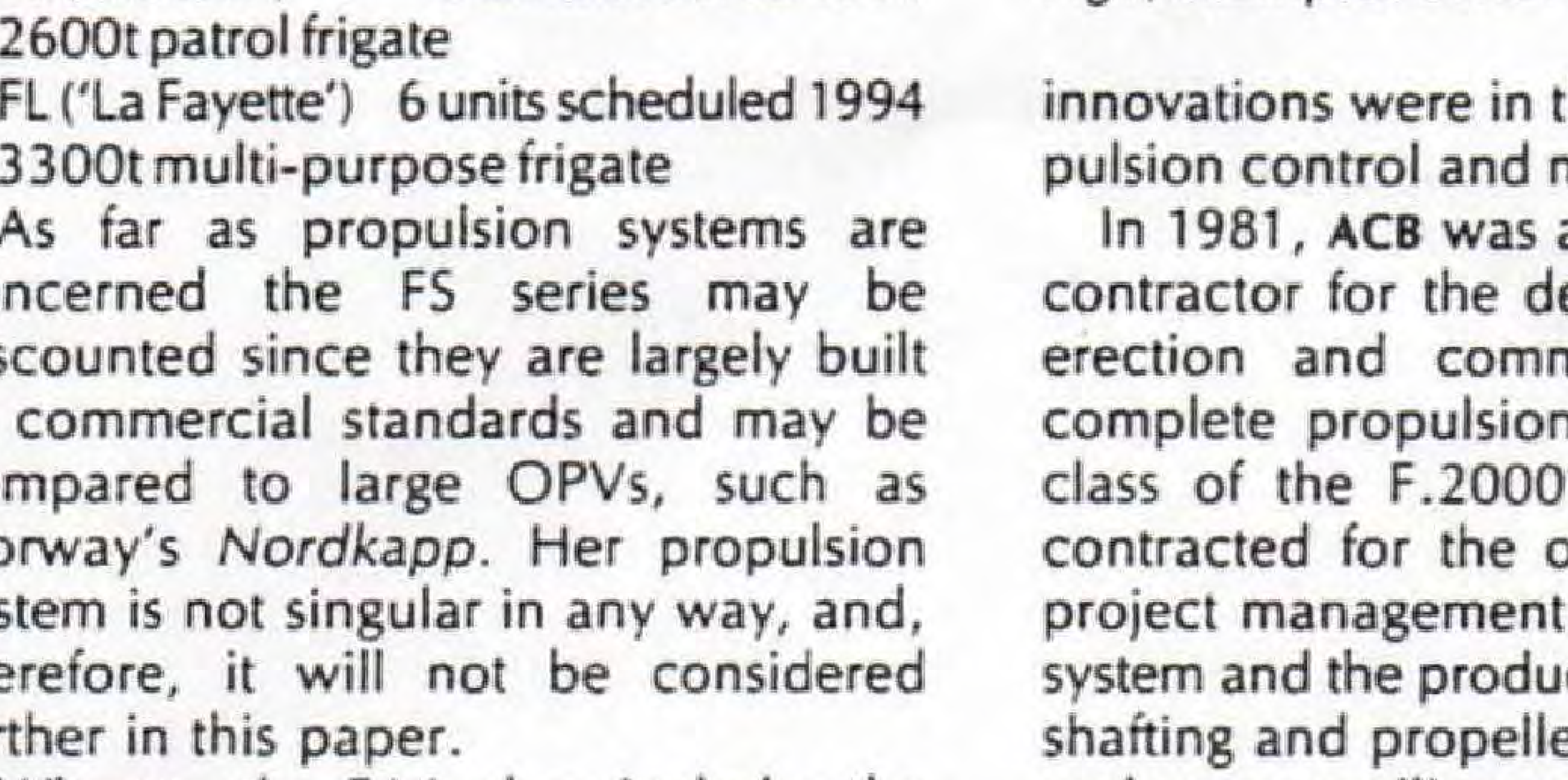
It is now opportune to assess the evolution and trends of the French-designed CODAD models, by means of a comparative review of the power plants from the F.2000 to the actual *La Fayette*.

Propulsion concept

As regards the propulsion systems design, the following conceptual requirements were of major importance:

a) complete independance and redundancy of the two propulsion plants,
b) location of the enginerooms and the auxiliary machinery spaces to provide the maximum degree of survivability consistent with the overall space constraints of the ship,
c) wide range of sustained ship speeds — from about 8kts to maximum speed without limitation,
d) capability for long periods of loitering mode around 6kts,
e) underwater noise objectives equivalent to or better than the '70s generation ASW destroyer performances,
f) shock resistance to NATO standards,
g) powering capability within a wide range of climatic conditions (−15 to +40°C air inlet temperature).

Though the required installed powers were quite different for the three classes *ie*: F.2000: 35 000m.hp, FAA: 43 000m.hp, FL: 21 000m.hp, the same CODAD propulsion model and a similar propulsion arrangement were retained.



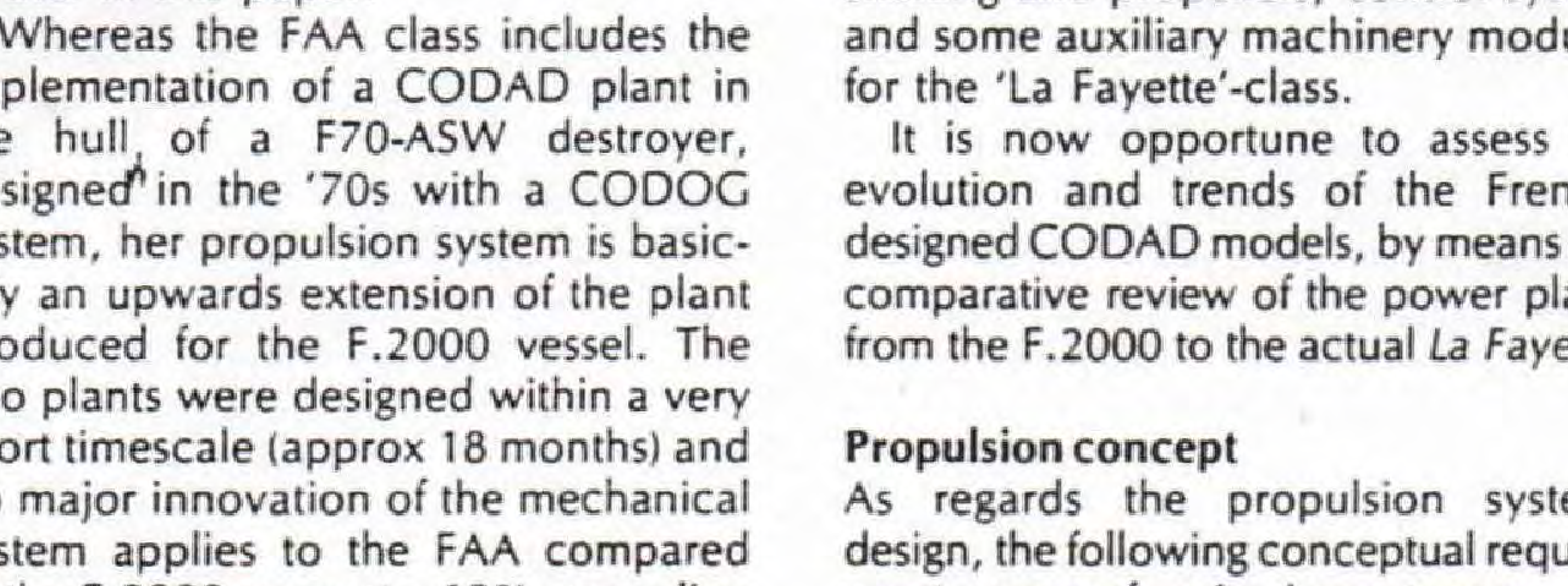


Fig2, an example of a distributed arrangement (FS.1500), left, and a concentrated arrangement (FAA), below

CODAD propulsion plants have been in worldwide naval service for up to 30 years, mainly for large patrol vessels and frigates. They are also popular on merchant vessels, using medium-speed diesel engines.

In the case of frigates (see fig1) the concept has been used since the beginning of the '60s (initiated by the French Navy in the 'Cdt Rivière'-class), disregarded in the '70s due to the emergence of gas turbines but regaining popularity in the '80s with the availability of high-speed diesel engines both in standard and LCR (Low Compression Ratio) versions featuring an acceptable power to weight ratio for such vessels.

Two types of engineroom layout may be considered: the so-called 'distributed' and 'concentrated' arrangements (see fig2).

For the paramount objective of survivability, the concentrated arrangement is

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preferred, though a volume penalty is incurred, mainly in terms of the overall length of the machinery block which is increased by the length of one gearbox. Using the concentrated arrangement, the propulsion plant compartments for each shaft may be separated.

Two diesel engines are installed side-by-side in each engineroom. To avoid reversing the location of one propulsion unit, with respect to the gear, the two engines rotate clockwise while the other two rotate in an anti-clockwise direction.

In the F.2000 class, the space constraints were such that the two propulsion rooms are adjacent. On both the FAA and FL, it was possible to separate the two main enginerooms by one auxiliary machinery space. To further increase the survivability, the impact resistance may be improved by doubling one of the bulkheads, thereby providing three bulkheads between each plant.

It is noticeable that the applied philosophy is identical to that employed for the power plant layout of the US Navy's DD.963-class, a ship of approx double the size of the 'La Fayette' series.

The ship cruise operating mode is with two engines operating, one powering each shaft from each engineroom. According to the projected operating profile, such mode will run for 85% of the sea time with the following consequential advantages:

- during all this time, the ship is operated with a 100% redundant power availability,
- each engine is run for only 57.5% of the ship operating time; with the selected engine type, the engine major overhaul is not expected before every ten years of ship life.

Components
Diesel engines

Selected prime movers are from SEMT Pielstick PA6 range, medium-speed type (1050rpm designed running speed).

The PA6 engine series is known world-wide since its introduction 15 years ago as the cruise engine of the French ASW destroyers.

The F.2000 and FAA feature the introduction of the LCR version of the same model on combatant vessels.

Since a power capability of some 20 000m.hp in tropical conditions is sufficient for the FL ship, the use of standard engines is possible. The innovative feature stands in the adoption of the sequential turbocharging (STC) device.*

The concept consists in supercharging the engine with only one turbocharger for loads up to 60% of the rated power, the other one being activated only for higher power demands.

The physical impact is a re-arrangement of the two turbochargers side-by-side over the output shaft and the fitment of air and gas flaps on the relevant intermediate ductings.

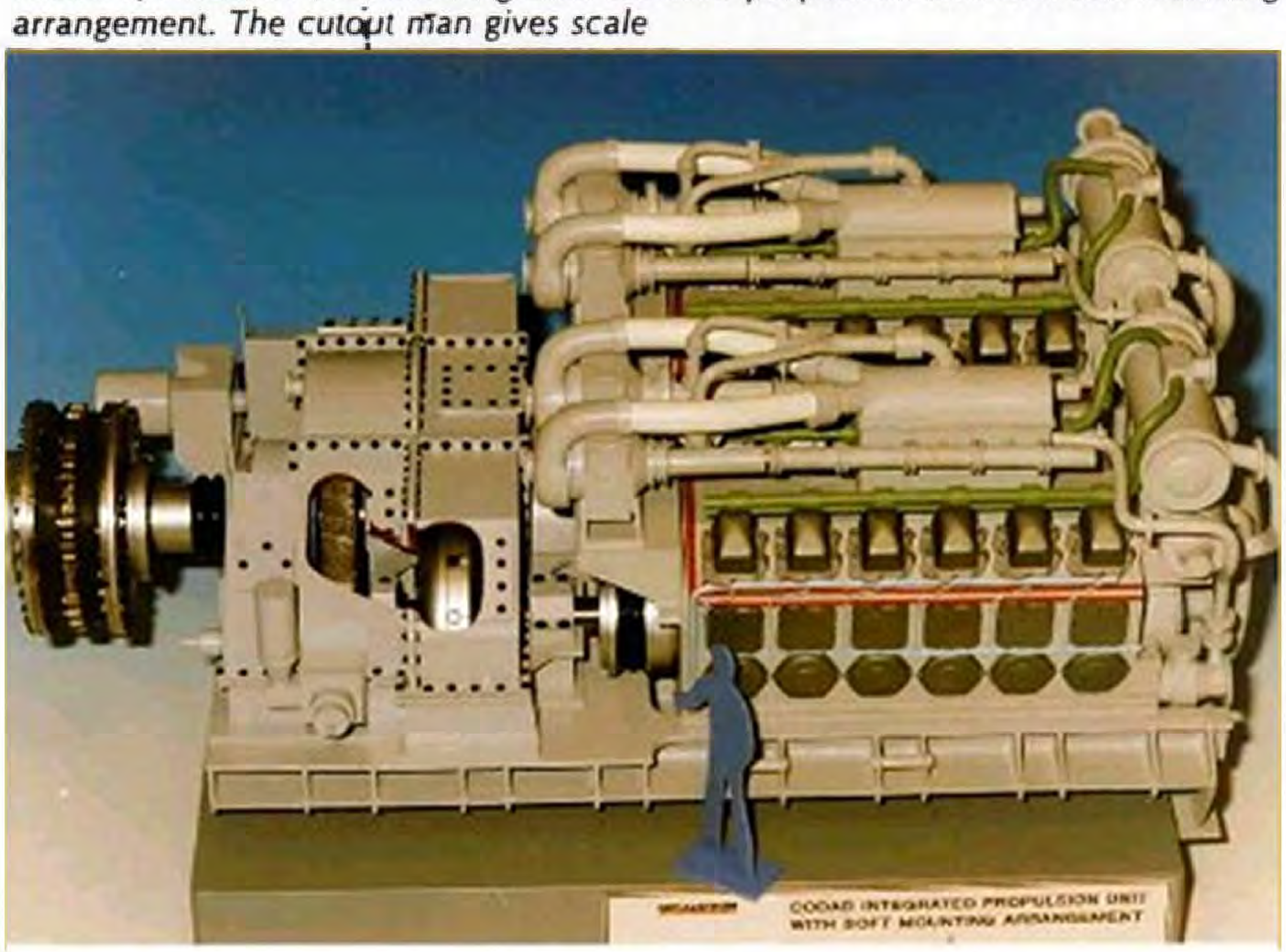
The effects of such a device are the following:

- increased power rating (10%),
- slight weight penalty (less than 5%),
- considerable reduction of fuel consumption at low loads (approx 10% at 25% mcr),
- improved reserve torque capability at low speed (increased by 140% at half speed),
- reduced smoke emission at low load,
- resistance to fouling phenomena.

All above performances demonstrate the advantages of the STC system for naval applications, for which continuous runnings at loads below 30% of rated power are currently operational.

*See MARITIME DEFENCE, December 1990, pp416-417.

Photo 1, model of the ACB integrated CODAD propulsion unit with soft mounting arrangement. The cutout man gives scale



Power transmission

In principle, the transmission by way of a twin input/single output gearbox appears to be quite simple since a single speed stepdown and a balanced power sharing of the two inputs are all that is necessary. However, the silent operation requirement has also to be fully considered in respect of the propulsion train.

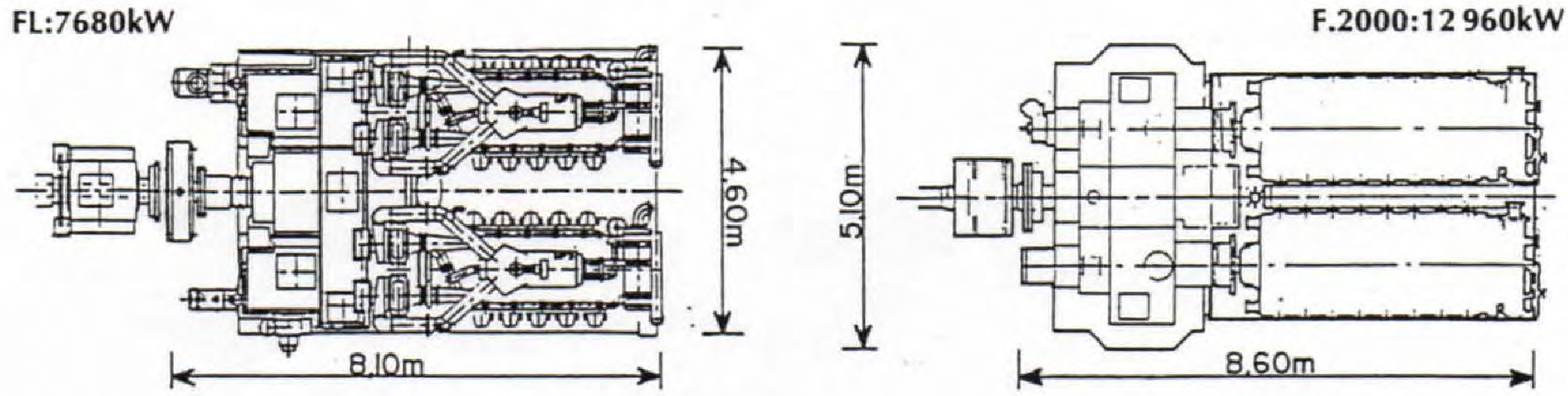
It was experimented and experienced that an efficient soft single-mounting of the considered diesel engine operating at low rotational speed (this is achieved in the silent mode of such a CODAD model) fulfilled the requirement. A further improvement of the performances would not be achieved (by a double mounting for example) unless transmission train vibrations are also efficiently attenuated. In this respect, 'hard elastic' mounting of the gearbox may be considered but such a method will not be efficient in the low-frequency range and may even be detrimental to the overall noise performances if a special intermediate structure of dedicated mass and stiffness is not integrated within the gearbox foundation arrangement (refer to the DDG.963 arrangement for example). In consideration of the above limitation and risk areas, the retained solution for the French vessels was to arrange an integrated propulsion unit, composed of the two diesel engines and of the combining gearbox, on a common sub-base, itself soft-mounted on the ship structure (photo1).

A consequent advantage is that such an integrated unit, being soft-mounted, is subject to a reduced shock load factor. In this manner, the problem of producing a sophisticated and reinforced gearbox in order to fulfill both requirements of low source noise and high impact resistance is eliminated.

However, difficulties remain:

- on one hand, in the design of an efficient sub-base in respect of vibration transmission, structural integrity for gearbox and engine mounting and inherent shock impact resistance,
- on the other, in the design of an efficient output shaft coupling in respect of the same criteria and at the same time capable of the misalignments due to the displacements of the propulsion unit under ship motions and shock loads.

The design of such integrated CODAD propulsion units was first produced by ACB for the F.2000 and naturally extended to the FAA and FL vessels. It may be



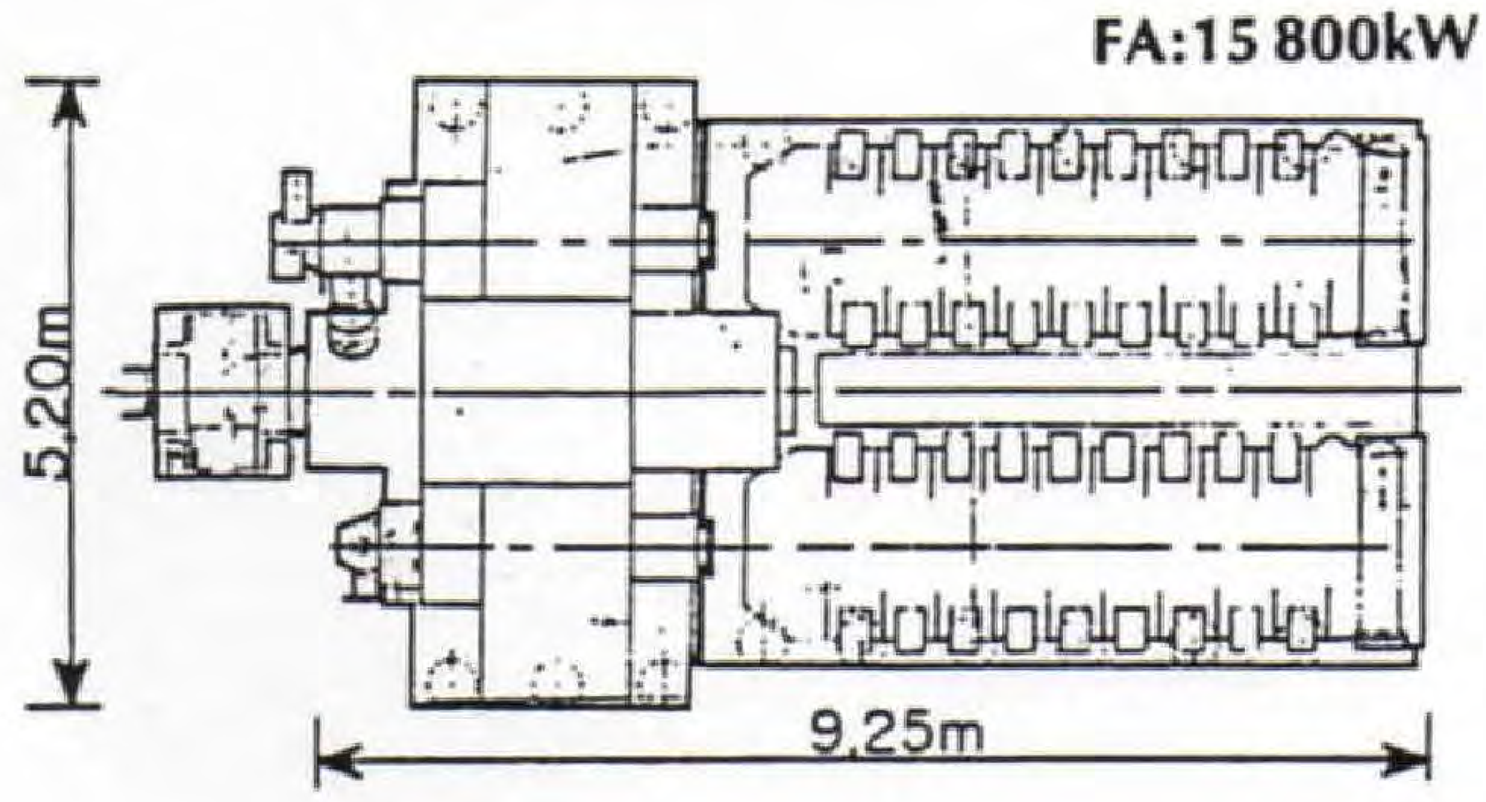


Fig3, a comparison of powers and sizes of three machinery units

of interest to compare the evolution of the design over the period of nine years between the respective deliveries of equipments for the F.2000 and the FL classes (see fig3).

On the F.2000, the sub-base is independently produced for the support of the two engines and then connected to a reinforced lower casing of the gearbox by means of a vertical flange (see fig4). The output coupling is made by way of a cardan shaft, made of two toothed couplings, and arranged as a quill shaft through a bull-gear in order to save the necessary length for the required angular misalignment.

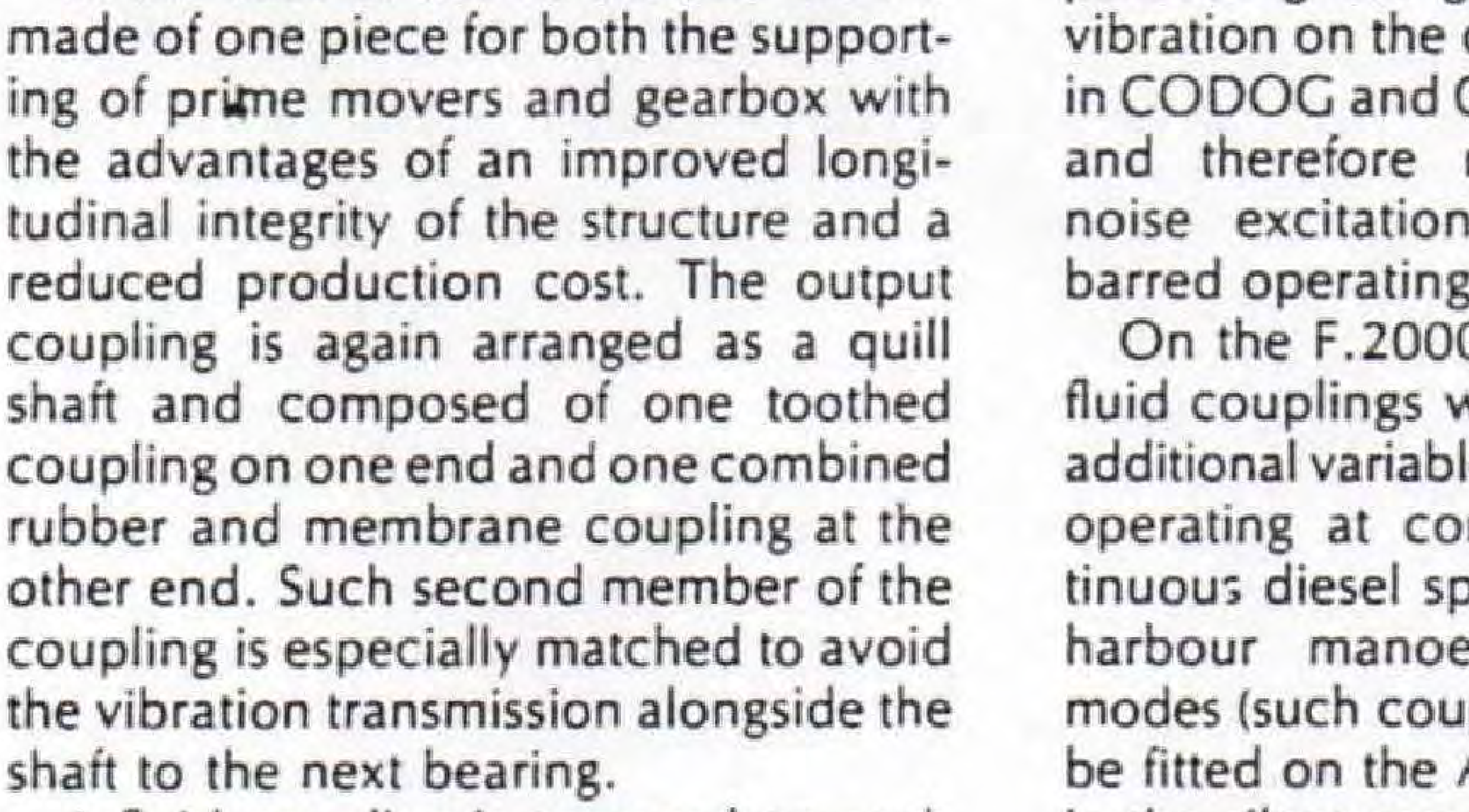
In the case of the FL the sub-base is made of one piece for both the supporting of prime movers and gearbox with the advantages of an improved longitudinal integrity of the structure and a reduced production cost. The output coupling is again arranged as a quill shaft and composed of one toothed coupling on one end and one combined rubber and membrane coupling at the other end. Such second member of the coupling is especially matched to avoid the vibration transmission alongside the shaft to the next bearing.

A fluid coupling is arranged on each engine input. These couplings are used as a clutching and declutching device, torsional vibration isolation before the gear meshing and flexibility element into the connection of the two engines when running in parallel (this enables an easy and efficient load sharing ability).

ACB has produced more than 500 units of such fluid couplings for marine applications. In naval applications, they were found to be highly efficient in protecting the gearbox from torsional vibration on the diesel input drive (both in CODOG and CODAD arrangements) and therefore reducing the gearing noise excitations and avoiding any barred operating range.

On the F.2000 and FAA types these fluid couplings were equipped with an additional variable-speed control device, operating at constant minimum continuous diesel speed, and used for the harbour manoeuvring and loitering modes (such coupling from ACB will also be fitted on the ANZAC frigates for use in the silent operating mode).

On the FL series such a device is not fitted since manoeuvring and loitering are achieved using the controllable-pitch propeller, while silent operation was not required on these modes.



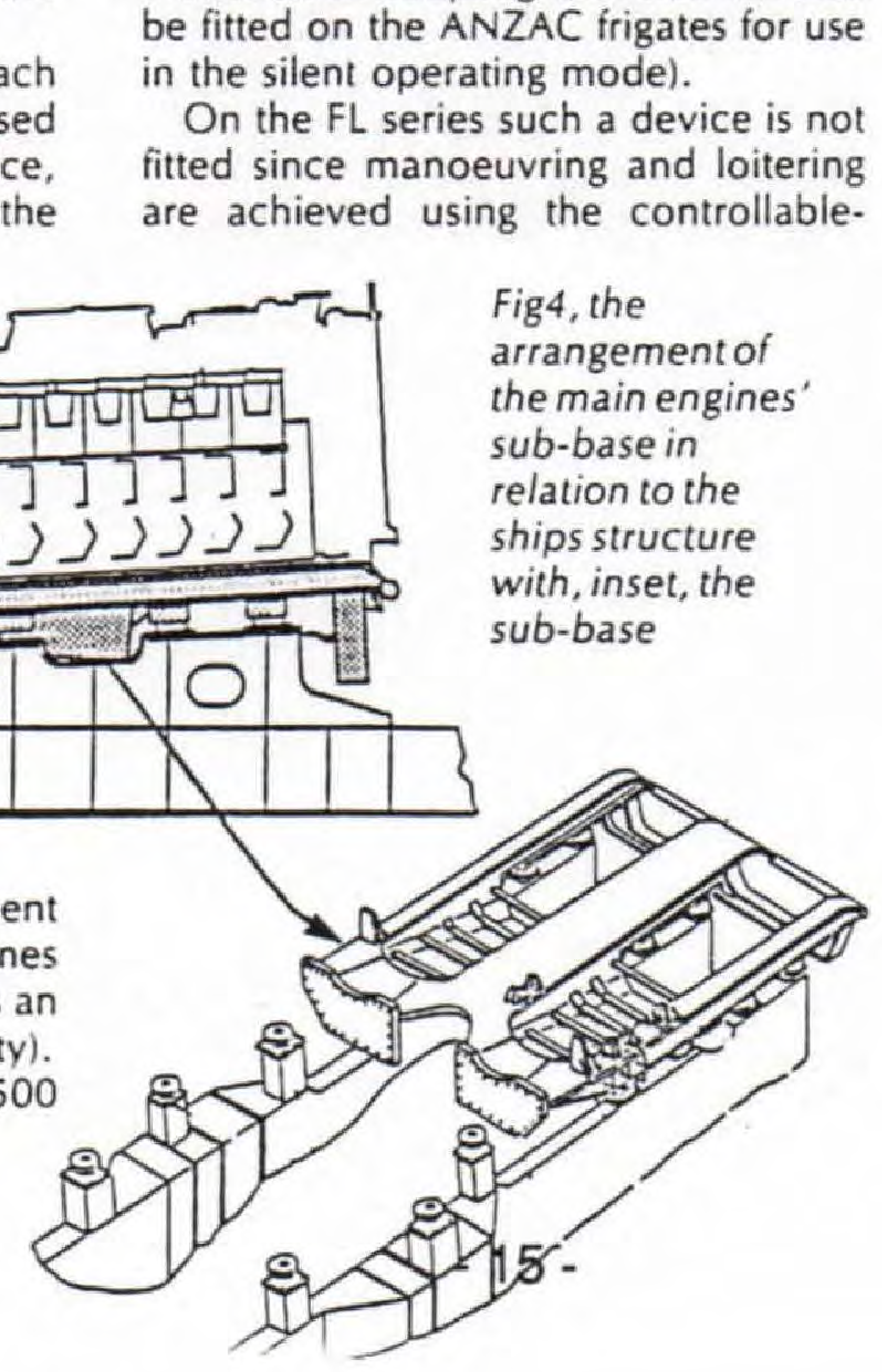


Fig4, the arrangement of the main engines' sub-base in relation to the ships structure with, inset, the sub-base

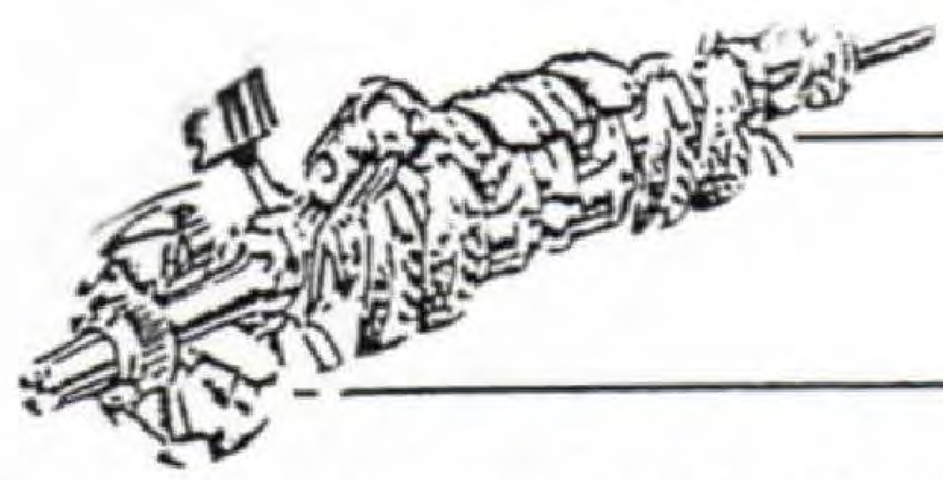
Separately-mounted thrust blocks are arranged immediately abaft the propulsion units. For the three classes (F.2000, FAA, FL) the blocks are of a similar design, using the tilting-pads concept and forced oil feeding from the main gear lube-oil system.

Due to the oil flow and thermal dissipation requirements for the fluid couplings and to the sizing of the gear attached pump to provide the required flow rate at minimum engine rpm, the lube-oil system is of significant volume. In respect of the modular construction concept applied for the FL types, this lube-oil system is arranged as a self-contained module, also elastically-mounted for noise and shock attenuation.

It is anticipated (for the FL ship) that all the provisions taken at the design stage (modular concept of the propulsion units and lube-oil system) and at the workshop production stage (pre-drilling of the engine mounting for example) may save up to 5000 man-hours during on-board erection of the propulsion plant.

Propellers

On the F.2000 and FAA classes where manoeuvring performances were not a highly-weighed factor, fp propellers are used. Astern operation is achieved by way of the optional reversing facility of the selected engines. In the harbour manoeuvring mode, one engine is set ahead and the other set astern for each plant and manoeuvring is achieved by filling/emptying the respective fluid



coupling. The loitering mode is achieved using the variable-speed control of the fluid coupling. Minimum continuous ship speed of 4kts is achieved.

On the FLs, where the patrol role calls for increased manoeuvring capabilities, crp propellers were selected as they were also for the patrol frigates (FS).

Emphasis was put on constructional and design arrangements with a view to improving the cavitation and noise performances. When comparing the FL to the F.2000, the following measures were taken:

- reduction of the tip speed by 20%,
- reduction of the power load factor by 34%,
- increase of the tip hull clearance by 25%,
- change of the blade number from four to five,
- increase of the blade skew from 20 to 33°.

In addition, numerical models were developed for provision of cavitation and performance characteristics under unsteady conditions. It is now possible to assess those characteristics in non-parallel flow (inclined shaft), transient operations and off-design conditions. These tools enable the hydrodynamist to finalise an almost perfect design before a model is produced for basin test for local adjustments.

For the FLs, the propeller blades are fully-machined to produce the following advantages:

- the fidelity of reproduction of the hydrodynamic profile emanating from the design office,
- the required repeatability in carrying out the operation in order to cater for individual blade interchangeability.

Shafting and propellers are designed and produced by ACB, with non-ferrous castings from LIPS, Netherlands. This was the opportunity of finalising the establishment of the new joint venture, acbLIPS, now exclusively in charge of worldwide marketing for all propulsor products from ACB and LIPS for naval applications.

Controls and monitoring

Controls

The basic philosophy for the propulsion controls and monitoring system has evolved over the past decade, together with the technological development of the equipment.

On all three classes, main automatic control is achieved from either the bridge or the machinery control room (MCR). Separate control is also available at the MCR and, in the case of FAA and F.2000 at local stations in each propulsion compartment. These local stations are deleted on the FLs as the compartments are not manned in any condition of operation.

Back-up manual controls are also available at the local level, located close to each equipment, on all three ships.

From the technological standpoint, the design has developed drastically from the use of relays on the F.2000 to the programming of standardised PLC. On the FLs, individual PLC's are dedicated to each plant and located in each engineroom. Engine electronic governors have replaced the hydraulic ones.

Monitoring

On all three classes, the requirement exists for complete independence of the monitoring system from the control system. When necessary, sensors are doubled to assume both functions separately.

On the F.2000, the monitoring system is centralised at the MCR and basically composed of individual indicators hard-wired to each engineroom.

The FAAs and FLs feature the introduction of data collecting units (DCU) and visual display units (VDU). On the FL three DCUs per plant are located in each engineroom and connected to the visualisation computer by means of serial data links. Two VDUs are arranged on the propulsion console, one for each plant, but are of sufficient capacity for the whole propulsion system in order to obtain a 100% redundancy. The propulsion VDUs are connected to the supervisor console equipped with one VDU also connected to the shipboard network where data of other main systems (power generation, auxiliaries, fire fighting, *etc*) are available.

This system is the normal monitoring method. Its design was flexibly made for further connection to condition-based maintenance tools at a later stage.

In case of damage on the normal system, a 'secondary' monitoring system, composed of hard-wired indicators for the critical parameters, is arranged on the MCR propulsion console.

The technological evolution of the equipment used in the control and monitoring systems has offered the following advantages:

- a large number of data is collected and may be treated for several purposes (status monitoring, failure analysis, condition based maintenance, *etc*),
- console sizes are reduced due to the deletion of the relay techniques and a great reduction of the number of indicators,
- cabling work is reduced by the use of serial data links,
- PLCs and DCUs may be dedicated to individual equipment and located close to it, in respect of the survivability requirement,
- manning for the operation and surveillance of the power plant is reduced due to centralisation of commands and displays.

The propulsion control and monitoring system for *'La Fayette'* was designed and produced by ACB Automation Department. It will soon be workshop tested on a simulator.

Conclusions

This comparative survey of recent French achievements in CODAD propulsion plants has shown the evolution over the last ten years of this propulsion concept, which has proven to be a valuable solution for the concerned classes of frigate.

Future warships with greater power requirements will not necessarily utilise CODAD propulsion. However, many of the basic principles underlying the developed concept will be equally applicable.

The Marine Nationale's FAA Cassard *with a high-power CODAD installation*