AN ADVANCED TECHNOLOGY ASW FRIGATE FOR THE YEAR 2000

BY

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This article describes the result of a ship design exercise carried out as part of the MSc degree course in naval architecture at University College London. It was undertaken by a team of two naval architecture students[1] *and one marine engineering student*[2]*, supervised by the Professor of Naval Architecture and his staff.*

ABSTRACT

The proposed frigate is equipped with new sensors and weapon systems. Low ship resistance is obtained by a long slender hull form, with two small side hulls for transverse stability. It has full electric propulsion and contra-rotating propellers.

Introduction

The Advanced Technology Frigate F 2000 is a proposed 4200 tonne warship which attempts to meet the future requirements of anti-submarine warfare. The design must use the latest technology, even if some of it has not yet been fully developed, and provide uncomplicated methods of upgrading. This makes the design exceptionally difficult. Not only does a thin line need to be drawn between what can safely be assumed to be available within the near future and what cannot, but also the design requires the incorporation of alternative solutions for the case where the desired technology is not ready for production.

Principal Design Requirements

Future submarines will be very quiet and increasingly difficult to detect with passive sonar only. The new ASW frigate must therefore be able to locate and identify a submarine in unfavourable conditions using active and passive means. Additionally, the frigate must rely on other sources of information such as magnetic anomaly detection from aircraft and satellites, which requires access to relevant data links and communication lines. A good sonar suite and data-processing facilities are essential to enable the future ASW frigate to perform her primary task of protecting own forces and shipping routes from submarine attack. The main ASW weapon is the torpedo, either ship-launched, deployed by helicopter, or missile-launched.

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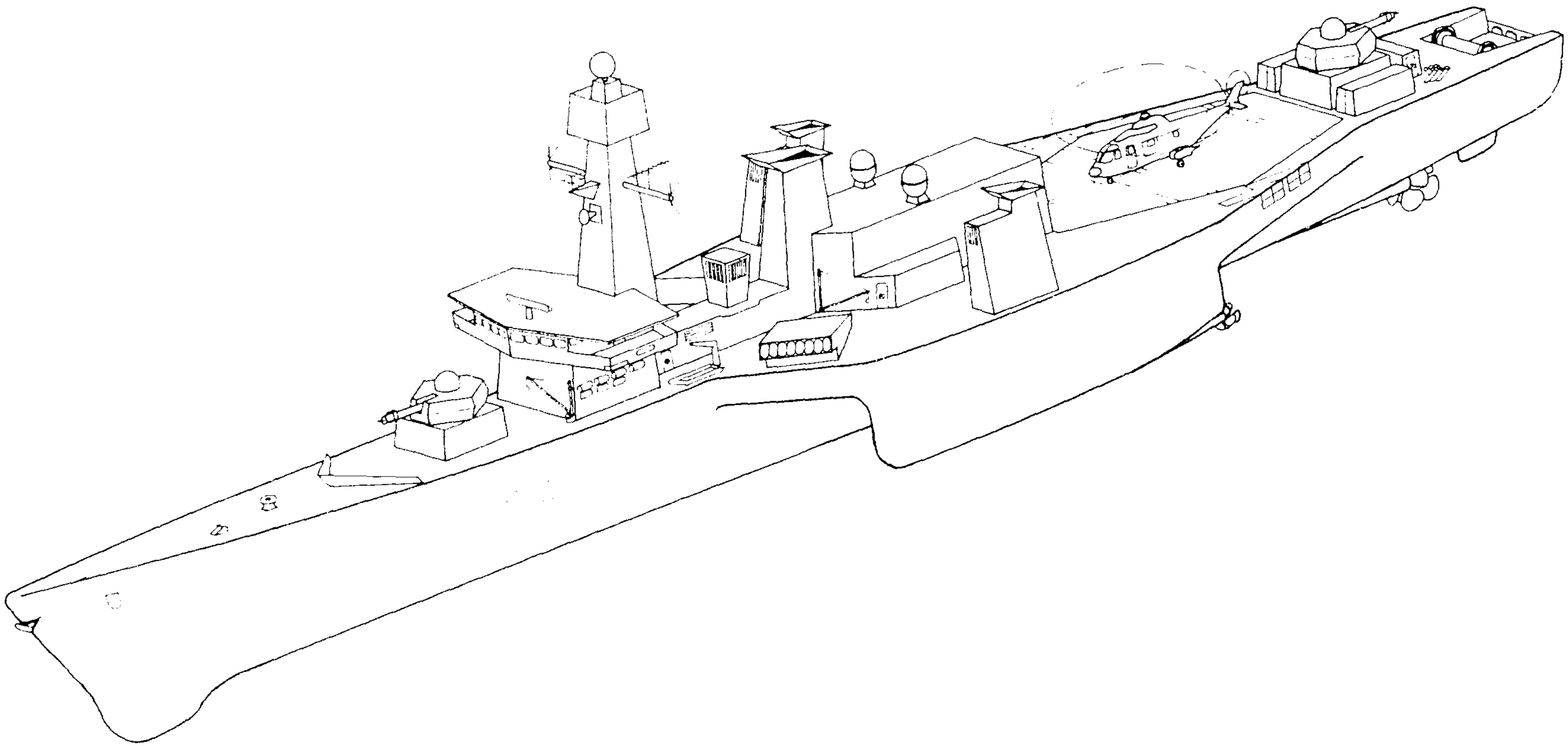


Fig. 1—Advanced Technology ASW Frigate, F 2000

The advanced technology frigate therefore provides full support for an ASW helicopter and a highly effective torpedo-carrying missile system. Finally, the frigate is able to protect at least herself against missile and aircraft attack. This requires a good radar or other means of detection, and a highly capable quick reaction area and point defence system. This is provided by two directed electromagnetic energy weapons in the form of Lasers. A recent study conducted by the Massachusetts Institute of Technology suggested that destructive Laser weapons could be miniaturized to the size of a 5-inch gun mount within the near future.

Above all, the Advanced Technology Frigate must have a very low acoustic signature and reduced radar cross section, magnetic and infra-red signatures. The payload of the Advanced Technology Frigate is summarized in TABLE I.

TABLE I—*Payload*

W/C System:	Ferranti 500 Weapon Control System
Comms:	SCOT, VHF, UHF, HF
Sensors:	sonar T 2050
	towed array sonar T 2031 Z
	static array sonar
	MESAR fixed phased array radar
	navigation radar 1007
	infra-red sensor
ESM/ECM:	3 Seagnat launchers
	torpedo decoy T 675
	UAF 1
Weapons:	16 Super Ikara torpedo-carrying missiles
	16 Sting Ray ship-launched torpedoes
	32 Sting Ray helicopter-launched torpedoes
	2 high energy laser systems
Aircraft:	1 helicopter EH 101

Slender Hull and Low Noise

To satisfy the extremely low noise requirement, perhaps the most important and remarkable feature of the proposed solution is a novel low-resistance hull form which requires only a small main machinery package. In selecting the hull form, the design team chose to exceed current limitations on conventional monohull design. The result of extensive research on the one hand, and compromise on the other, is a frigate with a triple hull configuration as shown in FIG. 1.

During most ship design processes, the required hull form is optimized for low resistance seakeeping as far as possible. In the case of the Advanced Technology ASW Frigate, low underwater noise is extremely important. The achievement of this essential aim generally requires significant design skill and important attention to detail, as well as sophisticated technical solutions to individual noise problems.

Probably the best solution to deal with noise is not to generate it in the first place. This method works best when applied to the loudest source of noise of a warship—the propulsion system. The use of electric propulsion motors and elimination of mechanical gearboxes has already brought about significantly reduced noise levels in present frigates. However, further reductions are possible if the overall generated power is reduced. The Advanced Technology Frigate is therefore designed with an exceptionally slender hull form with a remarkably reduced resistance (length to beam ratio = 14·2). Hence only a small engine power is required and consequently the total generated noise is low. This achievement is supported by other noise reduction measures, the most important of which are fully electric propulsion three sets of contra-rotating propellers, and location of all prime movers (three gas turbines) above the waterline. Although contra-rotating propellers have a higher efficiency, they may not necessarily be quieter than conventional propellers. However, the total propulsion power is divided among six propellers, which are consequently only lightly loaded. This means a considerable delay of cavitation onset and hence a low noise, even at higher than typical towed array speeds.

An important side effect of this long slender hull is the reduced fuel consumption and hence lower operating cost.

Development of the Triple Hull Configuration

From the payload of the Advanced Technology Frigate and using empirical formulae based on past experience, the required internal volume and displacement were estimated. After several iterations, the displacement was fixed at 4200 tonnes, including design and future growth margins. The extremely slender hull (length to depth ratio = 14·5) presented structural and stability problems which had to be solved.

In particular, GM values were initially negative unless the centre of gravity of the ship was close to the keel. This is hard to achieve in conventional warships, and almost impossible for the proposed Advanced Technology Frigate. The design should have a large stability margin to permit a rise of the centre of gravity during future updates. Moreover, it is assumed that periods between refits will become shorter as the development in electronics technology increases. The ship therefore employs modular components. Updating is thus fast and efficient, which results in a long service life.

With all prime movers located above the water line, the initial vertical centre of gravity would be so high that it became apparent that the ship required some assistance in transverse stability. In order to maintain the slender hull form, a solution was adopted which is more than a thousand years old: small side hulls, in a configuration similar to the recent design of the *Ilan Voyager* designed by Nigel Irens.

This concept, applied to a frigate, opens a whole range of new possibilities which never before were within the designer's reach. But it also presents many additional problems.

Side Hull Configuration Problems

Among the most important questions are the following:

- What is the best size for the side hulls and the best side hull/main hull displacement ratio?
- Where is the best side hull location (transverse distance from main hull and longitudinal position)?
- How are the side hulls joined to the main hull?
- What will the hydrodynamic interference effect be on overall ship resistance?
- How will the seakeeping properties be affected by the side hulls?
- Will the total ship resistance be larger than for a conventional monohull of comparable size?
- What are the implications on weight and cost?

The most important question is: 'Can all the disdavantages be offset by the advantages of the side hull concept, so that it is worthwhile to proceed with it?'.

Since there is a requirement for low ship resistance, the powering aspect was dealt with first.

Resistance Prediction

In the absence of any model test results for triple hulls, the power estimation and resistance prediction are based on the assumption that Series 64 Resistance Data for long slender monohulls provide the best possible approximation. Therefore, the most important hull parameters are closely related to the Series 64 parameters.

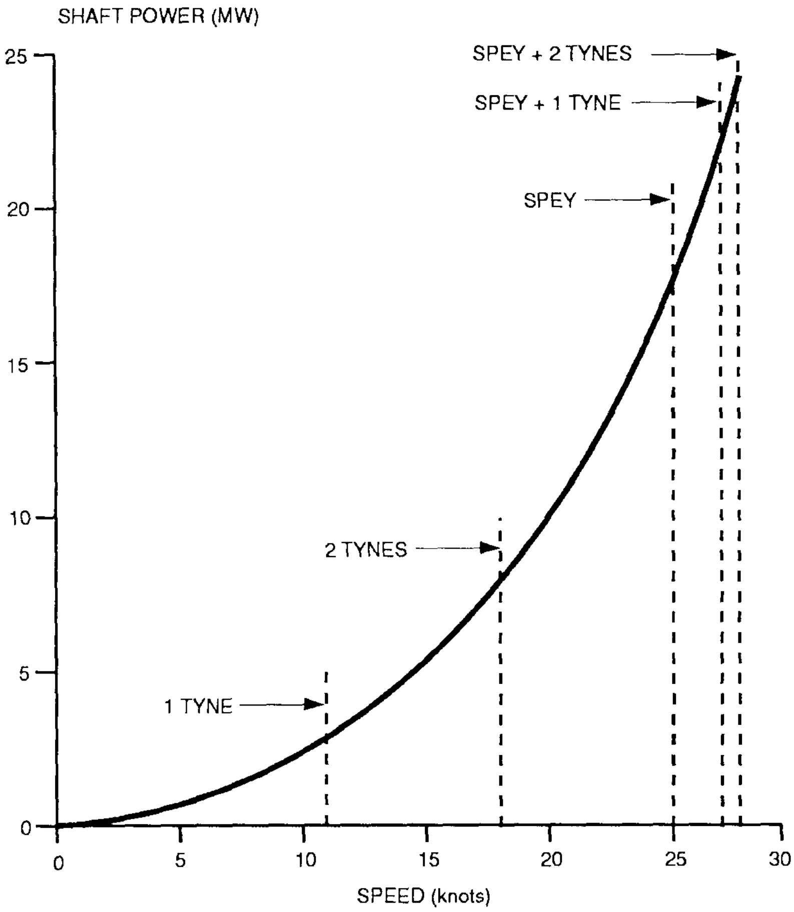


FIG. 2—PREDICTED POWER SPEED CURVE

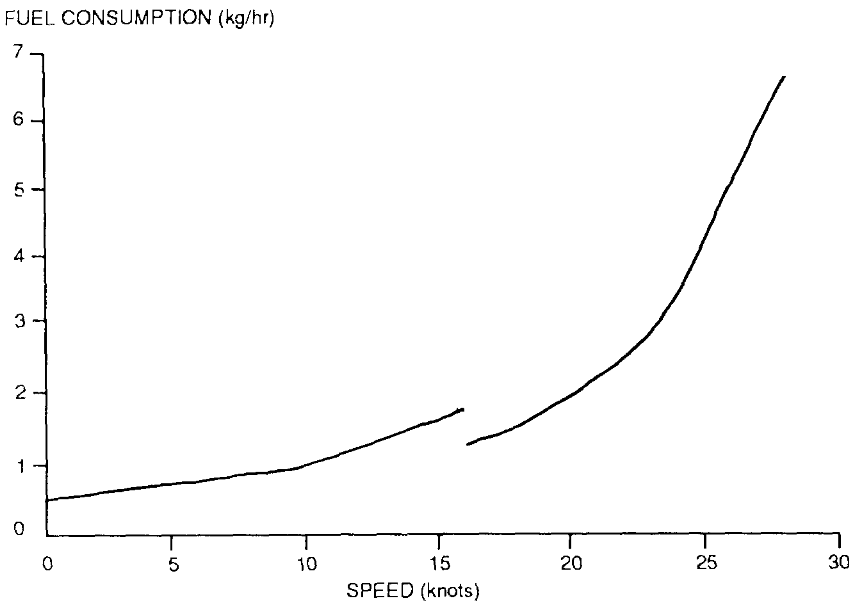


FIG. 3—FUEL CONSUMPTION CURVE

Initial Power estimates were made early in the design for different side hull proportions. Since the overall resistance was always low, there were no significant changes. In all cases, depending on the displacement ratios of main/side hull, the shaft power was between 21 MW and 24 MW for 28 knots, including a 10% margin for uncertainties caused by interference effects. Circular M has a significant influence on resistance and was kept constant at 9·66. Therefore the propulsion system was designed for a requirement of 24 MW shaft power.

Fig. 2 shows the estimated power speed curve, Fig. 3 the corresponding fuel consumption, Fig. 4 the endurance, and Fig. 5 the underlying operational profile. Table II summarizes the main machinery package.

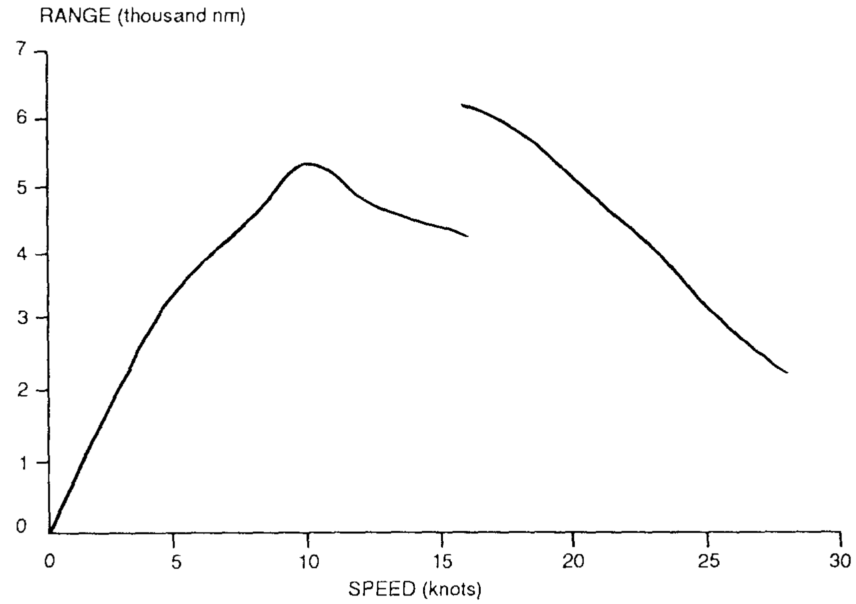


Fig. 4—Endurance curve (on 507 tonnes of Dieso)

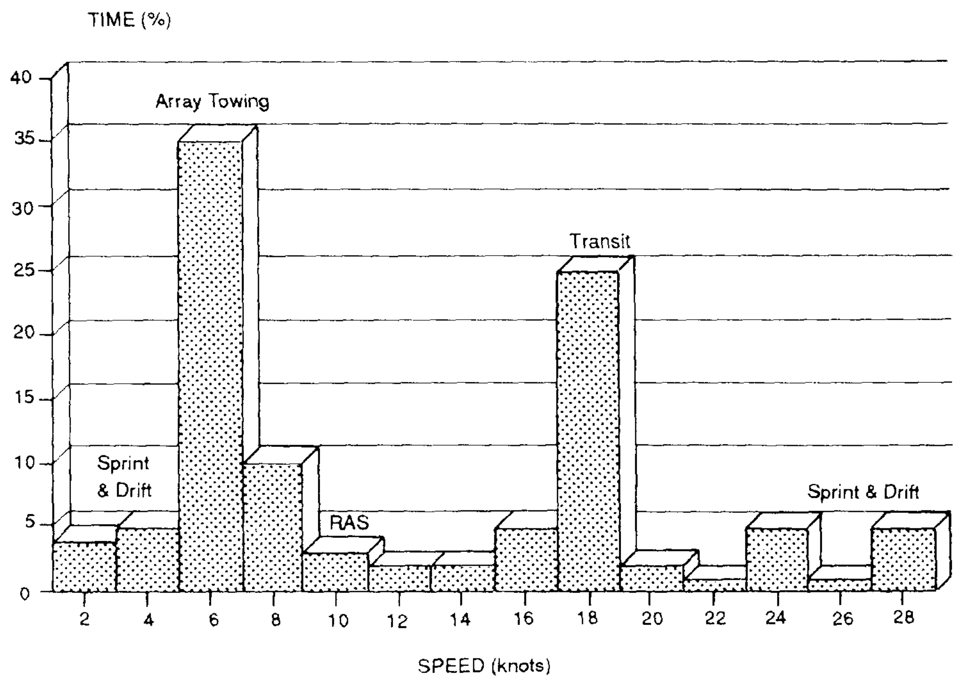


Fig. 5—Typical ASW mission operational profile

TABLE II—*Main machinery package*

1 RR Spey ICR + ac generator	22 MW
2 RR Tyne RM1C + ac generators	4 MW per unit
2 electric propulsion motors	9 MW per unit
4 electric propulsion motors	1.6 MW per unit
2 contra-rotating propellers	D = 4·18 m n = 170 rev/min
4 contra-rotating propellers	D = 1·60 m n = 480 rev/min
Speed	28 knots

Advantages of the Triple Hull Frigate

A value of 24 MW of shaft power at 28 knots indicates that there is an advantage in the long thin ship with side hulls concept, although this first estimation is only very crude. The attempt to solve all the questions listed earlier has to be balanced against powerful advantages:

- inherently greater flexibility in ship layout due to unusual upper deck shape and side hull volume;
- more flexibility in upper deck layout;
- possibility of arranging propulsion motors in side hulls;
- spreading of prime movers over the ship and side hulls;
- increase in reliability and survivability of ship's power plant, better protection of main hull equipment;
- good low speed manoeuvring capability using differential thrust on side hull propellers;
- vertical position of centre of gravity not critical;
- improved damage stability by providing three independent bodies for buoyancy.

This list indicates that the side hull concept in general is not totally unsuitable for the type of warship that is to satisfy all future ASW requirements, particularly low noise levels. The most important hull characteristics are summarized in TABLE III.

Layout

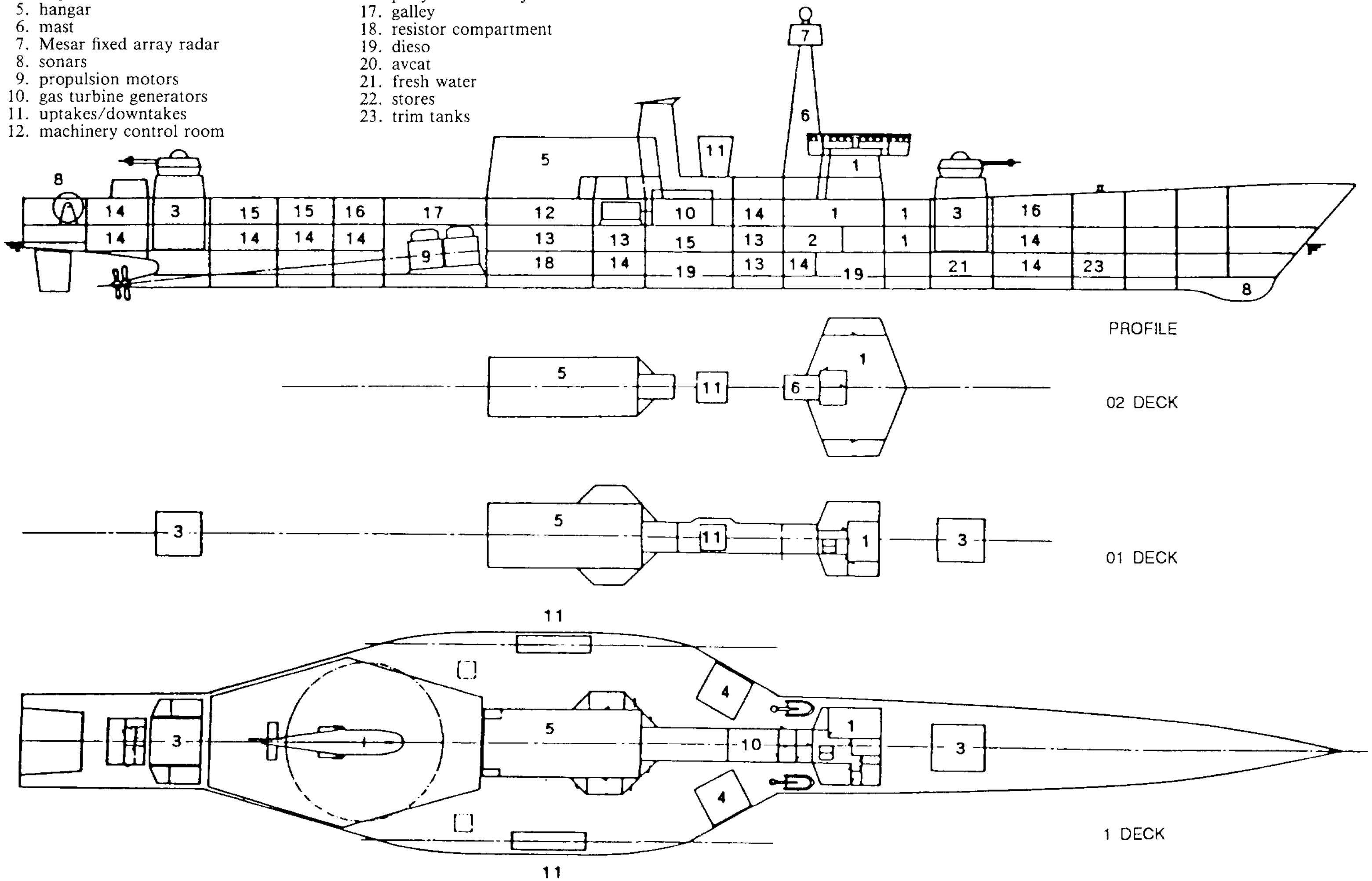
The layout of the Advanced Technology Frigate is shown in FIG. 6. The size and position of the side hulls was determined according to seakeeping and stability requirements. Transverse metacentric height is largely influenced by the second moment of area of the waterplane about its longitudinal axis. In the case of side hulls, the side hull waterplane area and its radius of gyration about the main hull centre line are the governing factors, outweighing all other contributions to transverse GM. In order to ascertain the ability to

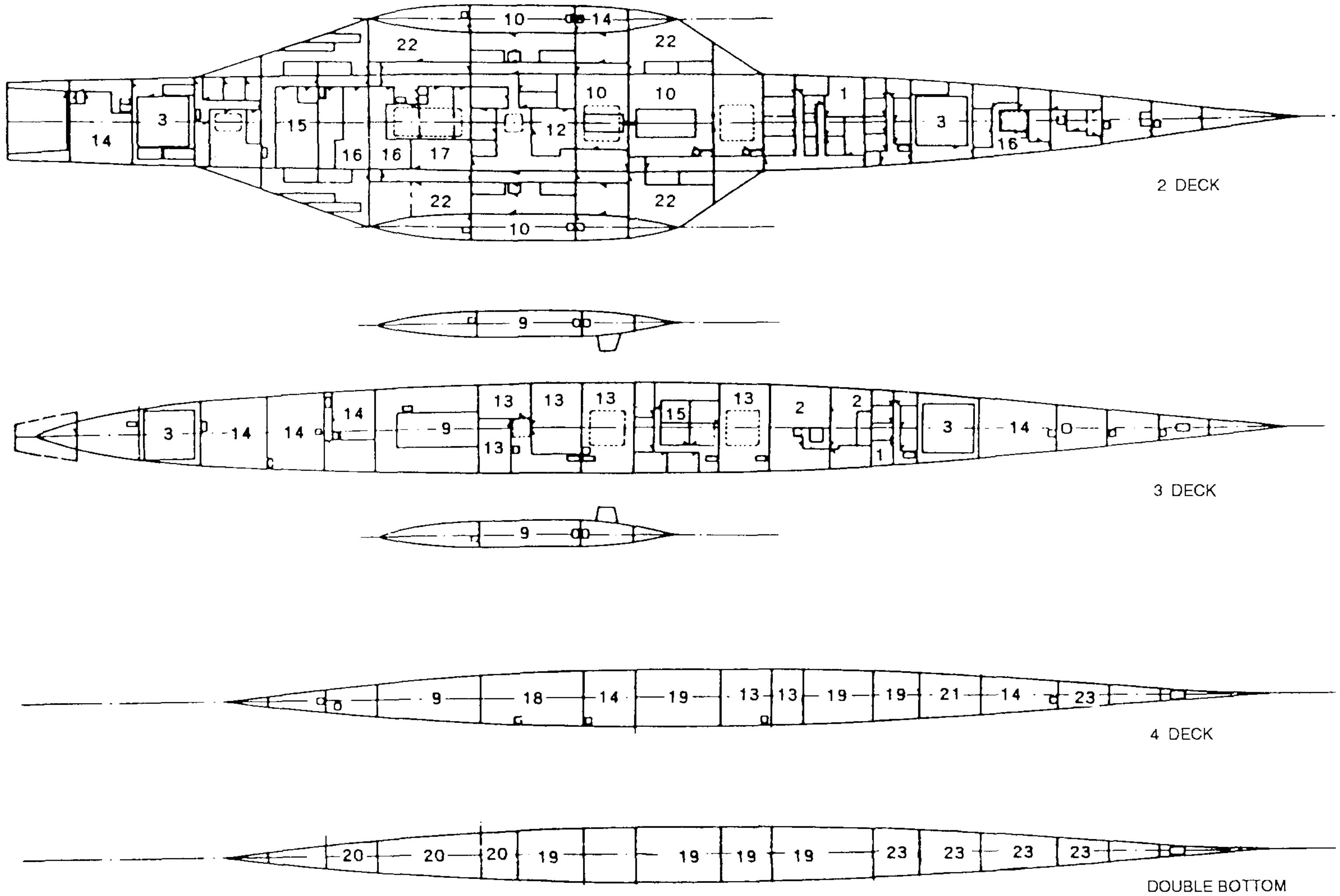
TABLE III—*Hull characteristics*

Deep Displacement:	4200 tonnes
Standard Displacement:	4200 tonnes
Length B P	148·7 m
Length O A	154·7 m
Beam W L (centre hull)	10·44 m
Beam max. (centre hull)	11·60 m
Beam extreme	27·50 m
Depth of hull	10·23 m
Draught (mean)	5·22 m
C_p	0·630
C_m	0·714
Flare amidships	7°
Side Hull inclination inwards	7°

FIG. 6—DECK PLANS OF ADVANCED TECHNOLOGY ASW FRIGATE, F 2000

1. bridge and officers' accommodation
2. operations room
3. high energy laser modules
4. Super Ikara launchers
5. hangar
6. mast
7. Mesar fixed array radar
8. sonars
9. propulsion motors
10. gas turbine generators
11. uptakes/downtakes
12. machinery control room
13. switchboards, motor generator sets, converters
14. auxiliary machinery compartments
15. chief petty officer accommodation
16. petty officer and junior rates accommodation
17. galley
18. resistor compartment
19. dieso
20. avcat
21. fresh water
22. stores
23. trim tanks




2 DECK
3 DECK
4 DECK
DOUBLE BOTTOM

fit propulsion machinery into the side hulls, their maximum waterplane area at a given distance yielding acceptable stability was determined and the size of the electric motors which provide useful power up to cruising speed estimated. Longitudinally, the side hulls are located near the centre of pitch. This effectively fixes the position of the flight deck, which must be wider than the stern of the ship. The overall configuration is not optimized with regard to interference effects between the wavemaking of the main and side hulls. This can best be dealt with during model tests, and remains a risk area.

A single deck, box-like structure connects main hull and side hulls, with continuous bulkheads and decks running athwartships over the entire beam of the ship. This permits the dissipation of longitudinal and (much smaller) transverse bending stresses amidships into the remaining structure.

There are 4 decks in the main hull. Internal decks are relatively high (between 2·7 and 3·0 m). This is justified because:

(*a*) Deck space between 1 deck and 2 deck needs to be large to accommodate the large scantlings necessary to strengthen 1 deck. Additionally, the box outboard of the main hull is internally stiffened, both on the deck and the deckhead. Primary services also run through under 1 deck. A useful deck height in the box must be maintained as well as structural continuity.

(*b*) 2 deck supports gas turbines and generators. Although the Spey gas turbine penetrates 1 deck together with its generator, it requires strong support on 2 deck. Deep beams decrease the useful deck height between 2 deck and 3 deck, which is therefore also relatively large. Machinery spaces on 2 deck do not have natural bilges, and this may require construction of a false deck to act as a bilge. This can only be achieved if there is sufficient deck height below.

Deck height between 3 deck and 4 deck is reduced, because there are no such severe constraints as in the higher decks. The double bottom (1·5 m) appears large, but in the slender hull it still does not give the same deck area as a smaller double bottom in a wider ship.

All prime movers are located above the waterline. The high centre of gravity does not have a severe impact on the design, as sufficient initial stability is ensured by careful side hull design. Electric motors are positioned as far down and aft as possible. This minimizes shaft length, power losses, vibration risks and watertight bulkhead penetrations. Prime movers are well distributed, with the two Tyne gas turbines situated in the side hulls. Switchboards and motor generators, from which the hotel load is supplied, are in two compartments, well separated and split diagonally. There are auxiliary machinery spaces located in the vicinity of the main gas turbine compartments, mainly containing equipment necessary for gas turbine operation like HP air compressors and cylinders, fuel centrifuges and lub oil pumps.

The Machinery Control Room (MCR) is situated in the centre of the ship, where it is well protected, and where it can be reached without excessive cable runs. It is supported by two independent ship systems computers, located beside the MCR and in the bow of the ship. Sensor data is preprocessed and fed into the data bus, where it can be processed by any one of the computers. A third computer room beside the Operations Room contains the combat systems computer, which is supplied by its own independent data bus. All data cables are fibre optic for reduced weight, higher reliability, faster data transmission and decreased EMP sensitivity.

Fuel tanks are not water-compensated in order to avoid the problems of fuel contamination (which is especially dangerous for an all gas turbine ship) and discharging before replenishing. Instead, there is sufficient capacity for separate sea water trim tanks in the forward section of the ship. Flooding of these tanks decreases the trim by the stern that the vessel takes on as the fuel is consumed. In the event of a required fuel overload the trim tanks can be used as fuel tanks after thorough cleansing. In the future, they could be made permanently available for dieso fuel as water-compensated fuel tanks, if a method can be found to physically separate the fuel and water, for example using a flexible membrane or a bladder. The fuel would pump up the bladder, which forces the water out of the tank by expanding. This technique could similarly be applied to all fuel tanks, thus increasing the number of available trim tanks and hence giving greater flexibility and margins when applying trim corrections, if so required by a different future load distribution.

Accommodation spaces are designed in accordance with the Naval Engineering Standard, NES 107[3]. Provision was made to accommodate female as well as male complement in separated deck areas. The location of accommodation as well as normal working areas was chosen to lie as close to the roll centre of the ship as possible to maximize crew comfort and found to be within permissible motion and acceleration levels.

Stability

Intact Stability

Initial stability was estimated using the wall-sided formula. The initial GM thus calculated was used to determine the required position and size of the side hulls.

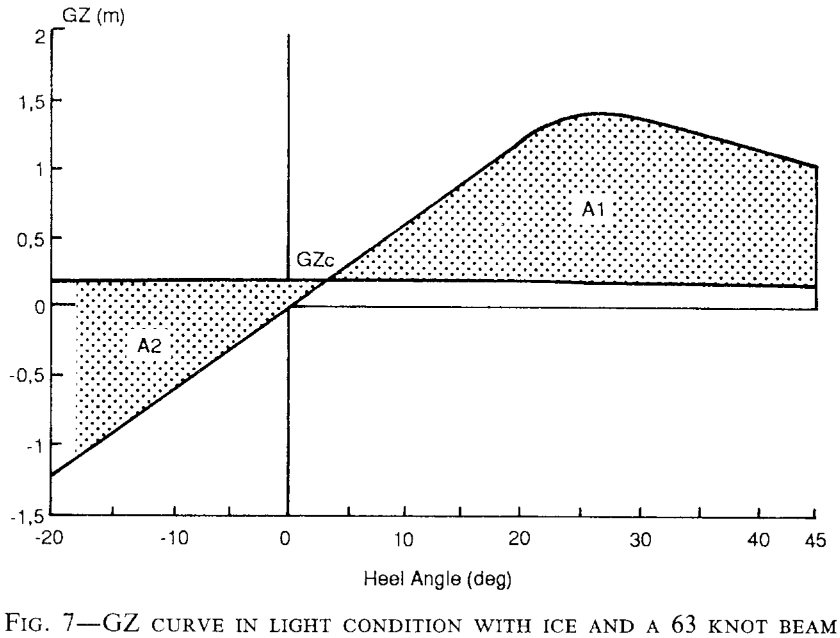


FIG. 7—GZ CURVE IN LIGHT CONDITION WITH ICE AND A 63 KNOT BEAM WIND (SEE CRITERIA IN TABLE IV)

Since none of the computer programs available at UCL was able to handle the effects of the side hulls, GZ curves were constructed by hand using the integrator method as described by Lewis[4]. The critical GZ curve, light condition with ice in beam wind, is shown in FIG. 7. It is only approximate, but it conveys an idea of the superb stability that can be achieved with the proposed triple hull frigate.

TABLE IV—*GZ curve criteria in light condition with ice*

	Required	Actual
Area under curve up to 30°	>0·051 mrad	0·68 mrad
Area under curve up to 40°	>0·085 mrad	0·89 mrad
Area under curve between 30° and 40°	>0·033 mrad	0·21 mrad
Maximum GZ	>0·24 m	1·3 m
Angle at maximum GZ	>30°	22°
GM fluid	>0·15 m	2·96 m
Angle of heel	<30°	3°
GZc/GZmax	<0·60	0·15
A1/A2	>1·40	2·65

TABLE V—*GZ curve criteria with one side hull flooded*

	Required	Actual
Maximum GZ	>0·3 m	0·7 m
Angle of heel	<20°	17·5°
GZc/GZmax	<0·60	0·11
A1/A2	>1·40	1·95
Wind velocity	32 kt	32 kt

Damage Stability

Four different conditions were investigated:

- aft main hull flooded;
- midship main hull flooded;
- forward main hull flooded;
- one side hull flooded.

The floodable length is 22·2 m, which was extended over the entire compartment length covered. In all conditions the ship is able to meet all stability criteria with comfortable margins. The critical case is that of one flooded side hull, which is shown in FIG. 8. Not only is vital buoyancy lost, but the weight of the damaged side hull adds to the heeling angle. If the heeling angle becomes so large that water penetrates the box, there is very little scope for meeting the damage stability criteria, and appropriate action such as counterflooding must be considered.

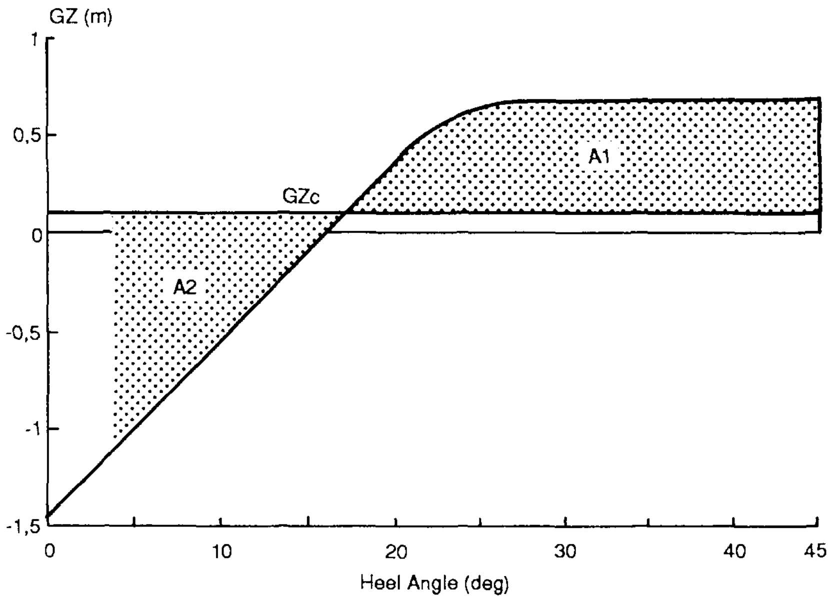


FIG. 8—GZ CURVE WITH ONE FLOODED SIDE HULL AND A 32 KNOT BEAM WIND (SEE CRITERIA IN TABLE V)

It is also necessary to take into consideration the possibility that one side hull might loose its transverse structural strength as a consequence of a direct missile hit, and, as a result of a pivot forming in the box, might cease to contribute to transverse stability or disintegrate completely. The limiting case in transverse stability is therefore a single side hull, with which the ship is able to survive.

Cost

Generally, the application of advanced technology lags behind its development because it is not sufficiently tested or proven, or because it is too expensive. It is therefore extremely difficult to obtain a realistic estimate of the cost of a ship which employs high technology weapon systems that are not even fully developed. This is particularly true for the two high energy Laser modules. The unit production cost is partly based upon estimates which are assumed to bear similarity to existing weapon systems. Otherwise they would probably not find their way into military applications anyway, as defence budgets continue to be cut.

Other cost estimates are derived from empirical formulae provided by University College London with added contingencies and corrected for 1990 prices. The cost estimation summary is shown in FIG. 9. It contains all applied margins.

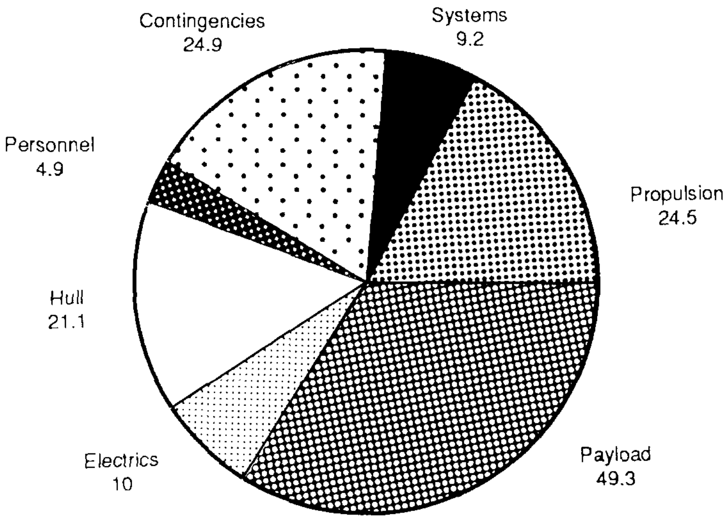


FIG. 9—COST ESTIMATE SUMMARY, IN M£. TOTAL, WITH CONTINGENCIES, M£ 143.9

Life cycle costs are expected to be lower than for conventional warships, mainly due to reduced fuel consumption and shorter refit periods owing to the modular construction of weapon and electronic systems.

Other Design Aspects and Risks

A further important feature of the Advanced Technology Frigate is the low manning level. Operational procedures, automation and low maintenance allow a complement of 109, although accommodation space is designed for 130, thus providing a sufficient margin for training and future growth.

The sea state affects the operation of any ship. The seakeeping ability of any naval vessel is important, so much so that in recent designs it is considered one of the higher priority items[5]. Seakeeping qualities of the triple hull ship in head seas were investigated and found to be superior to a conventional monohull of comparable displacement, mainly due to the greater hull length.

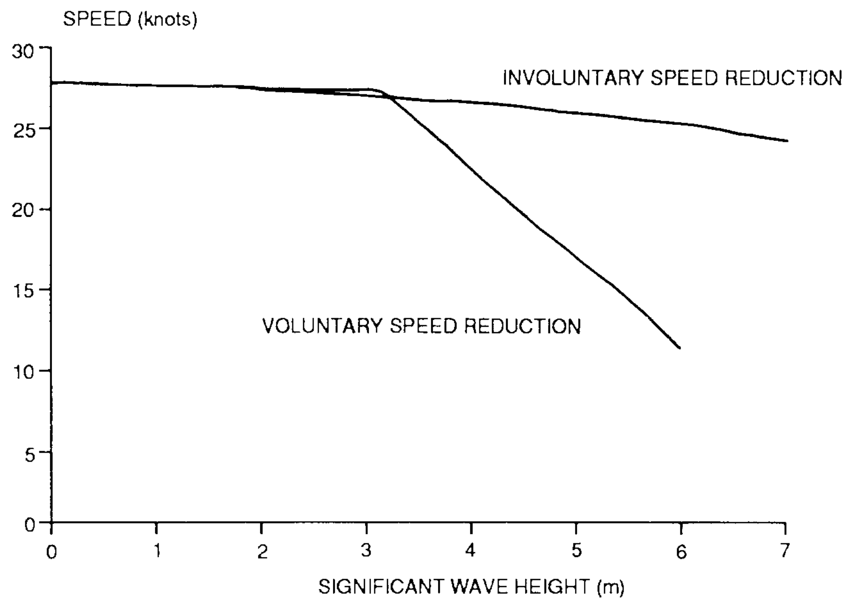


FIG. 10—SEAKEEPING PROPERTIES IN A HEAD SEA

A permissible speed envelope can be determined from voluntary and involuntary speed reductions due to various sea states. This is shown in FIG. 10. Again, model tests are recommended to obtain a better seakeeping analysis.

The main hull has a 7° flare, and side hulls and superstructure are sloped 7° inwards in an attempt to minimize the radar cross-section. Tetrahedrals were avoided altogether, but the overall effect of the triple hull configuration itself on radar cross-section reduction also remains to be verified in model experiments.

The most significant design risk is that of hydrodynamic interference of the three hulls. Although this problem was appreciated during the resistance prediction, the effect on underwater noise could not be investigated.

Summary

This 4200 tonne Advanced Technology ASW Frigate stretches the long thin ship concept to the limit. Although side hulls are required to maintain stability requirements, their impact on the design is beneficial in most aspects rather than harmful. Low ship resistance reduces the required engine power, and low engine power generates less noise. This power is distributed over one large and two smaller pairs of contra-rotating propellers, which are only lightly loaded, thus reducing cavitation noise. During design, transverse stability can be 'tuned' to the desired level by altering the position of the side hulls.

The triple hull configuration has higher structural weight and cost than a conventional monohull, but structural cost forms only a small portion of the total unit production cost. The weight penalty is smaller than for SWATHs, and offset by reduced operating costs and a small main machinery package. This concept offers great flexibility for upper deck layout and machinery arrangement.

The payload consists of modern weapon systems and advanced sensors. Both high-energy destructive Laser weapons are modularized and alternative close-in or point defence weapon systems can be substituted. Similarly, all torpedo magazines are containerized to facilitate fast replenishment and easy upgrading. In order to maintain the ability of future modernization, allowance for large margins in terms of weight, chilled water and electrical power has been made in the design.

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