UK AND US FRIGATE DESIGN A COMPARATIVE STUDY

BY

M. H. STONEHOUSE, MSc, CEng, MRINA, RCNC
(formerly of Sea Systems Controllerate, London)

AND

L. D. FERREIRO, PE, CEng, MRINA
(Naval Sea Systems Command, Washington, DC)

This article is a shortened version of one submitted to the Society of Naval Architects and Marine Engineers and is printed here with their permission.

ABSTRACT

The development of a naval ship reflects not only its mission, but the accumulated experience of that navy as expressed in its design standards and practices. This paper examines the differences in those design practices between the US and the UK navies, and the resulting impacts on ship size and cost. The purpose of the study was to explain why, given similar missions, US and UK frigates differ so greatly in size and cost. In a joint project, each navy developed a conceptual frigate design based on a common combat system and these were then compared on a general basis. However, differing national practices in certain areas masked other important differences in the designs. Therefore, alternative designs were developed which eliminated those variations, allowing a detailed comparison of shipboard systems. Considerable effort was spent translating one nation's weight and space classification to the other's. Differences in system weights and areas indicated where the variations in design standards and practices occurred; the underlying reasons for these differences were then examined. Finally, construction costs were compared and analysed.

Introduction

Background

Over the past 20 years, many comparative warship studies have indicated that, for broadly similar requirements, UK and US frigate designs could differ by over 1000 tonnes. Therefore, representatives from the United States Naval Sea Systems Command (NAVSEA) and the United Kingdom Sea Systems Controllerate (SSC) agreed that a joint study to investigate the reasons behind this difference would be worthwhile. This paper summarizes the results of that study. Its aims are to:

(*a*) confirm the view that, for common payload and requirements, US and UK frigates (designed according to national practices) differ significantly in displacement:

(*b*) identify the design policies, standards and practices which are responsible for these differences:

(*c*) compare the impacts of those differences on vessel costs.

We should note that this study was conducted during 1987 and 1988, and represents the current thinking at that time. As both design practices and technologies have evolved since then, the results and conclusions of this study may not represent the latest in either US or UK design. We emphatically note that this study does not attempt to say which design practices are 'best' (if that is even possible), but rather serves to illustrate how highly competent organizations on both sides of the Atlantic can arrive at different solutions to similar requirements.

The views expressed in this article are those of the authors and not necessarily those of the UK Ministry of Defence, the US Department of Defense or the US Department of the Navy.

Method of Study

We agreed that a comparison of conceptual designs, rather than of existing ships, was the best procedure for this study, for reasons outlined below. We undertook two parallel design studies; one conducted in the US by the Preliminary Design Division of NAVSEA (SEA 501), using US design methods and practices; and the other conducted in the UK by the Director, Future Projects (Navy) of SSC (DFP(N)), embodying UK design methods and practices. The resulting ship descriptions were then compared to reveal any differences and to allow their detailed analysis.

It was apparent from the start that we would need a common basis from which to compare design standards and practices. Although previous analyses of warship designs (e.g., the works of Kehoe *et al.*[1] and Garzke & Kerr[2]) have been quite thorough in illustrating many of the differences in national practices, they have always compared existing ships which even though having broadly similar roles, differ in their military requirements (payload, range, speed, etc.). This precludes a meaningful correlation of the underlying ship designs, since so much of a design centres around supporting the ship's mission.

TABLE I—*Common mission and payload requirements*

Endurance 5000 nm 19 knots*	*Speed* 27 kts sustained, 28 kts maximum } deep & dirty condition
AAW Mission 3D Multifunction Radar 2D Air Search Radar Local Area Missile System 2 Close-In Weapons Systems Electronic Warfare/Decoys	*ASW Mission* Bow Sonar Towed Array (space only) 1 ASW Helicopter Magazine Torpedo Launcher Towed Decoy
ASUW Mission Surface-to-Surface Missiles 127 mm Gun	*Other* Operations Room (CIC) External Communications

*Note that US endurance speed is typically 20 knots

To form a more correct analysis, we decided to compare US and UK conceptual ship designs, developed from the same military requirements; in particular, the payload had to be common to the ships, especially to ensure identical demands on the platform. Accordingly, we arbitrarily defined a common weapons payload and set of mission requirements (see TABLE 1). This covered not only functional aspects but also the payload demands on the platform. It is worth noting that, although the actual payload is not of great significance, we did try to produce a balance of capabilities in anti-submarine warfare (ASW), anti-air warfare (AAW), and anti-surface warfare (ASUW).

In addition to the common payload, we recognized that certain other elements necessary to synthesize a design have a significant impact on the platform size (specifically, manning, protection and propulsion). Although these are generally determined by national policy, their impacts could mask smaller but important areas of difference embodied in the design process itself. (NB For classification reasons, certain areas which would affect a ship design have not been addressed in this article.)

We decided to conduct the study in two phases. The first phase was conducted using national baseline designs, with common payloads but using national practices for manning, protection and propulsion. The second phase used a variant of the US baseline design, but having the same manning, protection and propulsion as the UK baseline. In Phase 1, the baselines were examined side-by-side to give an overall comparison of the kind of ships that might be produced in each country; and by comparing the US baseline and variant, the impacts of policies for manning, protection and propulsion could be determined. The Phase 1 ships were designed to a very rough level of detail to allow these comparisons. In Phase 2, comparing the UK baseline with the US variant allowed an investigation of more subtle design practices; accordingly, the Phase 2 designs were carried out to a greater level of detail. This process is shown in FIG. 1.

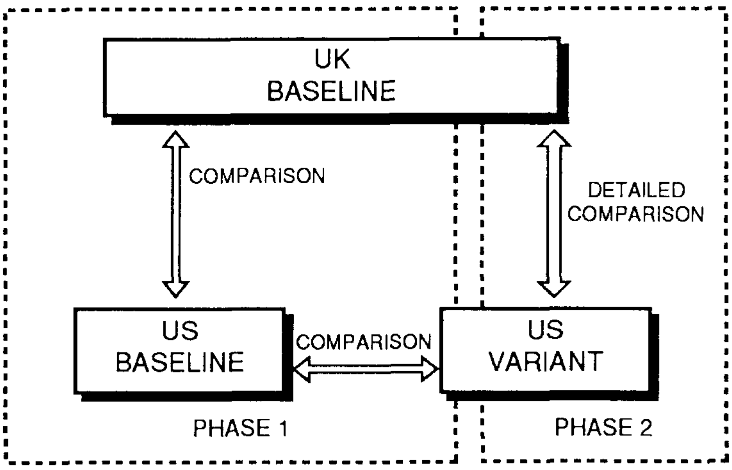


FIG. 1—STUDY METHODOLOGY

PRELIMINARY COMPARISONS (PHASE 1)

National Baselines

As stated, the national baselines were designed with common payloads, but using the manning, protection and propulsion conforming to national practices. The particulars of these designs are shown in TABLE II. As can be seen, the two baselines differ by about 1300 tonnes, of which 1000 tonnes comes from lightship, and 300 tonnes from loads. The US ship is 8 m longer than the UK ship. The arrangeable areas and total volumes of the two ships are equivalent.

TABLE II—*Comparison of baseline designs*

	US Baseline	*UK Baseline*
LBP (m)	133.0	125.0
Beam (m)	16.1	15.9
Depth (m)	9.5	11.9
Draft (m)	5.4	4.4
LS weight (t)	4755	3780
FL displ (t)	5832	4548
Arrangeable area (m^2)	4730	4933
Hull vol (m^3)	14215	15620
Deckhouse vol (m^3)	4423	3120
Total vol (m^3)	18638	18740

FL: Full Load
LBP: Length Between Perpendiculars
LS: Lightship

Baseline Design Differences

Three major differences in the baseline designs were identified, which would mask the more subtle differences. These were armour protection, manning and accommodation and main propulsion plant. These differences are described below.

Protection

Both ships are designed with equivalent levels of protection against fragmentation damage. Both countries armour combat systems spaces (e.g. magazines, electronics spaces, etc.) There are differences in armour protection policies between the US and the UK (notably the vital space concept), which affect the location, quantity and weight of armour, these differences mean that the armour budgets are not identical between the two ships.

Accommodation

The US baseline carries 290, compared with 220 in the UK baseline. The breakdown of manning for each is shown in TABLE III.

TABLE III—*Comparison of manning*

US BASELINE	*Officers*	*CPO*	*Enlisted*	
			PO	*Non-rate*
Ship's Manning	18	19	153	59
10% Margin	2	2	15	6
Helo Detachment	4	1	0	11
Total	24	22	168	76
UK BASELINE	*Officers*	*Senior Rates*		*JR*
		CPO	*PO*	
Ship's Manning	18	34*	35	80
10% Board Margin	2	3	4	8
7% Advancement Margin (SR)	—	2	2	—
5% Training Margin	1	2	2	4
Helo Detachment	4	1	0	18
Total	25	42	43	110

*Includes 4 Warrant Officers

Both the US and UK put a 10% margin (Board Margin in the UK) on shipboard manning to allow for future growth. The UK has two additional margins, Advancement Margin (to allow for promotions of senior rates during commission) and a Training Margin to allow for midshipmen to be accommodated while under training.

There are many differences in manning policies in the US and UK, as evinced by comparing the ship's complement. Of greatest note is that the UK carries a higher percentage of CPOs than the US (20% of the total crew, v. 7%). Another typical difference includes machinery watchkeeping. A standard UK frigate would have 3 watchkeepers (including 1 roving watch) on each of 4 watches (12 total). A US frigate would have 7 watchstanders on each of 3 shifts (21 total).

Both nations are closely scrutinizing their watchstanding and maintenance policies, in an effort to reduce manning. Any direct policy comparisons, other than this cursory one, would be likely to be outdated in the future.

Propulsion

The US baseline has a single-screw COGAG plant with a CPP propeller, similar to that of the FFG 7. The UK baseline has a twin-screw CODOG plant with two fixed-pitch propellers. This is typical of national policy for frigate designs. Both nations prefer two drive trains for reliability. UK technical policy is that twin screw plants are also inherently more survivable. US technical policy, however, is that unless a twin screw plant has two well-separated engine rooms, the vulnerability is no better than a single screw plant, and that the impact of separated engine rooms is considered too great for a frigate.

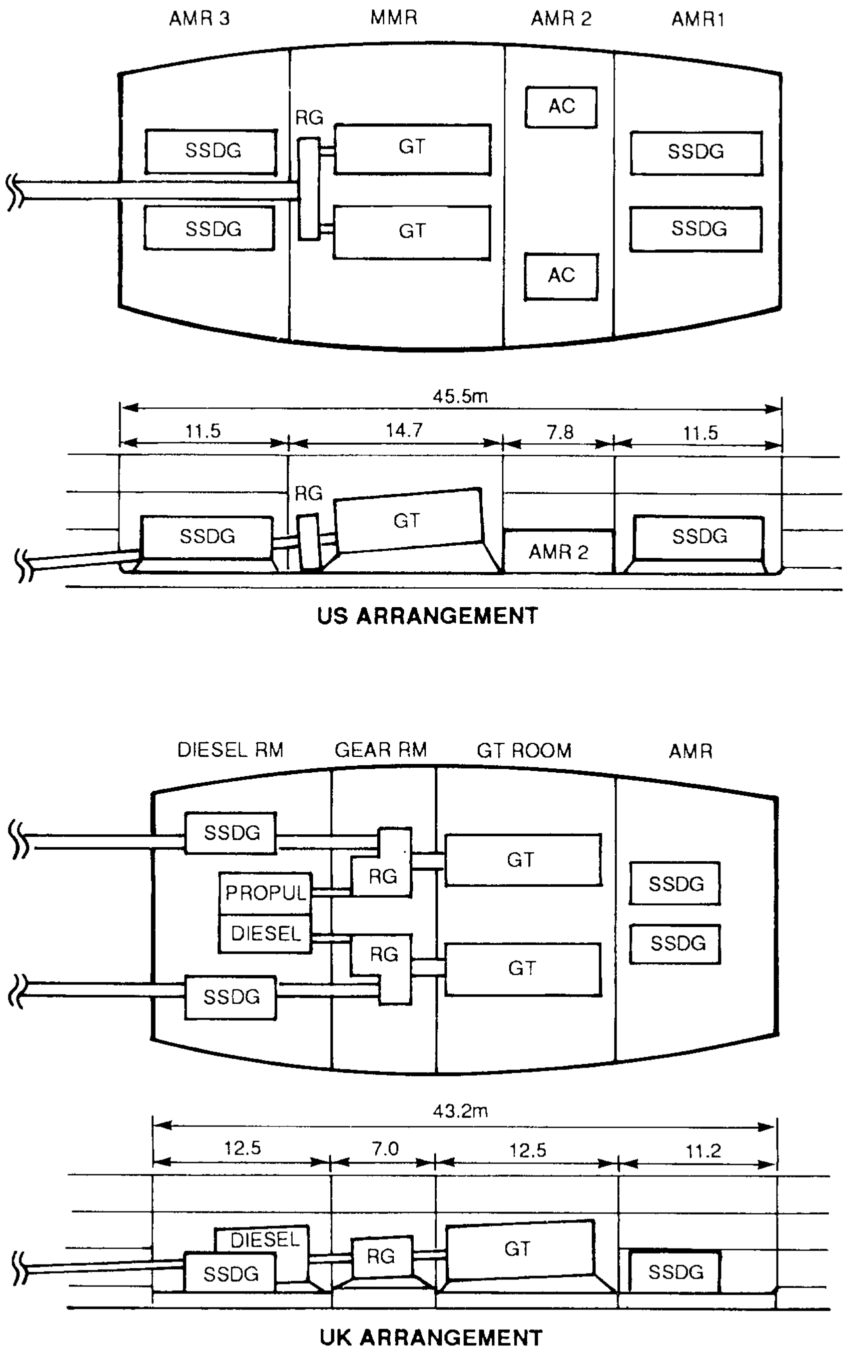


FIG. 2—COMPARISON OF BASELINE MACHINERY ARRANGEMENTS
AC: Air Conditioning Unit
AMR: Auxiliary Machinery Room
GT: Gas Turbine
MMR: Main Machinery Room
RG: Reversing Gearbox
SSDG: Ship's Service Diesel Generator

The US plant has two gas turbines, rated at 19 267 kW each, connected by a single reduction gear to a single 5.2 m diameter controllable pitch propeller. The UK plant has two medium speed diesel engines rated at 4850 kW each for cruise propulsion, and two gas turbines rated at 18 000 kW for boost, connected to two 4.2 m diameter fixed pitch propellers. FIG. 2 compares the two machinery arrangements (including the baseline electrical plants), and TABLE IV shows the difference in propulsion equipment weights. (NB In this and all following tables, weights are expressed in metric tonnes, areas are in square meters, and volumes in cubic meters unless otherwise noted. Some errors are present due to rounding.)

TABLE IV—*Comparison of propulsion plant weights*

Weight Group	*US Baseline Weight*	*UK Baseline Weight*
230 Propulsion Units	48	142
240 Transmission and Propulsor Systems	175	227
250 Propulsion Support Systems	60	66
260 Propulsion Fuel/Lub Systems	20	21
290 Fluids and Repair Parts	35	38
TOTAL	338	494

Development of US Variant Design

The next step was to develop a variant of the US baseline by removing the above differences with the UK ship (which, as stated, would mask subtle differences in design). The US variant was designed with UK protection, manning, and propulsion plant. The general characteristics are compared with the UK baseline in TABLE V.

TABLE V—*Comparison of US Variant with UK Baseline*

	US Variant	*UK Baseline*
LBP	133.0	125.0
Beam	16.1	15.9
Depth	9.5	11.9
Draft	5.1	4.4
LS weight	4740	3780
FL displ	5578	4548
Arrangeable area	4640	4933
Hull vol	14462	15620
Deckhouse vol	4210	3120
Total vol	18672	18740

The US variant is the same length as the US baseline, as this was set in both cases by the minimum required for topside design considerations. The increased propulsion system volume is offset by the reduced volume for accommodations, with the result that US variant has almost identical dimensions to the US baseline. The US variant has a smaller draft than the US baseline, as it displaces 250 tonnes less (mostly in loads). This is due to the smaller manning and to the reduced fuel for the diesel cruise engines (compared with the gas

turbines). The lightship weight drops only 15 tonnes; the reason is that the overall weight decrease for UK protection and manning is offset by the heavier CODOG propulsion plant.
(NB A side study was also conducted, putting US protection, manning and propulsion on the UK baseline. The results were similar.)

DETAILED COMPARISON AND ANALYSIS (PHASE 2)

The UK baseline and the US variant were next taken to a more detailed level of design, to be compared further in Phase 2. Before that could be done, we had to classify the weights and areas in a common system. We then compared the ships in overall terms (size, layout and stability), including an analysis of the US vital space policy. Finally, we conducted a detailed comparison and analysis of the ships and their systems, using the weights and areas as the basis for this phase of the study. All further comparisons are between the UK baseline and US variant, unless noted otherwise.

Translation of NES to SWBS/SSCS

By far one of the most tedious processes in this effort was choosing which classification system (American or British) to use in comparing the results of the study, and then translating from one to the other. The British system for both weights and spaces is contained within the Naval Engineering Standard (NES 163). The American system for weight classification follows the Ship Work Breakdown Structure (SWBS), and for space the Ship Space Classification Systems (SSCS) is used. We decided to use the American systems because of their somewhat greater detail in classifying weights and spaces.

TABLE VI—*NES weight redistribution to SWBS*

Description	*NES Group*	*Weight*	*SWBS Group*	*Weight*
Hull Structure	1	1577	100	1577
Propulsion	2	449	200	494
Electric Plant	3	246	300	256
Comms/Control	4	200	400	191
Auxiliaries	5	325	500	499
Outfit	6	408	600	364
Armament	7	78	700	87
Groups 1-7		3283		3468
Margin		312		312
Loads	8	953	F00	768
Full Load		4548		4548

To our knowledge, a complete translation between NES and SWBS/SSCS had never been undertaken. It involved a very detailed look at what was actually included in each sub-sub-group. For the most part, the weight breakdowns are similar, both NES and SWBS following a 7-section classification. The area classifications are quite different, as NES uses the same 7-section classification as the weight breakdown (hull, propulsion, etc.), while SSCS uses a much different 5-section system (mission support, personnel support, etc.), TABLE VI shows the overall redistribution of NES weights to SWBS for the UK baseline. It should be noted that these translations, while done as carefully as possible, undoubtedly contain errors that may have crept into the detailed comparisons.

General Analysis—Size and Layout

The inboard profiles and plan views of the UK baseline and US variant are shown in FIGS. 3 and 4. The US ship is 8 m longer (LBP) than the UK ship, and 10 m longer overall. This is primarily the result of greater topside length requirements, due to increased overall length of the machinery spaces. In the UK ship, the after generators fit in the after engine room, but in the US ship the larger generators require a second AMR. The resulting uptake arrangements lead to a longer topside length than the UK ship. The US ship is another 2 m longer overall to accommodate the Vertical Replenishment (VERTREP) zone forward of the gun, and the aft open deck mooring area, which are not present on the UK ship. The UK ship is deeper amidships because of the long raised 01 deck, whereas the US ship has a short raised focsle deck forward. These choices do not represent national practice, but are rather the designers' choice for this exercise. The US ship has slightly higher deck heights than the UK ship—2.68 m versus 2.61 m (a 2 inch difference).

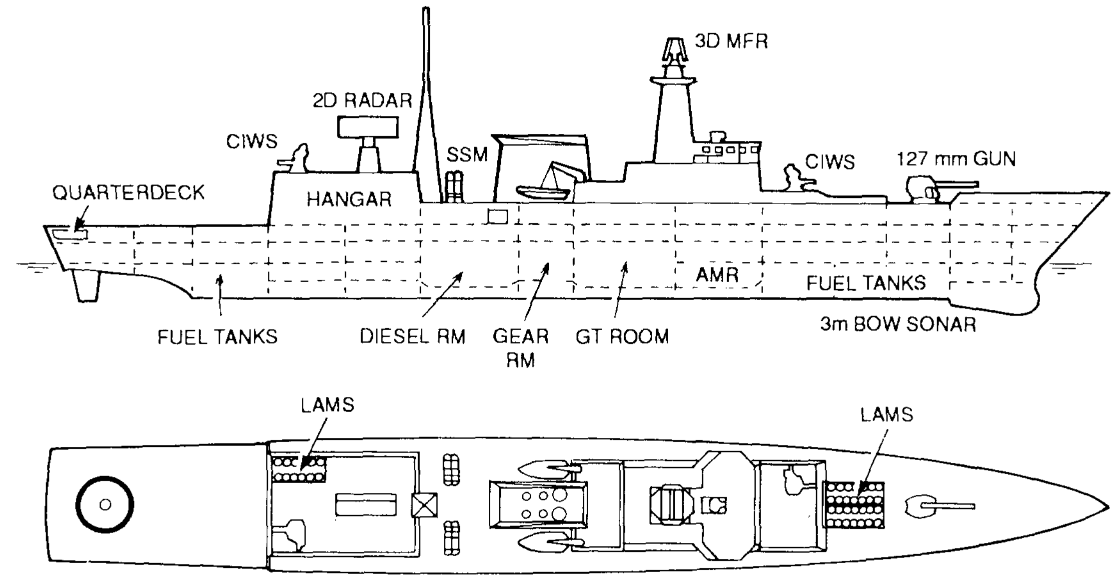


FIG. 3—UK BASELINE (ABBREVIATIONS ARE EXPANDED IN TABLE I)

The UK ship has a collision bulkhead located 9% LBP aft of the forward of it. The collision bulkhead is 5% LBP aft of the FP in the US ship, but no penetrations are allowed through it, so the forward section is void space. The UK ship has more tanks (forward and aft) than the US ship. The US ship has all its fuel tankage in the inner bottom.

The UK design splits the missiles, forward in the hull and aft in the superstructure, to ensure that they are not all destroyed with one hit. US practice is to locate all missiles within the hull for protection, so they are all grouped forward. The UK ship has a quarterdeck located aft under the flight deck, containing the towed decoy and mooring area. This reduces the required topside length. For stability reasons, the US does not do this, instead providing a closed space in the stern for the decoy, and fitting a small mooring area on the main deck aft of the helicopter landing zone.

The beams at the waterline are similar, since stability requirements are akin. The UK hull has a prismatic coefficient of 0.62, and a maximum section coefficient of 0.82; the values for the US ship are, respectively, 0.60 and 0.80

(this is not indicative of any differences in national practice, especially given the very preliminary nature of these studies). The US ship draws more water, primarily because it is heavier, but also because of its slightly finer hull form.

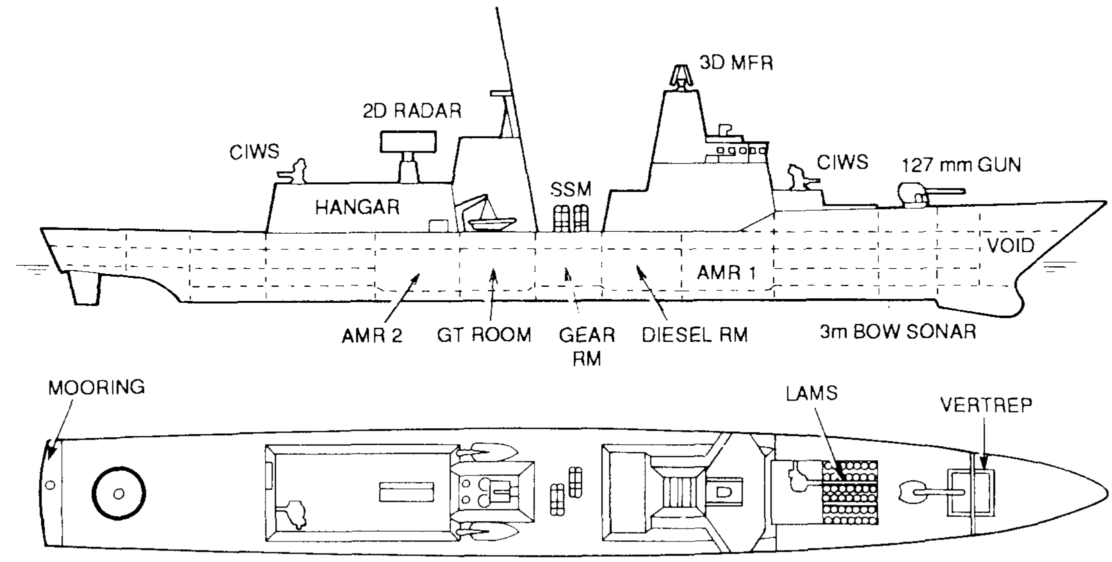


FIG. 4—US VARIANT

General Analysis—Stability

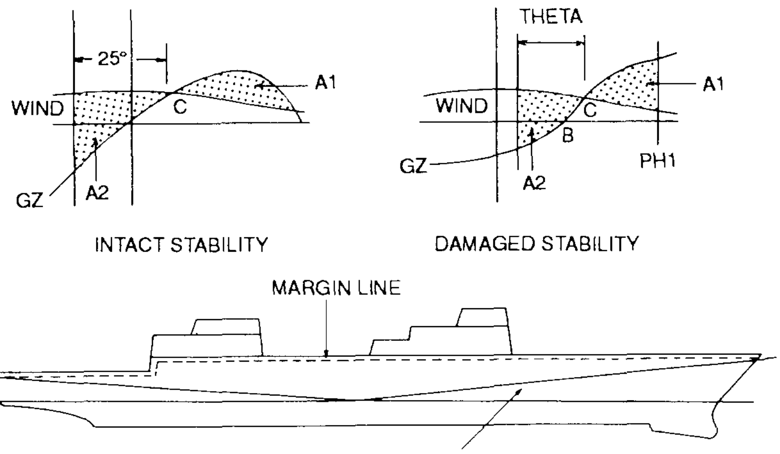
Both nations rely on the stability requirements first set out by Sarchin and Goldberg[3] in 1962.

In the early stage of design, a ratio of metacentric height (GM) to beam is used to ensure that the ship will meet the stability criteria. Both countries intially use a GM/B ratio of between 0.10 to 0.13 for ships with clean ballast systems. A comparison of the stability criteria are shown in TABLE VII (all numbers are given for the end-of-service-life condition for the US design, and a design point usually 10–15 years ahead for the UK design).

One difference between the criteria is that the US uses a 'margin line', defined as a line 8 cm below the weather deck, to determine the maximum allowable trim after damage. The UK does not apply a margin line criterion in defining damaged stability although loss by plunging is investigated. The US policy essentially prohibits an aft mooring area like the UK; any damage aft would trim the ship well above the margin line at the stern.

To determine watertight subdivision, the UK determines the flooding level at particular bulkheads that is produced by either a 30° heel or a 10° trim, while for the US ships it is determined by the combination of damaged trim to margin line, 15° heel, a specified roll—11° for a 5000 tonne ship—and 1.2 m wave height which produce the 'V-lines' used to determine watertight integrity and design head for each bulkhead. The result of the differences between these design criteria are illustrated in FIG 5. The shaded portions represent the assumed flooding due to damage for each ship. The standards of both countries allow non-watertight penetrations above these levels; as can be seen, the US standards permit far fewer non-tight openings for cables, pipes, vent trunks, etc., which also translates to higher weight. It should be noted that the UK criterion for V lines has subsequently altered from that applied here.

TABLE VII—*Comparison of US and UK stability criteria for frigates*



	US	*UK*
	Light Condition (Seagoing)	
Loadout for stability calculations	All crew 1/3 provisions 1/3 stores 1/2 fuel 1/3 ammo	All crew 1/2 provisions 1/10 stores Fuel worst case Ammo worst case
	Intact Stability	
Maximum heel in turns Beam winds (see diagram)	15° 100 knots A1 ≥ 1.4 A2 GZ@C ≤ 0.6 max GZ	20° 90 knots A1 ≥ 1.4 A2 GZ@C ≤ 0.6 max GZ C ≤ 30°
Icing	Determine max. allow. wind with 6″ ice	Max. allow. wind 63 knots with 6″ ice
	Damaged Stability	
Length of opening	15% LBP	15% LBP or 21 m, whichever is greater
Trim after damage	To margin line (see figure)	Not considered
Stability curves	THETA = 10° (for 5000 t ship)	THETA = 15°
(see diagram)	PHI = 45° or downflood angle B (list) < 20° A1 ≥ 1.4 A2	PHI = 45° or downflood angle B (list) < 20° A1 ≥ 1.4 A2 GZ@C ≤ 0.6 max GZ

Vital Spaces

A major difference in philosophy between American and UK warships is the concept of vital spaces. In US parlance, vital spaces are defined as 'those in which continued operation is essential for maintaining ship control, propulsion, communication, seaworthiness and fighting capability'[4]. This concept is separate from 'zoning', which is employed by both the US and the UK. Zones in a ship are the spaces between designated transverse bulkheads, typically three to five zones in a frigate. Each zone has independent Heating, Ventilation and Air Conditioning (HVAC), Collective Protection System (CPS), damage control and egress to the weather deck, they are separated from other zones by watertight, fumetight and fire-resistant bulkheads. A vital space is like a zone within a zone; the vital space is independent of the surrounding zone, being surrounded by tight bulkheads and having emergency access. The intent is that,

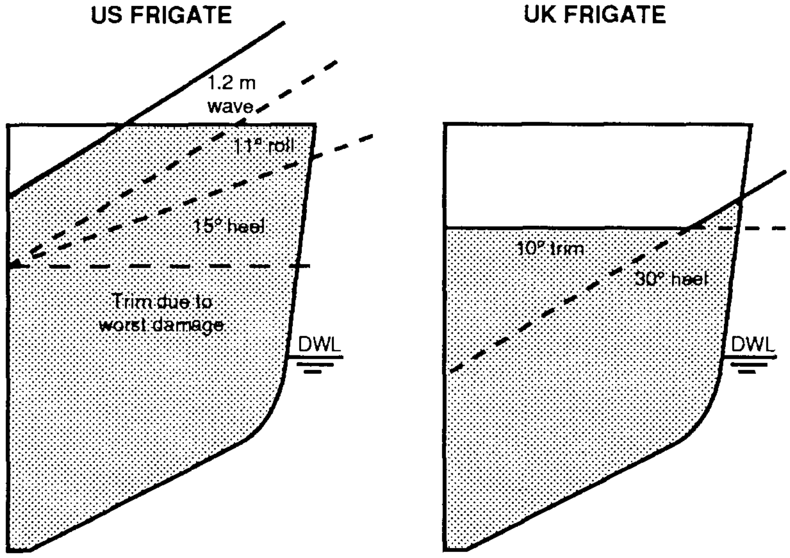


FIG. 5—COMPARISON OF DESIGN FLOODING LEVELS AT BULKHEAD 36 m ABAFT THE FORWARD PERPENDICULAR

even if the rest of the zone is damaged (e.g. by fire), the vital space can continue to function. Examples of vital spaces are: CIC/Ops, radio, radar and IC rooms, magazines, machinery rooms, fan rooms and steering gear rooms.

The concept of vital spaces is not employed in UK ships. The basic philosophy is that the entire zone is a vital space, and that wartime damage will be so extensive within a zone that separate vital spaces will not matter. The impacts of the vital space concept include: increased ballistic protection; more access (including escape trunks); more water/fumetight bulkheads, ventilation closures and insulation; and dedicated cooling for electronic spaces.

Detailed Comparison—Weights

FIG. 6 shows a comparison of the weights. As can be seen, the lion's share of the weight difference is in Group 1 (Structures). By fiat, Groups 2 (Propulsion), 4 (Command and Control) and 7 (Weapons) are the same between the ships; the small differences in Group 4 are due to more cabling in the longer US ship. These groups are therefore not included in the following discussion.

The following comparisons are grouped at the two-digit level, but broken out in more detail to identify particular systems. We did not further investigate systems that showed little or no difference between the US and UK ships (e.g. SWBS 540, Fuel Systems, showed only a 1 tonne, or 2% difference). In this and all following comparisons, positive differences mean that the US value is higher, while negative differences means that the UK value is higher.

Group 1—Structures

The primary differences in structural weights are in the hull girder, bulkheads and trunks, deckhouse and foundations. Differences in inner bottom configurations, as well as other criteria, account for these variations.

Shell, Decks, Platforms (SWBS 110/130/140)

	US wt	UK wt	diff
Hull Girder	1174	926	248

This group, comprising the primary longitudinal hull structure, by far accounts for the greatest difference between the US ship and the UK ship. It is

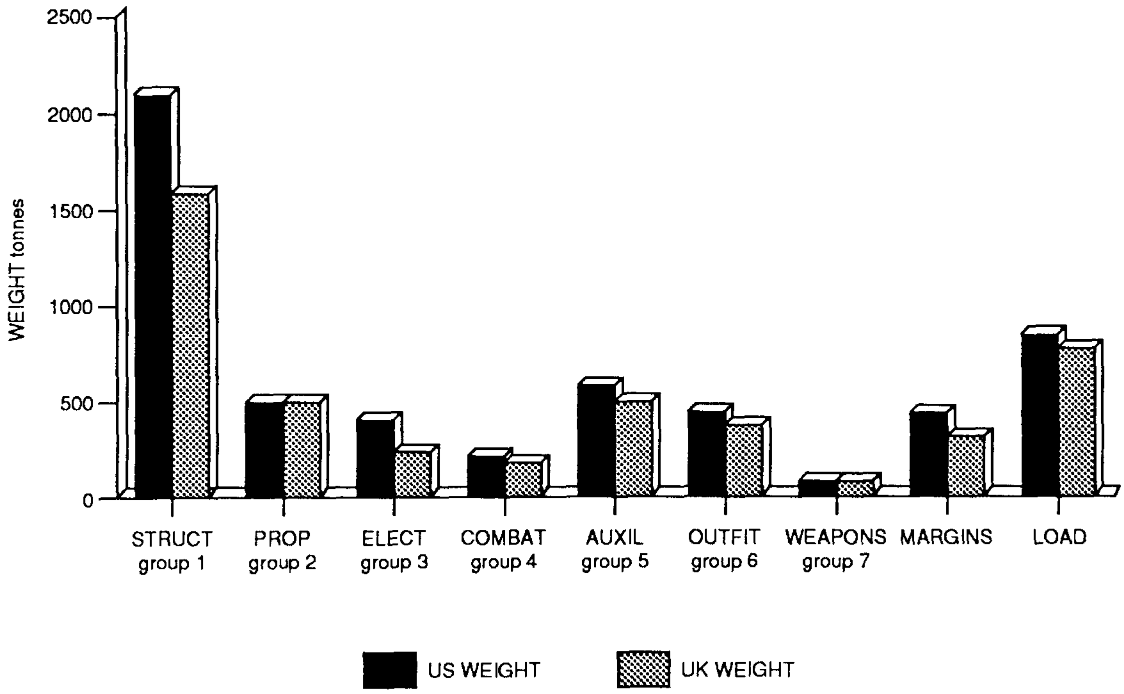


FIG. 6—WEIGHT COMPARISON OF US VARIANT AND UK BASELINE

also one of the most difficult to analyse properly, because of the myriad design factors that go into the design of the ship's hull girder; for example, each country uses different approaches to estimate the bending moment and hull stresses. The US ship is longer and heavier, which increases the bending moment. It is also shallower, which makes for a less efficient girder (however, other studies have shown this does not in fact significantly increase total weight).

To remove the effects of displacement, length and hull depth on the calculations, the US conducted a side study, using the identical hull form as the UK baseline, and estimated a hull girder weight for it based on US practice. For the same 4548 t hull, the US-designed hull girder weighed 196 t or 21% more than the UK's. Next, each country designed a midship section for that hull. The resulting sections near midships are shown in FIG. 7, with a comparison of the particulars given in TABLE VIII.

The US hull girder (including transverse frames) weighs 22% more per unit length than the UK girder. This is mainly due to the more extensive inner bottom of the US ship. For these designs, the extent of the inner bottom is not driven by section modulus requirements (neither ship is even close to the stress limits). It is, rather, a matter of national design practice, and accounts for the bulk of the difference between hull structure weights. The US traditionally uses a wide inner bottom for survivability from underwater damage and more tankage located in unarrangeable spaces, especially under the machinery rooms. UK ships traditionally use deep tanks fore and aft for fuel and ballast, and have rather narrow inner bottoms.

TABLE VIII—*Comparison of US and UK midship sections*

	US Midship	*UK Midship*
Design Bending Moment	260 MN-m	313 MN-m
Max. Primary Stress	80 MPa	120 MPa
Frame Spacing	2.4 m	1.0 m
Moment of Inertia	20.8 m^4	16.9 m^4
NA height above keel	6.3 m	5.4 m
Midship weight/length	9120 kg/m	7465 kg/m

In the course of our research, we uncovered many other differences between the structural design practices and standards of the two countries. They do not appear to contribute much to the hull girder weight differences, but are noteworthy just the same. We must emphasize that these standards based on historical information dating back as much as 30 years. Design criteria change, and this paper does not assume that they will be the same in the future.

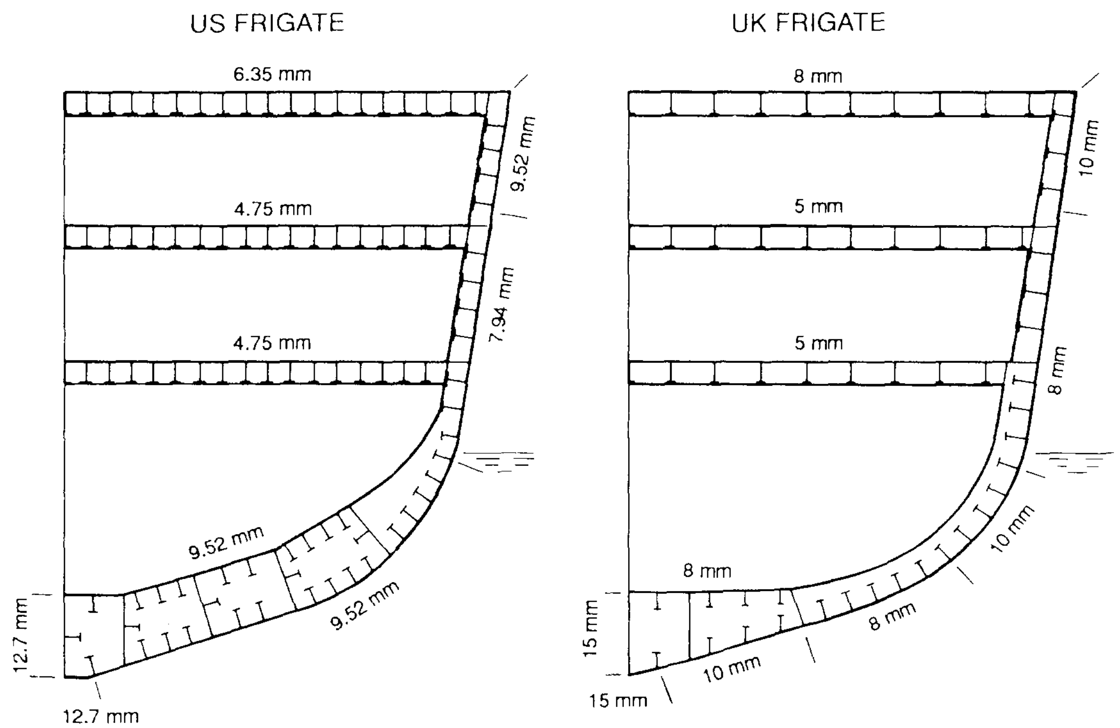


FIG. 7—COMPARISON OF US AND UK SECTIONS NEAR MIDSHIPS (IDENTICAL HULLS)

Midship Bending Moment Calculation. This usually involves static balance on a wave. In the US, the wave height used is $0.607\sqrt{\text{LBP}}$, which for a 125 m ship is a 6.8 m wave. In the UK, the wave height is now taken as a constant 8 m, which is based on empirical observations of real waves of frigate length (100–200 m). The total bending moment is calculated as sum of the static plus wave-induced moments; however, the wave-induced moment is multiplied by 1.4, based on safety factors derived from experience, and to allow for slamming loads. (The UK has also used probability-based methods to derive hull girder strength). In this design, the UK design bending moment is 20% higher than for the US.

Design Service Life and Allowances. The estimated life of a US warship is about 30 years, while the UK often designs for 25 years. The fatigue loading on the hull girder is not usually calculated explicitly during design, but its effects are accounted for in the detailed design practices and allowable stress limits.

Hull Material. The US uses High-Strength Steel (HSS), with a yield of 351 MPa. The UK uses B-quality steel, similar to HSS but with a yield of 310 MPa. One major difference is that the US uses HY-80 (yield = 550 MPa) at the upper side shell, deck edge and at the turn of the bilge as a crack arrestor, as it does not consider HSS to be tough enough to stop cracks from spreading around a hull section. The UK does not follow that practice.