UK AND US FRIGATE DESIGN A COMPARATIVE STUDY

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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	*ASW Mission*
3D Multifunction Radar	Bow Sonar
2D Air Search Radar	Towed Array (space only)
Local Area Missile System	1 ASW Helicopter
2 Close-In Weapons Systems	Magazine Torpedo Launcher
Electronic Warfare/Decoys	Towed Decoy
ASUW Mission	*Other*
Surface-to-Surface Missiles	Operations Room (CIC)
127 mm Gun	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.

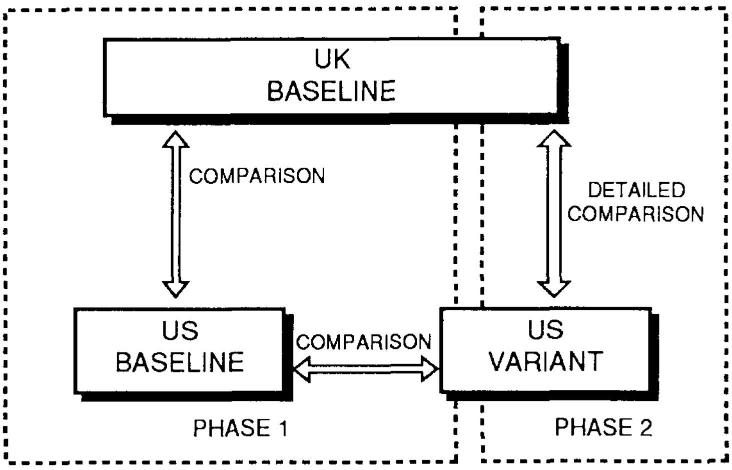


FIG. 1—STUDY METHODOLOGY

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.

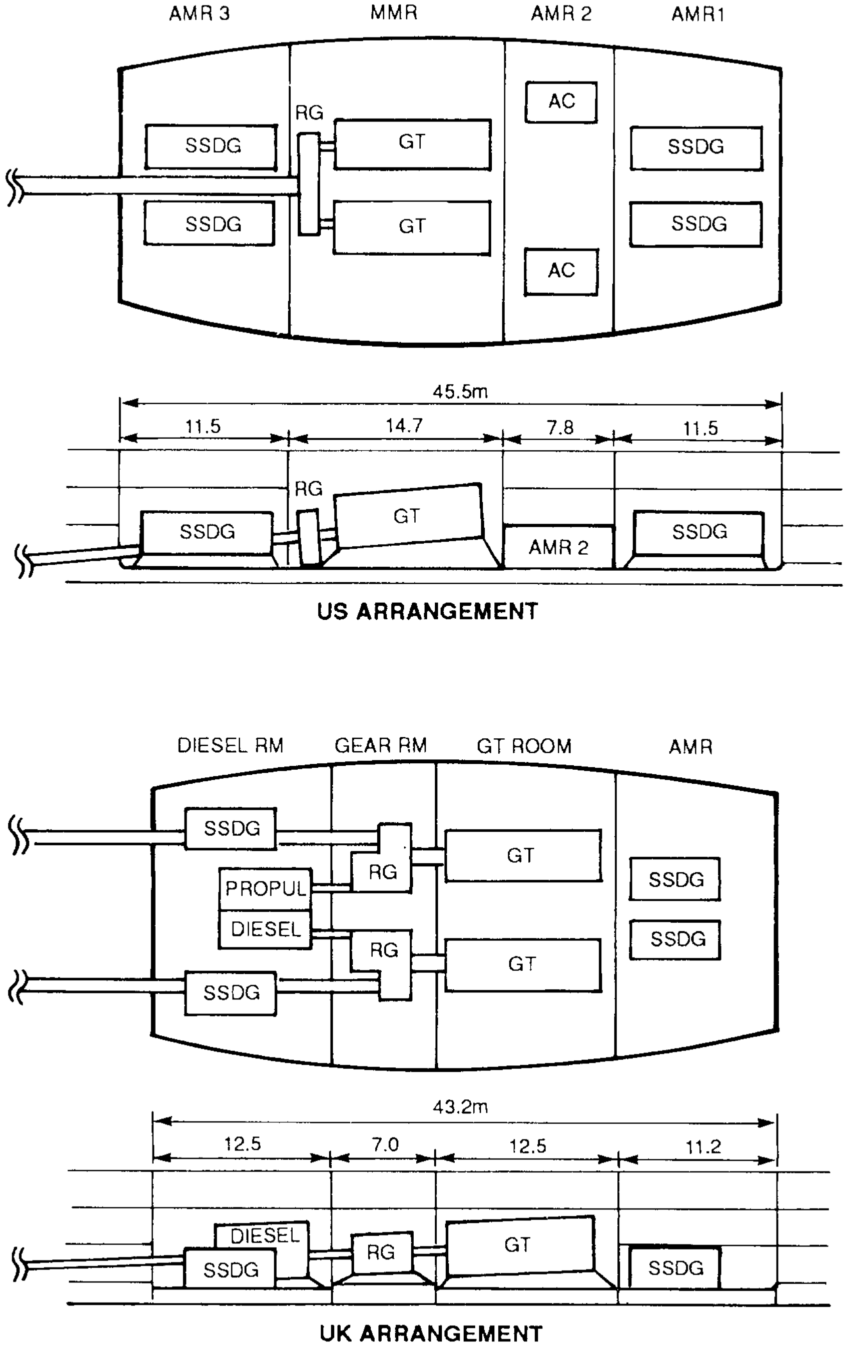


FIG. 2—COMPARISON OF BASELINE MACHINERY ARRANGEMENTS
AC: Air Conditioning Unit
AMR: Auxiliary Machinery Room
GT: Gas Turbine
MMR: Main Machinery Room
RG: Reversing Gearbox
SSDG: Ship's Service Diesel Generator

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).

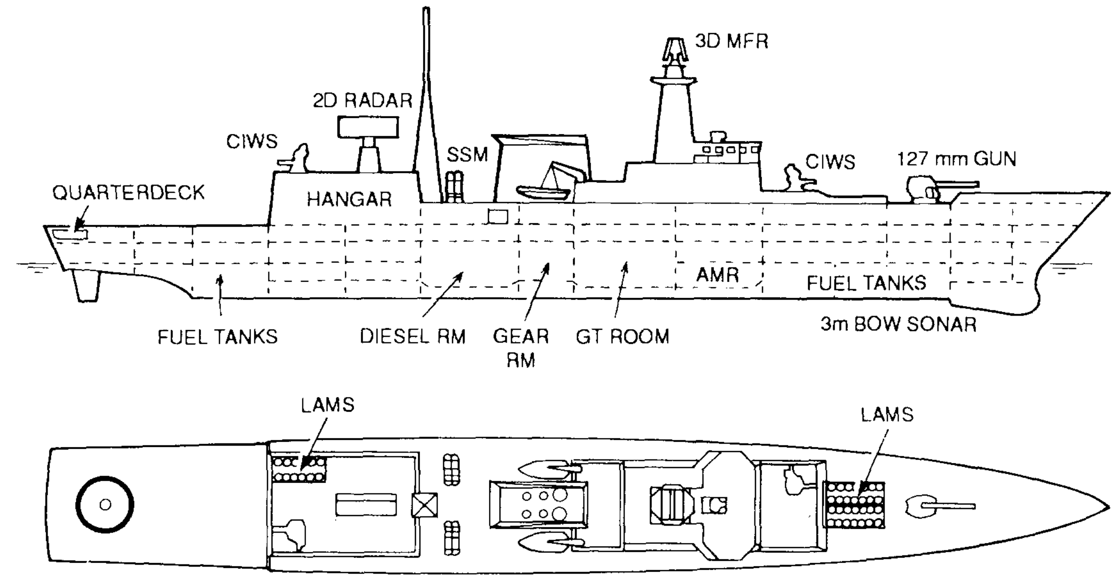


FIG. 3—UK BASELINE (ABBREVIATIONS ARE EXPANDED IN TABLE I)

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.

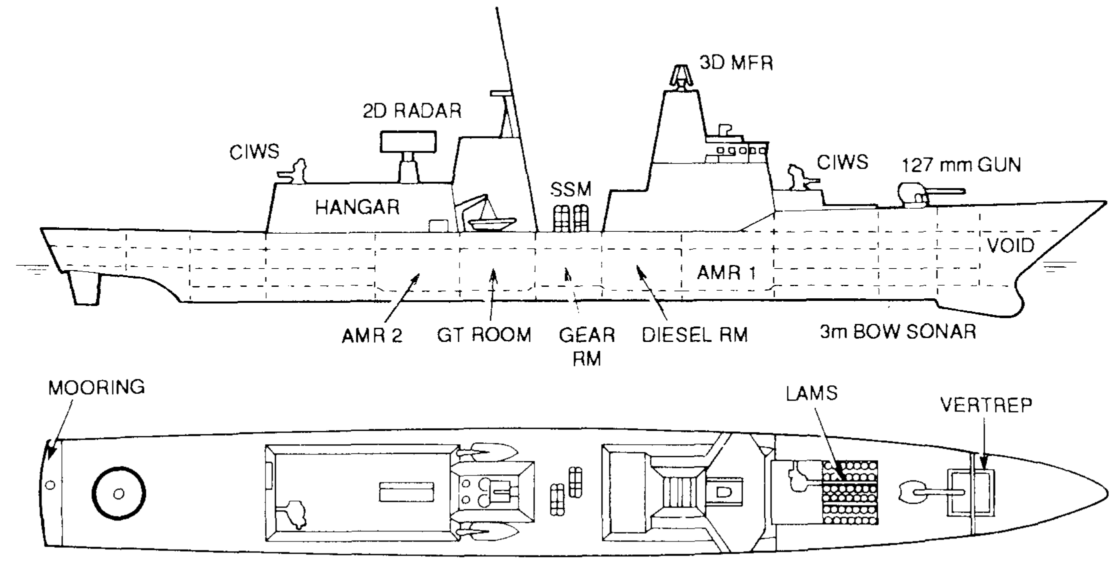


FIG. 4—US VARIANT

General Analysis—Stability

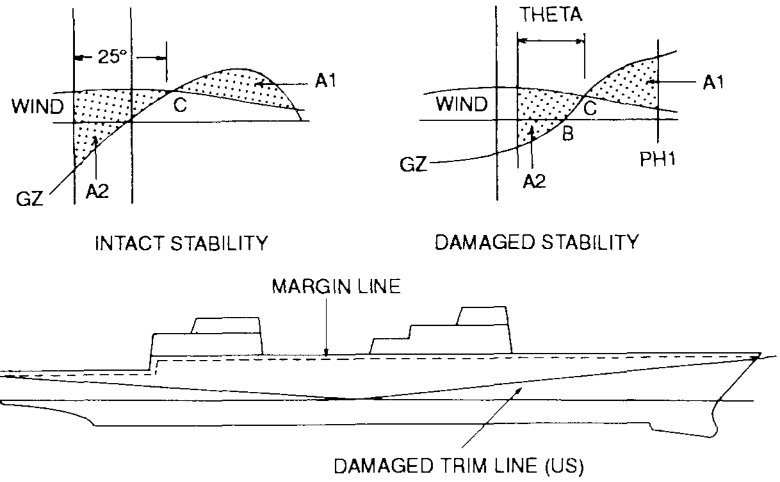
Both nations rely on the stability requirements first set out by Sarchin and Goldberg[3] in 1962.

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	15°	20°
Beam winds (see diagram)	100 knots A1 ≥ 1.4 A2 GZ@C ≤ 0.6 max GZ	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,

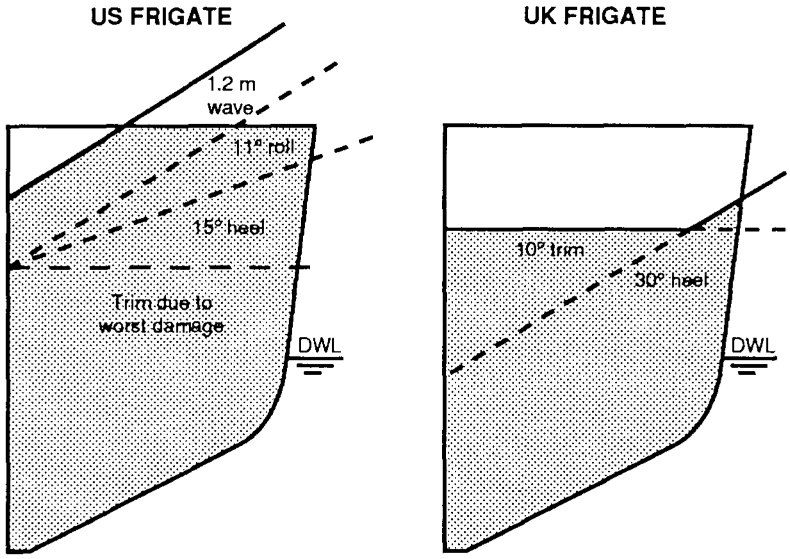


FIG. 5—COMPARISON OF DESIGN FLOODING LEVELS AT BULKHEAD 36 m ABAFT THE FORWARD PERPENDICULAR

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

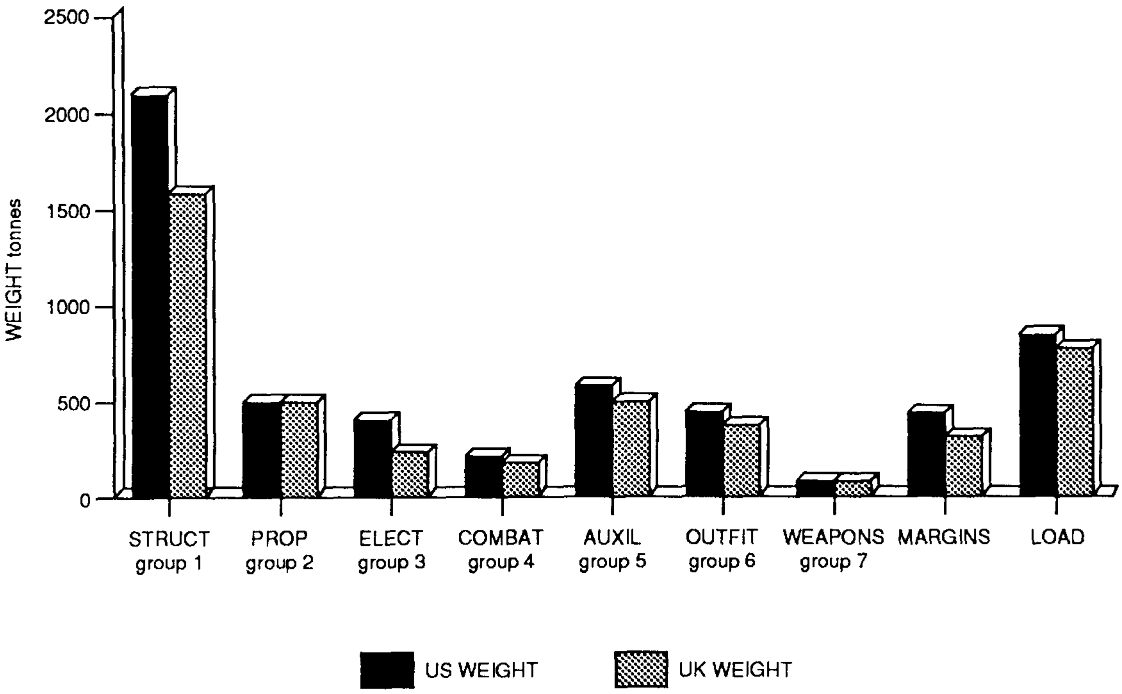


FIG. 6—WEIGHT COMPARISON OF US VARIANT AND UK BASELINE

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.

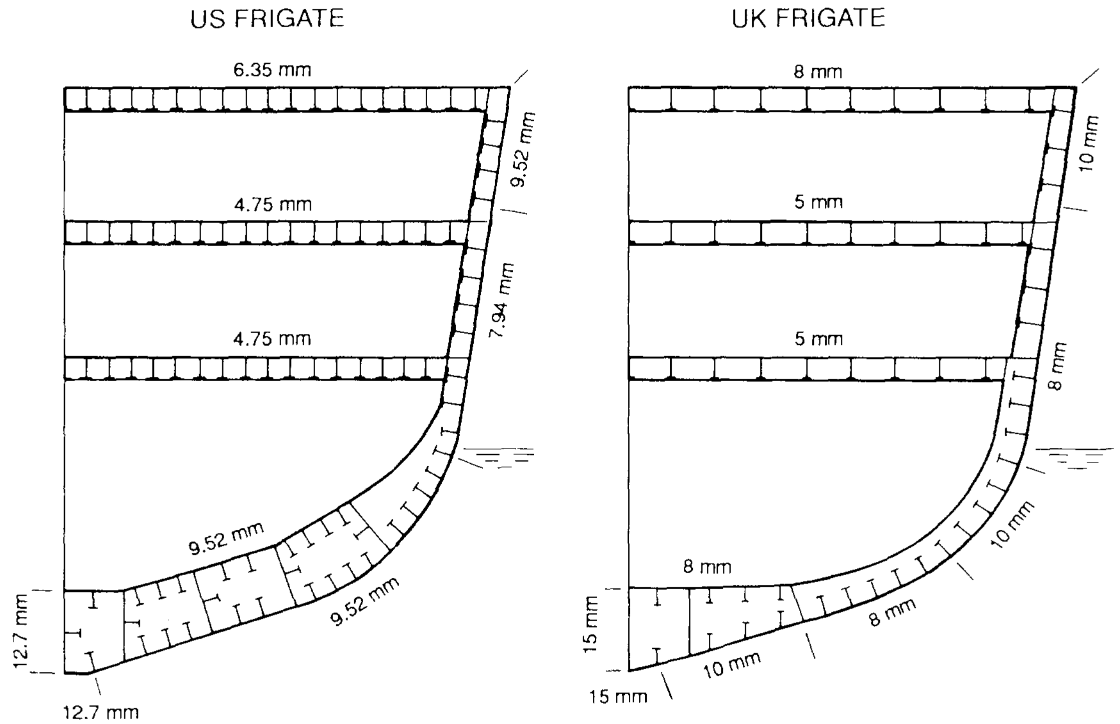


FIG. 7—COMPARISON OF US AND UK SECTIONS NEAR MIDSHIPS (IDENTICAL HULLS)

Midship Bending Moment Calculation. This usually involves static balance on a wave. In the US, the wave height used is 0.607 $\sqrt{LBP}$, 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.

Allowable Stress. A major difference is that the US allowable primary stress is lower than the UK, because the US combines primary and secondary stresses, where the UK assumes they act separately*. The US allowable primary stress for HSS is 146 MPa, which is 40% of the yield strength, and the total allowable tensile stress—primary plus secondary—is 276 MPa, or about 80% of yield (and somewhat less for compression). The UK allowable primary stress for B-quality steel is 240 MPa in tension and 210 MPa in compression, or between 70% and 80% of yield. Since the stresses are not combined, this is also equivalent to the total allowable stress. As can be seen in TABLE VIII, neither design is dominated by hull bending; in both cases the primary stresses fall well below the maximum allowable. The governing criteria for structural design are local loads, hydrostatic loads and minimum plating thickness for ruggedness and corrosion.

Deckhouse Contribution to Longitudinal Strength. Although not done for this study, common UK practice is to allow the deckhouse at least to partially contribute to longitudinal strength; depending on the design, it could be considered between 50% and 80% effective. This serves to increase the hull moment of inertia and reduce the hull girder stress (10–20%, depending on the configuration). The US practice is to not make allowances for the contribution of the deckhouse to longitudinal strength; any contribution is considered as design reserve. Both countries design their deckhouses to resist bending loads imposed by the hull.

TABLE IX—*Additional weight of US Variant hull structure, compared with UK Baseline*

Hull structure of UK baseline	926	
US framing	+ 46	(+ 5%)
More extensive inner bottom	+ 150	(+ 16%)
Hull structure for bigger ship	+ 52	(+ 6%)
Hull structure of US variant	1174	

In summary, for the same size ship, a US hull girder will be heavier than a UK one primarily because it uses a more extensive inner bottom structure. The hull structure of the US variant also weighs more because the ship itself is longer and heavier. This is recapped in TABLE IX.

Hull Structural Bulkheads (SWBS 120)

	US wt	UK wt	diff
Longitudinal Bulkheads	86	63	23
Transverse Bulkheads	108	89	19
Trunks and Enclosures	38	6	32

On a hull density basis (t/m^3) the bulkheads in the US ship are 30% denser than in the UK ship. As each bulkhead type serves different functions, the reasons between US and UK practices are proposed in the following paragraphs.

Longitudinal bulkheads provide hull stiffening, and act as deep tank and vital space boundaries. Typically, US warships have a pair of longitudinal bulkheads, extending from the weather deck to the inner bottom and running between the after engine room bulkhead and the transom to stiffen the structure

*Primary stress is from hull bending. Secondary stresses are due to local, sea and weather loads.

against propeller-induced vibration and to support the aft end against overhanging loads in drydock (they also provide reserve strength after damage). The UK designs tend to avoid the use of longitudinal bulkheads; the stern structure is designed for and checked against propeller-induced vibrations and overhanging docking loads. This appears to be a difference in design philosophy rather than in requirements; however, the difference between vibration levels in US and UK ships has not been determined, and we could not compare drydock stress calculations. Transverse bulkheads divide the ship into watertight compartments, provide transverse strength for the hull girder and are generally sized to resist lateral hydrostatic loads. The design flooding head for US ships are generally more severe than for UK ships, similar to that shown in FIG. 5. The design standards of both nations allow for some plasticity of plates under severe loading, while keeping the stiffeners within the elastic region.

The use of vital spaces in US ships also accounts for some of the higher longitudinal and transverse bulkhead weights. Since vital spaces must be watertight and fumetight, they are surrounded by structural rather than joiner bulkheads.

The difference in the number and type of trunks and therefore the weights, is explained by several factors:

(*a*) The US requires at least one escape trunk from the lowest level of each machinery space (to get below a fire) to the damage control deck, whereas the UK requires emergency escape hatches in the machinery overheads to the next deck.

(*b*) In US ships, manned vital spaces below the damage control deck require access to trunks to that deck.

(*c*) The US has a more extensive stores and ammo strikedown system than the UK, which require separate package conveyor trunks and ammo strikedown trunks.

(*d*) The US underway replenishment (UNREP) system uses sliding padeyes that retract into trunks below decks, where the UK uses bulkhead-mounted ones.

Deckhouse Structure (SWBS 150)

	US wt	UK wt	diff
Deckhouse Structure	269	163	106

Both the US and the UK use steel deckhouses; while this has been the norm in the UK for many years, it represents a considerable change for the US, which for 30 years has used aluminium as a means of saving weight (it may be worthwhile to note that the reason for switching back to steel had less to do with fire protection than with maintenance, i.e. less cracking). For the purpose of this study, neither ship was designed to withstand high blast overpressure.

The difference between the SWBS 150 weights is somewhat deceptive, since the US ship has a 35% larger deckhouse. A comparison of densities shows that the deckhouse of the US frigate is 22% denser than that of the UK ship. The UK actually uses higher deckhouse design loads than the US, although minimum scantlings in both countries are usually dictated by ruggedness and construction considerations. The reasons for the heavier deckhouse structure of the US ship are by no means clear; we have pursued several possible explanations, but have not yet arrived at a satisfactory answer.

Group 3—Electric Plant

The primary differences in electric plant weights are in the generator and support systems. This is due to the use of medium-speed diesel generators by the US, compared with smaller higher-speed units used in the UK.

Ship Service Generators and Support (SWBS 310/340)

	US wt	UK wt	diff
Main Generator & Support	270	129	141
Emergency Generators	0	5	−5
Batteries	2	1	1
Power Conversions	18	17	1

Both the US and the UK have four 1200 kW diesel generators, in two sets of two separated for survivability. The US ship is designed to accommodate medium-speed DG sets, while the UK ship is designed for the higher-speed DG sets normally selected for use in UK combatants. This is the reason for most of the difference in electrical plant weight. Medium-speed DGs are much heavier than the equivalent higher-speed sets, and require much bigger mufflers, lub oil and jacket water systems; they are also considerably larger, as shown in FIG. 8. Comparing the US variant with the UK baseline, use of medium-speed DGs require a longer, deeper AMR forward and a separate AMR aft (the aft DGs in the UK ship fit into the diesel machinery room); this had a great impact on ship arrangements, and was in fact a major reason that the US ship was longer than the UK one.

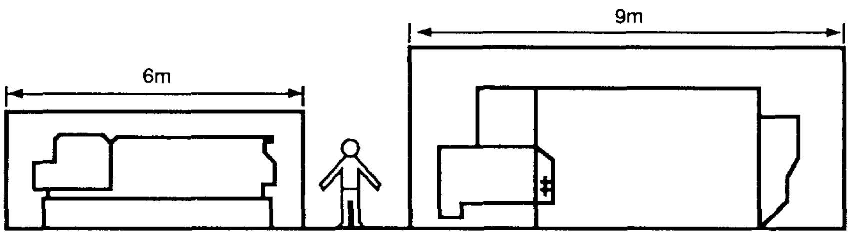


FIG. 8—COMPARISON OF UK AND US GENERATORS

The US, of course, tries to buy American, and many of the US Navy-qualified generator sets are medium-speed (the US Navy had problems with some high-speed generators, so leans towards medium-speed sets). They are typically found in US submarines, amphibious vessels and auxiliaries. The UK has used British-built, Royal Navy-qualified higher-speed generator sets for many years.

The UK ship has a 250 kW salvage generator for in-port and emergency use. This provides enough power for submersible pumps and emergency lighting. The US does not generally fit emergency generators except in nuclear and steam ships. The difference in battery weight is due to the batteries carried by US ships for stores pallet trucks. Both ships have equivalent uninterruptible power supplies and solid-state frequency converters for 400 Hz loads.

Group 5—Auxiliary Systems

The primary auxiliary systems differences are in the air conditioning system, firemain and firefighting systems, and replenishment systems.

Climate Control (SWBS 510)

	US wt	UK wt	diff
Compartment Heating	7	4	3
Ventilation	46	41	5
Machinery Ventilation	28	23	5
Air Conditioning	61	38	23
Refrigeration	3	2	1

Both ships use a full-time air filtration and pressurization system to defend against contamination from nuclear, biological and chemical warfare. This is called the Collective Protection System (CPS) in the US, and Citadel in the UK. It should be noted that, where the UK has had Citadel for some time, the US is only now putting it in its ships. However, the UK until recently used only a part-time system; a proposed full-time system, under the name Total Atmospheric Control System (TACS), is in many ways similar to the US CPS (e.g. both operate full-time at an overpressure of 0.005 bar).

Some of the differences in climate control systems are due to the differences in required ambient air and sea conditions, and compartment conditions, as shown in TABLE X.

TABLE X—*Comparison of HVAC criteria*[5,6]

	US	*UK*
Heating		
Min air temp	−12°C	−10°C
Sea temp	− 2°C	+ 1°C
Compartment DB	18°C	18°C
Ventilation		
Replen. rate (m^3/man/sec)	0.0024	0.0025
Air Conditioning		
Max air temp DB	32°C	31°C
Max air temp WB	27°C	26°C
Sea temp	29°C	30°C
Compartment DB	27°C	29°C
Compartment RH	55%	50%

Although CPS and TACS are in many ways similar, there are differences in basic design philosophy that account for these variations:

(*a*) The UK TACS recirculates the internal air much more than the US CPS. This reduces the heating load (and thus the heating system weight). This also increases the air conditioning load, but the required compartment temperature for the UK is higher.

(*b*) US vital spaces (e.g. communications, CIC/Ops, and machinery spaces) must have their own independent source of air. This increases both the cooling loads and the number of fan rooms. These spaces in UK ships receive air in common with the rest of the zone; the machinery spaces, although a separate zone, receive air from the rest of the ship (it is the last point before the air is dumped back into the atmosphere).

(*c*) The ventilation ducting must be watertight when passing through main bulkheads. The US V-lines are more stringent compared with the UK criteria (see FIG. 5), so there are more watertight penetrations, which increases the weight.

(*d*) Both ships have three air conditioning plants, and have the ability to run with one down. The UK ship has three 370 kW plants, while the US has three 530 kW plants, or 40% more A/C and electronics cooling. The reason for the difference in capacity is that the US typically puts more margin in its A/C plant design to allow for future growth (US ships typically receive more through-life combat system upgrades than UK ships).

Sea Water Systems (SWBS 520)

	US wt	UK wt	diff
Firemain & Flushing	83	58	25
Countermeasures Washdown	2	2	0

Both ships have five main pumps (one per zone). The US typically uses a vertical offset loop firemain, that is, one side of the loop is on the main deck, the other two decks below. The UK system is a horizontal loop (i.e. both sides are on the main deck) with a third line near the keel on the centreline. Extensive cross-connection of the system is common to both navies.

The US sizes the system to handle the single largest hazard on the ship (usually a magazine fire) plus continuous cooling loads and dewatering, with 25% of the firepumps inoperable (i.e. three of five working). The UK sizes the system based on fighting a major internal fire and a flight deck fire, plus vital cooling loads and dewatering, using all pumps on line. Normal cooling and flushing loads can be handled on two of the five pumps. The actual firefighting loads are equivalent; however, the US requirement to handle it with three rather than all five pumps means that each pump must have about 66% more capacity.

In fact, both navies have adopted standard pump sizes to meet these requirements, and this drives the actual system size. The standard pump size in the US Navy is 230 t/hr, while the standard for the Royal Navy is 150 t/hr, the total capacity of the firemain system in the US ship is 1150 t/hr and in the UK ship it is 750 t/hr.

Air and Gas Systems (SWBS 550)

	US wt	UK wt	diff
Compressed Air System	38	30	8
Fire Extinguishing	18	8	10

The main difference in compressed air systems lies in the Masker air belt system, which both countries fit around the machinery spaces to mask radiated noise. The US machinery box is longer, so requires a larger system. Both countries have propeller noise-masking (Prairie in the US, Agouti in the UK).

The fire extinguishing systems differ in that the US tends to have a much more extensive fixed firefighting system. The breakdown of the system is shown in TABLE XI.

TABLE XI—*Comparison of US and and UK firefighting system weights*

	US Weight	*UK Weight*
Halon	7	3
AFFF	10	4
CO_2	1	1

Both ships have Halon fitted in the main and auxiliary machinery spaces. The US, however, also fits it in flammable and paint stores, aviation fuel pump rooms, and the towed array compartment. Both ships have fixed, cross-connected AFFF (Aqueous Film-Forming Foam) in machinery spaces, but the US also fits AFFF in the helo hangar, flight deck, and pump rooms.

Ship Control Systems (SWBS 560)

	US wt	UK wt	diff
Steering Control	16	14	2
Rudder	32	26	6
Fin Stabilizers	22	18	4

Neither country has a precise analytical method of determining rudder size; rather, they size it as a percentage of the underwater lateral area, and use model tests to ensure that the ship is directionally stable with rudders fixed, and that it meets the manoeuvring requirements. These requirements are in fact similar between both countries. However, US rudders are larger for the same immersed lateral area, some 3.25% of that area, while the UK rudders are about 2.7%. The reason for this difference is not entirely clear, given similar requirements. However, this trend is historically evident in both US and UK ships, regardless of factors such as sonar dome size and location, propeller diameter, etc. that would logically affect rudder size. It would appear that, for both countries, the choice of rudder size is based on what has worked in the past.

Replenishment Systems (SWBS 570)

	US wt	UK wt	diff
Replenishment At Sea	12	8	4
Stores Handling	7	0	7

The total US replenishment and strikedown system weighs almost twice that of the UK. The replenishment-at-sea system includes both fuelling-at-sea (FAS) and stores/ammo replenishment. Both ships have three stations port and starboard for fuelling-at-sea and solid replenishment using fixed bulkhead-mounted padeyes. However, the US ship has a retractable sliding kingpost, for bringing over heavy loads such as missiles in high sea states. The US ship also has a forward VERTREP station for bringing ammunition and stores via helicopter. This does not add directly to the weight, but does affect topside length requirements. The UK stores-handling weight is zero (this does not include weapons handling) because:

(*a*) stores are manually handled on deck, and struck down by hand through existing hatches; and

(*b*) the food stores are on the same deck as the galley, so no hoist is needed.

The US ship, on the other hand, makes extensive use of electric pallet trucks for handling stores on deck, and has dedicated strikedown conveyors and trunks for bringing foodstuffs below.

In summary, the US ship has a more comprehensive replenishment and strikedown system than the UK ship. As will be addressed later, this is a result of the greater dependence of US warships on their Navy's logistic support system.

Mechanical Handling Systems (SWBS 580)

	US wt	UK wt	diff
Anchor Handling	39	29	10
Mooring and Towing	8	9	-1
Boat Handling	14	16	-2
Aircraft Handling	28	28	0

The largest difference is in the anchor handling system. The US requirement is to hold the ship in 73 m of water with a 70 knot wind and 4 knot current. The UK requirement is to hold the ship in 60 m of water with a 55 knot wind and 4 knot current.

Both ships carry two rigid inflatable boats (RIBs) with slewing arm davits, which replace older, more cumbersome motor whaleboats. Helicopter handling is by fiat identical; in fact, the US normally uses a helo haul-down and traversing system (RAST) while the UK uses a deck lock and traversing system (Harpoon) with no haul-down.

Group 6—Outfit and Furnishings

The primary differences here are in bulkheads and floor coverings, insulation and damping, and stowage.

Hull Compartmentation (SWBS 620)

	US wt	UK wt	diff
Non-Struct Bhds Sheathing	55	30	25
Floor Plates and Gratings	40	27	13
Ladders	7	5	2
Airports and Windows	1	1	0

The US ship has twin outboard passageways versus the single one on centreline in the UK ship, as well as having interconnecting passages athwartships. Therefore, there are more compartments bounded by passages in the US ship, which requires more non-structural bulkheads. As we could not separate out the weights of sheathing at this stage of design, we were unable to determine how they compared.

Both countries have gratings in the machinery rooms, but the US also makes extensive use of gratings in stores areas, steering gear rooms and pump rooms to cover pipes and other protrusions. The false floors are found in the CIC/Ops space and external communications in both navy's ships, but in the US ships they are also in the computer, radar and IC/gyro rooms as well as in machinery control.

Preservatives and Coverings (SWBS 630)

	US wt	UK wt	diff
Painting	33	30	3
Cathodic Protection	1	1	0
Deck Covering	27	40	-13
Hull Insulation & Damping	97	67	30

The difference in deck covering weight is attributable to:

(*a*) differences in naval shipbuilding standards—the allowable deck distortion in UK ships is 9 mm, versus 6 mm for US ships, so more fill-in is required;

(*b*) non-skid paint is generally used on all exposed decks of UK ships, whereas the US ships generally have it applied around high-traffic areas and in specific walkways on deck.

Another difference (more in comfort than in weight) is that, while the US only allows carpeting in CO and XO quarters, wardroom and CPO lounge, the UK allows it in all officers quarters, CPO and PO quarters, wardroom and all recreation spaces.

The weights of insulation include acoustic, fire, and thermal insulation. In fact it is difficult to sort out which is which (as a good design combines the properties when possible), but the following differences in design practices explain the difference in weights:

(*a*) *Acoustic*. Machinery space noise requirements are more stringent for the US: 84 dB versus 90 dB for the UK.

(*b*) *Fire*. Both ships have 25 mm of fire insulation at the fire zone bulkheads, but vital spaces in US ships also have the same thickness insulation around them. UK ships do not employ the vital space concept.

(*c*) *Thermal*. US standards specify about twice the thickness of thermal insulation at the boundaries than UK standards.

Stowage Spaces (SWBS 670)

	US wt	UK wt	diff
Stowage Aids	52	35	17

Although the UK ship carries more stores, the additional material does not need extensive stowage aids. The US uses large modular cabinets to stow spare parts (generally small electronics), while the UK uses rather lighter racks and bins.

Special Purpose Systems (SWBS 690)

	US wt	UK wt	diff
Spares Repair Parts (Total)	32	65	-33

The total amount of spares and repair parts (from SWBS group 2–6) is shown here because the level of detail at this stage of design does not permit comparing specific parts between countries. The US counts the spares in the lightship weight, and they are therefore taken into account in applying margins. The UK considers them to be load items, so they are not margined.

The UK carries double the weight of spares and repair parts that the US does. Electronics spares typically comprise 85% of the on-board spares for US ships, which are fairly light; UK ships carry comparatively more main machinery and damage control spares than the US, and these are bulky and heavy (plate metal, pipe, main engine parts, etc). The US combatants depend on their fleet of supply and repair ships for such items. The US Navy logistics network is much larger than that of the Royal Navy; for example, in 1987 there were 9 destroyer tenders in the US fleet, compared with 1 in the UK fleet[7].

UK warships are, on the whole, more self-sufficient than the US ships; in other words, they carry more stores, more spare parts and have less capability for replenishment at sea than US ships. The US logistics force is the largest in the world, and the US warships depend on this system during their long deployments. The UK Navy role does not require it to maintain the same level of global presence, so its logistics force is correspondingly smaller; to compensate, its ships must be more self-sufficient. A prime example of this is the fact that the INVINCIBLE Class VSTOL carriers are fitted with a spare main engine in each machinery space, and can replace the engine at sea unaided (which has been done). No US warship has this kind of capability.

Design Margin and Service Life Growth

'Design margin' here refers to the anticipated increase in weight and vertical centre of gravity (VCG) during acquisition design and construction. 'Service life growth' is the allowance made after the ship is completed for through-life weight/VCG increase. In reporting the displacement of a new ship, only the design margin is included.

Lightship Margin

	US wt	UK wt	diff
Lightship Margin	431	312	119

For this study, the US designer used a 10% margin on lightship weight, while the UK designer used 9.5%. However, as noted, neither system fluids nor spares (total 166 t) are included in the UK lightship weight, but they are for the US ship. Therefore, the US ship carries about 17 t more margin for the same weight. The rest of the difference is due to the much heavier lightship weight of the US ship.

The US design policy is to allow an 8% margin on vertical moment to account for VCG growth. This is accounted for in the UK design by applying the weight margin at 1 m above the weather deck.

The US Navy has a blanket policy that allows for through-life growth of 10% of the full load, with a 0.33 m VCG allowance. The UK discriminates between planned growth (upgrade) and unplanned (paint, crew additions); the first is called 'Board Margin' and is generally about 5% of the ship's full load, applied at 1 m above the weather deck; the second is called 'Growth Margin' and is typically 0.5% per year of full load displacement, and 0.3% per year of VCG, until mid life refit (usually 10 years). The total through-life weight growth is about 10% full load, comparable to the US.

Loads

The largest differences are in the stores and ship's fuel.

Stores (SWBS F30)

	US wt	UK wt	diff
Provisions and Stores	32	48	-16

The US has different endurance periods for chilled, frozen, dry and general stores, being 30, 45, 45 and 90 days respectively. The UK has a 30 day endurance period for everything. The US stores requirements *in toto* is 2.9 kg/man/day, while for the UK it is 6.3 kg/man/day. Based on the endurance requirements, there are 127 kg of stores for every American sailor, and 159 kg for every

TABLE XII—*Comparison of habitability standards for equivalent rates—areas in m² (ft²)*

	UNITED STATES	UNITED KINGDOM		UNITED STATES	UNITED KINGDOM
	Commanding Officer	*Commanding Officer*		*Warrant Officer*	*Warrant Officer*
Accom. type	Suite	Suite	Accom. type	2-man cabin	Single cabin
Eating	Cabin	Cabin	Eating	Wardroom	CPO dining hall
	Area/man	Area/man		Area/man	Area/man
Berthing	13.00 (140.0)	7.00 (75.3)	Berthing	5.06 (54.5)	3.72 (40.0)
Dining	13.50 (145.0)	17.00 (183.0)	Recreation	(In messing)	0.75 (8.0)
Sanitary	3.72 (40.0)	3.90 (42.0)	Messing	2.40 (26.0)	0.37 (4.0)
			Sanitary	0.65 (7.5)	0.32 (3.4)
	Executive Officer	*Executive Officer*		*Chief Petty Officer*	*Chief Petty Officer*
Accomm. type	1-man cabin	1-man cabin	Accom. type	12 man bunkroom	4 berth cabin
Eating	Wardroom	Wardroom	Eating	CPO mess	CPO dining hall
	Area/man	Area/man		Area/man	Area/man
Berthing	11.15 (120.0)	8.00 (86.0)	Berthing	2.23 (24.0)	2.13 (23.0)
Messing	2.40 (26.0)	2.40 (26.0)	Recreation	0.65 (7.0)	0.75 (8.0)
Sanitary	3.72 (40.0)	2.80 (30.0)	Messing	0.43 (4.6)	0.37 (4.0)
			Sanitary	0.60 (6.5)	0.32 (3.4)
	Department Head	*Department Head*		*Enlisted—Petty Officer*	*Petty Officer*
Accom. type	1-man cabin	1-man cabin	Accom. type	Sleeping area	6 berth cabin
Eating	Wardroom	Wardroom	Eating	Crews mess	PO dining hall
	Area/man	Area/man		Area/man	Area/man
Berthing	8.64 (93.0)	7.00 (75.3)	Berthing	1.60 (17.0)	1.60 (17.0)
Messing	2.40 (26.0)	2.40 (26.0)	Recreation	0.31 (3.4)	0.75 (8.0)
Sanitary	0.65 (7.0)	0.65 (7.0)	Messing	0.37 (4.0)	0.34 (3.7)
			Sanitary	0.46 (5.0)	0.22 (3.4)
	Officer	*Officer*		*Enlisted—Non-rate*	*Junior Rate*
Accom. type	2-man cabin	2-man cabin	Accom. type	Sleeping area	Sleeping area
Eating	Wardroom	Wardroom	Eating	Crews mess	JR dining hall
	Area/man	Area/man		Area/man	Area/man
Berthing	5.06 (54.5)	4.67 (50.2)	Berthing	1.60 (17.0)	1.44 (15.5)
Messing	2.40 (26.0)	2.40 (26.0)	Recreation	0.31 (3.4)	0.51 (5.5)
Sanitary	0.65 (7.0)	0.65 (7.0)	Messing	0.37 (4.0)	0.28 (3.0)
			Sanitary	0.46 (5.0)	0.28 (3.0)

British sailor. In addition, each British sailor gets 1 litre of beer per day, which accounts for 6 tonnes of difference. US ships have been dry since WW I. The UK ships carry 25% more stores per man than the US ship, which is in keeping with the general observation that UK ships tend to be more self-sufficient.

Fuels and Lubricants (SWBS F40)

	US wt	UK wt	diff
Diesel Fuel	595	471	124
Aviation Fuel	55	55	0
Lub Oil	24	25	-1

The US ship is larger than the UK one, which means it needs more power and more fuel. The UK also computes endurance at average displacement, which accounts for the ship getting lighter as fuel is burned; the US simply uses full load. The US uses a 10% margin on the endurance power to account for fouling; the UK uses a 15% margin. Both use a 5% tailpipe allowance to account for unusable fuel. The US uses a 5% fuel expansion allowance, a 5% plant deterioration allowance and an instrumentation allowance (for torsion-meter inaccuracy) of 3%. These are not included in the UK design.

The greater size of the US ship accounts for about 40% of the difference in fuel weights; instrumentation and fuel expansion allowances account for 25%; using full load instead of average displacement accounts for about 20%; and differences in early stage powering calculations account for the extra 15%.

Non-Fuel Liquids (SWBS F50)

	US wt	UK wt	diff
Fresh Water Potable	33	46	-13
Sanitary Tank Liquid	0	19	-19

US Navy ships are required to store 151 litres of potable water per man as a backup to the distillers. Royal Navy ships carry 208 litres per man, almost 40% more than the US.

Both ships use a modern vacuum collection and holding system; however, the waste disposal standards for the two countries differ. Neither country permits its ships to dispose of sewage in harbour or within 3 nm of shore. US Navy ships only partially treat their sewage using a flow-through chemical process, so the collection tanks are only sized for 12 hours of operation, enough to get them out of the 3 nm limit. UK ships extensively treat their sewage before discharge (to meet MARPOL regulations) using biological means; this means that the tanks are sized to hold sewage for 7 days, enough for the bacterial maceration to occur.

Detailed Comparison—Areas

FIG. 9 shows a comparison of the areas in each area group for the two navies. By fiat, the Group 1 (Mission Support) areas are equivalent.

Group 2—Personnel Support

Living (SSCS 2.1)

	US area	UK area	diff
Officer Living	193	197	-4
CPO/SR Living	149	199	-50
Crew/JR Living	331	400	-69
General Sanitary	10	1	9
Entertainment	7	11	-4
Training Classrooms	14	0	14

There are several differences in the manning philosophies of the US and UK, and it is often difficult to make exact correlations between the two. This is also the case with habitability spaces. The biggest difference is that the US Navy considers petty officers to be part of the enlisted crew, so are berthed with them in large (40+ men) sleeping areas; in the UK they are considered 'senior rates' like the chief petty officers, and are berthed separately from the enlisted, in 6-man cabins. The UK ship carries four Warrant Officers, acting as the non-officer heads of divisions; but their US equivalent, also a warrant officer, would not normally be embarked in a ship smaller than a destroyer, so the position is taken by a Chief Petty Officer. So, the above numbers for living spaces are skewed by differences in manning allocations.

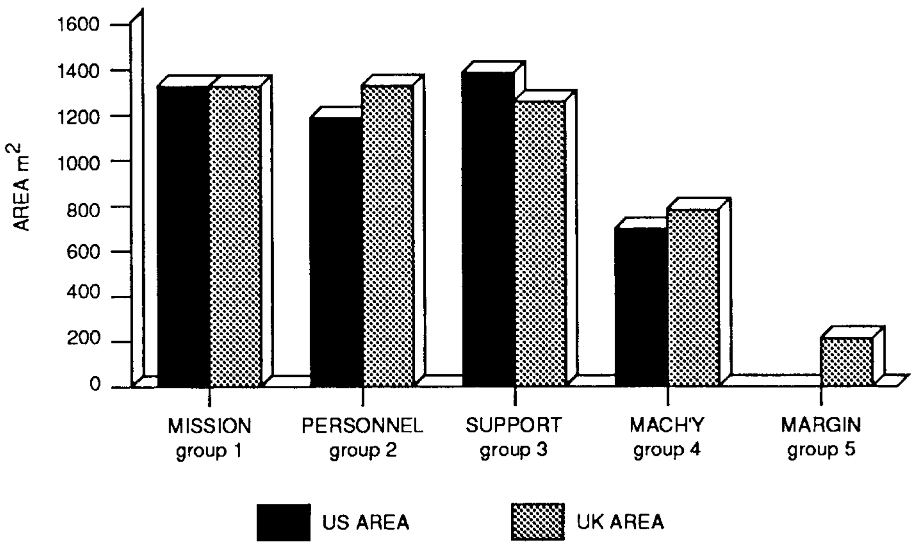


FIG. 9—AREA COMPARISON OF US VARIANT AND UK BASELINE

A better way of comparing habitability standards is to show allocated areas per person for equivalent rates, which is shown in TABLE XII. Note that the words 'messing' and 'berthing' are used in the American sense. In the UK, 'messing' refers to the living space. Although these numbers indicate relative roominess and level of privacy, they cannot compare the 'standard of living' of each nation's crew. Overall, total habitability areas are comparable, except that petty officers have more room and privacy in UK ships (since they are considered senior rates). Also, in UK ships, more space is devoted to recreation, and less to berthing, than in US ships.

Visits to both American and British frigates confirm these observations. On the whole, British crews are berthed in smaller groups than their US counterparts (less than 40 in UK berthing spaces, versus up to 70 in US ones). Although US ships have somewhat roomier berthing compartments, the larger number of men in each results in a comparative lack of privacy and 'homeyness'. Senior rate berthing in UK ships have adjacent recreation areas which includes a bar; the officers' bar is in the wardroom lounge. The crew recreation spaces in UK ships tend to be larger and better fitted than in US ones. US ships have a separate crew training classroom to keep the mess halls free, while UK ships use the dining halls for this purpose.

Group 3—Ship Support

The biggest area differences occur in damage control, office area, maintenance, stowage and passageways.

Damage Control (SSCS 3.2)

	US area	UK area	diff
Repair Stations	22	16	6
Firefighting	22	10	12

As noted in the section on air and gas systems, the US ship has a more extensive AFFF and Halon system than the UK ship. The larger area devoted to firefighting in the US ship is due to the greater number of AFFF stations in the ship, and the larger amount of space devoted to storage of Halon cylinders.

Administration (SSCS 3.3)

	US area	UK area	diff
Administration	120	49	71

The amount of paperwork handled aboard ship has increased dramatically for both nations, but more so for the US. A recent study showed that a typical latter-day US frigate carried 20 tonnes of paper requiring 25 m^3 of volume. The push in both navies is for more automation and less paperwork; at the moment, both navies use small computers to handle routine administration, but hard copies of everything are still around.

US ships typically have more offices than UK ships, with greater overall area, as shown by this comparison of equivalent office spaces found in US and UK frigates:

(US)	(UK)
• Engineering Dept Office • Weapons Office • Technical Library	• Combined Technical Office
• Executive Dept Office	• Ship's Office
• Operations Dept Office	• Routine Office
• Supply Dept Office • Stores/Spares Issue	• Supply Dept Office (in naval stores)

Ship Maintenance (SSCS 3.6)

	US area	UK area	diff
Shipboard Maintenance	101	57	44

The only significant difference occurs in engineering maintenance, which includes filter cleaning shops, electric and propulsion plant shops, and a general workshop. The US ship has almost twice the area, and this is borne out by more direct comparisons of existing US and UK frigates. However, comparing the amount and type of equipment found in the workshops does not show a significant difference between the two country's ships. It appears that US workshops are simply roomier than UK ones.

Stowage (SSCS 3.7)

	US area	UK area	diff
Stowage and Handling	325	337	-12

As mentioned earlier, the UK ship carries more damage control and main machinery spares and repair parts than the US ship, which require more stowage space.

Access (SSCS 3.8)

	US area	UK area	diff
Interior Access	706	616	90

The US ship has 15% more access area than the UK ship, the result of having two outboard passages versus a single centreline one. The US philosophy is that the twin passages allow better personnel flow and provide some protection for vital spaces; the UK philosophy is that a single passage saves volume and provides easier access to spaces.

Group 4—Ship Machinery

The biggest area differences occur in propulsion uptakes and emergency generators.

Propulsion (SSCS 4.1)

	US area	UK area	diff
Propulsion Intake/Uptake	362	421	-59
Propulsion/Damage Control	69	40	29

The cross-section of the propulsion system trunking is by fiat identical; the greater area in the UK ship is due to the fact that they go through one extra deck. The larger propulsion/damage control of the US ship is indicative of the fact that there are normally more engineering watchkeepers than in UK ships.

Auxiliary Machinery (SSCS 4.3)

	US area	UK area	diff
Refrigeration	7	7	0
Emergency Generators	0	30	-30
Frequency Conversion	21	36	-15
Degaussing	12	19	-7
CHT/Pump Rooms	58	41	17
Gash/Compaction	10	19	-9
Fire Pump Rooms	16	10	6
Fan Rooms	166	180	-14

Most of the differences in areas devoted to auxiliary machinery are minor, and do not reflect substantial variations in design practice. The biggest difference is the fact that the UK ship carries an emergency generator whereas the US ship does not.

Group 5—Unassigned and Margin

Unassigned and Margin (SSCS 5)

	US area	UK area	diff
Unassigned	0	50	-50
Margin	0	190	-190

The UK allows a 3% area margin in its designs during the early stages. This has not been typical of US design practice.

Detailed Comparison—Volumes

FIG. 10 shows a comparision of the volumes. The UK ship has more arrangeable area, meaning greater arrangeable volume.

Tanks (SSCS 3.9)

	US vol	UK vol	diff
Ship's Fuel Tankage	728	582	146
Aviation Fuel Tankage	68	68	0
Ballast Tankage	211	200	11
Fresh Water Tankage	33	46	-13
Pollution Control Tankage	2	18	-16
Voids	360	87	273
Unassigned	219	30	189

The major differences in tankage volumes have already been explained; for instances, the US ship carries more fuel, the UK ship has more fresh water, and the UK sewage holding tanks are sized for 7 days, versus 12 hours for the US. The US ship carries 33% of the fuel weight in clean ballast, while the UK ship has 40% ballast tankage.

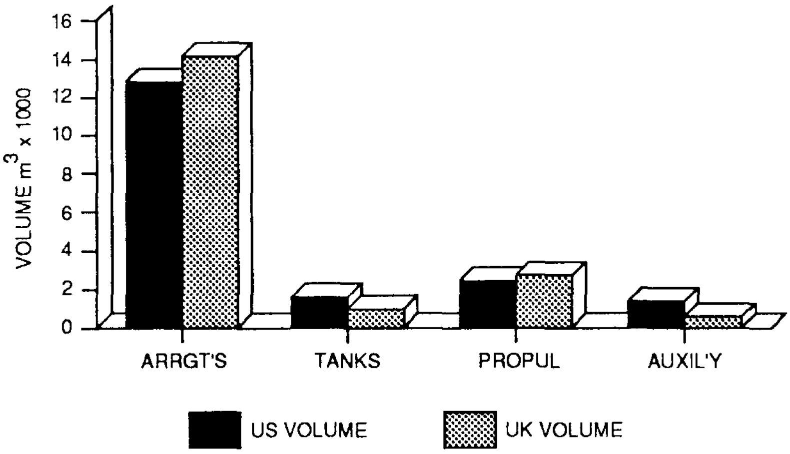


FIG. 10—VOLUME COMPARISON OF US VARIANT AND UK BASELINE

The difference in void volume is considerable, and is as explained earlier due to the differences in requirements for the collision bulkhead. The US does not allow any access forward of that bulkhead below the damage control deck, while the UK puts storage spaces there (with limited access). The unassigned tankage on the US ship is simply due to having more inner bottom volume than required (it is otherwise unusable). No margin is designed into it.

Machinery (SSCS 40)

	US vol	UK vol	diff
Propulsion Machinery	2601	2784	-183
Auxiliary Machinery	1594	780	814

The propulsion machinery volumes are almost identical, the greater UK volume being the result of smaller inner bottom. The more-than-double difference in auxiliary machinery volume is due to the much greater size of the US electrical generators; compared with the UK sets, they require two deck heights versus one, need a longer AMR forward and require an additional AMR aft.

COSTS

To establish in monetary terms what these differences in standards and practices meant, the designs were costed to a rough-order level for comparison purposes. Actual costs are commercial-in-confidence, so are given here in relative terms only.

It was obvious that, due to national differences in labour rates, material costs, and accounting methods, the cost of the US frigate could not be directly compared with the UK frigate to establish the real cost of design practices. So, we first estimated the cost of the UK baseline as if it were built in the US, to eliminate the effects of different national price levels for the same ship. Next, we compared the cost of the US variant with the (US-built) UK baseline, to give the cost difference of US design standards and practices. Finally, the US baseline was costed and compared.

Probably of greatest interest is a comparison of the same ship built in the US and the UK, shown here in TABLE XIII. These relative costs do not include combat systems, except for the installation costs. The cost categories are an abbreviated format, not the standard ones used in the US or UK. The total first-of-class (FOC) cost of the (UK-built) UK baseline is given as 100. All costs are referenced to that basis. A discussion of each category follows:

TABLE XIII—*Relative costs for UK Baseline (excluding combat systems). UK-built ship, FOC Cost = 100*

	US Built	*UK Built*
Labour + Overhead	25	20
Material	24	21
Profit	5	3
Margin + Changes	9	9
Design/Plans	45	47
Total FOC Cost	108	100

(Labour + Overhead) Although a typical US yard would require fewer labour hours than a UK yard to construct the ship, the labour rate is higher. For example, the mean shipyard wages in 1987 for the US and UK were, respectively, $14.26/hr and $8.91/hr[8]. The US shipyard wage scale is about 60% higher in real terms than the UK. This difference is not peculiar to the shipbuilding industry, however. The average labour rate for all industries in 1987 was $9.86/hr in the US and $6.87 in the UK[9].

(Material Cost) This is the delivered cost of raw materials, subcontracted production efforts and purchase of parts (including vendor production and engineering services). For the same amount of materials for the same ship, the US must pay 13% more than the UK. Part of this is due to higher labour costs for subcontracted services.

(Profit) This is given as a percentage of the material, overhead and labour cost. The US typically allows for a higher profit than the UK.

(Margins + Changes, Design/Plans) These are comparable between the two countries.

With the (US-built) UK baseline FOC cost as 108, the US variant FOC cost was 124. This represents a 15% increase over the (US-built) UK baseline, which is therefore the real 'cost' of US design standards and practices, as compared with those of the UK. About one third that increase is from labour & overhead and a third is from design and plans; the added material cost accounts for only a sixth of the increase. Going from the US variant to the US baseline, the cost decreases (from 124 to 122, or −2%), mainly because of the simpler propulsion plant.

In summary, a ship costs 8% more to build in the US than in the UK, and US design practices cost 15% more than the UK's in real terms. Finally, a US designed-and-built frigate will cost about 22% more than a home-grown UK frigate. To recap:

UK frigate (built in UK)	100
Build the same ship in US	+ 8
Use US standards/practices	+ 16
US prot., manning, propul.	− 2
US frigate (built in US)	122

CONCLUSION

This study has confirmed that, for a common mission and payload, a US frigate will displace over 1000 tonnes more, and cost 20% more, than a UK frigate. There are many reasons for the greater size of the US ship, but the most significant factors are outlined below:

Survivability Requirements. These drive a number of ship design practices and standards, including:

(*a*) vital spaces—this US design philosophy increases ballistic protection, access requirements, bulkhead weights, insulation, etc. over the UK design;

(*b*) firefighting and damage control—US combatants have more extensive chemical fire extinguishing systems, and the firemain system has greater redundancy. The US practice of providing dual passageways is primarily for personnel access for damage control.

Design Reserve and Service Life Growth. US design practices are typically more conservative than the UK, but this is in part because US warships are designed for a longer service life than UK ships, and receive more extensive through-life upgrades. US structural practices and endurance fuel calculations, for example, have more built-in design reserves. Systems such as air conditioning generally have more growth capability than in UK ships.

Manufacturing Base. That is, allowance in the design for competitive purchase of domestically-manufactured equipment. In this study, the greatest effect is on diesel generator selection, where the current US preference for medium-speed diesel generators has great impact on ship size and arrangements, compared with the UK's higher-speed sets.

In addition, we found two areas where US and UK philosophies were noticeably different (but which, taken as a whole, did not greatly affect ship size). They were:

Logistics Support. UK warships are much more self-sufficient than US ships; they carry more food stores, ship's stores, spares and repair parts. US combatants rely heavily on their larger logistics support fleet, and in consequence they have more extensive replenishment and strikedown systems.

Manning and Habitability. US combatants typically have more crew, but UK ships have a higher proportion of CPOs; also, British POs have a higher standard of accommodation. UK warships allot less space to berthing and more to recreation, and often have more amenities than US warships. UK berthing spaces generally have fewer men than in US ships.

This study was carried out at the conceptual level, so the differences between the US and UK ships represent trends rather than actual realizable differences. This article illuminated some of the differences between American and British warship designs, and demonstrates that both countries have evolved distinct but very rational approaches based on their accumulated experiences. We believe that such comparative studies are valuable for mutual understanding, as well as for providing fresh ways of looking at problems. We hope this article may serve as a guide to any future efforts in this field.

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