THE IMPLICATIONS OF AN ALL ELECTRIC SHIP APPROACH ON THE CONFIGURATION OF A WARSHIP

BY

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This is an edited version of the paper that was presented at INEC 2004 – Marine Technology in Transition. *Organized by the Institute of Marine Engineering Science and Technology and held in Amsterdam, 15 – 19 March 2004.*

ABSTRACT

It has been stated that one of the advantages of an all electric approach to prime power generation and distribution on a frigate is that it 'frees the ship designer from the tyranny of the shaft'. While there has been considerable effort devoted to the marine engineering system concerns in producing the All Electric Ship, there has not been a commensurate level of investigation into the ship design implications. The article presents a series of studies using the SURFCON graphically centred preliminary computer aided ship design tool, based on the Design Building Block approach which originated in the Design Research team at UCL. This tool is incorporated in the Graphics Research Corporation Ltd PARAMARINE CASD suite and thus enables graphically descriptive and naval architecturally balanced ship designs to be produced. Explorations have been undertaken, for a monohull frigate concept design on how an advanced electric machinery fit could be configured to provide a more effective and survivable overall ship design.

Introduction

This article addresses the implication of the adoption of an All Electric machinery fit, on the configuration of a modern warship. This is done with particular reference to a generic frigate design case, as the most ubiquitous example of warship design practice.

The Electric Ship has been the subject of considerable effort and many expositions in recent years,[1,2] particularly describing the substantial developments by the US Navy [3] and through the Anglo-French programme.[4] The descriptions produced of both these latter activities have commented on the wider ship design advantages of adopting such a form of machinery plant for both ship propulsion and power generation but have primarily focused on the marine engineering issues rather than the overall ship design consequences. One clear message of general ship design applicability from the proponents of the All Electric Ship (AES) is that an all electric installation:

> "Releases the ship designer from the tyranny of the shaft line".

Just how valid this might be is explored for a specific range of frigate studies.

From a ship design point of view it is recognized that in warship preliminary design the choice of the propulsion system is a major determinant of the overall size, style and cost of the eventual design solution. Thus in the three linked phases of the first stage of the design of a major new naval ship programme, those of

Concept Exploration, Concept Studies and Concept Design,[5] the choice of the propulsion system figures alongside the material features of the combat system or major payload (in the case of an aircraft carrier or amphibious vessel) as a principal design determinant.

In such preliminary ship design work, traditionally the demands of the prospective main propulsion fit are seen by the naval architect as significant in terms of overall ship space and weight drivers. Thus the main and auxiliary machinery spaces have been seen as 'inevitably' located deep and centrally in the ship as a single block at least initially. In weight terms the propulsion and power generation fit is second only to the structural weight in contribution to ship lightweight. Thus at least as far as machinery spaces' overall length is concerned, there is a need for the marine engineer to produce an outline layout of the machinery spaces relatively early in preliminary design, especially in the case of the corvette/frigate/destroyer range of combatants. This is seen as leaving little scope on the part of the naval architect and marine engineer, jointly or independently, to explore much in the way of interaction between the major machinery spaces architecture and that of the rest of the evolving ship architecture. This was probably largely justifiable with the pre-All Electric 'tyranny of the shaft line', but is no longer sensible. There is therefore an urgent need to explore the choices and interactions between the domain of the marine engineer and that of the naval architect, as the custodian of the overall ship architecture. This has become possible through recent advances in computer aided preliminary ship design, built on the ship design methodology pioneered by the first author, and which are briefly outlined in the following section of the article.

SHIP CONFIGURATION AND THE DESIGN BUILDING BLOCK METHODOLOGY

Ship architecture and how it is produced as part of the evolution of a new ship design is a major aspect of ship design which has, in general, been somewhat neglected by the profession of naval architecture. It was precisely this aspect that was identified in 1980[6] as being a key to a more creative approach to naval architecture, for the following reasons:

- Many of the features and aspects of design could not be properly addressed with the traditional sizing approach but could be incorporated with the better design methods and tools becoming available.
- The advent of computer aided graphic design methods, then in their infancy, but now reaching a level of maturity and being usable with personal computers.[7]

The manner in which exploration of ship internal configuration and layout helps to open up many of the more protracted and less readily analysable aspects of ship design has been taken further by the first author, firstly in considering the integration of configuration in initial ship design [8] and more recently placing this approach to the design of ships (and other complex systems) in a wider context.[9] The current section draws on proposals which have been presented on ship layout or the architecture of ships, and how such an approach enables ship designers to explore alternative ship arrangements.[10]

The Example of Frigate Architecture

In 1987 BROWN presented a paper entitled *The Architecture of Frigates*,[11] which drew on his experience of preliminary warship design and on research undertaken at University College London.[8,12,13] BROWN's paper was largely a comprehensive survey of many of the aspects and constraints impinging on frigate layout design.

He emphasised how, for a frigate and similar combatant vessels, the key to the internal layout is the design of the upper or weather deck disposition of:

- Weapons.
- Helicopter arrangements.
- Radars.
- Communications.
- Bridge.
- Boats.
- Seamanship features.
- Machinery uptakes and downtakes.
- The access over the deck and into the ship and superstructure.

(FIG.1) shows an updated version of BROWN's frigate configuration from Reference 14.

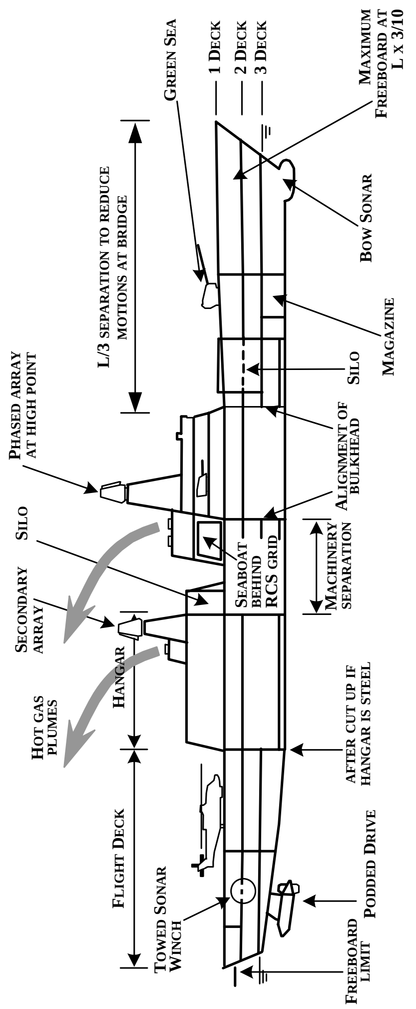

FIG.1 – FRIGATE LAYOUT CONSIDERATIONS[14]

Integrated Ship Synthesis

Production of a warship's general arrangement is done by the well-established method of using damage stability and structural continuity considerations to determine main transverse bulkhead disposition and thereby controlling the evolution of the general arrangement, within a previously determined envelope of the hull form. Competing with these requirements are the needs of the marine engineer who has minimum lengths for machinery and locations fixed by shafts, intakes, exhausts etc. An alternative logic, that of using the disposition of the principal spaces in the ship to determine both the initial sizing of the ship and the selection of hull dimensions and form parameters was presented in the first paper proposing the architecturally driven design synthesis.[6] In 1986 an example of a sequence for allocating the various compartments in a frigate design was published.[8] This sequence was not suggested as the recommended way of obtaining the layout, but rather as a suitable start point for an integrated synthesis to take and to utilize the ship arrangement, produced by such a sequence, to size, dimensionalise and select hull form parameters. It was also argued that with integration of the ship architecture, weight, space and form parameters, alternative layouts could be explored while the hull form and dimensions were still fluid. The ability to readily alter the layout was also held to justify the initial adoption of a conventional layout sequence, but only **provided** that ability and to re-sizing the design could then be exploited (rather than this layout being adopted and closing down the option of configuration exploration). The 1986 paper also proposed a progressive design approach of 'circles of influence' to address compartment relationships and thereby yield a 3-D block layout, around which a hull form could be 'wrapped' (see (FIG.2) taken from Figure 11 of Reference.8). However in all these cases the traditional machinery configuration meant that the layout synthesis assumed that the propulsion and power generation spaces were largely excluded from this exploration and only impacted on the main operational and infrastructure spaces through the presence of intakes, uptakes and removal route considerations.

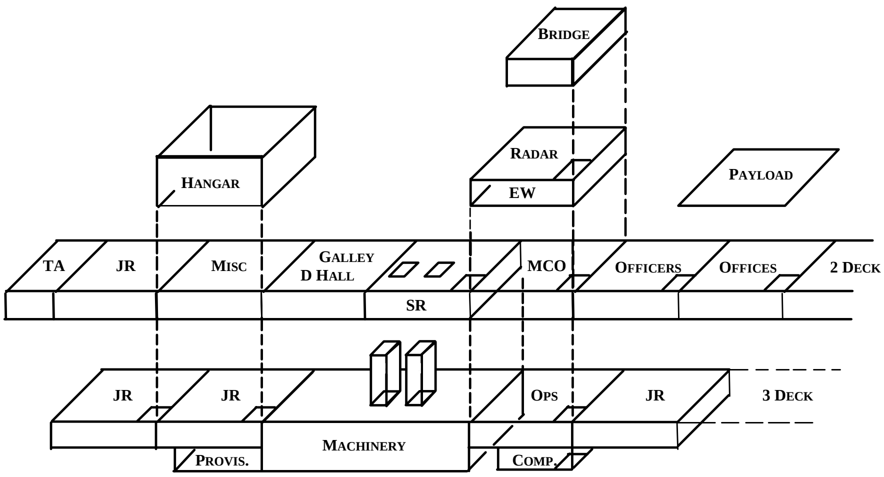

FIG.2 – *ab initio* FRIGATE COMPARTMENT BLOCK SYNTHESIS[8]

Design Building Block Approach

While the integrated synthesis approach was demonstrated in the 1980s, it was not until computer graphics had advanced sufficiently in the early 1990s that the approach outlined above could be adopted in a working design tool.[15] The Design Building Block approach to producing a new ship design was presented in

Reference 16 at Figure 5, reproduced below at (FIG.3). This diagram summarises a comprehensive set of analysis processes most of which are unlikely to be used in the initial setting up of the design or even early iterations around the sequence of building blocks, geometric definition and size balance. In fact several of the inputs shown in FIG.3 are either specific to the naval combatant case, such as topside features, or omit aspects which could be dominant in specialist vessels, such as aircraft carriers or cruise liners, where personnel and vehicle flow are likely to dominate the internal ship configuration.

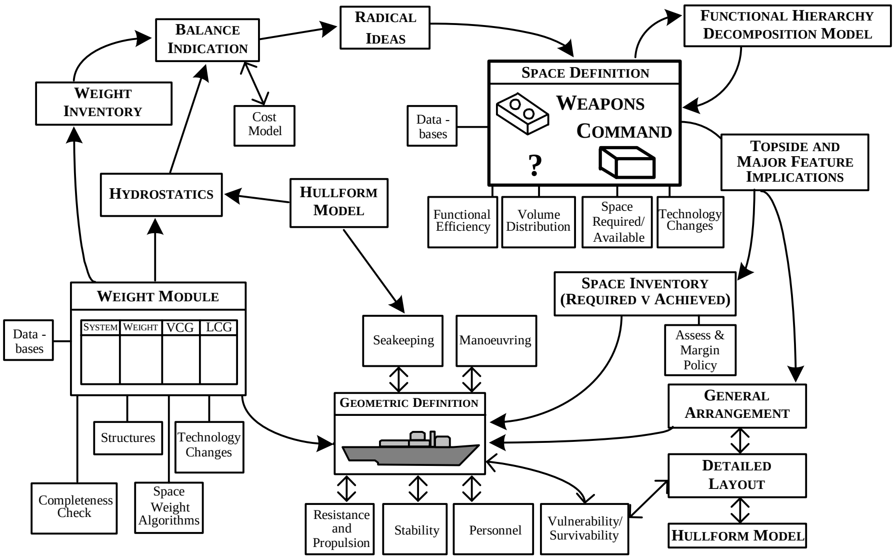

FIG.3 – OVERVIEW OF THE DESIGN BUILDING BLOCK METHODOLOGY APPLIED TO A SURFACE SHIP[16]

A further feature of the Design Building Block (DBB) approach that was outlined in some detail for the 1997 UCL prototype system and which has recently been fully incorporated in the SURFCON element of PARAMARINE, is that of the 'Functional' breakdown.[15] This was adopted in preference to the usual weight breakdown essentially based on the shipbuilding trades (i.e. steel, machinery, electrics and outfit, plus the combat system in the case of naval vessels). This more functional breakdown (i.e. float, move, fight or operations and infrastructure) has advantages. The more traditional breakdown can inhibit the designer from considering radical solutions, not just to the layout but also to the engineering choices, in contrast to the DBB approach with the early introduction of the architectural element, which is seen as a means of exploring more innovative configurations.

A further feature is the use of the term Master Building Block to denote how the overall aggregated attributes of the building blocks can be brought together to provide the numerical description of the resultant ship design. The advantage of providing the Design Building Block capability of SURFCON as an adjunct to the already established ship design suite of PARAMARINE[7] was that the audited building block attributes within the Master Building Block could be directly used by PARAMARINE to perform the necessary naval architectural calculations to ascertain the balance or otherwise of the configuration just produced by the designer. Typical information held in the Master Building Block includes:

- Overall requirements:
  - ❑ Ship speed.

  - ❑ Seakeeping.
  - ❑ Stability.
  - ❑ Signatures (in the case of a naval combatant).
- Ship characteristics:
  - ❑ Weight.
  - ❑ Space.
  - ❑ Centroid.
- Overall margins:
  - ❑ Weight,
  - ❑ Space.

  (And their locations for both growth and enhancement.)

The Design Building Block, as the fundamental component of the SURFCON approach, can be regarded as an object in the design space and as a 'placeholder' or 'folder' containing all the information relating to a particular function within the functional hierarchy. Data that can be contained within a building block is of several categories, as follows:

- Numerical Data:
  - ❑ Weight.
  - ❑ Power.
  - ❑ Manning.
- Constraint Data
  - ❑ Mast spacing.
  - ❑ Proximity of antennae and processors.
- Parametric Data
  - ❑ Structural mass of hull – dependent upon, say, hull length).
- Geometric Data
  - ❑ Volume.
  - ❑ Area.
  - ❑ Shape.
  - ❑ Location.
- Descriptive Data
  - ❑ Name.
  - ❑ Explanatory notes on function and performance.

As the design description is built up and modified, all features of the building blocks are utilized by the system. The geometric definition (shape and location) is used to constantly update the graphical display, whilst data properties are indicated in a logical tree diagram of the design, as shown in (FIG.4) along with the block representation and a tabular view of the numerical information. Some characteristics that do not have a specific spatial extent are still represented in the graphical display; for example, weight centroids are shown with the traditional 'centroid' icon. This parallel graphical and numerical display permits the user the 'drag and drop' blocks in the design space.

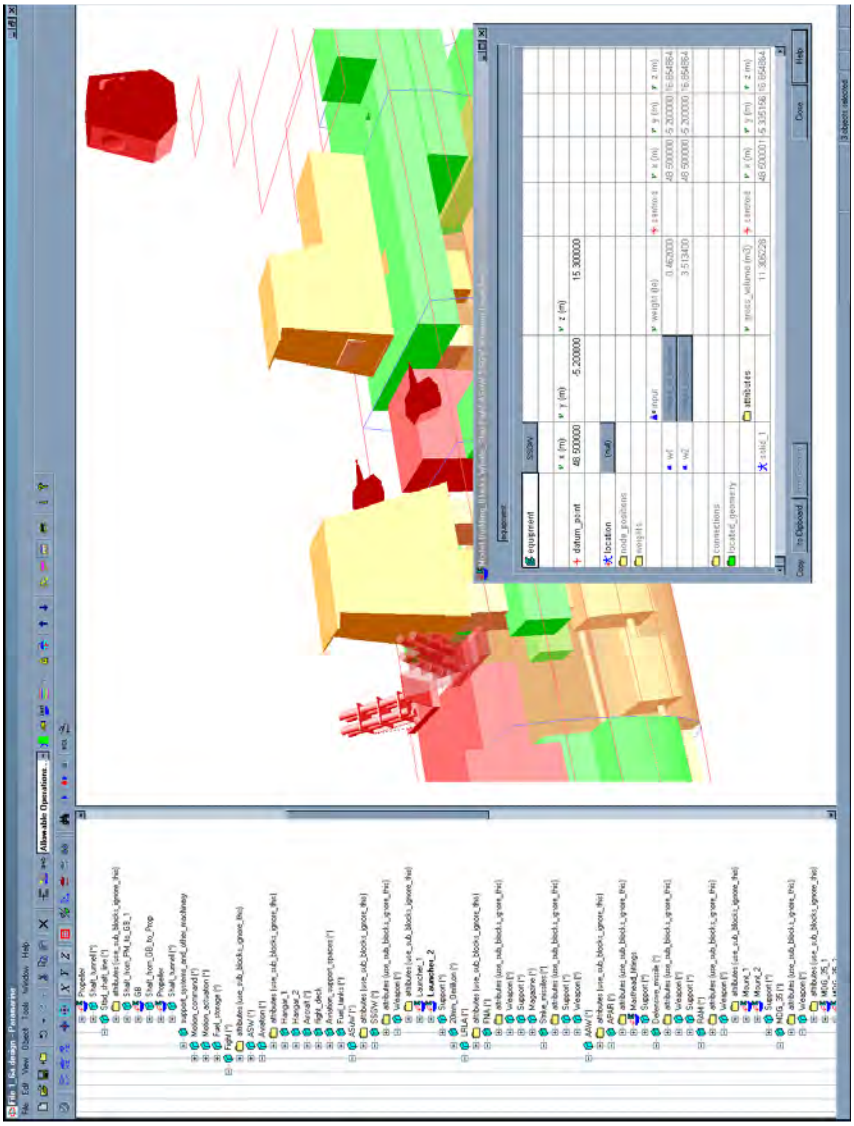

FIG.4 – MULTIPLE VIEWS OF A DESIGN BUILDING BLOCK

The DBBs are particularly useful when comparing different machinery fits as it is possible to assess the impact of, say, pods versus traditional shafts. Each component of machinery associated with the propulsion system can be identified with a design block and the total ship impact readily assessed. For example, it is not sufficient to just compare the mass of each alternative system but also to consider how the weight of each system impacts on the ship in terms of trim, stability, power demands and additional structural weight.

SURFCON has been used by the UCL Design Research Centre for design investigations for both the UK MoD and the US Navy Office of Naval Research, with the 'Mothership' studies undertaken in conjunction with BMT[17] being recently outlined in the public domain. The tool has also been recently employed to explore design for production in initial design for a range of ship types as part of the UK Shipbuilders and Ship repairers Association shipbuilding initiative.[18] The examples in the next section, from recent investigations considering the impact of an All Electric machinery fit, demonstrate that ship architecture can be investigated in reasonable depth at the initial design stage of a ship concept design investigation. This facility widens the scope for early exploration of a greater range of ship design drivers and fosters the approach to creative ship design that has been advocated by the UCL Design Research Centre.

EXAMPLE OF MONOHULL – CONVENTIONAL VS ALL-ELECTRIC PROPULSION

The following is an example of the use of the DBB approach and the SURFCON system, applied to the design of a large multi role frigate. The comparison of the overall ship designs is given in Table 2 and the subsequent diagrams show the machinery spaces arrangements with the major equipment highlighted and the adjacent tabular listings highlight the machinery and design implications of each design study. A standard mechanical fit is used as the baseline with the AES variants becoming progressively more extensive in exploiting the all electric potential and culminating in a speculative design.

The baseline vessel (Option 1) has a standard twin shaft mechanical transmission system and it is broadly similar to the Royal Navy's Type 45 Destroyer in size but with a multirole capability and enhanced speed and endurance, see Table 1. All options are sized to meet the same performance characteristics as the baseline.

Option 2 shows the simplest adaptation of the AES concept, as adopted in the Type 45. This provides the full flexibility of operation but makes very little advantage of the possibilities in layout flexibility. The location of the prime movers has hardly moved from the conventional mechanical case other than that they are now not inclined at the shaft angle. The gearbox has been replaced by a motor and generator. Considering just transmission efficiencies, an electrical system is less efficient than a mechanical system with 80-85% being typical for the former and greater than 95% typical for the later. Hence the larger installed power in Option 2 compared with the baseline.

An important feature of AES architecture is that the propulsor is now only physically connected to a motor. This can be mounted in a conventional form as in Option 2 or in a pod as in Option 3. Pods have many advantages not least is improved hydrodynamic efficiency and pod manufacturers have claimed that this more than compensates for the increased transmission losses. There are operational issues with pods such as underwater noise and shock, but of more concern in configurational terms is that they concentrate the weight of the motor and propeller further aft. This is exacerbated by the loss of buoyancy aft as the hull form is optimized for water flow into the pods. Additionally the ship no longer has thrust blocks and instead the force is transmitted to the hull at the pod/hull interface, again much further aft than before.

Propulsion plant can now be distributed through out the ship both longitudinally and vertically to improve survivability, as shown in Option 4. Although flexibility in operation is not being considered in this article, there is one clear aspect where it impinges on layout design. Engine running hours can be varied much more readily when they are connected to an electrical distribution system. Engines that are more accessible and easier to maintain can be run in preference to those more difficult to access. This also opens the way for locating an engine where previously it would not be considered because access and/or removal is difficult, particularly in cases where it need only be run on the rare (for a warship) occasions that the ship is at full speed.

As there is no longer a requirement to match the engines to the propeller characteristic, the size and number of engines is also fully flexible and Option 5 takes advantage of this and demonstrates a main machinery fit of 4 smaller 13MW engines. A top speed of 19.5 knots (compared to a probably over generous 24.5 knots for Option 3) can be achieved on single engine operation which is sufficient for most operations. There is also a case for making two of the main engines simple cycle.

The survivability of a ship can be improved by increasing its watertight subdivision and providing separation of the main machinery. As can be seen in Options 1, 2 and 3 the main machinery rooms are the longest and largest compartments below the waterline. Longitudinal subdivision is possible but not acceptable from a stability point of view. In an AES ship the engines could be mounted transversely, which could provide a greater number of much shorter machinery spaces. The bearings of the generators and gas turbine would have to be strengthened since they would see greater gyroscopic forces as their axis of rotation would now be normal to the ship's roll and yaw axes instead of its pitch and yaw axes. Option 6 takes this a stage further and considers the hypothetical case of mounting the gas turbines vertically with intake upper most. This has a number of advantages, see FIG.11. No installation like this yet exists but the basic technology does. Vertical mounting of large generators is common in hydroelectric plants and aero gas turbines regularly operate at large angles of inclination. Option 6 is speculative but it demonstrates that the flexibility AES provides still has many opportunities to explore.

The Designs

The example designs developed for this article represent a multi-role vessel intended to fulfil the key user requirements specified for the Future Surface Combatant, see Table 1. Complement and accommodation demands were estimated from the payload, using the system detailed in the UCL SDE Data Book.[19] The accommodation provision for all variants was identical, 28 officers, 16 chief petty officers, 33 petty officers, 65 rates and 50 special forces personnel. Maximum Activity Load for the hotel load was estimated at 2.7MW, based on the payload and accommodation. The flight deck and hangar positions were kept fixed.

TABLE 1 – *Payload and Requirements*

FUNCTION	EQUIPMENT
ASW	Bow sonar 2050. Towed Array 2087. Magazine Torpedo Launch System. Surface Ship Torpedo Defence. Anti Submarine Warfare MERLIN helicopter.
ASuW	8 Surface to Surface Guided Weapons. Anti Surface Warfare MERLIN/LYNX helicopter. 2 x 20mm Oerlikon. 2 x General Purpose Electro Optical Device.
LRLA	1 x 155mm Future Naval Artillery system. 4 x MK41 strike length Vertical Launch System (VLS).
AAW	Advanced Phased Array Radar. 2 x Infra Red Search and Track systems. IFF system. 4 x MK41 strike length VLS. 2 x RAM Inner Layer Missile System.

	2 x 35mm Close In Weapon System.
C^4I	2 x Navigation radar 1008. BAE SSCS Combat Management System. Integrated Communications System inc. SCOTT SATCOM. Link 16/22. Co-operative Engagement Capability.
ECM/EW	Jammer 675 CUTLASS ESM 4 x 2 DLB floating decoy 8 x SEA GNAT decoy projectors
SPECIAL FORCES	Accommodation for 50. Second hangar used to store boats or helicopter. Large boat crane by hangar.
EARLY ENTRY	30 knt threshold maximum speed, Sea State 3, 10% margin. 7,000 nm at 20 knots cruise speed, Sea State 3, 10% margin. 45 days stores.

In total, six designs were developed, including the baseline and five different electrical machinery fits. The use of the SURFCON tool allowed the designs to be assessed and balanced:

- Total ship weight = total displacement.
- Total volume and area required ≤ area and volume supplied.
- Propulsive power required ≤ propulsive power supplied.
- Electrical generating power required ≤ Generating power supplied.
- Chilled water demand ≤ Chilled water supplied.
- Variables (Dieso, fresh water) demand ≤ Variable supply.
- Stability = compliance with NES 109 for intact and damaged cases.

Weights, spaces and auxiliaries requirements were estimated using the UCL Ship Design Exercise Data Book so no sensitive information is contained in the model. Other information was sourced from previous UCL MSC ship designs, which featured IFEP propulsion architectures.[20,21,22]

TABLE 2 – *Summary of the designs*

	Option 1: Baseline	**Option 2: Baseline + IFEP**	**Option 3. IFEP + Pods**
Waterline length	141.0 m	149.0 m	147 m
Overall length	147.0 m	155.0 m	153.0 m
Waterline beam	17.1 m	18.3 m	17.95 m
Overall beam	18.81 m	20.13 m	19.75 m
Draught	5.1 m	5.49 m	5.36 m
Depth, midships	12.3 m	12.69 m	12.56 m
Depth, bow	14.3 m	14.69 m	14.56 m
Displacement, deep	6035 te	7287 te	6915 te
Enclosed volume	21019 m^3	22631 m^3	22090 m^3
GMtf intact, deep	1.78 m	2.7 m	2.9 m
Trim by stern, deep	0.14m	0.53m	0.48m
Total installed generator power	50 MW	66.42 MW	66.42 MW

Propulsive coeff.	0.65	0.56	0.67/0.64
Power for 30 knots	50.6 MW	64.4 MW	52.4 MW
Power for 20 knots	9.9 MW	12.9 MW	11.2 MW
Prime Movers	2 x WR21 ICR GT (4 x 1.5MW ICR GTA) hotel only	2 x WR21 ICR GTA 3 x 4.9MW GTA 1.2MW Battery	2x WR21 ICR GTA 4.9MW GTA 1.5MW ICR GTA 1.2MW Battery
Transmission	Mechanical	Electrical, 6.6Kv	Electrical, 6.6Kv
Motors	(Gearbox)	2 x 30MW AIM	2 x 30MW PMM
Propulsors	Conventional 2 x 4.5m Props	Conventional 2 x 4.5m Props	2 pods, scaled on Shottel SSP
MMRs	2	2	2
AMRs	2	2	2

	Option 4 Distributed Prime Movers	**Option 5. Small Prime Movers**	**Option 6. Vertical GTAs.**
Waterline length	147 m	148 m	147 m
Overall length	153.0 m	154.0 m	153.0 m
Waterline beam	18.0 m	18.1 m	17.9 m
Overall beam	19.8 m	19.91 m	19.7 m
Draught	5.39 m	5.4 m	5.34 m
Depth, midships	12.59 m	12.6 m	12.54 m
Depth, bow	14.59 m	14.6 m	14.54 m
Displacement, deep	7022 te	7073 te	6863 te
Enclosed volume	21626 m^3	23132 m^3	22159 m^3
GMtf intact, deep	2.5 m	2.7 m	2.6 m
Trim by stern, deep	1.00 m	0.77 m	0.92m
Total installed generator power	56.4 MW	56.2 MW	56.4 MW
Propulsive coeff.	0.67/0.64	0.67/0.64	0.67/0.64
Power for 30 knots	52.9 MW	52.9 MW	52 MW
Power for 20 knots	11.2 MW	11.4 MW	11.1 MW
Prime Movers	2x WR21 ICR GTA 4.9MW GTA 1.5MW ICR 1.2MW Battery	4x 13.3MW ICR GTA 2 x 1.5MW ICR GTA 1.2MW Battery	2 x WR21 ICR GTA 4.9MW GTA 1.5MW ICR GTA 1.2MW Battery
Transmission	Electrical, 6.6Kv	Electrical, 6.6Kv	Electrical, 6.6Kv
Motors	2 x 30MW PMM	2 x 30MW PMM	2 x 30MW PMM
Propulsors	2 pods, scaled on Shottel SSP	2 pods, scaled on Shottel SSP	2 pods, scaled on Shottel SSP
MMRs	2, 1 on upperdeck	3, 1 on upperdeck	4, 2 vertical and 1 on upperdeck
AMRs	2	2	4

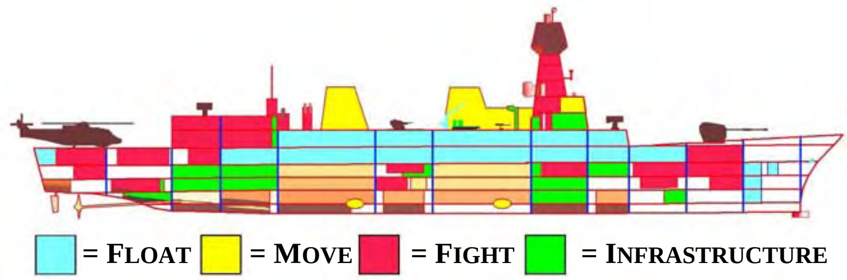

FIG.5 – PROFILE OF BASELINE MULTI ROLE FRIGATE (OPTION 1)

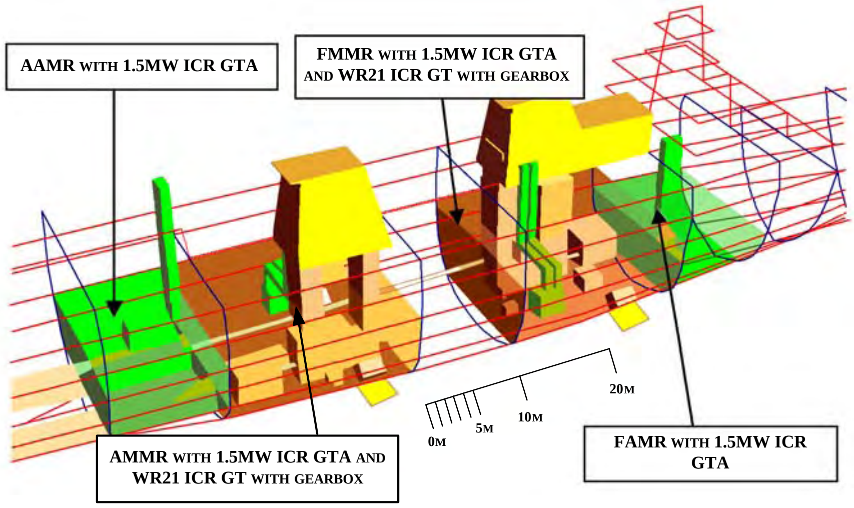

FIG.6 – MAIN AND AUXILIARY MACHINERY SPACES OF OPTION 1

1. The overall dimensions of the vessel were fixed early in the design by the upperdeck length. This was determined by the FIGHT and MOVE blocks placed at the Major Feature Design Stage.[10]
2. The choice to have one WR-21 and one GB in each main machinery space leads to long main machinery rooms. This does not compromise damaged stability, but would reduce system survivability.
3. Use of a midships VLS battery restricts the use of central machinery spaces for Gearboxes.
4. The long machinery spaces cause accommodation to be placed over the machinery on No. 2 Deck

The layout adopted for the design is relatively conventional, to concentrate design effort on the machinery systems layout.

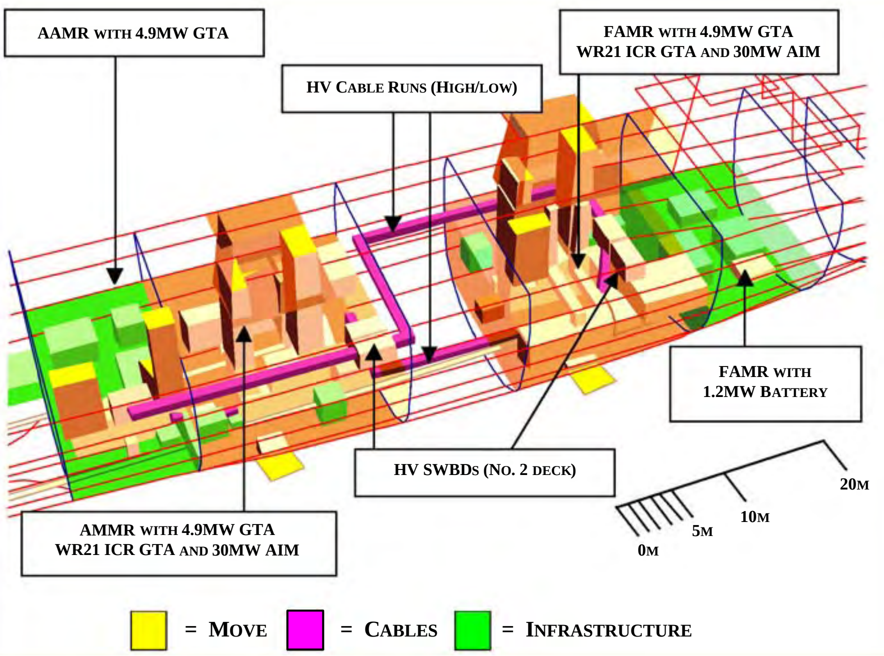

FIG.7 – MAIN AND AUXILIARY MACHINERY SPACES OF OPTION 2 (BASELINE + IFEP MACHINERY)

1. The machinery spaces are not reduced in length compared to the baseline design, due to the inclusion of the alternator. The overall configuration of this vessel is unchanged, as the drive motors are accommodated in the main machinery spaces with the motor controllers over.
2. AMMR has reduced double bottom height to allow fitting of Advanced Induction Motor, which is assumed to be approximately 4m in diameter and length and 190 tonne in mass.[4, 23]
3. Note HV IFEP cable runs (Purple). Approximately 133 tonne of HV cables are required. HV cables runs pass between the GTAs in the main and auxiliary machinery spaces. They are in a high (starboard) – low (centre) configuration. The low run passes through a box keel, which reduces tank volume.
4. The HV switchboards and cables on No. 2 Deck cannot be next to accommodation or magazines. The accommodation on this deck is on the starboard side of the ship to allow for a services passageway inboard of the main starboard passageway.
5. The large increase in transverse metacentric height compared to the baseline is due to the addition of large items of machinery low down in the ship.

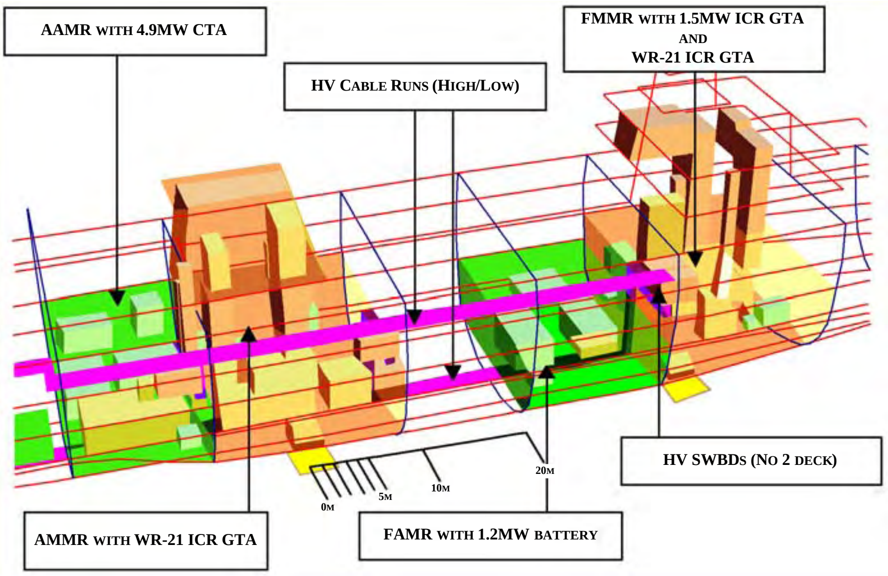

FIG 8 – MAIN AND AUXILIARY MACHINERY SPACES OF OPTION 3 (BASELINE + IFEP + PODS)

1. Advanced Induction Motor based pods are impractical, due to the large diameter. The pods used are scaled from conventional SCHOTTEL double ended pods using a ratio of 1/3 on weight and diameter, corresponding to the ratio of Permanent Magnet Motor/Advanced Induction Motor weights and diameters at powers around 5-10MW.

2. The pod machinery room aft takes up two decks and pushes the towed array forwards. It would also limit the use of aft VLS batteries if the design was configured in that way.

3. To compensate for the weight of the pods aft and prevent excessive trim by the stern, the forward main machinery room is placed under the superstructure. This leads to an undesirable mix of trunking and electronics spaces and would increase ducting losses on the GTAs.

4. Approximately 170 tonne of HV IFEP cables are required. Vertical connections between the two runs are provided at each switchboard.

5. The machinery spaces can be reduced in length to 15m. However, the increased displacement of the vessel leads to an increase in length overall, to keep resistance down.

6. Note the higher Propulsive Coefficient due to the use of pods. Aft sections in this vessel were flattened in an attempt to model a similar buoyancy distribution, but this is an area of uncertainty as the hullform is not exactly defined at concept.

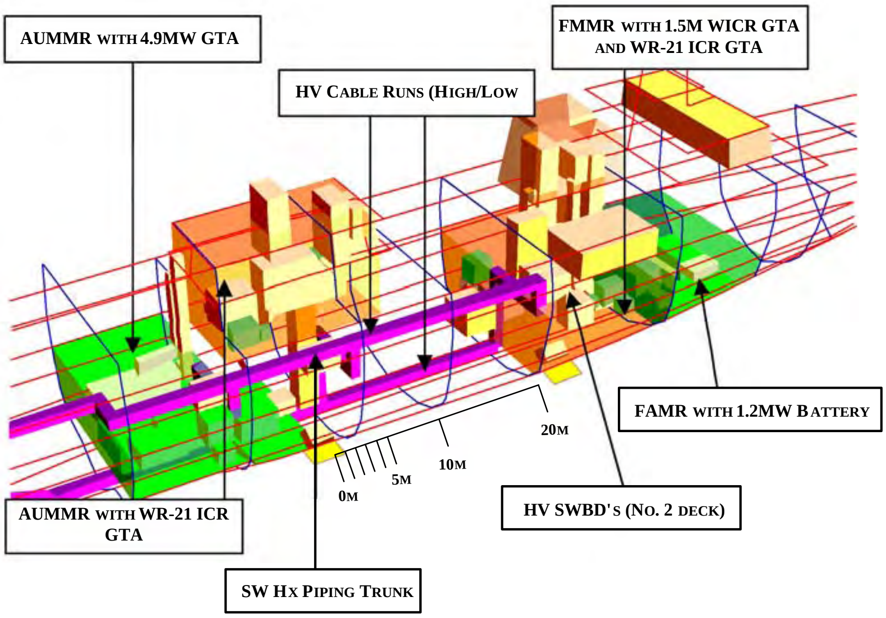

FIG.9 – MAIN AND AUXILIARY MACHINERY SPACES OF OPTION 4
(BASELINE + IFEP + PODS + DISTRIBUTED PRIME MOVERS)

1. The After Upper Main Machinery Room is near the accommodation spaces aft, so acoustic and thermal insulation would be required. The position of the machinery space close to the hangar splits the aviation workshops port and starboard.
2. A services trunk was added below the After Upper Main Machinery Room to represent the ICR Saltwater/Freshwater Heat Exchanger equipment. This passes through stores spaces below the machinery room to a small AMR on No. 5 Deck.
3. Upperdeck machinery spaces can be considerably smaller for the same equipment, as they do not have to extend the full width of the ship, and could not due to upperdeck arrangement demands. This may require an increase in AMR volume to accommodate displaced systems.
4. Approximately 160 tonne of HV IFEP cables are required.
5. In this design, the FMMR is moved aft of the superstructure, reducing interference between operational spaces and ducting but at the cost of increased trim by the stern.
6. The Metacentric Height is decreased by the use of the upperdeck machinery. At this stage of the design process, the beam/draught ratio chosen leads to excessive stability, so this is not a problem. Comparison of the options presented shows that the effect of raising the main machinery may be small on a ship of this size.

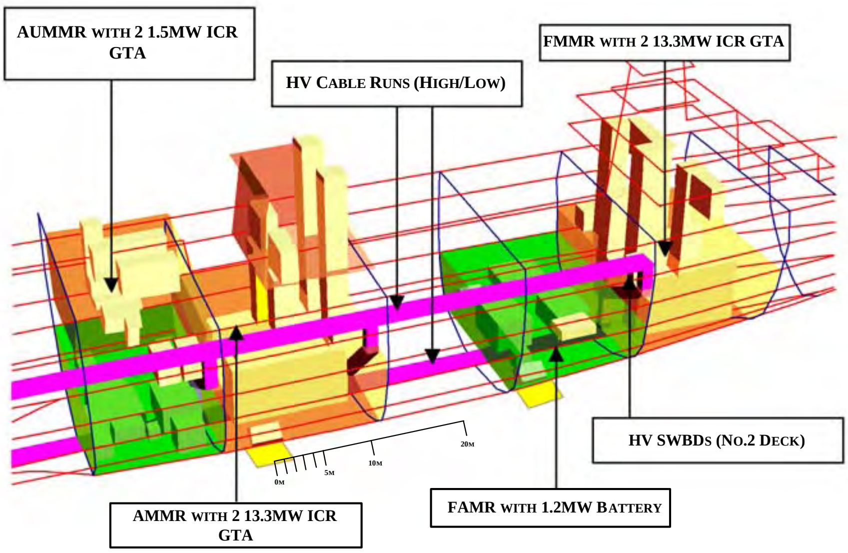

FIG.10 – MAIN AND AUXILIARY MACHINERY SPACES OF OPTION 5
(BASELINE + IFEP + PODS + SMALL PRIME MOVERS)

1. The FMMR is under the superstructure, and has the same undesirable mix of vents, electronics spaces and accommodation above it as is found in Option 3.
2. The upperdeck machinery space aft would require increased acoustic and thermal insulation, as it is over the Special Forces accommodation.
3. Although the shorter machinery spaces allow more flexibility in layout, they are constrained by their interaction with other spaces, such as the electronics rooms and aviation workshops.
4. Approximately 180 tonne of HV IFEP cables are required in this design.

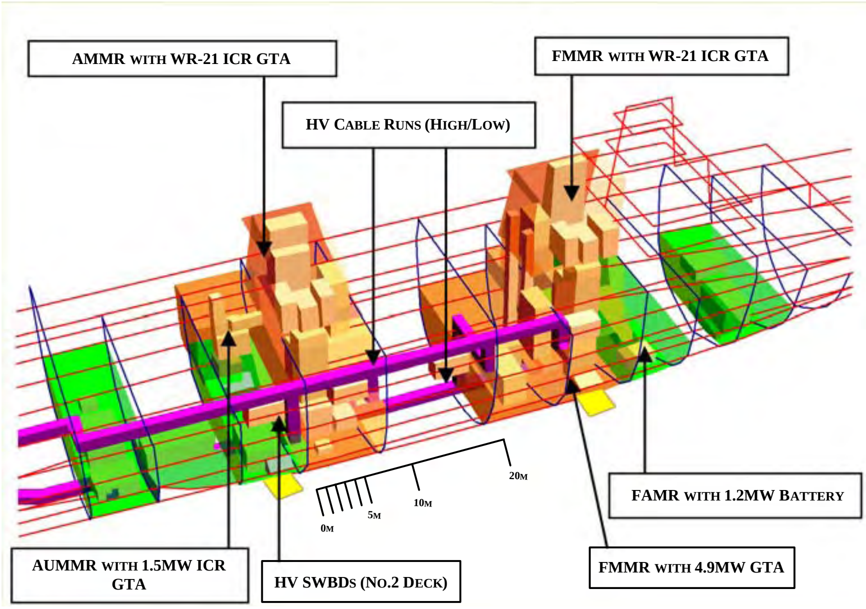

FIG.11 – MAIN AND AUXILIARY MACHINERY SPACES OF OPTION 6 (BASELINE + IFEP + PODS + VERTICAL GTAS)

1. A significant area of concern in this design is the very large holes in the upper deck created by the vertical MMRs. These are 7.5m by 12m wide, and would have a significant effect on the structural design.
2. Approximately 177 tonne of HV IFEP cables are required.
3. This design was intended to have superior system survivability, hence the division of AMRs. These smaller spaces can be placed over the FW tanks etc., so some systems runs would be shortened. Conversely, the larger number of watertight bulkheads would increase systems and structural costs.
4. The greatly reduced length of machinery spaces means that no accommodation is over machinery spaces in this configuration. However, some accommodation spaces are now on No. 3 Deck.
5. Damage Control philosophy in this design might have to be examined, as up flooding from damaged main machinery spaces would be more likely. The SCC/HQ1 space has been moved to No. 1 Deck to compensate.
6. Air flow into the vertical GTs is improved, the trunking route is shorter and the cascade bend before the LP turbine is eliminated. Removal is also easier as it is now a straight lift.

CONCLUSIONS

This article has looked at how ship configuration can be brought more centrally into the initial ship design process, how the Design Building Block approach, pioneered by the UCL naval architecture and ship design research effort, can be used to explore one of the claimed ship design consequences of the current moves to exploit electric propulsion developments in naval combatants.

Through a specific large surface combatant design study, a range of AES arrangements have been introduced into the design and balanced design studies presented showing both the overall ship design impact and the arrangements for each study's machinery spaces. Given the investigation has been limited to a specific ship type with overall combat and ship performance characteristics, any conclusions are likely to be provisional; however the following initial conclusions from this investigation are seen to be:

- Large GTAs limit the scope for their placement beyond the usual midships deep location.
- Shafting elimination gives ship layout advantages but pods and their adjacent conversion machinery introduce further local layout and structural constraints.
- The need to maximize survivability is a major determinant in selecting layout options.
- Arranging GTAs vertically has some advantages in machinery space demands but raises other design impacts that require further investigation.
- High voltage cable runs have a significant ship impact mainly due the constraints on which compartments they can be adjacent to but also their weight.
- Electric ship options are likely to be heavier than non electric equivalents, resulting in impact on overall initial ship cost, however the through life cost advantages are likely to more than balance this.

Overall the advantage of being able to explore different machinery configurations has further justified the design utility of the UCL Design Building Block approach in its current form provided by the SURFCON addition to GRC Limited's PARAMARINE preliminary ship design system.

It is further considered that the studies of the monohull combatant presented should be extended to multihull forms, particularly Trimaran variants, where it is considered the configurational advantages suggested by AES machinery fits could show greater advantages in the overall ship impact.

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