DRAFT VERSION

A CASE STUDY IN PRELIMINARY SHIP DESIGN

D J Andrews and **R G Pawling**, Design Research Centre, UCL, UK

SUMMARY

There have been a large body of papers on preliminary ship design, both in the Transactions and elsewhere in the ship design literature. However when these are considered, it is generally the case that they are either describing a specific ship design or talking in general about different ways in which ships may be designed. What this paper therefore sets out to provide is a detailed description not so much of a general process, with examples to illustrate the generality or to overly focus on the end point of a particular ship design process, but rather to take a given detailed case study of a design, worked up in some depth. The example chosen is a trimaran option of the US Navy Littoral Combatant Ship produced by the authors as the result of an investigation for the US Navy's Office of Naval Research into the capability of the UCL Design Building Block approach to Preliminary Ship design and specifically its realisation in the SURFCON module of the Graphics Research Corporation's PARAMARINE ship design tool. The paper is considered to be unique as a published exposition on preliminary ship design in that the intermediate steps in the evolution of the detailed concept study are given in some technical depth along with the presentation of the major design issues as they arose through the concept process.

The paper commences with the justification for the presentation of this investigation into the nature of preliminary ship design, including a survey of previous work in the field. The specific DBB approach is briefly outlined, as is the basis of the particular case study, before the main part of the paper presents the main steps in the specific case study, through technical and graphical descriptions. The discussion considers the insights the case study provides, as well as their limitations, before presenting conclusions on the nature of preliminary ship design for complex vessels, typified by the modern multifunctional naval combatant.

1. INTRODUCTION – NEED TO PRESENT A PSD CASE STUDY

It might seem there have been a lot of papers on preliminary ship design and the first of the authors has produced more than a few of these. However, when both the authors' papers and other papers on ship design are considered, it is generally the case that they are either describing a specific ship design or talking in general about different ways in which ships may be designed. In the former case, especially when the design is only completed to a preliminary design or concept level, then it is usually just the final design outcome, rather than a detailed step-by-step description of the evolution of the design for which a level of technical description is provided [1, 2]. If it is a completed design of a built ship then some detail of the early evolution is usually provided, as this is crucial and records major design choices, but these details are not sufficiently comprehensive to understand how the preliminary design itself evolved. (See for example Ref.3 for INVINCIBLE Class, Ref.4 for Type 23 Frigate and Ref.5 for the US Navy SPRUANCE and TARAWA Classes.) When it comes to generic expositions on ship design, if covering the whole process, insufficient detail is provided to outline the preliminary steps beyond, at best, a few technical examples [6, 7].

What this paper therefore sets out to provide is a detailed description, not so much of a general process with examples to illustrate the generality or to overly focus on the end point of a particular ship design process but rather to take a given detailed case study of a design, worked up in some depth, through all the preliminary stages of that design study. By detailing the specific intermediate steps in some depth, the process of preliminary design can then be analysed and discussed. It is hoped this detailed sequencing of a design evolution can then be used to better inform discussion on how the preliminary phase, as the most crucial in design decision making, can continue to be practised given the rapid changes in design practice and the growing numbers of design tools available to ship designers.

In looking at this specific example, which is presented in the central sections of the paper, for the purposes of this investigation of preliminary ship design, it has become clear that most discussion of ship design in general and preliminary design in particular has focused on what might be considered to be design managerial, organisational and process perspectives. An example of this is the first author's 1994 paper on preliminary warship design, which spelt out the stages in preliminary design that had been adopted by the UK Ministry of Defence's Future Projects Design Group that he headed up in the early 1990s [8]. In particular it laid down a graduated process, appropriate to a major new warship concept, with three overlapping stages within the overall concept phase. Example projects that were being addressed were the next escort (which subsequently became the Future Surface Combatant [9]) and the Future Carrier (CVF) [2], both of which were commencing concept consideration at that time. The three stages were denoted as:

- Concept exploration;
- Concept studies;
- Concept design.

Each stage had a distinct objective in ensuring by the end of the overall concept phase, namely, what the UK MoD now denotes as Initial Gate [10], that a comprehensive exploration of the solution space, a comprehensive study of the main parameters and style issues, and a comprehensive investigated trade off study have been preformed. This was intended, preferably, to result in a single preferred option, which matched the emergent (and affordable) operational requirements and was the basis for proceeding into Feasibility (now designated Assessment by UK MoD [8]). This exposition was done with design examples but not showing the intermediate steps to each concept design, which the current paper is intended to show.

Two earlier papers by the first author [11, 12] described the overall and the preliminary ship design process as part of that author's particular approach to ship design that culminated in the general exposition of his "Architectural" approach to ship design in 2003 [13]. Several examples of applying this approach to preliminary design tasks in the real world are summarised in Ref.14 and these outputs can be compared to purely academic exercises using the approach, such as those early cases described in Refs. 11 and 12. The UCL based description of the ship design process and the subsequent architecturally focused design development is reviewed along with other process descriptions in the next two sections, to place in context the stages adopted for the specific design example of this paper. This example is then presented in the subsequent main sections of the paper before the concluding discussion on the insights, gained from this study, on the nature of preliminary ship design along with any limitations in the study.

Before this scene setting review of preliminary ship design, it is sensible to say a few words on the scope of the case study. This is necessary, as any such example needs to be placed in context, given it is presented as a means of enlightenment on what has been acknowledged, by many eminent practitioners, to be a complex process [15, 16 17]. Ref. 18 at Table 4 distinguished between a range of types of ship design in terms of their degree of novelty, from a stretch version of an existing design to the extreme of a radically new technology, typified by the US Navy's 1970s 3KSES combatant [19]. Neither the least or the most novel of this design spectrum would be appropriate examples to choose, nor, indeed, would the type ship or evolutionary design approaches, since they are heavily constrained by the designs they draw upon. We are thus left with essentially new or ab initio designs, which might be designs conventionally produced by the methods discussed in the next section, or designs produced by the "architecturally integrated approach" of Refs. 13 and 14. Amongst the advantages the first author has propounded for this latter approach is that it can readily address both conventional ships and radical configurations. So the example chosen is indeed an unconventional hull form configuration, that of the Trimaran, which was adopted for the design study in question to achieve the high speed laid down by the customer. It is open to debate as to whether it might have been better, in the case of the current exposition, to choose a more conventional monohull, however there were felt to be certain advantages in stretching the architectural design approach to a demanding set of requirements. It could also be argued that the trimaran configuration is no longer a purely research concept and, while still lacking the extensive database of the monohull naval combatant, it has some reasonably coherent and mature design procedures [20, 21].

The second point with regard to the choice of case study is that it commenced with a very clear set of requirements. This was a consequence of the particular customer's objective in getting the authors to undertake the study, as is explained in Section 4. In this respect it is considered, from an overall design procedural level, that the case study is a little artificial when compared to the concept design studies normally undertaken for a major new class of warship for (say) the UK Ministry of Defence. A precise and unaltered set of technically specific requirements (as can be seen from Section 4) is unlikely to be available at the start of the process described in Ref. 8. Rather the main driver of the pre-Main Gate ship design process is to elucidate the initial requirement perception of the operational or naval staff and to inform that dialogue with a trade off process that balances the operational needs with what is perceived to be affordable [22]. So it needs to be accepted that this current presentation of a case study is primarily to provide a detailed sequencing of the technical evolution of what would (probably) be just one option (as a radical configuration) among several. Furthermore its requirement would be far less clear at design commencement and the eventual "preferred option" at Initial Gate would usually emerge from a difficult and often protracted trade off exercise, where affordability looms large. So the lack of the "requirement elucidation" element in the case study has the advantage of not complicating the main objective of the paper as a technical case study in preliminary ship design evolution. With this proviso it is now appropriate to briefly review the general process of preliminary design, which the case study is intended to enlighten.

2. THE PROCESS NATURE OF PRELIMINARY SHIP DESIGN

Given the overriding importance that the initial process is intended to create a new ship design by setting the "skeleton" on which the subsequent design is built, it can be considered surprising that there has been little direct discussion, over the years, on the specifically technical nature of that process. This is considered to be due, at least in part, to the fact that the vast majority of ships are evolved directly from specific previous designs. However, it is also in part due to the sensitivity of individual preliminary design organisations in revealing the commercial or security aspects of their "Intellectual Property". The clearest exposition on the preliminary design of mercantile ships is that by Watson and Gilfalian [23], now some 30 years old. Perhaps the nearest equivalent from the naval ship design field is, surprisingly, from the highly sensitive world of submarine design. This is the three page "submarine design procedure" presented by Burcher and Rydill [24] in their classic text book on concepts in submarine design. Unlike Reference 23 this does not give specific algorithms, though much of the book provides the basis for populating the various steps in the sizing procedure. However neither of these submarine or mercantile expositions takes a particular example and shows its stepwise development through the initial design process, hence the intention behind the current paper to provide such a description.

Lest it be thought there have been few publications on the nature of preliminary ship design, attention is specifically directed to the first State of the Art Report on Design Methodology presented at the 1997 International Marine Design Conference (IMDC) at Newcastle University [25]. This first author of the current paper both edited that report and specifically wrote the sections on Preliminary Ship Design Methodology and on Naval Ships and Submarine Design Methodology. These two sections are considered, with their 33 and 64 references respectively, to provide a comprehensive review of the literature in the field and those references are listed at Appendix for the current reader. An update on the mercantile and naval ship design methodology was provided in the 2006 IMDC State of Art Report on Design Methodology, also edited by the first author [26]. A further recent "state of the art" overview was provided by Gale in Chapter 5 of the 2003 SNAME publication "Ship Design and Construction" and which is entitled "Ship Design Process" [6], however like so many of the publications reviewed in the IMDC State of Art Reports, this focuses largely on procedures and issues related to the environment in which ship design is practiced, rather than specifically on the progressive technical steps.

The use of computers to undertake a range of design explorations has also been characterised by presentations of a general nature with usually one or two example design outputs presenting the end of the concept process, rather than detailed expositions of the technical process including specific intermediate design solutions. An early naval ship design example, somewhat akin to Reference 23, was due to Eames and Drummond [27]. There have also been examples of a range of comparative design studies being presented, notably by Garske and Kerr [28] and Mistree et al [29], which give insights into the nature of concept exploration through altering various input parameters. An early computer supported investigation by Andrews [30] varied both inputs and hull form parameters and this has been greatly extended by more recent work at UCL by McDonald et al [31] and, specifically using genetic algorithms, by Vasudevan and Rusling [32]. What all these studies reveal is the nature of specific worked up and balanced design studies as options or variants in exploring, either specific requirement impacts (e.g. speed, margins, payload) or form or dimension choices, in terms of ship performance or affordability. What they do not specifically reveal is the manner in which a given design option is both chosen and then developed to a given level of definition through a set sequence of intermediate balanced design steps as presented in the current paper.

Because so many real designs evolve in response to the dialogue with the requirements owner, the technical nature of the preliminary design development is often obscured, or just the major design choices are recorded for posterity, if at all. Thus for example, Bryson [4] shows three intermediate design studies in the case of the Type 23 Frigate evolution from a 100 m light frigate to the 123 m final medium sized frigate design. However, aside from the completed design, little in the way of detail is given for each intermediate study, apart from profile drawings. In this one case, significantly more information is provided in a Ministry of Defence produced schedule history of the full process of that design's development from 1979 to 1983 in a four page bar chart, which has been reproduced in a UCL internal publication handed out to the Naval Architecture MSc Course students [33]. However even this comprehensive design history only records major design decisions and specific design related activities rather than comprehensive technical descriptions of the intermediate design steps. The most comprehensive design evolution description provided in open literature on a US Navy design, at an equivalent level to this Type 23 design history, was provided by Leopold and Reuter [5]. In that SNAME paper they largely describe the specific separate design processes for the SPRUANCE Class Destroyers in terms of the general arrangement, envelope definition, subdivision (and stability), structural design and subsystem design to a level more appropriate to feasibility than just initial concept design. That is to say at a level that is normally required at the conclusion of preliminary design leading up to contract definition. Leopold and Reuter do show four alternative cut away profiles from what are said to be at least nine "alternative (configurational) concepts" that the Littons team examined. However, again no technical detail is given on these alternative design studies or, indeed, any earlier concept studies that led to these configurational design options from which the final design was developed.

Before outlining the actual process used in the case study presented in this paper, it is considered sensible to spell out, in a little more detail, the overall concept process in terms of three initial design stages, comprehensively presented in the first author's 1994 paper on the preliminary design of warships [8] and already listed in the third paragraph of the introductory section. Considering each in a little more detail:-

a) Concept Exploration
This initial design phase can be said to comprise a wide ranging exploration, which starts at the initiation of investigations for a new ship design. It should be an extensive investigation of all possible options and typically include modernising existing ships, modifying existing designs and exploring the full range of, for example:-

(i) packaging of the primary function (e.g. aircraft, weapons or sensors for a combatant; cargo/passengers for auxiliaries or merchant ships);
(ii) capability of the ship to deliver the functions (e.g. speed, endurance, standards);
(iii) technology options to achieve the functions and capability (e.g. existing technologies, enhanced materials and systems, enhanced technological/ configurational options, reduced technology levels).

These explorations may well be cursory or may show the need to pursue several distinct options and may require research programmes or revisiting (not for the last time) the operational concept. In the example presented here, this stage is assumed to have been undertaken prior to this particular study (effectively by the US Navy leading up to the published preliminary requirement specification).

b) Concept Studies
Assuming only one or two options are to be taken forward, the wide ranging but cursory nature of the initial exploratory stage is unlikely to have investigated in any depth the perceived design drivers and the impact of various choices on function, capability and technology. This stage is dependent on the type of vessel (i.e. combatant, aircraft carrier) and degree of novelty (e.g. conventional monohull, unconventional configuration), as well as a range of issues to be addressed from payload demands through speed and endurance to style issues, such as those associated with design life, signatures, survivability and complement standards. All these issues normally merit investigation before the design is too fixed. They can also significantly influence the downstream design but, more importantly, they need to be debated with the requirements owner, since their impact on the ship's performance and affordability should be part of the requirements elucidation dialogue before the form and style of the solution is too precisely fixed. Again, in the example presented here, most of these investigations of a requirement/style nature were predetermined by the customer for the study (i.e. Office of Naval Research on behalf of Naval Sea Systems Command (NAVSEA) of the US Navy).

c) Concept Design
This final stage prior to approval to commit to a more substantial design effort (i.e. in UK MoD terms, prior to Initial Gate decision) is primarily focused on the design (and costing) information necessary to ensure the approval to proceed is based on sufficient information and that the process beyond that approval proceeds coherently. Typically the stage is dominated by cost capability trade-off studies and the interaction with any associated operational analysis. It can be appreciated that to enter into this last concept stage with inadequate exploration of the solution space or of the style and performance issues, is unwise as any submission to proceed is likely to be vulnerable to probing by approval authorities of the decisions on such issues. This just emphasises the inherently "political" nature of naval ship acquisition at the front end of the process and why it is often protracted and seen to be unsuccessful and apparently costly. For the case study presented, such issues are seen to be more related to the design and acquisition environment, which well addressed in US Navy organisational papers (such as Tibbitts and Keane [34]) and also in Reference 8 and the Appendix.

All this scene setting has been presented to show that the case study has to be seen as primarily a specific technical design development task in preliminary ship design, from which much of the political and process procedure has been excluded, in order to focus on the manner in which the technical design has actually been undertaken. This is considered to be justified in that to show the wider procedural issues, which have been addressed in numerous generic papers [8, 34 and listed in the Appendix) and indeed in papers on specific ship designs (again see references in the Appendix), would deflect attention from the detailed technical design evolution, which it is considered has not been previously presented. However, it is necessary to bear in mind the specific focus of this study and the means by which the study has been insulated from many of the "realities of naval ship acquisition".

3. THE SPECIFIC DESIGN BUILDING BLOCK PSD PROCESS

In order to present the specific design approach adopted for the case study, it is considered sensible to provide some of the justification for its adoption here. Betts [35] in a keynote paper to the 2000 International Conference on Marine Design discussed, in terms of warship design, the needs for tools to be used in preliminary design. The first author listed at Table 5.2 of Ref. 13 (and reproduced at Table 1) Betts "Needs" alongside a summary of the types of CAD tools available for Preliminary Warship Design (PWD).

Needs for Preliminary Warship Design Tools	Current Types of PWD CAD Tools
1. Utilise data for assessment of performance, risk and Through Life cost. 2. Useable by knowledgeable design team. 3. Deal comparably with conventional and unconventional ship concepts. 4. Provide reasonable (preliminary) solutions. 5. Assist communications with design team and all stakeholders, especially those evolving the operational requirement.	1. Optimisation – black box, fuzzy methods, Genetic algorithms, neural networks. 2. Expert systems, knowledge based. 3. Decision Based Design and MCDM. 4. Configuration based, including Design Building Block approach. 5. Simulation Based Design and Virtual Prototyping.

Table 1. A Listing of Betts [35] Analysis of Preliminary Warship Design Tools Needs with the current range of Types of Tools available [13]

In justifying the adoption of a configuration based approach (item 4 of Table 1) the first author in Ref. 13 went on to list the features required of a preliminary ship design approach. Thus these should provide:-

- Believable solutions, i.e. solutions which are both technically balanced [36] and sufficiently descriptive [37];
- Coherent solutions, which mean that the dialogue with the customer should be more than merely a focus on numerical measures of performance and cost, by including a comprehensive visual representation (noting that SURFCON provides considerably more than an artist's impression of the outside of the ship);
- Open methods, in other words the opposite of a 'black box' or a rigid/mechanistic decision system, so that the description is responsive to those issues that matter to the customer, or are capable of being elucidated from customer/user teams;
- Revelatory insights, in particular identifying likely design drivers, early in the design process to aid design exploration in initial design and beyond;
- A creative approach, not just as a "clear box" but actually encouraging "outside the envelope" radical solutions and a wide design exploration.

The logic underlying the SURFCON tool realisation of the UCL Design Building Block approach was spelt out in Ref. 13. In essence this approach gives a primary focus to ship architecture and ensures that is produced alongside the traditional numerical sizing and naval architectural balance in the initial design synthesis. The Design Building Block approach to producing a new ship design is outlined in Figure 1. 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 in early iterations around the sequence of selecting and placing Design Building Blocks, hull geometric definition and size balance. In fact several of the inputs shown in Figure 1 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 amphibious warfare vessels, where personnel and vehicle flow are likely to dominate the internal ship configuration, rather than, say, topside configuration in a surface combatant.

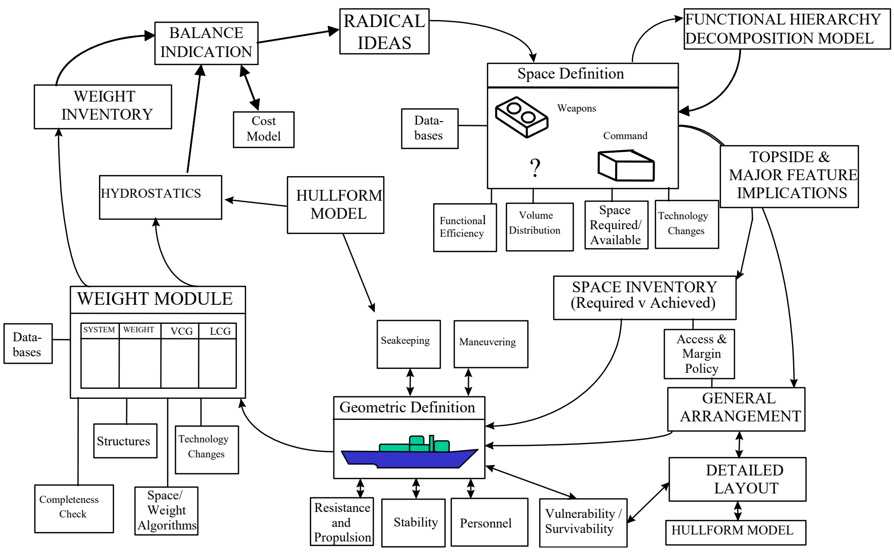

Figure 1 Overview of the Design Building Block approach applied to Surface Ship initial design [13]

The SURFCON realisation of the Design Building Block approach to preliminary ship design is described by the authors in Ref. 37 as is its place as a module within Graphics Research Corporation's PARAMARINE ship design suite [38]. A feature of SURFCON is the use of the term Master Building Block to denote how the overall aggregated attributes of the Design 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 well established commercial ship design suite of PARAMARINE, is that the audited building block attributes within the Master Building Block can be directly used by PARAMARINE, so the necessary naval architectural calculations can be performed to ascertain the balance or otherwise of the configuration just produced by the designer. Typical information held in the Master Building Block includes:
Overall ship 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.

As the design description is built up and modified, all the features of the Design Building Blocks are normally utilised by the system. The geometric definition (shape and location) is used to constantly update the graphical display, while data properties are indicated in a logical tree diagram of the design, as shown in Figure 2 and described in more detail in Ref. 37. Figure 2 also shows the block representation and a tabular view of typical numerical information from a specific analysis of the design. It has been argued in Ref. 13 and, through the design studies (several for industry and navy) summarised in Ref. 14, that the ideal features of a preliminary ship design approach, listed in the five bullet points below Table 1, are achieved by this Design Building Block approach to preliminary ship design. This is seen as a further demonstration of the revelatory nature of this approach and of the specific tool and is well demonstrated by the case study presented in the current paper.

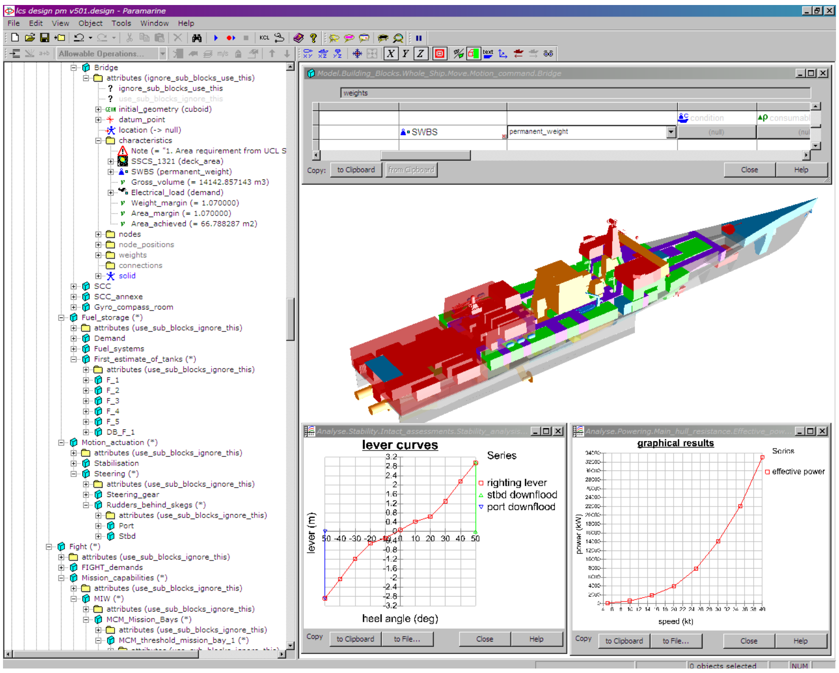

Figure 2: SURFCON representation showing the three panes for tree structure, graphics (Design Building Blocks) and tabular interfaces, with the results of stability and resistance analyses also visible.

4. THE ORIGIN OF THE CASE STUDY

The case study arose following an invitation for the authors to visit the US Navy's Office of Naval Research (ONR) Headquarters, the Naval Sea Systems Command (NAVSEA) and the Naval Surface Warfare Centre Carderock (NSWCCD), all in Washington D.C., to present the SURFCON realisation of the Design Building Block approach to preliminary ship design. From this visit a draft statement of work for a task entitled "Evaluation of Object-Oriented Ship Design Technology" was produced. Subsequently a contract was placed with UCL for the design work to be undertaken in late 2003 and early 2004. The primary objective of the work was to demonstrate the SURFCON – PARAMARINE toolset and the ability of the DBB approach, through a comparative evaluation by UCL and NSWCCD, to design advanced hullforms. The US Navy's Future Naval Capability for littoral combat and power projection was targeted for this demonstration and hence the Littoral Combatant Ship (LCS) requirement was selected and a trimaran option designed to that requirement (summarised in Table 2). This relatively detailed requirement removed many of the usual Requirement Elucidation issues referred to in Section 2 of this paper.

LCS Flight 0 Critical Design Parameters		
Category	**Threshold Level**	**Objective Level**
Total Price Per Ship	Meet Cost As an Independent Variable (CAIV) target in the REP	Exceed CAIV target in the REP
Hull Service Life	20 Years	30 Years
Draft at Full Load Displacement	20 feet	10 feet
Sprint Speed at Full Load Displacement in Sea State #	40 knots in Sea State 3	50 knots in Sea State 3
Range at Sprint Speed	1000 nautical miles	1500 nautical miles
Range at Economical Speed	3500 nautical miles (>18 knots) with payload	4300 nautical miles (20 knots) with payload
Aviation Support	Embark and hangar; one MH-60R/S and VTUAVs, and a flight deck capable of operating, fueling, reconfiguring, and supporting MH-60R/S/UAVs/VTUAVs	Embark and hangar; one MH-60R/S and VTUAVs, and a flight deck capable of operating, fueling, reconfiguring, and supporting MH-60R/S/UAVs/VTUAVs
Aircraft Launch / Recover	Sea State 4 best heading	Sea State 5 best heading
Watercraft launch / Recover	Sea State 3 best heading within 45 mins.	Sea State 4 best heading within 15 mins.
Mission Package Boat type	11 metre RHIB	40ft High Speed Boat
Time for Mission Package Change-Out to full operational capability including system OPTEST	4 days	1 day
Provisions	336 hours (14 days)	504 hours (21 days)
Underway Replenishment Modes (UNREP)	CONREP, VERTREP and RAS	CONREP, VERTREP and RAS
Mission Module Payload	180te (105te mission package / 75te mission package fuel)	210te (130te mission package / 80te mission package fuel)
Core crew Size	50 Core Crew Members	15 Core Crew Members
Crew Accommodations (Both core crew and mission package detachments)	75 personnel	75 personnel
Operational Availability (Ao)	0.85	0.95

Table 2: LCS threshold and objective requirements [39]

A summary of the operational concept for the US Navy LCS is given in Ref. 39 and the important issue in that requirement, for the purposes of the theme of this paper, is that the LCS is perceived as a self-deploying, forward operating vessel able to carry out a wide range of possible missions. Thus it is not intended to operate on its own, but rather as part of a squadron of vessels, each with a payload focused on a specific mission. As such, the LCS requirements emphasise the use of modular payloads to permit a change of role as the strategic scenario develops and to see the individual ship is part of a larger system within a network–centric warfare vision.

This modular approach is described by the US Navy as a “seaframe”, where the core LCS fit has a limited payload of defensive weapons, sensors, command and communications equipment and the main warfighting payload is modular, deployable and removable. This is similar to the aerospace concept of an “airframe”, where the mission is defined by payload carried under the aircraft’s wings or in a bomb-bay. The other feature of the LCS requirement, which had a major influence on the design study, is a capability to both deploy trans-ocean at conventional speeds and, once in the littoral, to ramp up to much higher speeds (e.g. a Threshold Level of 40 knots - see Table 2). A numerical description of the threshold mission payload, including core ship weapons and sensors, mission modules and hangar and payload bay dimensions, was provided to the authors by NSWCCD. Thus from the beginning of the case study the two most demanding requirements were seen to be the use of modular payloads, deployed aft, and a very high speed requirement for an ocean going sustainable vessel.

5. DEVELOPMENT OF THE CASE STUDY

5.1 THE OVERALL PROCEDURE USED IN THE CASE STUDY

Previous UCL ship design studies using SURFCON led to the development of a broad general approach to using the tool in preliminary ship design [14]. This consists of general descriptions of the overall approach, rather than detailed procedures, ensuring the application of the approach to a wide variety of ship design types. The first task within the project was for the UCL DRC to produce a more detailed procedure for the US Navy users. This took the US Navy designer through four stages of design used in the Design Building Block approach, as implemented in the PARAMARINE software.

As outlined in Ref. 37, each of the four main stages represents an increasing level of definition of the preliminary ship design. At each stage an appropriately holistic and numerically balanced definition of the ship design is produced, using assessments of as wide a range of performance aspects as is sensible at that stage in the design evolution. Table 3 illustrates typical design decisions taken at each stage, which are outlined for the Case Study in the remaining sub-sections of this section and Section 6.

Design Preparation
Selection of Design Style
Topside and Major Feature Design Phase
Design Space Creation
Weapons and Sensor Placement
Engine and Machinery Compartment Placement
Aircraft Systems Sizing and Placement
Superstructure Sizing and Placement
Super Building Block Based Design Phase
Composition of Functional Super Building Blocks
Selection of Design Algorithms
Assessment of Margin Requirements
Placement of Super Building Blocks
Design Balance & Audit
Initial Performance Analysis for Master B.B.
Building Block Based Design Phase
Decomposition of Super Building Blocks by function
Selection of Design Algorithms
Assessment of Margins and Access Policy
Placement of Building Blocks
Design Balance & Audit
Further Performance Analysis for Master B.B.
General Arrangement Phase
Drawing Preparation

Table 3: Design Building Block design stages showing major design choices [37]

5.2 DESIGN PREPARATION STAGE

The aim of this stage was to identify the capabilities required. These capabilities are translated into metrics appropriate to the Design Building Block hierarchy:-

- Maximum Speed;
- Range and endurance speed;
- Endurance of mission;
- Payload equipments and space demands;
- 'ilities' e.g.: producability, accessibility, maintainability, adaptability;
- Accommodation requirements.

At this stage of the design major stylistic aspects were also selected, for example;-

- Hullform topology;
- Technical design standards.

This allowed the assembly of a "design framework" containing sufficient data to start the design process, but with no explicit definition of the design. Examples of the data that were contained by this framework included:-

- Early stage design algorithms;
- Weight and space grouping systems (i.e. UK and US standards [40, 41];
- Data on equipment, particularly major machinery features.

From the metrics and stylistic aspects some of the design generators were identified and these then informed the definition of the initial layout of the design. For this study several decisions were taken in the Preparation Stage that strongly influenced the design, specifically:

- The topology of the vessel was specified as a trimaran, and a Series 64 hullform [42] was provided by NSWCCD as the basis for the main hull;
- The LCS requirements indicated that the design would be high speed (in the region of 40 knots) and shallow draught (20 feet, 6.1m). The high maximum speed suggested that a set of waterjets were the most likely choice of propulsor, although this was not finalised at this stage.

5.3 MAJOR FEATURE DESIGN STAGE (MFDS)

The main aim of the MFDS is to develop the overall layout and spatial style of the design using, primarily, those Super Building Blocks directly specified by the requirements, such as payload items (FIGHT category – see Ref. 37 for explanation of the DBB functional grouping of the building blocks) and main machinery spaces (MOVE). The initial configuration for the LCS study is shown in Figure 3, and consists of the following Design Building Blocks:-

- Mooring space on fo'c'sle;
- Bridge;
- Two Main Machinery Rooms (MMRs), each containing one generic MT-30 size gas turbine with intake and exhaust;
- Two shafts and waterjets;
- 57mm gun and magazine;
- Combat Information Centre (CIC);
- Payload bay, containing ten payload items;
- Hangar bay, containing eight payload items;
- Deployment ramp for payload items out of stern;
- 20mm Close-In Weapons System and workshop.

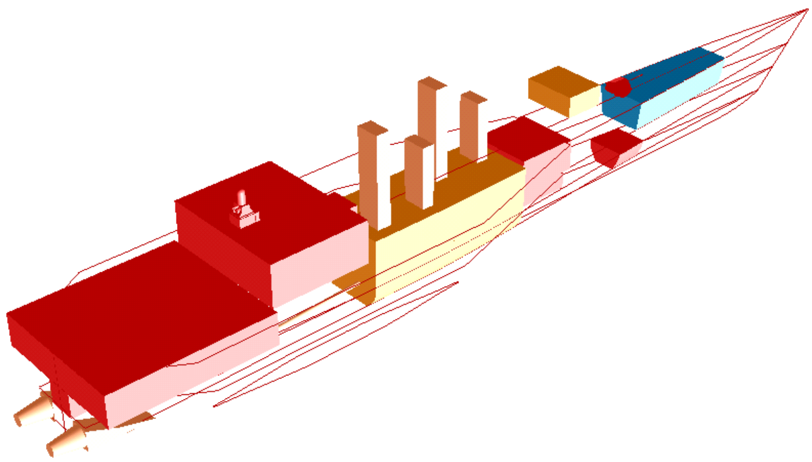

Figure 3: Initial configuration of the LCS design generated in the Major Feature Design Stage

This set of initial DBB includes the largest FIGHT items, and specifically those required for the main mission. It also includes the basic MOVE group blocks, given that high mobility featured significantly in the LCS requirements document. The hullform was quickly sized using the UCL Ship Design Exercise method outlined in Figure 1 of Reference 12 and this enables the designer to get a first estimate of propulsive power required. Initial estimates of intact stability and required metacentric height (GM) were used to generate an approximate side hull configuration by specifying a required waterplane inertia (area and transverse position). Table 4 provides a summary of the initial ship characteristics.

Number of DBB	18 (in 11 discrete SBBs and grouped BBs)
Displacement	2830te
Enclosed Volume	14100m3 (Required) 15300m3 (Available – includes voids)
Length, main hull, waterline	126.2m
Major Decisions	
• 18 basic SBB placed to generate the design. • Overall configuration established • Strong interaction between FIGHT and MOVE groups identified • CIC initially placed forward • Split GT Main Machinery Rooms amidships • Decks placed • Hull length corresponding to estimated displacement greater than required for layout alone • Approximate side hull configuration defined	

Table 4: Summary of the initial LCS design

The ship design at this stage was very rough, but allowed the main drivers in the design to be revealed and examined, from which an early evaluation of the overall topology of the likely solution space was possible. In each stage of the initial design process the design was iterated to a "balanced" condition, specifically in trim, stability and powering (including maximum speed and tankage for the specified range), as can be seen with the machinery configuration. During the MFDS the option of waterjets, machinery spaces, shafts and slow-speed propulsors was examined and a number of alternatives assessed, two of which are shown in Figure 4.

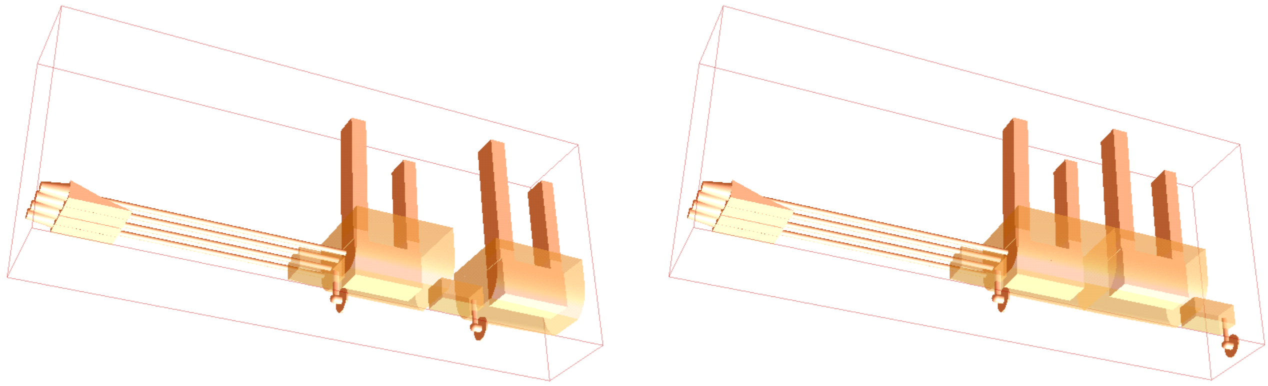

Figure 4: Two machinery configuration options considered in the MFDS of the LCS design

The MFDS also incorporated the first estimate of structural weight, using typical values for overall structural density and the volumes of the three hulls, box and superstructure blocks. Structural weight densities were drawn from open-source data and previous UCL trimaran research (see Ref. 39 for details). Figure 5 and Table 5 show the definition of the design at the end of this stage, with a considerably greater number of DBBs than at the start of the stage.

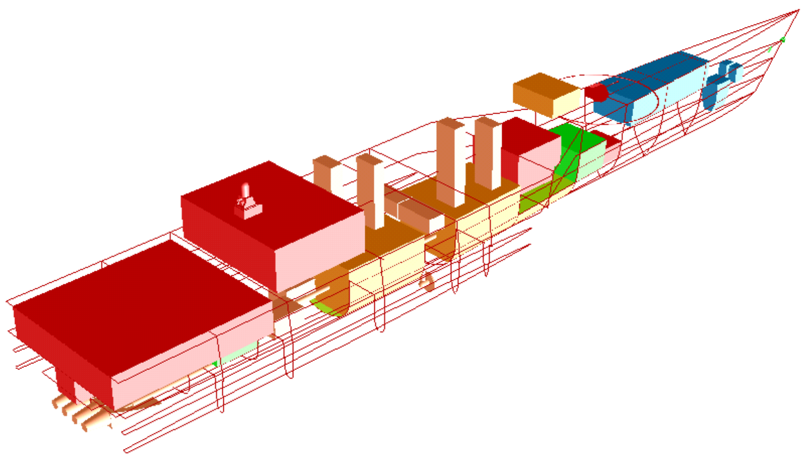

Figure 5: The LCS design at the end of the Major Feature Design Stage

Number of DBB	47 (in 15 discrete SBBs and grouped BBs)
Displacement	2900te
Enclosed Volume	21000m3 (R) 24000 m3 (A)
Length, main hull, waterline	135m
Major Decisions	
• 46 SBB placed to be confident in the design • Fuel tanks placed • Initial Auxiliary Machinery Rooms placed forward and aft • Hull lengthened due to increased displacement • Cruise pods placed amidships • Waterjet configuration changed to a row of 4 smaller jets • Bulkheads placed based on configuration	

Table 5: Summary of the LCS design at the end of the Major Feature Design Stage

5.4 THE SUPER BUILDING BLOCK DESIGN STAGE (SBBDS)

At this stage of the process the definition of the design is refined by incorporating the secondary drivers on the configuration and assessing the impact of the primary design drivers already identified. Super Building Blocks (SBB), indicating blocks of what will evolve into a number of closely related ship compartments, representing all the main features of the design are placed in the configuration. Following this the hullform can be defined, with some confidence, in more detail. SBBs placed at this stage for the LCS case study included:

- Main access routes;
- Deep magazines;
- Command spaces (CIC in US Navy designation);
- Communications spaces (as a large flat);
- Accommodation spaces (as three large flats);
- Auxiliary machinery spaces.

At this stage a hullform parametric survey was undertaken to determine the impact of hullform shape options on the overall design. Performing this procedure, after the overall configuration of the vessel has been initially modelled, importantly enabled the designer to incorporate the effects of the main configurational blocks on the choice of hullform parameters, something not readily possible without an architecturally based model. In this trimaran design, the main hull parameters were chosen to reduce resistance while still achieving a practical layout (e.g. ensuring sufficient space for the propulsion machinery in the slender main hull). The side hulls were then designed to provide the required stability based on intact GM. Figure 6 and Table 6 show the main Super Building Blocks arranged at this stage.

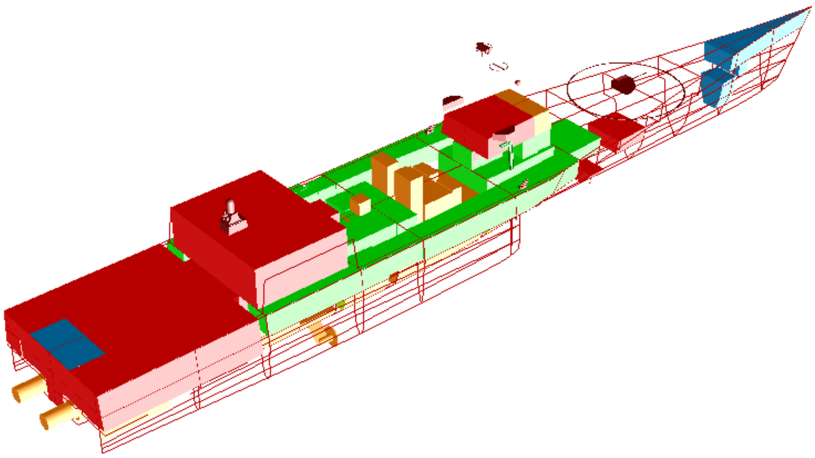

Figure 6: Super Building Blocks placed in the LCS design

Number of DBB	110 (in 33 discrete SBBs and grouped BBs)
Displacement	3100te
Enclosed Volume	18913m3 (R) 22700m3 (A)
Length, main hull, waterline	135m
Major Decisions	
• Both main GTs moved to a single MMR • Defined cruise GTA machinery spaces • Moved cruise pods aft of midships • Waterjets changed to final staggered configuration • Position of main items in all SBB defined • Accommodation placed as 6 large blocks • Possible conflict between cruise GTA ducting and superstructure identified • Side hull dimensions defined	

Table 6: Summary of the LCS design at the end of the Super Building Block Design Stage

Several major features of the layout were then examined by generating and comparing alternate configurations, such as locations for the CIC, which was ultimately placed under the hangar. With the positions of bulkheads, decks etc. determined, the SBBD Stage included the second estimate of structural weight, using equivalent thicknesses, material densities and areas of main structural elements. This was deemed necessary because the unconventional nature of the trimaran and its relative novelty result in a relatively high structural weight fraction [21], leading to concern that the demanding top speed might prove difficult to achieve. The equivalent thicknesses were calculated using a spreadsheet based tool used in the UCL MSc Ship Design Exercise [43]. At this stage alternative structural and material configurations were also considered leading to the choice of aluminium main hull and box, with composite superstructure and side hulls, as a steel option proved prohibitively heavy for such as high speed vessel with a large area of structural material, typical of a multihull configuration.

5.5 DESIGN BUILDING BLOCK STAGE (DBBS)

In the DBB Stage, a design is worked up to a sufficient level of detail to satisfy the designer that he or she has sufficiently addressed the levels of risk and uncertainty appropriate to this point in the overall design process. The process is a generally iterative one, namely, defining the configuration, assessing performance in regard to naval architectural and wider design issues, and, finally, modifying the configuration to maintain balance and improve performance. At this stage relatively detailed investigations into structural configuration and internal layout may be deemed necessary. There are seen to be four possible approaches when modifying the Design Building Blocks at this stage:-

a. Commence with those blocks already seen as causing design unbalance or conflict;
b. Select the largest blocks first before tackling smaller blocks;
c. Select the most constrained blocks before those less constrained;
d. Start with the FLOAT blocks, then the MOVE blocks, followed by the FIGHT blocks, and, finally, the INFRASTRUCTURE blocks.

For this case study, the DBBs were sized using algorithms in the UCL MSc Ship Design Exercise [44]. Features of the ship design previously defined were re-examined, including side hull and haunch design, which were modified to improve damage stability. This was done largely by an iterative process of synthesis, analysis and selection. For the case of the haunch design in a trimaran, it is usually possible to produce a design that gives the required waterplane area at any given angle of roll (for simple damage cases). However, since this was not seen to be a critical design driver at the initial design phase of this study, the development of such a refinement was considered beyond the scope of this phase of demonstration of the DBB approach for the given LCS exercise.

More detailed aspects of the design, such as the layout of auxiliary machinery spaces and distributed ship services systems, were also considered at this stage. Figure 7 shows the SURFCON model of the final design study, with all blocks and equipment items visible, and Table 7 gives details of the model, giving a clear indication of the level of the design definition in comparison with the earlier design stages detailed at Tables 4, 5 and 6. Finally, Table 8 gives the principal particulars of this final design modelled at Figure 7.

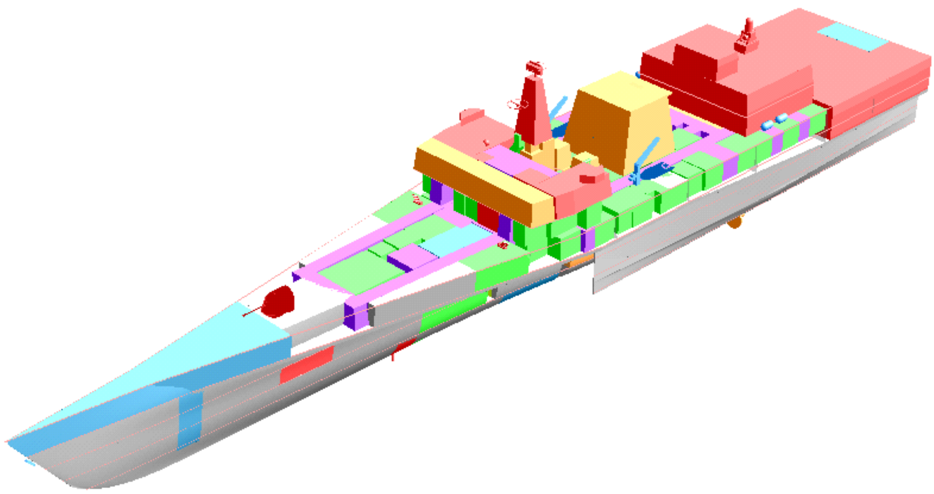

Figure 7: SURFCON model of the final LCS case study design

Number of DBB	343 (in c. 25 SBBs and 11 grouped DBBs)
Displacement	3212te
Enclosed Volume	19500 m3 (R) 26000m3 (A)
Length, main hull, waterline	136.3m

Table 7: Summary of the final balanced LCS case study design

Main Hull		
Length, wl	136.3	m
Length, oa	141.3	m
Beam, wl	10.5	m
Beam, oa	11.4	m
Depth	13.4	m
Draught	4.4	m
Displacement	3050	te
Cp	0.575	
Cw	0.73	
Cm	0.826	
Cb	0.475	
Circular m	9.5	

Side Hull		
Length, wl	68.2	m
Length, oa	68.2	m
Beam, wl	2	m
Draught	1.9	m
Displacement	81	te
Cp	0.425	
Cw	0.596	
Cm	0.706	
Cb	0.3	
Circular m	15.9	

Overall		
Displacement, oa	3212	te
Internal volume	26000	m^3

Box		
Length of parallel section	68.2	m
Beam, oa	24.5	m
Internal decks	1	
Deckhead height		
Fwd	3.5	m
Aft	5.5	m
Double bottom height	0.5	m
Wet deck clearance		
Fwd	5.5	m
Aft	3.5	m

Table 8: Principal particulars of the final LCS case study design

6. THE FINAL CASE STUDY DESIGN

Although Table 2 shows a further "General Arrangement Phase" beyond the Design Building Block Stage, this was not proceeded with in the case of the LCS study for ONR as the primary aim was to compare the two separately produced, UCL and NSWCCD, design studies. Thus a worked up computer definition at the end of concept was considered sufficient. Clearly in a full design project going through feasibility, contract definition and into detailed "design for build", the lead into feasibility is likely to include a set of General Arrangement drawings, as in fact has been produced for some of the UCL design studies outlined in Ref. 14. Instead the level of definition and design decision making, enabled by adopting the DBB approach in preliminary design, is indicated in the remaining sub sections of this section by detailed features and choices made in the design case study. This is done in terms of the four functional groups already referred to and shown by the colour code of the SURFCON graphical models in the sequential stages in the previous section.

6.1 FLOAT GROUP

The largest space demand in the FLOAT functional group was the volume of void spaces in the main and side hulls. Figure 8 shows the extent void spaces, while Figure 9 shows the next largest demand in space, that of the main access routes. Figure 10 shows the rest of the FLOAT group (mooring equipment, ballast tanks, ship's boats and damage control equipment, with structure hidden, for clarity).

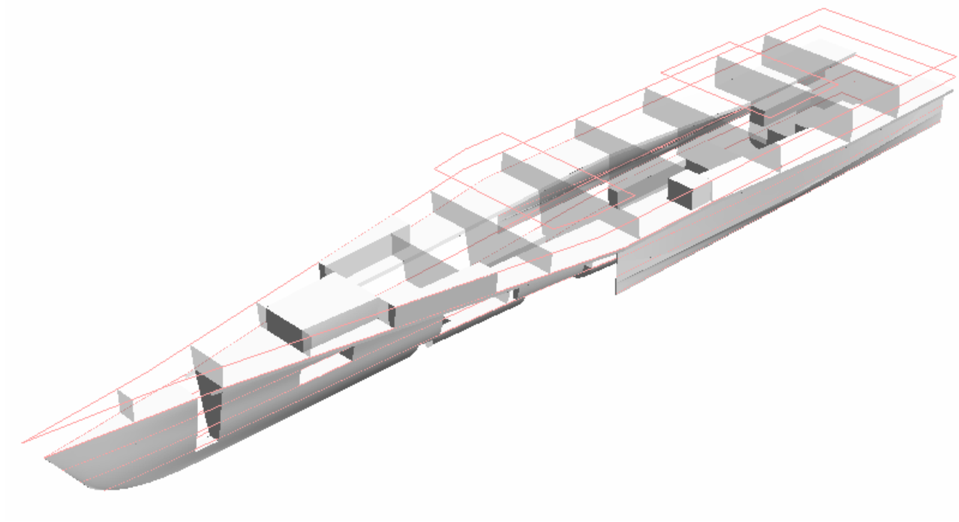

Figure 8: Void volumes in the LCS Case Study FLOAT Group

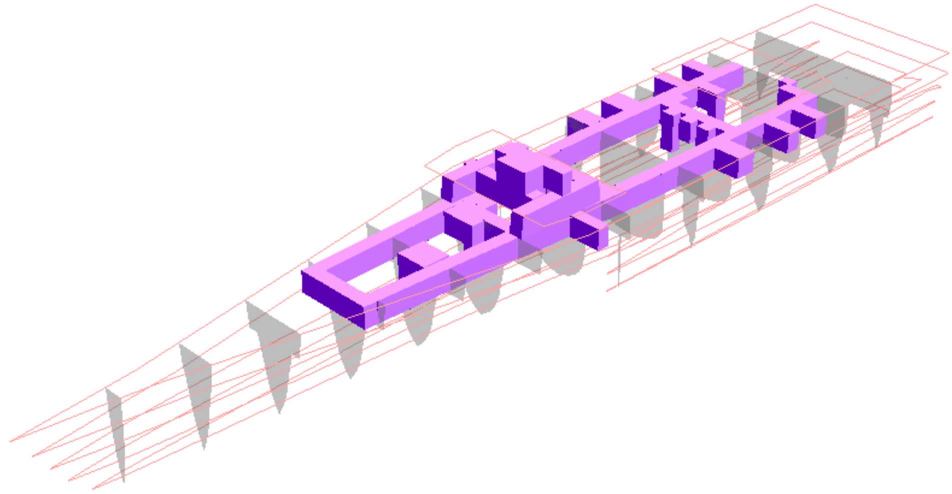

Figure 9: LCS Case Study access sub-Group

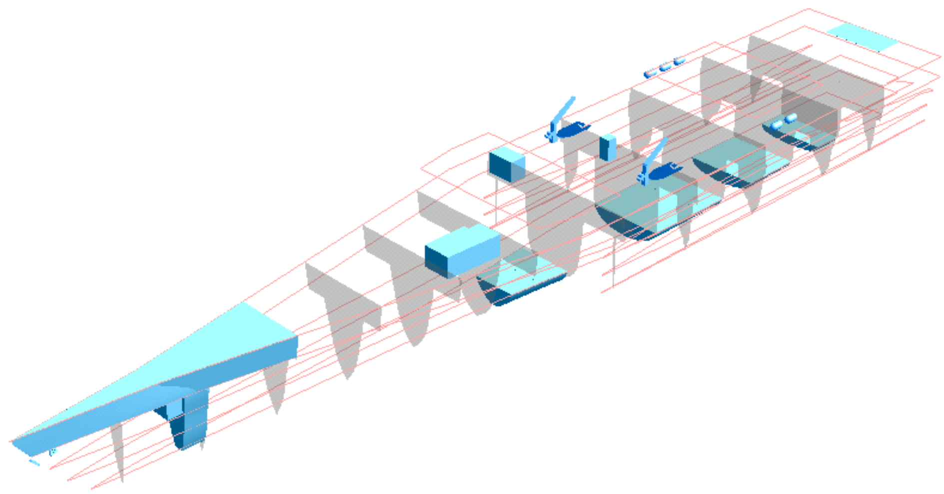

Figure 10: FLOAT Group Design Building Blocks for LCS Case Study

Although this design contained large amounts of void volume, this was necessary to meet top speed performance requirement. The voids in the main hull were a consequence of the long slender main hull necessary to reduce resistance and improve seakeeping, while the voids in the side hull provided damage stability. Although these voids were all grouped under "FLOAT", on this logic, some clearly arise as part of the "MOVE" requirement.

Figures 8, 9 and 10 also show the design's main watertight bulkheads. Some of these were placed with reference to key blocks, such as the ends of the main machinery spaces, hangar and side hulls. Other WTBs were placed to limit flooding at the ends of the hull, as was revealed by analysing specific damage cases. The vessel was designed to meet the requirements of the NES 109 damage stability criteria, with symmetric (main hull) and asymmetric (side hull) damage considered [45]. Examples of stability curves (GZ curves) produced using PARAMARINE for the intact and damage conditions are shown in Figure 11.

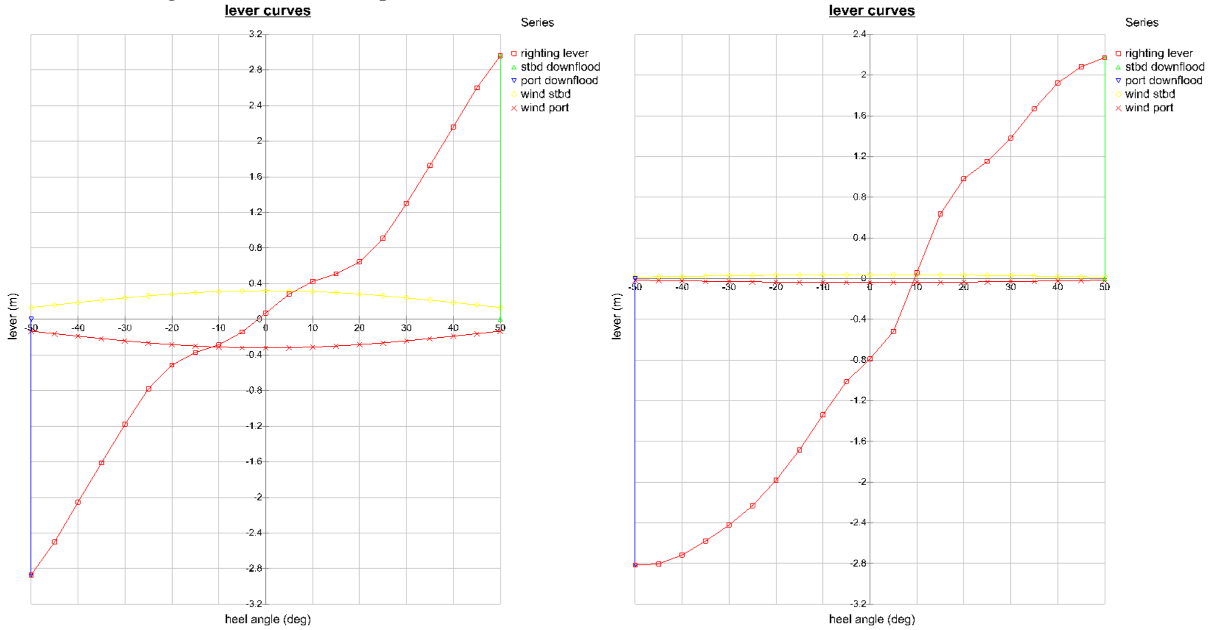

Figure 11: GZ curves for the deep load intact (left) and deep load damaged (right) conditions for the LCS Case Study design

6.2 MOVE GROUP

PARAMARINE analysis tools were used to estimate the effective power required for the maximum speed of 40 knots. As PARAMARINE at that time did not include objects for the estimation of propulsive coefficients (p.c.) for a ship with waterjet propulsion, the p.c. was estimated from typical values for waterjet vessels and that used to calculate shaft power required, as referenced in Ref. 39. Figure 12 shows the power / speed curve predicted using PARAMARINE for the final design.

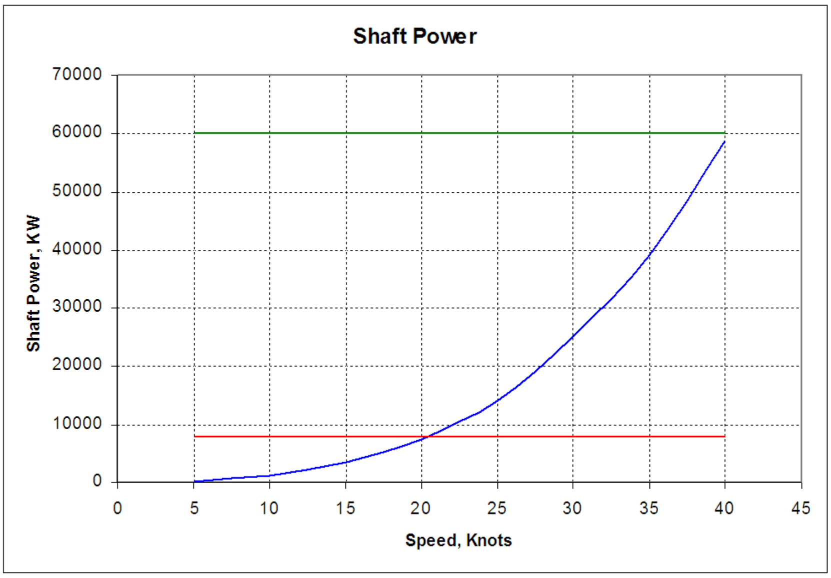

Figure 12: LCS Case Study design's Shaft Power / Speed Curve. (The RED line is the maximum power from the cruise pods and the GREEN line is the maximum power from the waterjets.)

Figure 13 shows the MOVE blocks as configured in the final design, while Figure 14 provides more detail on the arrangements of the main machinery. The requirement both for medium speed cruise and high speed sprint drove the design to a two-mode propulsion machinery solution. At cruise speeds (20 knots), propulsion is via two 4MW Permanent Magnet Motors in pods just aft of amidships. The power for these is provided by two, notational, 6.6MW advanced cycle gas turbine alternators in split machinery rooms positioned above the waterline.

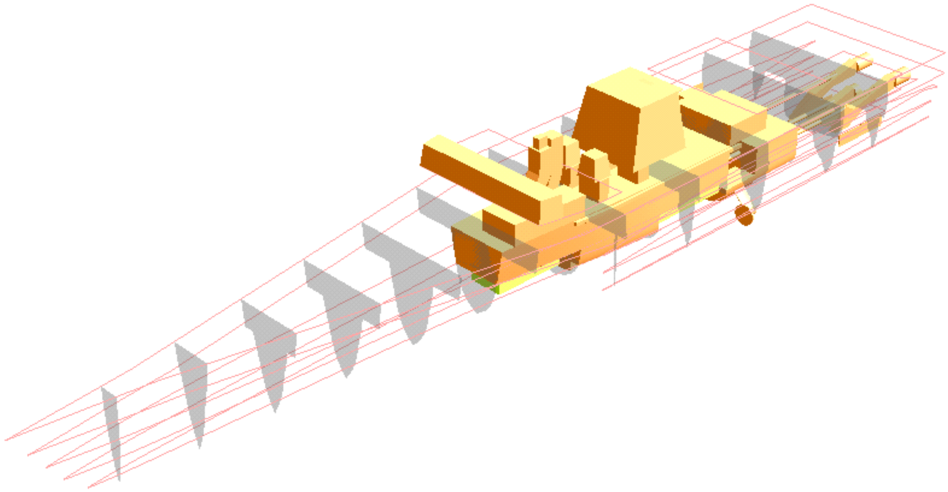

Figure 13: LCS Case Study Design Building Blocks for the MOVE Functional Group

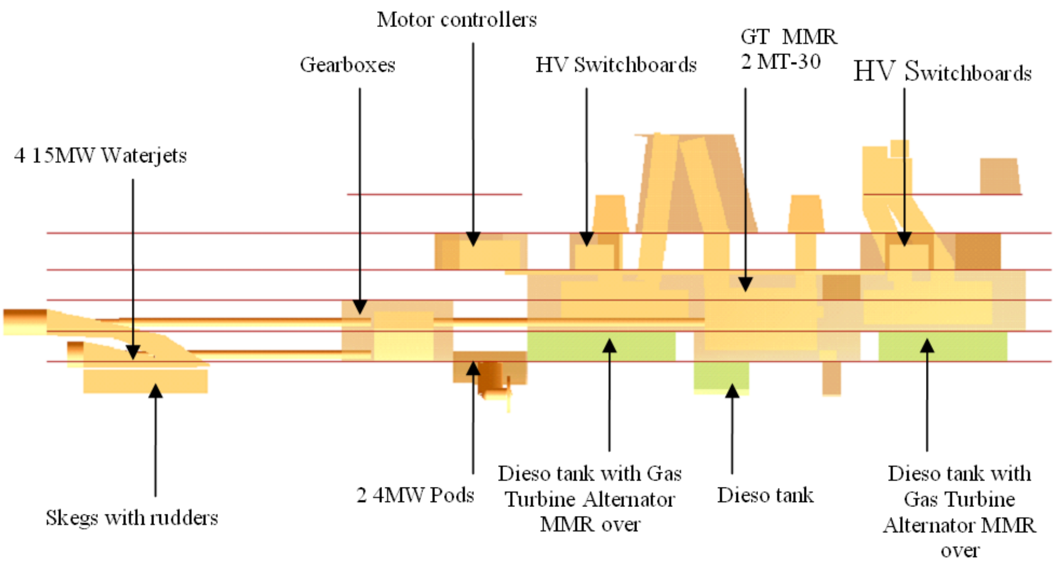

Figure 14: Propulsion machinery arrangements for LCS Case Study design

At higher speeds propulsion is provided by four 15MW waterjets at the stern, driven by two Rolls-Royce MT-30 Gas Turbines in a single Main Machinery Room. Multiple waterjets were chosen rather than the original two large waterjets (see Figure 3) for the following reasons:-

- Increased efficiency at part load;
- More flexible configuration at the stern;
- Smaller cut-outs in the stern structure to minimise potential strength problems.

With a small crew and limited access to the machinery spaces for repairs, the provision of multiple propulsion lines is also an important availability and survivability feature, as it gives a higher probability of the vessel being able to return to base, under its own power, in the event of damage to or failure of one or more of the propulsion lines.

6.3 FIGHT GROUP

The two main items in the FIGHT Functional Group were the payload bay and flight deck. Figure 15 shows all FIGHT blocks in the design. The payload bay contained a ramp for watercraft deployment that required access to the stern, this dictating its location at the stern. The width of the payload bay determined the minimum width of the box structure. Although a midships position for the flight deck would have been preferable for helicopter operations due to reduced local motions, the large intake and exhaust ducts for the gas turbines amidships led to the hangar and flight deck being located at the stern over the payload bay. An additional interaction between the FIGHT and MOVE Functional Groups occurred at the stern, where the payload ramp and waterjets competed for transom space. Figure 16 shows the hangar and payload bay with the payload modules within. The other FIGHT items of equipment were relatively small and with reasonably obvious locations so thus had little effect on the overall design. The trimaran configuration, beyond the powering advantages, also readily met the flight deck and payload demands for significant beam.

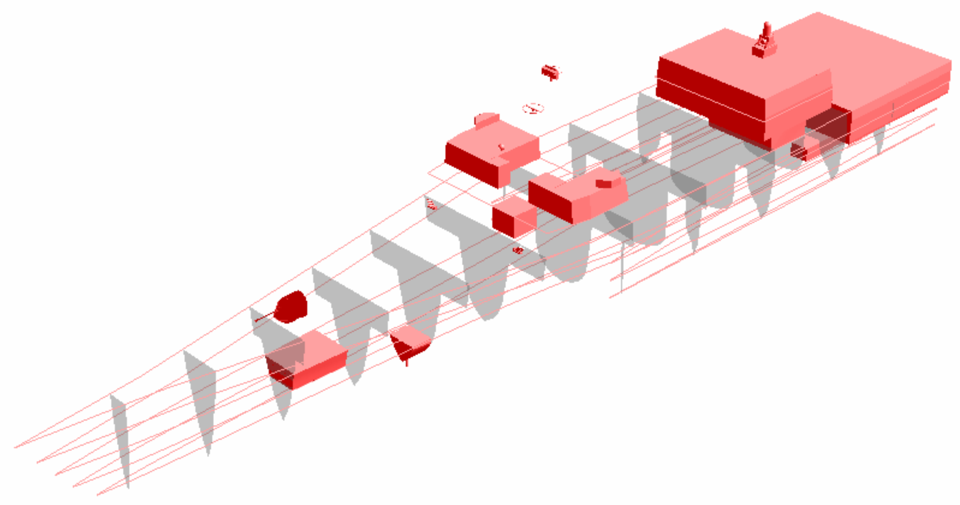

Figure 15: LCS Case Study design FIGHT Functional Group

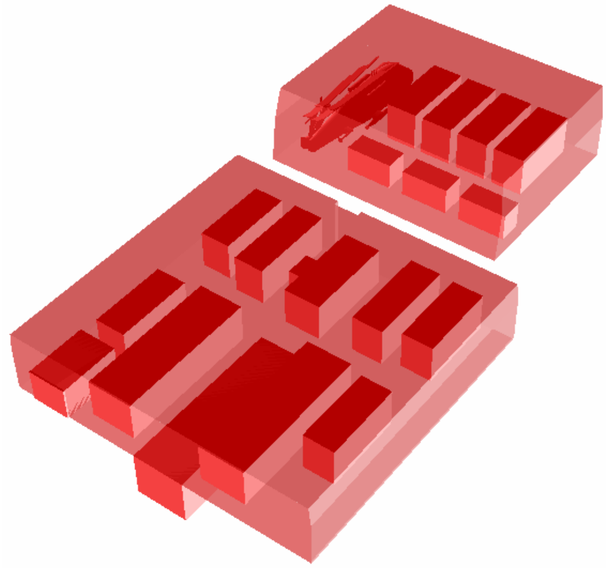

Figure 16: Hangar and payload bay showing payload modules and deployment ramp for LCS Case Study design

6.4 INFRASTRUCTURE GROUP

The largest area demand in the INFRASTRUCTURE Functional Group was that for crew accommodation (see Figure 17). Although the vessel was intended to have a small crew of 75, the use of cabin-based accommodation still led to an increase in the total area required, relative to traditional mess decks. The cabins were fixed in size and had to be arranged so that bunks were longitudinal, which increased the access area required. The trimaran box structure on No 2 Deck was vital in achieving a satisfactory layout, with the accommodation outboard and the various support spaces on the centreline, over the machinery rooms. This allowed the same area to be arranged in a shorter length just aft of amidships, keeping accommodation in a better location than in the case of a monohull.

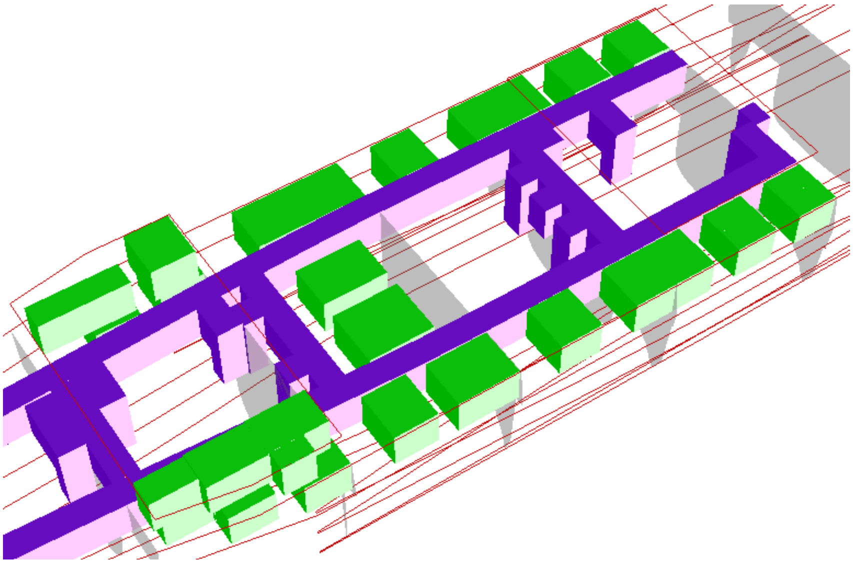

Figure 17: Accommodation blocks and access routes for LCS Case Study design

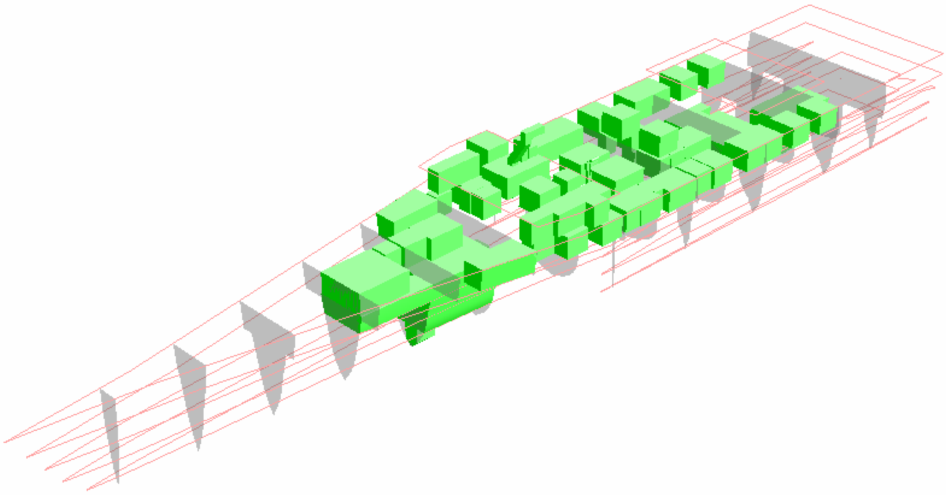

Figure 18: LCS Case Study design INFRASTRUCTURE Functional Group

The final design contained three Auxiliary Machinery Rooms (AMR), with systems split between them to provide redundancy in the event of damage. Unfortunately the four shaft lines aft resulted in a cramped Aft AMR. The vessel was divided into two damage-control zones; forward and aft, any further zoning was considered questionable given the concentration of assets onboard.

7. DISCUSSION OF CASE STUDY OF PRELIMINARY DESIGN

This section is divided into two sub-sections, the first considers the design drivers revealed by the DBB approach applied to this specific concept design study, while the second is a more general discussion on the nature of preliminary ship design emerging from the case study with its discrete steps in the concept design phase.

7.1 CASE STUDY DESIGN DRIVERS

Several drivers and significant interactions in the design were observed during the development of the UCL LCS study. Most of these arose from the layout of the vessel, and would have been difficult to detect without the integrated spatial model of the design provided by SURFCON.

The initial layout in the Major Feature Design Stage (Section 5.3) identified several key drivers. The mission payload required access to the water over the stern of the vessel via a ramp, but this conflicted with the waterjet position at the transom and led to selecting the staggered waterjet arrangement (see Figure 14). The MOVE and FIGHT groups also interacted due to the large ducting for the propulsion Gas Turbines, which restricted the position of the hangar and drove the flight deck to be positioned at the stern. The size of the payload bay also increased the minimum depth of the main hull, driven by the need for sufficient clearance for the deckhead in the payload bay and the wet deck height from the waterline under the stern of the box structure.

Although the payload requirements played a key role in generating the initial design, the high speed requirement had more influence on the ship configuration and the selection of ship equipment. In addition to the interaction with the FIGHT group, the long and narrow hull required for high speed had large voids forward and the four shaftlines aft occupied most of the hull aft, which could otherwise have been used for stores, tanks or support spaces. The need to minimise resistance also led to the adoption of many advanced light weight technologies, such as composite structures and shafts, as well as notational advanced cycle gas turbines for low speed propulsion. Design and growth margins were reduced relative to current combatants because of the propulsion power demands this would have entailed. This increased the perceived uncertainty and risk in the design.

The shallow draught selected for the side hulls (to reduce wetted surface area and interference with the main hull) required that the vessel would operate within a limited range of draughts, and so led to a ballasting system to compensate for the usage of fuel, stores and weapons. These tanks were mainly created in the double bottom, and so did not affect the layout directly, but were an additional complexity in the design. It was also considered there could be detrimental effects on seakeeping in certain conditions, although the side hulls were lengthened in order to reduce this. However, no seakeeping analysis was attempted on this design due to the limited time available. Further detailed comments on the trimaran LCS study are made in Ref. 39.

7.2 INSIGHTS ON THE NATURE OF PRELIMINARY SHIP DESIGN

In drawing any general conclusions one needs to be conscious of the provisos raised by the choice of any design example. In this case the design was quite specific, without the wide exploration either of different design concepts (such as the UCL Mothership study summarised in Ref.14) or of requirement (as for the FSC and CVF), nor a specific technology impact (such as the UCL Electric Ship study also summarised in Ref.14), nor a wider exploration of layout options (exampled by the UCL Joint Support Ship study [46]). Nevertheless the focused case study was useful in that it

was able to reveal the technical process in evolving the preliminary design;

while it was not a conventional monohull, it is considered that the trimaran configuration is largely a variant of the monohull, justified by the specific speed requirement, and broadly applicable to ab initio complex ship design.

A second proviso could be raised over the choice of design method, the Design Building Block approach, rather than a conventional numeric synthesis and parametric approach, possibly enhanced with an optimisation technique such as those referred to in the opening sections. The authors consider, unsurprisingly, that the DBB approach is superior in general for preliminary ship design, because of the insights it reveals, as we believe is shown in the case of this study on the nature of PSD. Thus the DBB approach reveals explicitly, through the graphical element, many design choices less likely to be obvious in a more conventional and essentially numerically centred design synthesis. For example, a sufficiently granulated definition of the ship's mass centroid is obtainable from the SURFCON model and this then justifies undertaking a comprehensive damage stability analysis in PSD, as it is so frequently a significant design driver. Another example is the ability to analyse early in design the surface area of the structural material to get beyond the traditional structural weight fraction used at concept and hence provide better assurance on the single largest component of weight. This also reduces the uncertainty of the basis of any cost capability trade off investigations informing the Initial Gate decision.

The DBB design evolution also shows more clearly the importance in PSD of getting early confidence on of what is found to be the design drivers, namely, in the LCS case study, the high speed and the modular payload. Design drivers are not just important downstream of the Concept Design, their identification can help de-risk the concept and also give more confidence in any cost capability exercise. Again it is argued the DBB approach, in broadening the PSD and evolving the design through the architectural definition produced at the heart of each design step, gives confidence to proceed further with the design. It needs also to be admitted that the particular case study presented here has not addressed some aspects likely to be of major importance in many concept ship designs, such as style issues or aspects like signatures and standards. However, these topics could have been investigated and to some extent were not seen as requiring specific investigation at the PSD phase in this specific case study, in part due to the relatively detailed and explicit set of requirements summarised in Table 2.

Turning to the insights that the case study is seen to reveal into the nature of Preliminary Ship Design, those can be considered at both a strategic design level and with regard to specific design process insights. While the "wicked problem" issue in complex design has, to some extent, not been addressed due to a clear requirement from the ONR customer for the study, it is possible to see how the emergence of specific design drivers, revealed by an integrated architectural and numeric synthesis and the evolution of a given design configuration, could readily inform a dialogue with the operational requirement owner (or naval staff in historic parlance). In fact the very nature of the architecturally led design study evolution better fosters such "requirements elucidation" [22] than a non-solution based requirement process, which specifically excludes the ship designer until a single design response is subsequently adopted. The architecturally based DBB evolution is ideal to involve the requirement owner and any vital specialist user, throughout the PSD process, since they can readily relate directly to the graphical model. What is more the ship designer can more directly explain to non ship designers should conflict emerges between the physical manifestation of the emerging design features and the necessary concerns of the naval architect in achieving a balanced and efficient design concept.

Looking at the specific process, one might ask how representative is the specific case study of complex Preliminary Ship Design. We have said that the study deliberately ignored the "realities of naval ship acquisition", despite these being a vital overlay on the concept ship designer's practice, because of the wish to focus on the purely technical aspect of sizing and evolving a given design study through to a reasonably defined design level. It can be seen from the example evolution, despite its restricted scope and particular requirement aspects including an "arbitrary" choice of hull form, that the primary technical concerns at concept are an amalgam of "classic" naval architectural issues of stability and powering together with achieving a balance of weight and space. In regard to the latter it can be further argued that the DBB approach gives the added advantage of making explicit the architectural characteristics of the spaces on the ship. This then reveals, throughout the PSD evolution, particular operational features that the design must eventually accommodate. Finally in this discussion it is worth stating again that any attempt to understand the nature of PSD is constrained by the needs, drivers and environment (or constraints) under which the specific design case is undertaken. Thus every design is different in its origin and constraints which means any approach needs to be flexible if it is to have utility in adapting to different acquisition strategies (see Ref. 8) and reflecting the five characteristic listed in the bullet points under Table 1 in Section 3.

8. CONCLUSIONS

The example presented in this paper is intended to extend the published literature on the preliminary design of complex multi-functional ships, typified by the naval combatant. It is believed that the case study and the associated design decisions, summarised in the accompanying explanation, well exemplify the general engineering design characteristic, which Ferguson [47] identified as being decision making. This is said to be based not just on numerical analysis but also ad hoc experimentation, experience, logical reasoning, personal preference and intuition. Thus only a small fraction of this process has been recorded but, with the steps detailed, more has been captured than would normally be the case.

This first exposition, showing a sequential set of design studies progressing to a reasonable comprehensive preliminary design, has the authors believe, not just demonstrated the utility of the DBB approach (in integrating the naval architectural numeric synthesis and the graphically based architectural synthesis) but also revealed how the decision making made by the concept designer is sophisticated and multifunctional. Furthermore the insights provide by the graphically driven CAD system are substantial and reinforce the authors' strong belief that any advances in concept design tools and methods should exploit the open ended and designer oriented decision making of such a design approach, rather than recourse to "black box" initial CAD systems, however apparently sophisticated the "workings within the box". It is further believed that the paper shows the means by which naval architects can regain control of the Preliminary Ship Design Process by giving the requirement owner/end customer/user confidence that the wider operational issues can be given their true prominence. This can be done not through "functional user requirements", which exclude design solutions, but through representations of the emergent physical options alongside appropriate technical analysis governing the realisation of the design.

It is hoped that the case study and the wider issues raised by this paper will encourage further debate to that in earlier more general papers on "creative ship design" [8, 11, 13]. These previous expositions have served to emphasise the growing awareness of the sophistication of PSD. This then means designers involved in preliminary ship design have to fight to ensure that the growing armoury of ship design tools and techniques do not restrict design exploration but rather enhance the initial phase of ship design, as the most creative and fascinating challenge to the future practice of ship design.

9. REFERENCES

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