Preliminary Design Of Conventional And Unconventional Surface Ships Using A Building Block Approach

by

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A Thesis Submitted for the Degree of

Doctor of Philosophy

University of London

University College

2000

Abstract

Current naval ship design programmes are considered to be inadequately served by the preliminary ship design methodologies used to develop initial design features. This is due to a reliance on numerical design approaches that do not fully reflect the complex nature of the naval ship design problem.

A new "Building Block" design methodology is demonstrated. This methodology uses design descriptions integrating functional, and architectural issues with numerical design descriptions as functional Building Blocks. The Building Block methodology allows designers to undertake decision making during preliminary design with knowledge of all important design issues.

The thesis scope includes all commonly encountered naval surface ship requirements for monohulls and also for unconventional hullform types, such as Trimaran. Justification for a new design methodology is presented in Part one of the thesis. General engineering design and specific naval design issues are detailed, leading to a discussion of current design methodologies. Comparison of alternative ship design methodologies highlights the need for an integrated approach based on architecture.

The requirement for an architecturally centred design methodology leads to the Building Block design methodology, detailed in Part two. Major surface ship methodology issues are detailed. The concept of the design generator is developed as being that requirement which defines the section of the overall ship design space in which a final design will reside. The discussion considers the application of the new methodology to monohull ships, focusing on an Escort Frigate requirement. The methodology is also applied to amphibious landing ships and small naval vessels, demonstrating the effects of size and operational requirements on applicability. The discussion also demonstrates the application to unconventional craft by development of Trimaran and SWATH designs, noting that the more complex unconventional design problems encountered, benefited from the Building Block methodologies' strengths.

Acknowledgements

Although I am the sole author, I would not have been able to develop the research presented in this thesis, without the help of many people, both directly and indirectly. I would like to acknowledge the support of the following people and organisations.

Firstly I would like to thank those whose training expertise enabled me to commence the thesis, David Fellows (and the Staff of SETC Manadon), Prof. Marcel Escudier (and the Department of Mechanical Engineering, University of Liverpool) and Ian Leach.

Secondly I would like to thank my friends from amongst the Ministry of Defence sea systems community and the staff and students of the Department of Mechanical Engineering, University College London, 1994-1997, for their friendship and generosity. In particular I would like to thank Alex, Annabel, Mary, Caryl, Richard, Mark and Jun Wu. The funding for this thesis has been indirectly provided by the Ministry of Defence and I would like to thank Simon Rusling, David Wilson and the staff of ADNA\SS for their assistance. I would like to thank Gavin Rudgely and Tristram Hughes for their support while developing the thesis.

In developing the contents of this thesis I have relied heavily on the experience, knowledge and understanding of Prof. David Andrews and David Fellows (again!), for which I would like to thank them. The research and friendship of Jon Bayliss and Adrian Spragg assisted the development of the methods demonstrated in this thesis. The application of the Building Block methodology to Cruise Liners [detailed in Appendix G] is presented with the permission of Thor Einar Kolstadlokken.

My final acknowledgements are given to my family. I would like to thank the Dicks and Howell families for their help and support. Without the special understanding of Joanne, Mum, Adam, Tim, Michael and Dad this thesis could never have been completed. I would like to thank them particularly and express my love. I dedicate this thesis to the memory of Grandma, Poppa and Granddad.

C. A. Dicks, B.Eng.(Hon's), A.M.I.Mech.E., R.C.N.C. Bristol, 2000.

Table of Contents

TABLES

FIGURES

Nomenclature

ACV	Air Cushion Vehicle
BB	Building Block
B.Eng.	Bachelor of Engineering
CAD	Computer Aided Design
CAESAR	Computer Aided Engineering of Ship Arrangements [UCL Ship Design Tool]
CAPSD	Computer Aided Preliminary Ship Design
CIWS	Close In Weapons System
CODLAG	Combined Diesel eLectric and Gas [Ship Machinery Configuration]
COEA	Cost and Operational Effectiveness Analysis
COEIA	Combined Operational Effectiveness and Investment Appraisal
COGOG	Combined Gas or Gas [Marine Propulsion Arrangement]
CONDES	Concept Design [Computerised Ship Design System]
CTOL	Conventional Take off and Landing [Aircraft]
DB	Double Bottom
DDG	Guided Missile Destroyer
DERA	Defence Evaluation and Research Agency
EMI	Electro-Magnetic Interference
EMS	Engineering Modelling System
ESM	Electronic Surveillance Measures
GODDESS	Government Defence Design System for Ships
HYSWAS	Hydroplane Small Waterplane Areas Single Hull
IFEP	Integrated Full Electric Propulsion [Electric Marine Propulsion System]
LBP	Length Between Perpendiculars
LCAC	Landing Craft Air Cushion
LOX	Liquid Oxygen
LPD(R)	Landing Platform Dock (Replacement)
LST	Landing Ship (for) Tank(s)
NES	Naval Engineering Standard
RADHAZ	Radiation Hazard
RAS	Replenishment at Sea
RCS	Radar Cross Section
RO-RO	Roll on Roll off
SBB	Super Building Block
SES	Surface Effect Ship
SMS	Submarine Modelling System [Part of SUBCON]
STOVL	Short Take off Vertical Landing

SUBCON	Submarine Design Computer System
SURFCON	Surface Ship Concept Design System [Proposed CAPSD System]
SWATH	Small Waterplane Areas Twin Hull
UCL	University College London
VSTOL	Vertical/Short Take off and Landing
(M)	Length Displacement$^{1/3}$ Ratio
GM	Metacentric Height
KG (or VCG)	Vertical Centre of Gravity

Part 1 The Need for a New Naval Ship Design Methodology

This thesis is in three parts with appendices. Each part considers a specific aspect of research into a novel preliminary ship design methodology[1]. Part one introduces the thesis, its subject matter and consists of Chapters 1 to 4. Part two introduces and demonstrates a novel design methodology. Part three concludes the thesis.

The opening chapter of Part one, Chapter 1, introduces the topic of the thesis, the methods of study used and the structure of subsequent chapters. The thesis investigates a new design methodology to be used in the earliest, preliminary, design stages of the naval ship procurement process. Prior to the presentation of this detailed investigation, an overview is presented of the relevance of the new design methodology to ship designers. Current methods and methodologies[2] used by the naval ship design community are examined and discussed.

Design covers a broad spectrum of methods used to create different artefacts. Methods used change with the design artefact's technology area, i.e. whether the design artefact is for engineering, architectural or other use. Thus Chapter 2 introduces methods and methodologies used in different design processes, defining common and different features and processes. Chapter 2 also considers the role of the two major "actors" [*Archer, 1965*] in the design process, the human designer and the relatively new but rapidly expanding role of the computer.

One of the most specific and demanding technology areas is that of naval ship design. In Chapter 3, a review of the requirements and features of typical naval design methodologies, together with limitations and advantages, is presented. This review encompasses current developments and research. The evolution of such methods is discussed in relation to the changing nature of design artefacts.

The final chapter of Part one, Chapter 4, specifies a requirement for a new preliminary design methodology for naval surface ships. A requirement is derived to

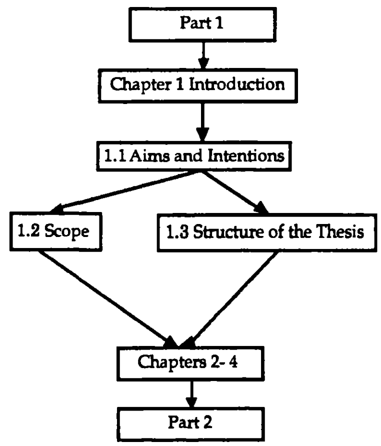
[1] From [*Compton's, 1998*]: "*Methodology: the science of method, or orderly arrangement; specif., the branch of logic concerned with the application of the principles of reasoning to scientific and philosophical inquiry.*"

meet the changing design, technological and procurement requirements influencing naval design. Alternative methodologies are compared and contrasted. The methodology chosen is then investigated and developed in greater depth in Part two.

[2] Methods are considered to be specific processes used in actual design evolution while a methodology is considered as a structured approach to tackling the perceived design problem. Cross [*Cross, 1984*] declared *"Design methodology ... is the study of the principles, practices and procedures of design in a broad and general sense. Its central concern is with how designing is and how it should be."*

1. INTRODUCTION

Figure 1-1 Schematic Diagram of Chapter 1



1.1 AIMS AND INTENTIONS

The thesis demonstrates a need for, and the attributes of, a novel preliminary design methodology for naval surface ships, using the capabilities of modern computer systems. Current methods of preliminary ship design for naval ships do not wholly meet the technological and management requirements of modern naval ship procurement programmes. As detailed by Andrews [*Andrews, 1984*], design processes are required that place great emphasis on the configuration and functionality of the design. This is a result of the need for design authorities to reduce the risk inherent in procurement programmes to ensure success. The need to assess the design more widely is shown by the demand for COEA/COEIA[3] processes in major procurement programmes.

The Building Block methodology is presented, as a new design methodology, with advantages over current preliminary design methodologies when applied to the dominant issues of modern naval ship design. In particular the Building Block methodology is suitable for the development of unconventional hull form based designs. Unconventional designs are currently under investigation by naval preliminary design teams, in the United Kingdom and elsewhere, to meet future naval requirements [for example *Betts, 1996*]. The research presented enables a subsequent

[3] COEA and COEIA are methods of investigating the conundrum as to the level of capability required from a military design artefact and the level of capability that can be afforded. COEA is detailed in [*Hockberger, 1993*]. COEIA is detailed by [*Kirkpatrick, 1996*].

development programme in which the purely theoretical methods presented here, will be implemented in an integrated Computer Aided Preliminary Ship Design [CAPSD] system to be provisionally known as SURFCON, the scope of which is detailed in Appendix A. The proposed features of SURFCON are based on the prototype system detailed in Section 5.7.2.

Chapter 1 introduces the research and fosters the overall direction of the discussion. Chapter 1 describes the progression from an examination of the nature of design [Chapter 2] through to recommendations [Chapter 9] suggesting areas of research exploitation. Chapter 1 consists of three sections. In this section the topics of the thesis are introduced. Section 1.2 states the scope of the thesis, setting discussion boundaries, placing the discussion within the ship design environment. Section 1.3 details the structure of the thesis.

Introduction To The Task

Traditionally the art and science of preliminary naval ship design has focused on the need to consider relationships between operational capability and ship weight [and hence cost] for a conceptual[4] ship design. This view of the naval ship design task with its use of the "weight equation"[5] is no longer considered valid [*Andrews, 1984*]. Technological change has forced the designer to consider, numerically, the space related aspects of the ship design [e.g. internal volume and deck areas] as an equal part of the design process [as detailed by *Andrews, 1984*]. Recent naval ship synthesis mechanisms[6] have included such numerical aspects of spatial issues at their core as ship designs have become dominated by less dense, modern propulsion and combat systems. It is demonstrated here that the synthesis methodologies required for modern naval ships should consider space as more than a purely numerical issue, and address configuration[7] and functional issues. A more comprehensive synthesis methodology is required that can adapt to prevailing design issues, providing the designer with

4 "Conceptual" is used to define a ship design of known gross characteristics but limited detailed definition, as developed from initial design cycles prior to detailed analysis of capabilities and features.

5 The weight equation suggests that each new ship design concept can be considered as a derivative of a previous design. Each element composing the ships weight can be estimated from the basis ship as a function of displacement. Hence as the "capability" of the design changes the total ship design increases or decreases in displacement accordingly. Typical scaling factors included the variation of hull structure with displacement$^{2/3}$ and propulsive machinery weight with displacement$^{0.6}$. The weight equation was considered useful when sufficient ship designs were in preparation that each new design was an evolution of the previous class, for example the annual destroyer design before the Second World War.

6 For example that of [*Hyde & Andrews, 1992*].

7 A ship's configuration can be considered as the arrangement of the internal hull spaces, superstructure, and ships systems within the hull.

information relevant to the current design requirement.

When considering large naval ships designs, such as aircraft carriers and amphibious assault ships, it has been recognised[8] that the dimensions, style and gross size of such ships are often dictated by the requirements of a system or feature necessary to perform the primary mission. The impact of that mission's requirements on the configuration of the ship design concept is important in that overall form is "driven" by specific design issues. Current, published, ship synthesis methods such as numerical methods [for example, *Hyde & Andrews, 1992*], optimisation methods [as detailed by *Keane et. al., 1990*] and concept exploration models [*Eames & Drummond, 1977*] do not fully recognise this. Unless the designer unofficially modifies ship synthesis methods to reflect the real needs and drivers of the design, or performs further informative design tasks separately from the main numerical design synthesis, such issues are not considered sufficiently.

In addition naval ship designers should be furnished with tools and methodologies allowing the satisfactory development of more unusual vessel types. Such vessels may include the SWATH [*Betts et. al., 1987*], HYSWAS [*Meyer, 1989*] and Trimaran [*Zhang, 1997, Pattison & Zhang, 1994*] concepts. Each ship type has its own special features, advantages and design requirements. Few synthesis methods allow the designer to investigate such concepts at a level of complexity beyond a simple numerical balance of weight and space. A simple synthesis based on balancing weight and space has, as part of the Trimaran research programme[9], been found by the author to be insufficient when exploring the major issues that need to be addressed in preliminary design.

While the technology and style of modern naval ship designs has evolved, the environment in which naval ships are procured has also changed. This is partially due to the movement to modular construction methods and increased use of virtual prototypes and simulation based design [*Jons & Schaffer, 1995, Jons et. al., 1994*]. A further major change is considered to be the proposed change from sequential processes towards a concurrent engineering approach [*Tibbitts & Keane, 1995*][10]. Such

8 Such issues have been reported in [*Honnor & Andrews, 1982, Andrews, 1986, St Denis, 1966, Eddison & Groom, 1997, Autret & Deybach, 1997, Downs & Ellis, 1997, Schaffer & Kloehn, 1991*].

9 The UCL and MOD Trimaran research programme is documented in [*Andrews & Zhang, 1995a, 1995b 1996, Andrews & Hall, 1995, Pattison & Zhang, 1994, Eddison & Summers, 1995, Bayliss et. al., 1996, Bayliss et. al., 1998a, 1998b*].

10 Tibbitts & Keane suggest that by using the methods of concurrent engineering and the integrated product team approach, the barriers that exist between design stages and between actors in the design process can be removed. It is considered that designs will emerge that are cheaper and better, developed in a shorter time frame.

developments suggest that it is desirable to define the design to a greater level of description at the earliest design stages, to reduce design time and cost. Greater definition should improve the realism of initial design concepts, allowing reduced likelihood of errors and omissions affecting subsequent design evolutions, thereby reducing risk [*Andrews, 1994a*], as examined further in Chapters 3 and 4. If such advantages are to be gained a more comprehensive design synthesis methodology is required that will allow all design issues to inform, and be informed by, the design description. The methodology must allow the introduction of extra design information, into the design description. The extra design information should not be purely numerical, but also relate to the architecture of the design. The likely manner in which a new design methodology will be implemented is through an integrated computer aided preliminary ship design tool. This tool would provide the benefits of large scale data storage and rapid performance of simple, repetitive design development tasks, allowing the designer to concentrate on the design issues. The introduction of such design support tools has benefited the designer as detailed in [*Andrews & et. al., 1996*]. Such a tool requires an effective underlying methodology. This methodology must be demonstrated, so that naval ship designers are confident of its utility. That is the task of this thesis.

This thesis provides the intellectual basis for, and prototype demonstration of design tools based on the methodology presented. Specific design tools have not been developed within this research to a commercial level[11]. The novel design methodology is independent of any specific computer programs or the constraints of any potential customer of the computer aided design system. The prototype computer aided design system described in Section 5.7 demonstrates the application of the methodology.

1.2 SCOPE

Applicability of the Design Methodology

The discussion of the new design methodology concentrates exclusively on naval ship design during the preliminary design stages. Both conventional monohull and unconventional hull types, notably multihulls, are considered. Naval ships can be considered as those ships whose design requirements are formed by a military

[11] Development of commercial quality software design tools is best undertaken by commercial software developers. However such development can only be undertaken once a specification of the design methodology has been developed. Hence the research detailed uses prototype tools indicative of what is required, and is considered achievable.

authority, with military capability rather than profit as the origin of the required functionality. Merchant ships [non naval ships in this context] are not specifically included or excluded from the methodology. However it is considered that, in general, the design of merchant vessels does not require the advantages presented by the methodology, to the same extent as naval design. A possible exception is the design of large passenger carrying vessels such as Roll on Roll off Ferries and Cruise Liners, which are largely driven by configuration issues [*Levander, 1991*]. Such transportation vessels are driven by similar requirements to those of military transportation ships, and as such can be distinguished from non transport vessels or "service ships". A subsequent study [*Kolstadlokken, 1998*] details the application of the concepts detailed in Part two to preliminary design of cruise liners of both conventional and unconventional form.

Within naval ship design, the scope includes all potential designs to meet a demanding military requirement to naval standards[12]. Auxiliary vessels such as Fleet Replenishment ships, designed for naval use but based extensively on merchant practice with limited naval standards are not specifically demonstrated but could be designed using the methodology. The methodology is intended for application to the design of major naval vessels such as escort ships, aircraft carriers, amphibious warfare ships and patrol vessels. Whilst other, specialist, vessels such as diving support and survey vessels could be developed, using the new design methodology, the research has not specifically considered them.

In Appendix B, the development of a submarine design produced using the methodology is included. This highlights differences between submarine and surface ship design methods, while demonstrating the submarine heritage of the new design methodology.

It is recognised that for specific design requirements unconventional[13] forms of hull, such as the SWATH, or Trimaran, may outperform "traditional" monohull designs. Recently the United States Navy has successfully built and deployed a class of SWATH ships as towed array sonar surveillance ships due to their improved

12 It is appreciated that much of the current emphasis of naval engineering is the application of commercial standards or derivatives of such standards to military problems as noted by [*Gibbons, 1999*] for structural design.

13 Unconventional is defined, in this case, as a craft which is not a monohull. Often an unconventional design's weight is not borne solely by the buoyancy of one immersed hull at all speed ranges. Thus the definition includes both vehicles employing dynamic lift [such as HYSWAS [*Meyer, 1989*]] and the multi hull displacement craft [such as the Trimaran [*Pattison & Zhang, 1994*].

seakeeping performance over equivalent[14] monohulls. The Ministry of Defence's Defence Procurement Agency is currently assessing the relative abilities of Trimaran and Monohull concepts to meet a requirement for a Future Surface Combatant [*Eddison & Summer, 1995, Friedman, 1997*]. It is considered that such unconventional forms place demands on the designer that current preliminary design methodologies cannot readily satisfy in their current form. The new design methodology presented allows a designer to readily produce designs of unconventional vessels reflecting their likely design drivers. The application to the design of unconventional vessels [Chapter 8] focuses on the two unconventional ship types that appear to have the greatest general warship design potential, namely SWATH and Trimaran.

Research Methods

In developing the new design methodology the following stages were undertaken, corresponding broadly to the discussion presented in Parts 1 and 2. The methods used represent a design process themselves, following the definition of design detailed by [*Simon, 1975a*]:-

- "Formulation of a problem statement": Examination of the suitability of current methods of naval ship design.
- "Synthesis of Alternatives": Investigation of alternative solutions to the problem statement and development of a solution.
- "Analysis and Testing": Example applications of the solution.

In this case the solution to the problem statement is a new design methodology and the overall task is considered meta design, the design of the design process [see Chapter 4]. The first task has been achieved by discussion with practising ship design experts. The failings of current ship design mechanisms were assessed. In addition several example designs were created using a "classical" numerical design procedure[15] [*UCL, 1994a*]. Due to the broad nature of naval ship design, different ship design methods were illuminated by postgraduate ship design exercises at University College London [UCL] and by contract research tasks at UCL investigating the Trimaran naval ship concept for the Ministry of Defence [*Bayliss et. al. 1996, 1998a, 1998b*]. From such

[14] Equivalence in naval ship design terms is a very difficult term to adequately define. Generally it suggests two designs which are of equal financial cost but different performance when compared with the operational requirement. A more accurate measure when dealing with fixed operational requirements is the equivalence of performance between two designs, leading to the cheaper of the two being most suitable. The idea of equivalence is referred to further in [*Andrews 1994b*].

investigations, the features of an ideal design methodology have been derived and are discussed in Chapter 4. Several potential design methodologies are compared. The most suitable has been developed into the new design methodology. The development of the new design methodology was undertaken in a sequential manner. A simplified design methodology was proposed and design studies undertaken to investigate the suitability of applying that methodology. Design studies were undertaken with design requirements specifically selected to investigate specific features of the methodology. Specific design activities are further detailed in Section 7.2. The results are presented in Chapters 7 and 8.

Comment on Research Approach

Naval ship design research is a discipline in which investigations that are exhaustive for both complexity and breadth are mutually exclusive due to time constraints. Within this thesis a compromise is drawn between the investigation of a wide range of different designs, to prove the versatility of the methodology, and the depth of each individual design investigation. As the aim is to demonstrate that the new design methodology can meet different design requirements, the compromise made aimed to provide sufficient knowledge of the methodology, rather than detailed investigations of individual designs. The design examples [Chapters 7 and 8] are superficial in comparison with the design studies produced by practising naval preliminary ship design teams. In addition it was necessary, given national security issues, to utilise fictional equipment data representative of the types of information required for a naval ship design exercise. This data draws extensively on that used in the student design exercise presented in [*UCL, 1994a*]. Similarly detailed topside design information is scarce for realistic design situations at the stage at which the new design methodology requires such information. Within the thesis, simplified topside design information is used, representative of the more detailed and accurate information that will become available as a result of a separate but linked topside research program at UCL [that reported on by *Bayliss, 1997, Andrews & Bayliss, 1998*].

A specific simplification applied to all the design examples presented is the

[15] Numerical design synthesis methodologies will be represented throughout this thesis by the procedures utilised by the Naval Architecture Research Group at University College London. This is due to the use of these procedures in the education of Ministry of Defence warship naval architects and its similarity to the methods used within that organisation. The UCL ship design procedure exists in three forms, [*UCL, 1994a*] the undergraduate naval ship design procedure, [*UCL, 1994b*] the undergraduate container ship design procedure and [*UCL, 1993*] the postgraduate naval and commercial ship design procedure. A similar procedure exists for submarine design [*UCL, 1995*].

reduced level of analytical assessment of design performance. This was undertaken to maximise the ability of the researcher to investigate the effectiveness of the design methodology rather than the effectiveness of the design itself. An example is the use of "solid" Metacentric height [*Rawson & Tupper, 1994*] as the stability requirement for a design, even though sufficient design information was available to undertake damaged stability calculations. This meant that complex and time consuming modelling of the ship design using a system such as GODDESS[16] was not undertaken. The assumptions made are described alongside the designs presented in Section 7.2.

The example designs have been developed as representative, yet simplified, naval ship design concepts. It has proven necessary to make design decisions to progress each design toward a solution. An example is the decision as to superstructure style, whether to use one fully structurally effective element or two deliberately in-effective deckhouses. A temptation when considering example designs is to ignore the real aim of the example design and to examine the resulting design itself. It is more important in the research methodology adopted to appreciate that a design decision was made and to note the impact of that decision on the effectiveness of the new design methodology. A detailed analysis of the correctness of specific design decisions made is not fundamental to the main research aim.

It is necessary to view the design studies presented as a means towards furthering the new design methodology. It is not practical or desirable to compare ship designs within this thesis with superficially similar ship designs due to the simplifications and the overall research objectives used in the design studies. When viewing design examples separately from their role in defining and refining the design methodology presented, caution should be applied.

1.3 STRUCTURE OF THE THESIS

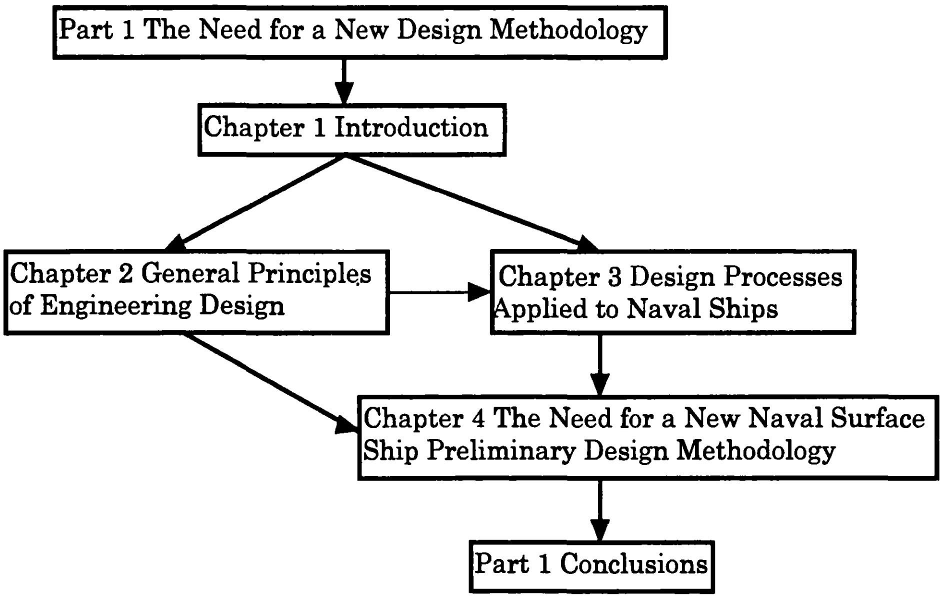
The thesis is divided into three parts and is further divided into 9 chapters:-

- Part one — The need for a new methodology [Chapters 1-4].
- Part two — Evolution of a new methodology [Chapters 5-8].
- Part three — Conclusions [Chapter 9, References, Appendices].

Part one progresses the discussion from an undefined problem to be solved, to a point at which a potential solution has been suggested but not implemented. Chapters 2 and 3 specify the role of design methodologies, the role of the designer and design

[16] GODDESS: the Government Defence Design System for Ships and Submarines [*Barratt et. al., 1994, Yuille, 1978, Pattison et. al., 1982*].

Figure 1-2 Structure of Part 1 of the Thesis



theory, in undertaking a design task. Chapter 2 reviews previous theoretical engineering design research. Chapter 2 also describes the current role, use and limitations of modern computer systems in aiding or even replacing the designer. The totality of the design process is considered with regard to the preliminary[17] phases.

Chapter 3 extends the discussion of Chapter 2, focusing on the use of design methods in naval ship design. Firstly design is considered in the midst of the complex technological and managerial task that is the development of a naval ship design[18]. The methods by which naval design processes operate are considered through current methods of achieving the synthesis of a naval vessel. Chapter 3 also considers the development of naval surface ships and briefly submarines, at the preliminary design stages. Finally recent changes to warship designs and the warship procurement environment are detailed. Such changes have, or should, affect the methods by which preliminary design of naval vessels is undertaken.

Chapter 4 details a requirement for a new surface ship preliminary design methodology. A discussion is presented describing the problems associated with applying the current design methodologies to the design requirements of modern naval

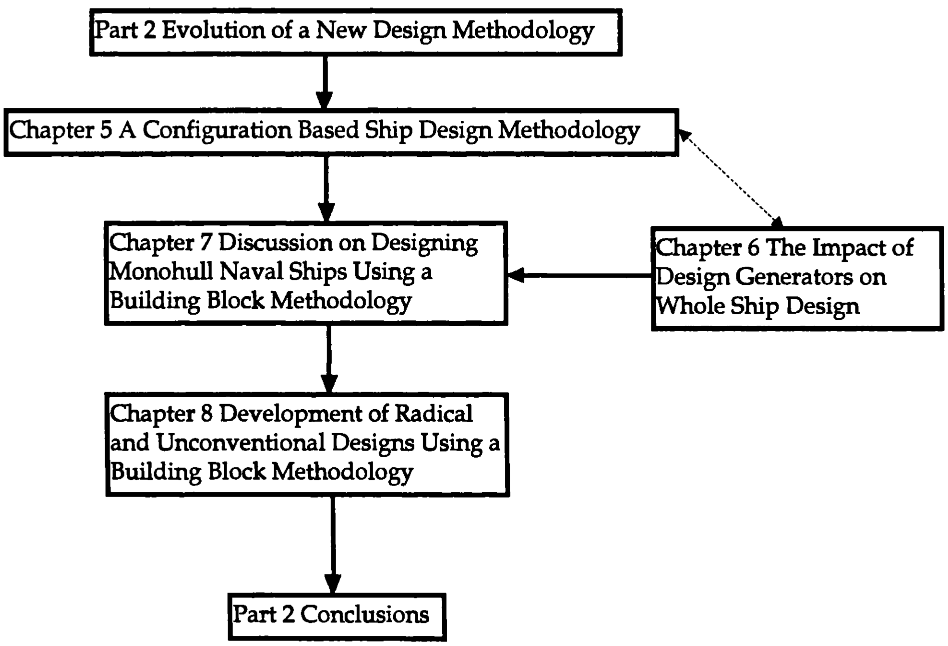
[17] Preliminary ship design can be defined as the exploratory design stage, in which multiple sparsely defined solutions to a design problem are considered for validity, prior to a detailed development of one design concept. The term preliminary is used to represent the earliest stages of ship design, in order to avoid the confusion that arises between British and American definitions of concept and feasibility design stages in formally defined ship procurement processes [such as *Pattison, 1989*].

[18] [Andrews, 1998] noted that for naval ships "*the design process is correspondingly many faceted, not only in a technical sense but also in the way in which technicalities can be interwoven with such diverse matters as national, international, politico-economic, environmental etc., considerations*".

ship designs. Following this the requirement for a new design methodology is formalised. Features of a perceived "ideal" design methodology are suggested. Alternative approaches to providing a new methodology are discussed and compared, with justification for selecting the new methodology.

Part two progresses the new design methodology from an outline of a potential solution, to a validated design methodology capable of designing all major naval surface ship types. Chapter 5 presents the new design methodology, specifying background logic, major features, and the specific design stages.

Figure 1-3 Part 2 Structure

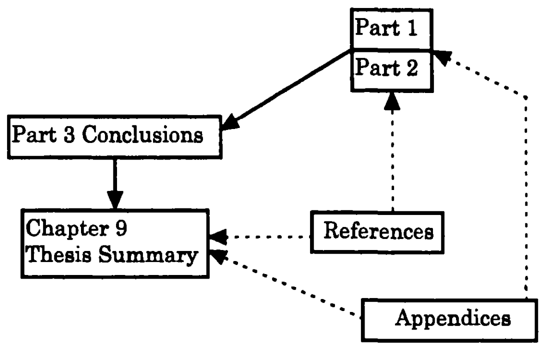


Chapter 6 details the importance of the architecture derived design generator concept [*Darkes, 1979*] when applied to the modern naval ship and the use of design generators as the key issue of design synthesis at the initial stages of the new design methodology. Such a concept has been detailed previously by Andrews [*Andrews, 1984*] but has not gained widespread acceptance from other practitioners, if judged by incorporation into ship design methodologies. Chapter 7 demonstrates the application of the methodology to the most commonly designed major warship, the monohull escort. In particular, the design of two comparative monohull escort designs to identical operational requirements is described. The designs were developed independently; one using a traditional design methodology based on a numerical design procedure methods [*UCL, 1994*]; the other using the new ship design methodology. Subsequently Chapter 8 applies the new design methodology to two currently developing types of forms of unconventional hullform designs. The structure of Part two is shown in Figure

1-3.

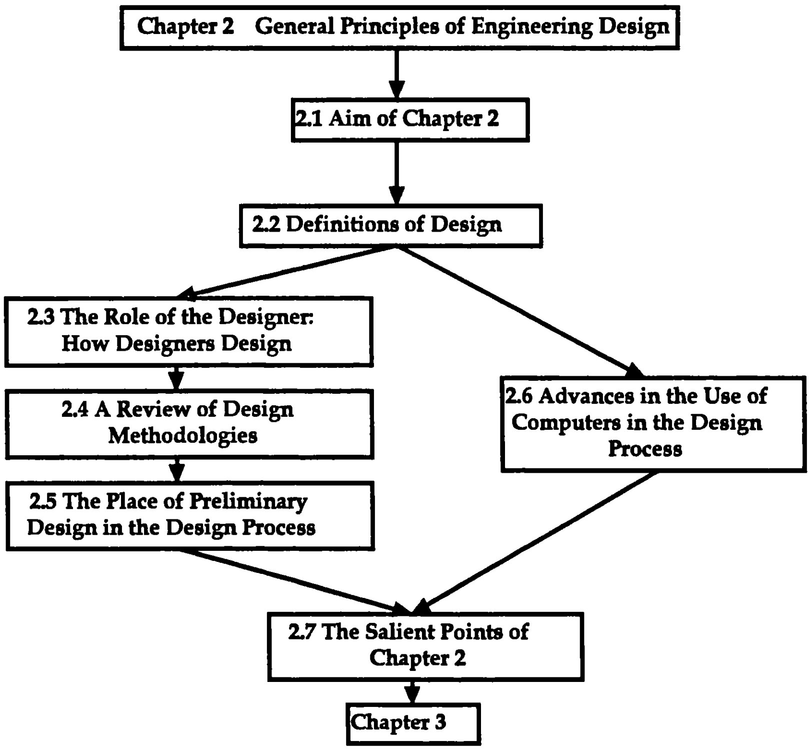
Part Three concludes the thesis and the logic is illustrated in Figure 1-4. Chapter 9 summarises the salient points of discussion and proposes research to be undertaken regarding methods of improving the design methodology. References and appendices provide supporting information as text, illustrations and general arrangement diagrams. A technical overview of a computer aided design system, proposed to apply the methodology within Ministry of Defence design projects is presented at Appendix A.

Figure 1-4 Structure of Parts 3 and Appendices



2. GENERAL PRINCIPLES OF ENGINEERING DESIGN

Figure 1-1 Chapter 2 Schematic



2.1 AIM OF CHAPTER 2

> *"Engineering Design is the use of scientific principles, technical information, and imagination in the definition of a structure, machine or system to perform specified functions with maximum economy and efficiency."* [Fielden Committee, 1963]
>
> *"We haven't the money so we've got to think."* [Lord Rutherford 1871 - 1937]
>
> *"Good design is as much a social science as a technical science."* [Tibbitts & Keane, 1995]

Unlike other forms of engineering and science, anyone can design. The majority of tools required are those formed by general education. It is also easier to criticise an existing design, than to design anew. What is not possible however, is for every designer to design well, or even for designers to agree on what is a well-designed artefact. A successful design relies on many individual tasks being performed well and the entire design process being well managed. There have been many attempts to describe methods by which successful designs are produced. These have been classified under a general heading of design theory. This chapter concentrates on the description of engineering design theory and the commonly held principles of design as starting points for the subsequent definition of naval ship design processes. This informs the requirement for a new design methodology for naval surface ships, detailed in Chapters 3 and 4.

The chapter commences with a review of design definitions and an introduction to the nature of design [Section 2.2] detailing the features that a good design process may possess. The role of the designer is examined [Section 2.3] regarding the types of design task likely to be performed and the skills a designer can bring to the process. A review of design methodologies allows the major design stages to be developed [Section 2.4]. This is continued by the definition of the specific nature of "preliminary" design [Section 2.5]. Given that computers are used increasingly, as both design aids and to undertake design directly, advances in computer design tools and methods are presented in Section 2.6.

2.2 DEFINITIONS OF DESIGN

Although design is considered a discipline that transcends the normal divisions of art, science and technology it is proposed to exclusively concentrate on issues relevant to engineering design. This is in order to render the problem more tractable given the immense scope of design. It is first necessary to define what we mean by design. The following quotations represent some possible answers to the question "what is design?".

> *"Decision making, in the face of uncertainty with high penalties for error."* [*Asimow, 1962*]
>
> *"A goal directed problem solving activity."* [*Archer, 1965*]
>
> *"The imaginative jump from present facts to future possibilities."* [*Page, 1965*]
>
> *"The performing of a very complicated act of faith."* [*Jones, 1966*]

Such descriptions lead us to some of the processes and features that should be present for a design task to be successfully achieved. Namely:-

- There must be a goal to achieve or problem to solve.
- There must a starting point to make Page's "jump" from.
- Decision making is an important activity.
- Imagination and Creativity[19] are required.
- There are high levels of uncertainty.
- Personal resourcefulness and intelligence are required for success.

The statement by Lord Rutherford at the start of this chapter suggests that that methods to be used in the design "act" [*Powell, 1995*] should have an impact on the cost of design evolution and production. Jones suggests that there is an effect of designing,

[19] Hence a good design process does not enforce a mechanistic approach.

which is to *"initiate change in man-made things"* [*Jones, 1970*]. Jones uses this definition to suggest that not only are engineers and architects designers, but that all manner of people are designers, from politicians to publicists. Jones also suggests that modern pressures have forced the designer, in his broad definition, to become more scientific and industrially aware. Such pressures lead to a view of engineering design described purely using scientific or mathematical processes [such as *Bell et. al., 1991*[20]]. The attempt to conform design to a scientific method was detailed by Jones [*Jones, 1970*] who suggested that a common theoretical foundation is not possible or desirable. One view of the usefulness of mathematical design was presented by Sir Rowland Baker [*Andrews, 1981a*].

> *"Mathematics was introduced into Design (rightly) but one of its side effects was the idea that Mathematics and Calculation could 'get it right'."*

This view point is considered particularly valid for many design processes where the complexity of the issues under investigation can be overly simplified by a purely mathematical approach and that creativity may be missing from such processes.

The traditional view of the designer is that of the artisan designer, located behind a drawing board, drawing the artefact to be designed by eye and hand co-ordination, employing a designer's "skill". Before calculation methods were codified into the methods used today, artisan designers designed by rule of thumb, and by experience. Often drawings were not produced and the artefact was designed simultaneously with its manufacture. However ill advised this process appears, it created many outstanding artefacts [*Jones, 1970*]. Experience is not gained without occasional failure borne by ignorance [for example the loss of *H.M.S. Captain*, [*Hawkey, 1963*]] and in modern society the "cost", whether in lawsuits or human life, of catastrophic failure is often unacceptable[21]. Design processes and theories have evolved, reflecting the era of their use in style, technical attributes and interaction with society. This can be shown by the increasing use of computer based Artificial Intelligence [*Turban, 1992*] and optimisation tools [such as *Keane et. al, 1990*] in design at a time when society appears to be obsessed with computer technology.

Many varied theories of design have been published, it often appears that two completely different design theories are feasible. A comprehensive discussion of design

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[20] [*Bell et. al., 1991*] used the mathematics of system dynamics to develop a representation of the fundamental aspects of an engineering design process. Design was modelled as a series of mappings between different model spaces with the model becoming less abstract at later stages.

[21] Fear of catastrophic failure leads operators to implement expensive safety management techniques, for example the United Kingdom Ministry of Defence's Safety Management System [*Pudduck, 1998*].

was presented by [*Mayall, 1979*]. Mayall's chapter headings, listed below, suggest, in summary, that design is made up of ten principles.

"Totality All design requirements are always interrelated and must always be treated as such throughout a design task"

"Time The features and characteristics of all products change as time passes"

"Value The characteristics of all products have different relative values depending upon different circumstances and times in which they may be used"

"Resources The design, manufacture and life of all products and systems depend upon the material, tools and skills upon which we can call"

"Synthesis All features of a product must combine to satisfy all the characteristics we expect it to possess with an acceptable relative importance for as long as we wish, remembering the resources available to make and use it."

"Iteration Design requires processes of evaluation that begin with the first intentions to explore the need for a product or system. These processes continue throughout all subsequent design and development stages to the user himself, whose reactions will often cause the iterative process to continue with a new product or system."

"ChangeDesign is a process of change, an activity undertaken not only to meet changing circumstances, but also to cause changes to these circumstances by the nature of the products it creates."

"Relationships Design Work cannot be undertaken effectively without establishing working relationships with all those activities concerned with the conception, manufacture and marketing of products and, importantly, with the prospective user, together with all the services he may call upon to assist his adjustment and protect his interests."

"Competence Design competence is the ability to create a synthesis of features that achieves all desired characteristics in terms of their required life and relative value, using available or specified materials, tools and skills, and to transmit effective information about this synthesis to those who will turn it into products or systems."

"Service Design must satisfy everybody, and not just those for whom its products are directly intended."

From Mayall's chapter headings it becomes possible to consider the vast scope of design and the many issues that render a design task more difficult, Notable issues are the inter-relationships between design features and the need to satisfy all customers, even in the face of conflicting requirements. However design management tasks are notably important, if Mayall is correct, particularly in the need to provide design information and the imposition of external forces on the design task. The change in perception of the design problem and design priorities suggest that design is much broader than a simple synthesis of constituent features to a comprehensive whole. The change of design priorities with time suggests that similar requirements, spread over time may lead to different design solutions. An important issue when considering the scope of naval ship design is a need to provide a capability to apply the final design to situations that were unforeseen during design. As noted by [*Brown, 1993*] many ships have been adapted to other roles as military requirements have changed, but not all designs provide a suitable platform for change.

A feature of design is the similarity between the design processes of different disciplines. The phases in two discipline's approaches to design can be shown to be very similar. Jones [*Jones, 1970*] presents Asimow's [*Asimow, 1962*] and the Royal Institute of British Architects' [*RIBA, 1965*] respective views of engineering and architectural design for comparison. An abbreviated version is at Table 2-1.

Stage	Engineering Design	Architecture Design
1	Feasibility	Inception & Feasibility
2	Preliminary Design	Scheme Design
3	Detailed Design	Detail Design
4	Planning	Production and Planning

Table 2-1 Comparison of Engineering and Architectural Design

Such similarities reflect the nature of general design with the transformation from requirement through initial ideas to a fully defined and produced artefact.

Techno-economic issues, reflecting both design artefact and design organisation introduce differences between disciplines. This was illustrated by Andrews [*Andrews, 1998*] who contrasted descriptions of an approach to engineering design[22] and an approach to Architectural design[23]. He concluded that the ship design process appears to be closer to the architectural design process, than the engineering design processes used for mass produced items. This can be considered to be due, at least in part, by the similarities in the level of complexity of the ship and architectural projects as well as a similar design environment. Differences between design processes for mass produced and bespoke artefacts can also be considered to be due to the environment in which such items are procured, the artefacts complexity and the methods by which design objectives are set.

The nature of a design process is reliant on the interaction between the designer(s), the wider project team and the design environment. In particular the corporate design culture for engineering design is important. Different corporations and technology areas have widely different attitudes to design. The issues regarding

22 Described in Andrews' Table 3 as "mechanistic, machine products, mass produced components, clear economic basis" based on [*Hubka, 1982*].

23 Described in Andrews' Table 3 as "architectural, complex design with human habitat / environment, bespoke design and build, complex procurement process" based on [*Broadbent, 1986*].

design failure, the ability of a single designer to influence corporate design policy, and the size and nature of the organisation, introduce these.

A conclusion from this is that other design disciplines may be able to contribute to the need to provide a modern naval ship design methodology. It will be shown in Section 2.4 that a synergy exists between the direction of design research advanced by practitioners of architectural design and also engineering design of large, complex systems such as ships and factories. This synergy can be used to identify methods of performing naval ship design in a manner suitable to the complex requirements and design environment, as will be advanced in Part 2 of this thesis.

2.3 THE ROLE OF THE DESIGNER: HOW DESIGNERS DESIGN

The role of the designer is crucial to the success of the design process. This is equally true for manually produced designs and computer based design techniques where a designer acts as the operator of an automated solution method such as Simulated Annealing [*Ingber, 1993*]. Design research has evaluated the workplace performance of the designer attempting to provide descriptive views of design. These have encompassed the many styles of design and skills required to perform the design act [*Archer, 1965*]. The designer does not necessarily work in the strictly sequential, regimented, manner that might be assumed from models of the design process [*Edmonds, 1995*]. Jones [*Jones, 1970*] suggests that the mental activities of the designer shows long periods of incubation of ideas and rapid "leaps of faith", with sudden inspiration identifying the core features of a design solution. This indicates that regimented, serial, design procedures are unlikely to be successful, and that a proposed design methodology should provide a general approach to performing design rather than a mechanical process to follow, allowing freedom of expression.

The designer needs to acquire several skills to be flexible and comprehensive in the design task. A design methodology tasked with aiding the designer should support the designer in achieving these characteristics. Such skills include:-

- Experience
- Communication
- Creativity
- Decision Making

Many design activities perform variant or adaptive design [*Pahl & Beitz, 1984*] in which features of one design are modified to meet a new design requirement. Such design tasks require a designer to select the design to be adapted and those changes to be made. The designer must judge the applicability of making those changes required.

This requires experience of design issues and design artefacts[24]. Such knowledge can be personal but for long term engineering design projects it is important that such design experience resides within the corporate design community. [*Brown, 1993*] raised the opinion that when corporate design experience is diluted or lost, needless design failures or disasters may occur. The importance assigned to corporate design experience was indicated by the discussion of Brown, Fuller, Pattison, Tirard and Andrews, in [*Andrews, 1994a*]. These discussions indicated the concern of experienced warship designers over the inevitable loss in design experience as the number of new ship classes introduced into the Royal Navy decreased, and the type of individual employed in design changed. Pattison [*Pattison, 1994*] noted that the progress being made in design research might only lead to a partial regaining of the design competencies lost.

The modern designer is rarely alone in the freedom to prepare the design as there are the needs of other interested parties to consider. For a large design team to successfully attempt the design task, emphasis must be placed on the communication of design issues to all parties. Taken to its logical conclusion, this may result in design by conference and integrated process and product development teams, as mooted by [*Tibbitts & Keane, 1995*]. The ability of a designer to communicate with all interested parties simultaneously may provide Jones' leap of faith as novel solutions to a common problem, viewed from many different positions, are brainstormed. An inability to communicate promotes an unsuitable design, as indicated by [*Betts, 1992*] who suggested from his own experiences that *"where major problems arise ... they ... stem from a breakdown in communications"*.

Creativity is an issue of great controversy, but it evident that the "greatest" designers, have possessed that quality. A definition of creativity was presented by Asimow [*Asimow, 1962*]:-

> *"Creativity: a talent for discovering combinations of principles, materials or components, which are especially suitable as solutions to the problem in hand."*

> *"Sheer number of inventions do not guarantee that a major technological change will occur. The key is always the inventor's act of insight by which certain elements are chosen, combined in innovative ways and made to yield a solution"[Bassala, quoted by Candy & Edmonds, 1996]*

The issue of creativity in modern design forms a barrier to the use of computerised, as opposed to computer aided[25] design. It is considered essential that the

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24 The type of design knowledge described as Design Epistemology by [*Cross, 1995*]. Cross also suggested that knowledge of design also existed in design processes [Design Praxidology] and in products [Design Phenomenology].

25 Computerised design can be considered as the programming of a computer to automatically solve a specified problem while computer aided design is the use of a computer system to aid the designer.

synthesis of a design artefact includes an element of creativity to allow divergence of design ideas, allowing radical[26] design solutions to emerge. [*Candy & Edmonds, 1996*] demonstrated the importance of "ideas" with their model of creativity, similarly Darke [*Darke, 1979*] noted the need for a key generator [see Chapter 6] to be considered in synthesis. It is suggested that without such issues being considered synthesis cannot occur.

In all areas of design, a need exists to produce a radical design solution on occasions, when the requirement is best met by such a solution. This was detailed by [*Andrews, 1984*] where a holistic approach to ship design suggests that the designers' idiosyncratic stamp is one of three inputs to the main synthesis[27] The designers idiosyncratic stamp draws on the model of creativity detailed by Daley [*Daley, 1982*]. Daley's philosophical model of creativity suggested that the element of design creativity of which we are conscious is a small subset[28]. Daley also noted that creativity transcends the bounds of verbal discourse. This forms a barrier to the "teaching" of creativity by the designer to a design computer.

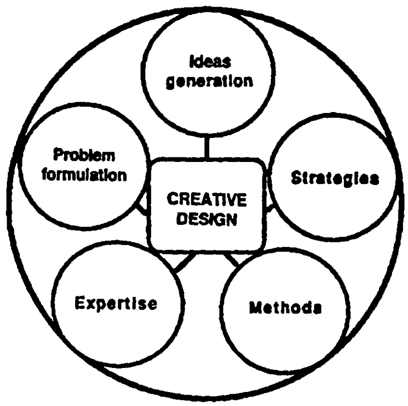


Figure 2-2 Elements of Creative Design [Candy & Edmonds, 1996]

As quoted previously Asimow [*Asimow, 1962*] considered design a decision making process. This view has gained credence and has spawned methods of design in which decision making is the major tool [such as *Koch et. al., 1995.*]. The view of the designer as decision maker is important as it defines the relationship between the designer and design information. To make rational decisions the designer needs access to all relevant design information in a clear and open manner. This should preclude the use of design methods, whether computer based or not, that act as a "Black Box" [*Jones, 1970*], as a "Glass Box" is more effective.

Jones detailed the Black Box paradigm as an inexplicable creative leap, while glass boxes were defined as explicable rational processes. When applying design tools a designer needs to apply judgement on the impact of the design tool and decision

26 Radical is used to suggest designs that have not evolved directly from tried and tested technology and arrangements.

27 The other inputs are task directed input and design process constraints.

28 The conscious element of design knowledge being the intersection of our value structures, verbal discourse and visual schema. Value structures were considered as the ordering of conceptual priorities based on, and to make sense of, our own experiences.

making processes on the design artefact. This assures that a well-founded decision is made and regimented decision making is avoided. Such judgement requires open "glass box" design approaches. This has implications on the design methodology used as many modern methodologies require the provision of design knowledge as mathematical data, to be manipulated rigidly using optimisation techniques [*Keane et. al, 1990*], genetic algorithms [*Goldberg, 1989*] or other formulaic methods. The use of such methods raises the issue of the basis for optimisation for complex design systems with large-scale human interactions. Such methods also hide decision-making processes from the designer, with the designer only capable of changing methods before design commences, by re-iteration. For design artefacts requiring creativity and decision making, such methods are often inappropriate. [*Pattison, 1994*] suggested that naval design systems utilising a black box approach *"are close to necromancy"*, and noted that such tools are not backed by a training regime, leading to possible inappropriate uses.

Having stated the major qualities required by a designer it is necessary to detail the types of task that a designer will undertake during a design process. The following represents a view of the major tasks to be undertaken by a designer throughout a design process:-

- Genesis
- Synthesis
- Analysis
- Functional Decomposition and Translation

Genesis is the initiation of a design activity. The initial leap from blank paper to an unproven sketch to an idea of the solution space[29]. Darke [*Darke, 1979*] considers such a suggestion as being driven by the design's key generator, as will be detailed in Chapter 6. Such a task can also be considered as the provision of the first point of a search path. As such it is often a black box process [*Andrews, 1984*], as in the use of Brainstorming [*Jones, 1970*]. Simon [*Simon, 1981*] suggested that the order of search was important and hence the Genesis step is an important consideration in the design process, as all further developments are undertaken from this starting point. From a different environment, Cole [*Cole, 1996*], quoted Harold Wilson, *"Always try to write the first draft. They may mess it around a lot later, but something of your ideas will survive"*. This approach can be considered analogous.

Synthesis is a design task that is essential to the provision of a successful design.

29 A design solution space is the abstract concept for a set of potential design solutions one of which becomes the final solution. Design can be considered to be the reduction of the size of the design space to a single design point representing the solution. This is an attempt to represent the multi-dimensional design space in a manner that the human intellect can visualise.

Synthesis is defined by Asimow [*Asimow, 1962*] as *"fitting together of parts or separate concepts to produce an integrated whole"*. Therefore, the act of creating a valid ship design from the myriad of individual ship design elements, equipment items and requirements, the major focus of this thesis, is a synthesis task. Andrews' [*Andrews, 1984*] definition of synthesis indicated this with the notion that synthesis is the integration of *"functional requirements by achieving gross characteristics within the constraints of the design environment"*. If this is true, the method by which synthesis is performed by the designer needs to be considered fully. Such methods should reflect the nature of the design environment. It is assumed in this thesis that the environment is the complex and interactive one of naval ship design.

An important feature of the above statements on synthesis is the degree of importance attached to the integration of design elements and their relationship to the whole design. i.e. the design must meet all design requirements individually and holistically. A major feature of a design synthesis process is the issue of divergence followed by convergence. It is considered necessary to start a design process in such a manner as to allow an expansion of the range of solutions under consideration [divergence]. This is then followed by a convergent design phase in which one or more potential designs, or groups of design features are selected and focused upon. Such features assure that the designer does not focus on the design solution that is initially the most appealing.

A major design issue, design analysis, is the rejection or acceptance of design features. Other terms for such a stage include refutation and evaluation. Design analysis is the process of assessing the suitability of the design artefact in comparison with requirements and constraints. The result of an analysis task is the acceptance of a design feature, its refinement, or its abolition. The issues involved in assessing the acceptability of a design feature are complex and usually include the following issues:-

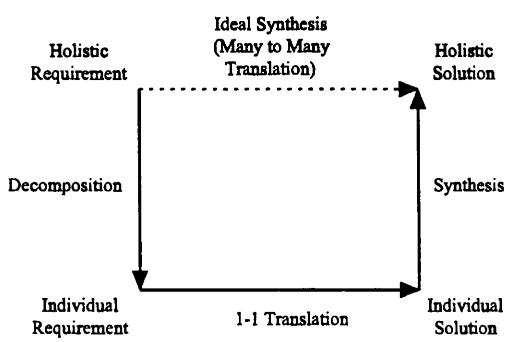
- Performance
- Cost
- Configuration
- Risk
- Compatibility with other design features
- Aesthetics
- Manufacturing Considerations

The designers' involvement in such issues is threefold. Firstly the assessment of the success of the design feature in the product achieving each task. Secondly the assessment as to whether a failure to meet a criterion is acceptable, given other design features. The final issue is selection of those changes necessary to produce an acceptable or better solution. The analysis task requires a designer to formally assess the current design and propose a route to the final design, using the results of analysis to inform the design path to be taken.

Functional decomposition is the sub-division of the overall design requirement into specific, separate [and, ideally, independent [*Suh, 1990*]], functions to be performed by the design. The ability to decompose the functional requirements of a design requirement into specific elements is a skill often required by the designer. If performed satisfactorily, it is possible to meet individual design requirements and subsequently integrate the sub-solutions to allow assessment of the solution in a holistic manner. This leads to the integration of the individual solutions, a synthesis task, being the most important feature of design. The task of synthesis is rendered more tractable by use of a suitable decomposition approach. The task of translation is the movement from each specific design requirement to a solution for that requirement [*Jones, 1970*]. This translation can be seen in Figure 2-3. An ideal synthesis method would translate all design requirements simultaneously to the overall design solution, but this is impractical for complex design tasks. The functional decomposition method used depends on the skill of the designer and the requirements of the design environment.

The result from the design tasks detailed in this section will be one design that is considered to be the most appropriate for the design requirement, considering all relevant issues. The measurement of appropriateness is a complex issue. Two measures of the most appropriate design can be introduced and one role of the designer is to judge which is the most appropriate measure in each instance. The two approaches are to seek the optimal design or to seek a satisficing design. The optimal design is the design that meets the requirements to the highest possible degree, such that no other designs are as suitable, given the [fixed] design requirement. The benefits of such a design are obvious, provided the requirement can be stated with such clarity, rigidity and simplicity that the optimum design can be defined.

Figure 2-3 Decomposition, Translation and Synthesis



With a single statement design requirement there should be only one possible interpretation of the requirement, leading to a unique definition of the optimum design. However if a second criteria is introduced, the problem instantly becomes harder to define. For example is the optimal design the lightest, the cheapest or a compromise between the two? If a compromise is required where should the compromise be? The need to compare disparate quantities causes the notion of the optimum design to become artificial when dealing with complex design requirements [*Simon, 1981*].

An alternative is Simon's concept of "satisficing" the design requirement [*Simon, 1981*]. Satisficing is the search for a design solution that meets all design requirements fully but does not attempt to provide the ultimate, optimum, solution. This relies on the selection of design features that reduce the design solution space sufficiently to allow only acceptable solutions to remain within it. Due to the potential for combinatorial explosion of possible solutions, satisficing is the only possible form of realistic design selection method amongst complex design artefacts. Simon also suggests that as the optimum design is never achieved for such complex requirements, the direction in which the designer directs the design search is considered important. The search direction decrees which of many satisficing solutions will be found and selected. This issue is important in design methodologies in which only a small part of the design space can be searched for alternatives in a reasonable amount of time. Thus the form of Genesis is considered important if the designer is to start a design search in a suitable location. The form of Synthesis is important to allow a satisficing solution to be developed and the use of Analysis is important if the designer is to prove that the design selected is indeed satisficing.

2.4 A Review of Design Methodologies

Section 2.4 presents a brief review of design methodologies. A study of design methodologies allows the important issues such as relationships between design stages, the formal nature of many design methods and the importance of configuration in design, to emerge.

Assuming Simon's stance that a satisficing design is considered to be the only achievable goal for complex design problems, and therefore, that the route by which design is performed suggests which solution is achieved, it is important to study, document and improve the methods by which design is performed. This ensures that the designer moves towards the satisficing design in a systematic, controlled manner. This approach leads to consideration of the burgeoning field of design research and the consideration of meta design, the design of the design process [*Smith, 1992*]. In the field of marine design [*Hoset & Erichsen, 1997*] detailed the evolution of design research in terms of published literature. Hoset & Erichsen considered that the published marine design papers and research can be categorised by era and by content as Table 2-2. The sheer volume of material produced by different authors has led to the selection of some of the more relevant design research concepts in this chapter.

Era or Technical Content Group	**Major Features of Literature.**
Pre World War 2	The published introduction of the concept that economic and technical aspects of the ship design should be considered together.
World War 2 - 1969	Introduction of the design spiral, specific approaches for form and size determination using design rules. A first awakening of the potential of computers in automating the design process.
Discussions of Designers Attitudes to Theory	Consideration of the need for theoretical, general, approaches to marine design rather than type specific design procedures.
Advancing a Theory of Design	Introduction of such theoretical approaches to design, treating design theory as a structured iterative approach relating a solution to the functional requirements.
Modern Design Theory and Advice for Practising Engineers	Developments in design theory and procedures using optimisation, configuration, decision making methods and artificial intelligence. Particular emphasis is placed on the use of computers in design.

Table 2-2 Major Historical Marine Design Research Areas [Summarised from Hoset & Erichsen, 1997]

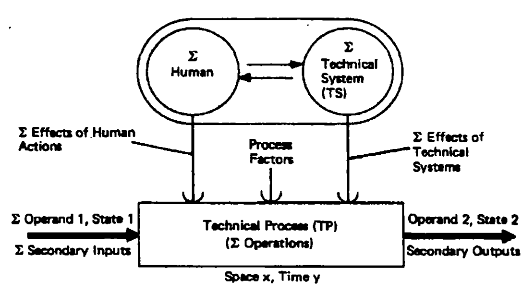
Cross [*Cross, 1995*] introduced the role of design research as the articulation, development and communication of design knowledge. This design knowledge was suggested to reside in people [Design Epistemology], in processes [Design Praxidology] and in products [Design Phenomenology]. Design Praxidology is the focus of this section with the introduction of some recent ideas as to the processes and methodologies by which designers undertake design. The majority of the research discussed here attempts to revoke Simon's denigration of traditional design practice.

> *"In the past much, if not most, of what we know about design was intellectually soft, intuitive, informal and cookbooky" [Simon, 1981]*

Two major approaches to defining design methodologies have been advanced, prescriptive and descriptive design methods. Descriptive design methods attempt to describe an overall approach to performing design and *"how design is done by the design* *engineer"* [*Cleland & King, 1993*]. [*Erikstad, 1991*] notes that the purpose of descriptive models *"is to describe how design is performed in a practical setting and to identify general characteristics of real world design processes"*. For example, Rittel & Weber [*Rittel & Weber, 1973*] detail characteristics of the urban planning problem. Descriptive design methods present aims and important features of a design process, without enforcing a direct method. Examples of descriptive design models include the various design spiral descriptions introduced by [*Evans, 1959, Andrews, 1984, see Chapter* 3]. Such authors have attempted to detail design as a sequential and iterative design process[30], without enforcing a rigid view as to the exact nature of processes to be followed. Care must be taken to avoid using the descriptive approaches, out of context, in a rigid prescriptive manner. Such descriptive design methods provide the basis for the more specialised, formal, "prescriptive" approaches to design. Descriptive approaches are considered more flexible than prescriptive methods, as the foibles of individual technology areas can be considered in view of the broad approaches advanced by a descriptive design method.

Prescriptive design methods attempt to detail the order and type of processes to be used in design. Several separate and distinct methods have been postulated, such as those advanced by Pahl and Beitz [*Pahl & Beitz, 1984*], and Hubka [*Hubka, 1982*]. Both postulate a method of entering and solving design problems. Hubka's Technical Process is the transformation from an initial state to an output (solution) state by human and technical system operations [Figure 2-4]. Similarly Pahl and Beitz define the technical system as the function that converts inputs in the form of energy, material, and signals into output in each form. The Pahl & Beitz systematic design model has been sufficiently defined and accepted to allow its incorporation as the German standard for the design of technical products [*VDI 2222, 1973*].

Figure 2-4 A Representation of a Technical Process [Hubka, 1982]



These representations, while generally applicable to design, are

30 [Erikstad, 1991] classified the design spiral approach to ship design as both a descriptive and a prescriptive design approach due to its specification of specific features to follow at each stage. This author considers that the illustrative steps detailed should not be followed religiously, are only indicative of the need to perform each design stage on multiple opportunities, and are so widely used due to the ease of understanding leading to a wide use in ship design tuition.

applied mainly to the design of engineering artefacts such as mass production mechanical assemblies and process engineering. The rigid approach adopted by such methods is not considered as applicable to complex design activities where the requirement is developed in conjunction with the solution [see Chapter 3].

Procedural or prescriptive design methods attempt to clarify a path from task to solution using a systematic decomposition of a design problem into its constituent function structures. Function structures, sub-sets of the holistic design requirement can be used to specify solutions for individual functions. Individual features can be synthesised to form different conceptual solutions. A resultant solution is assessed as being more suitable than others and is continued to the embodiment stage of design in which the design definition is increased in detail before being finalised. Illustrative examples are provided by Figure 2-5 and Figure 2-6. Figure 2-5 details the tasks of each

Figure 2-5 Design Process Steps [Pahl & Beitz, 1984]

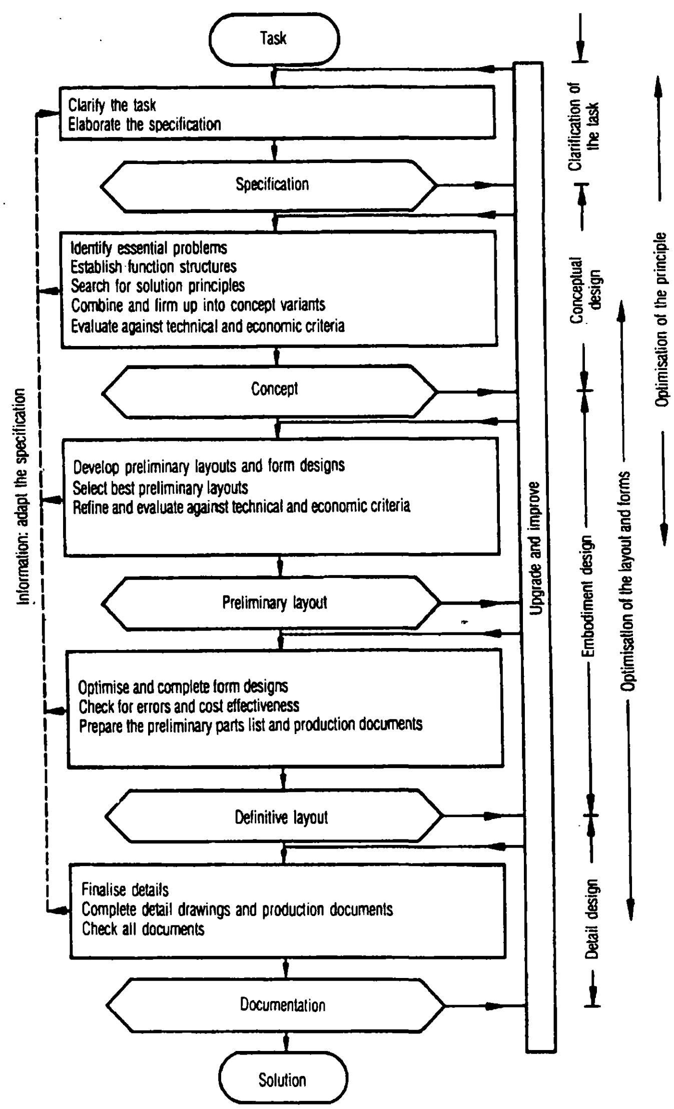
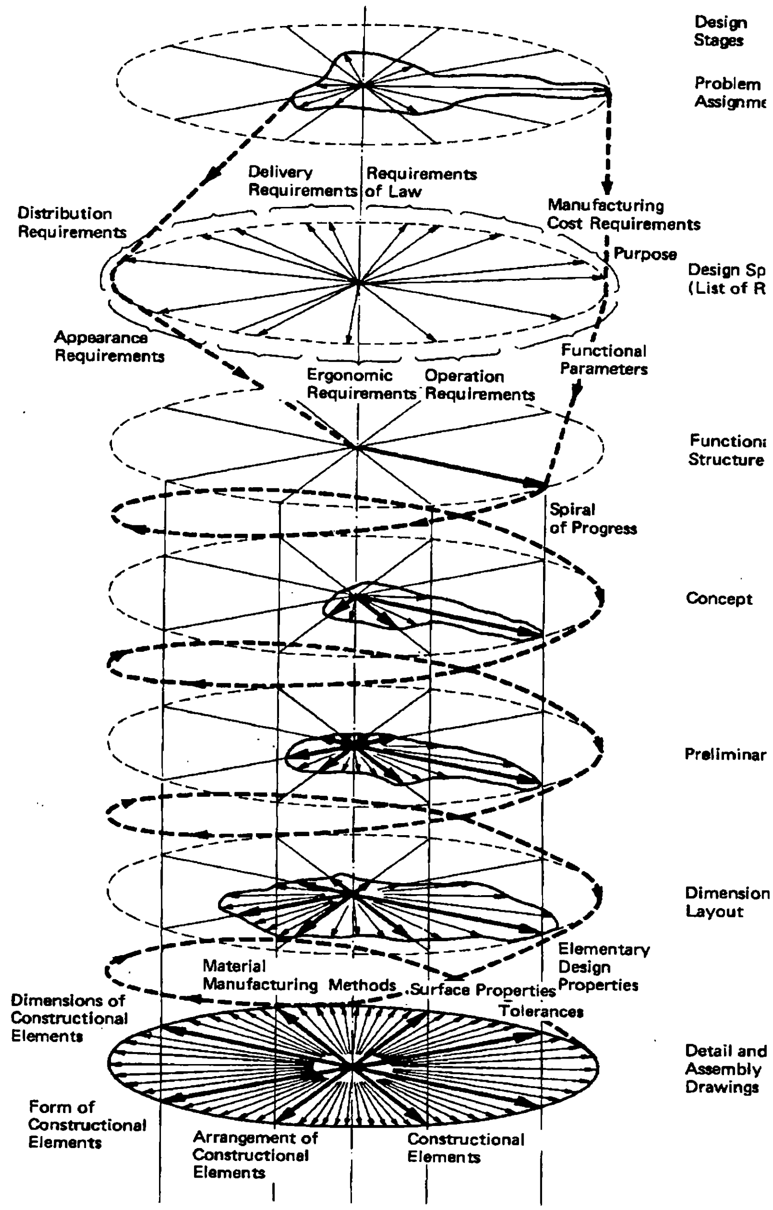


Figure 2-6 Representation of Design Completeness with Design Stage [Hubka, 1982]



stage of Pahl and Beitz's systematic design process.

Figure 2-6 demonstrates Hubka's representation of the degree of design completeness of design properties, which increases as design knowledge increases. This demonstrates that the issues considered in the preliminary design stages are not fully exhaustive, but are focused upon the initial information required to develop an outline of the solution to allow detailed design processes to begin.

Such representations of design form a framework from which much of the design research detailed here emerges. This is due to the description of the design process as the separate stages of requirement clarification, conceptual design, embodiment design and detailed design. Such descriptions closely follow the idea of separate preliminary and detailed design tasks, to be detailed later. However overly prescriptive methods may be considered undesirable as they attempt to conform design to one form, through an overly mechanistic process, lacking creativity, or the ability to react to specific process requirements.

A Universal Theory of Design:- Configuration

Research in design has suggested a requirement [*Logan & McDonnell, 1995*] for a domain independent or "Universal" theory of design. A domain independent theory is intended to allow, for example, "music designers" [composers] to converse in like terms with "engineering designers" [*Simon, 1981*]. Hillier[31], from the architectural domain suggested that a unified theory of design, if it exists, must have the layout of the artefact to be designed at its very heart. A similar notion was expressed for ship synthesis by Andrews, [*Andrews, 1984*] while Hubka's procedural model of design includes specific layout stages, post conceptual design [*Hubka, 1982*]. Hillier, using space syntax techniques[32] to describe the functionality and arrangements of large scale complex architectural entities, expressed this further [*Hillier & Penn, 1994, Hillier et. al., 1993*]. In [*Hillier et. al, 1993*] the growth of London [the design artefact] about its main arteries [the roads] was predicted by the investigation of the use of space within the city. Other examples include the change in the effectiveness of human motions occurring in a configuration of rooms after one of the rooms has an entrance blocked. The configuration aspects of such a design were stated as being chosen at an unconscious level by the designer, an argument reinforcing the need for creativity.

The urban planning research of Hillier has implications for all complex design issues. The research relates the complex interrelationships between design functions to two knowledge problems [*Hillier & Penn, 1994*]. These are the understanding of the functionality of the design artefact as a complex whole and the introduction of better designs from feedback. The proposed architectural solution is to model the design artefact using a spatially modelled, building centred view of design rather than the discipline centred view currently held by architects and building engineers. Within the architecture discipline the building centred view is used to propose the improvement of

31 A comment made while receiving a 1995 Design Research Society prize [*Logan & McDonnell, 1995*].

32 *"Space Syntax is a set of techniques usually, but not always involving computers for the analysis of spatial configurations of all kinds, especially where spatial configuration seems to be a significant aspect of human affairs, as it is in buildings and cities"* [*Major, 1996*].

housing estates, cities or individual dwellings by the measurement of space, which for architects, is the most important design feature. Applied to general design, Hillier's research suggests that the use of spatial arrangements is an effective method of modelling complex design artefacts. For large made to order systems[33] the introduction of configuration has been proposed [*Andrews, 1998*] as the key to developing suitable relationships between complex functional design issues. Andrews [*Andrews, 1998*] recommends the adoption of a combined engineering and architectural solution as the method of designing complex systems.

Particular examples of configuration in design include a layout based marine design and cost estimating system [*Guenov et. al., 1994*], the development of large made to order products [*Cleland et. al., 1994*], identification of suitable architectural arrangements of large made to order products [*Hills et. al., 1993*], and the conceptual design of offshore production platform topside designs [*Cleland & King, 1993*]. Hills et. al. used a combination of a simulated annealing algorithms, to generate near optimal candidate solutions, and a knowledge based artificially intelligent "Expert Critic" to interrogate each of the candidate designs and to assess it for satisfaction against "domain specific" and "generic spatial" requirements. The knowledge based nature of the critic allows the investigation of different types of design requirement, for example those compartments whose satisfaction is proportional to the "Manhattan" distance between them along access routes. [*Cleland & King, 1993*] used heuristic models and gross assumptions as to spatial requirements, to develop the size and configuration of the three major zones and major systems of an offshore production platform to inform the remaining design synthesis.

Another example of the use of configuration in design is the identification of advantageous production line configurations [*Tompkins, 1996*]. Tompkin utilises the relative arrangement of specific production functions as the key design issue, representing configuration by spatial networks detailing the design in non dimensional form. Such non dimensional forms have formed the basis of process engineering design methods. Such methods are most valid where the problem is purely a configuration problem and the issues of the magnitude of spatial requirements can be settled easily. Where both spatial constraints due to location and due to size are apparent the non dimensional approach is less valid.

33 Made to Order: A single or small run production design artefact such as a factory, ship or oil rig for which a specific customer is identified and consulted prior to design. Generally a prototype is not economically feasible.

In a paper to the Royal Society [*Andrews, 1998*], Andrews proposed that configuration should lay at the heart of a design methodology focused on the design of large, complex, made to order artefacts. His reasoning suggested that the complex design issues involved in such artefacts required a methodology focusing on all design issues, not just those amenable to mathematical description in order to include elements of the design process such as the removal of the distinction between detailed design and initial design stages by concurrent engineering practices, the introduction of integrated logistics support at the design stage, and the movement to simulation based design [see Section 3.5].

2.5 THE POSITION OF PRELIMINARY DESIGN IN THE DESIGN PROCESS

In Section 2.4, design has been modelled as a process encompassing many levels and stages. This thesis is concerned with the initial, "preliminary", stages of design, during which the initial properties of a design artefact and fully documented feasible requirements emerge. Different authors refer to preliminary design in different terms, varying as the design area changes. Terms for preliminary design stages include:-

- Concept / Conceptual Design [*Hubka, 1982*]
- Initial Design / Initial Sizing
- Feasibility Design [*Bryson, 1984*]
- Sketch Design

These are different in context, approach and task from more detailed design stages. In detailed design stages incremental, evolutionary, changes to the design artefact occur as valid design information develops. Such detailed stages are variously known as:-

- Contract Design [*Bryson, 1984*]
- Detailed Design [*Andrews, 1998*]
- Embodiment Design [*Pahl & Beitz, 1984*]
- Design For Construction

All preliminary design decisions are re-evaluated at later design stages. This leads to a suggestion that preliminary design stages are not particularly important and can be performed without great thought as to approach. Therefore it is important to clarify the requirement to perform the preliminary design task. Particularly important is the need to detail the importance of the preliminary stage relative to other design stages. The argument for a preliminary design stage with different procedures and methods from the later embodiment design stages can be based upon the idea that it is easier to modify design features when failing to meet requirements than it is to create a valid detailed design ab initio. The complex definitions required at later stages of design, to demonstrate compliance with detailed requirements, can only be introduced by attending to specific design features that are unsuitable. This suggests that detailed design is a process of removing problems associated with the features of the design introduced during preliminary design. However in order to be removed, the problems must first exist, as suggested by Suh [*Suh, 1990*]:-

> *"Design decisions made at the initial or upstream stage of engineering affect all subsequent outcomes".*

Erikstad [*Erikstad, 1996*] suggests this is important as initial stages of design provide a problem in which few constraints on the solution have been placed but also no solution exists. The first design decision places constraints on the solution, removing potential solutions from the design space. Equally though, it is not practical to *"not make decisions"* [*Erikstad, 1996*].

All engineering design processes are undertaken within a framework of financial restrictions on manufacturing and development costs. Therefore the constraints on design solution introduced by the initial design stages have an effect on the ability to plan the future cost implications of the design artefact. This was demonstrated by [*Andrews, 1994a*] who noted that the vast majority of the programme costs are implied by decisions made at the preliminary stages despite very few costs actually being incurred.

Thus a major feature of the initial stages is that design decisions have to be made. Such decisions affect subsequent process and design issues, without the knowledge of those issues that allow decision making to be performed properly. Erikstad [*Erikstad, 1996*] suggested that this has an impact on the freedom of the designer to make changes to the design artefact as the design knowledge increased.

When applied to complex design problems, the *"formulation of a wicked problem is the problem"*[34] [*Rittell & Weber, 1973*]. This suggests that the earliest stages of design act as an interface between the perceived first estimate of a requirement and the formalisation of the style of solution to meet a more detailed design requirement, which has emerged during the formulation of the solution. Preliminary designs provide clarification of achievable goals, elucidating the validity of the requirement. Thus the result from a preliminary design stage might be a revised requirement instead of, or as well as, an initial solution. This was postulated by [*Hubka, 1982*] in his general procedural model of the design process for technical systems, the first design stages of which are:-

- Elaborate or clarify assigned specification
- Establish functional structure
- Establish concept

Detailed design processes under the titles of "Laying out" and "Elaboration" follow these design stages. The formalising of the design review structure [*Bryson, 1984, Tibbitts et. al., 1988*] to include requirement specification as a major milestone is evidence of preliminary designs' importance in clarifying requirements.

Given a design task with a well-founded overall design concept the designer is capable of establishing the structure of possible solutions to the problem by decomposing the overall task to individual functions of the design. When applied rigidly and methodically by [*Pahl & Beitz, 1984*] a mechanical design task is decomposed to catalogues of potential solutions for individual sub functions. A mechanical establishment of function structures is known as catalogue design.

Alongside the increased specification of design requirements another major role of initial design stages is to act as the divergent design act[35], before convergence on a solution in later design stages. Divergence in design is required "*so as to have a large enough and fruitful enough search space*" [*Jones, 1970*]. This refers to the idea of design as the search for solutions, in which the order and breadth of search methods may affect the quality of the solution found. In design the complexity of the design artefact may demand that divergence takes the form of separate directed design evolution's, each to a low level of detail. Lack of divergence leads to "*a premature commitment ... to a solution to a design problem*" [*Purcell & Gero, 1996*] leading to design fixation. A danger associated with divergence is combinatorial explosion. This leads to insufficient attention being paid to each design alternative, with attendant dangers of selecting an inadequate design. The ability to develop and analyse large numbers of possible solutions leads to approaches to optimise design, as detailed in Chapter 4.

While revising the customer's expectations to those that are achievable, the role of preliminary design includes a need to place the design within the wider product development programme. This changes with technology area, but for the development of engineering design artefacts it includes all processes required to achieve the

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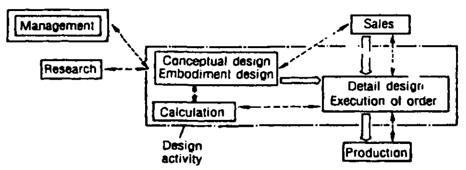
34 Rittel & Weber detailed the dilemmas facing planning authorities, noting that their problems were "wicked" in their nature with problem complexity forcing the designer to accept that, there is not a definitive problem statement, solutions to the problem are not "true or false" but "good or bad" and most notably that a complex design problem is unique and that the process of stating the requirement and defining the solution are essentially the same task.

introduction of the new design artefact into service. Preliminary design methods should determine the form of the design artefact ensuring that the required performance is provided. It must also further the assurance that financial restrictions are met, new technology is mature before implementation and production can be achieved within schedule. The relationship between engineering design and external influences was detailed by [*Pahl & Beitz, 1984*] here as Figure 2-7.

Figure 2-7 Organisation of the Design Activity [Pahl & Beitz, 1984]



This section has described the role of preliminary design as being the exploration of a design requirement, the provision of a potential solution to be evolved in detailed design stages. The study and improvement of the methods and processes used in the preliminary design of engineering artefacts, is therefore a valid exercise, potentially benefiting the whole design process by allowing better design decisions to be made, providing a more valid requirement and solution to the subsequent design stage.

2.6 ADVANCES IN THE USE OF COMPUTERS IN DESIGN

Much of modern design research focuses on the development of the use of computers within the design process. This section details briefly the types of computer based design aids under investigation. The majority of computer based design systems perform the tasks of design development by drawing, associated with draughtsman and these are not focused upon here. Such systems follow and enhance methods of design practised traditionally by paper and pencil. Methods used include sketches, and accurate design models, represented on a computer, to allow rapid changes to design features to be achieved. Such systems are also entering the preparation of production quality design data as detailed by [*Foster, 1998*].

Semi-Automatic design tools allow a designer to specify design problems as models of goals, requirements, constraints and design relationships, that a computer can manipulate then rapidly to a solution. Powerful mathematical techniques can be applied to solve relationships and perform the synthesis of the design artefact without recourse to the designer. The techniques used to solve the design include Optimisation [*Keane et. al, 1990*] and Simulated Annealing [*Ingber, 1993*]. In several approaches artificial processes analogous to Biological processes, Neural Networks [*Lippmann, 1987*]

[35] Divergent design may also occur in detailed design when dealing with sub-sets of the design solution

Technique	Utilisation	Reference
Goal Programming	DSIDES Decision Making Engine	*Peplinski & Mistree, 1997*
Optimisation	Ship Design	*Keane et. al., 1990*
Neural Networks	Ship Design	*Sha et. al., 1992*
Genetic Algorithms	Fluid Pipeline Design	*Tiley, 1996*

Table 2-3 Applications of Semi Automatic Design Aids

and Genetic Algorithms [*Goldberg, 1989*], relate the features of a successful design artefact to design requirements. Such systems operate in a manner similar to mathematical optimisation tools. Examples of design aids using the above systems are given in Table 2-3.

Such design aids provide quick methods of analysing combinations of potential design features and selecting a suitable combination. Such systems often act as a Black Box, with the consequent disadvantages. The advantages and disadvantages of such systems are detailed further in Section 4.3, however Burrows [published by *Candy & Edmonds, 1996*] detailed his personal view of modern computer aided design when applied to racing bicycle design.

> *"...There was no design element. They simply just drew it on the screen and simply changed the shape and then obviously used those to generate aerodynamic profiles within it rather than just draw a line on a piece of paper, they can obviously program them in. But I wouldn't call that design* [*Candy & Edmonds, 1996*].

This suggests that the important element of creativity was missing from the design system viewed by Burrows. This lack of creativity will be seen as a missing element of many design systems when applied to ship design in Chapter 4.

Design Support Tools

Design support tools do not automate the design process, but act as a stimulus for the human designer, removing tasks from the designer, allowing design investigations to continue. Edmonds [*Edmonds, 1995*] suggested that there was a role for this kind of intelligent design aid or "Human Complimentary Systems". This was demonstrated by computer based design tools that aid the design of advanced racing bicycles [*Candy & Edmonds 1996*]. Edmonds also suggested [*Edmonds, 1995*] that the way the designer works was not sequential and is partially parallel. A designer splits each main task into small sections and moves between each small section as the information from other tasks allow. This and the methods of operation of CAD systems led him to reject the design spiral [*Evans, 1959, Andrews, 1984,* see Chapter 3] as an accurate portrayal of a CAD based design process, a sentiment expressed also by Andrews

[*Andrews, 1998*]. Candy and Edmonds also rejected the idea that conceptual design is currently successfully achieved using a computer[36]. This suggests that more freeform design systems are required to respond to a designer's stimuli, as design issues emerge. The SUBCON submarine design system [*Andrews et. al., 1996*] can be considered to be an example of a freeform human complimentary system. SUBCON's role is to store design information in numerical and graphical forms, while allowing a designer to investigate design implications and decision making without performing the associated design data housekeeping tasks. The SUBCON system does not make design decisions in any form, but aids the designer by preparing results for analytical assessments of the current designs suitability. The freeform nature of the SUBCON system allows the designer to approach a design process from different directions depending on the design requirements.

Artificially Intelligent Systems

> *"Artificial Intelligence is the study of how to make computers do things at which, at the moment, people are better."* [*Rich, 1983*]

There are two ways in which artificially intelligent systems can be implemented within the design process. These are, their use as advanced human complimentary systems, and as design tools in their own right. In the first role intelligent systems provide design data for the designer based on existing design information. Such systems perform Case Based Reasoning[37] and are known as Case Based Design Aids [*Domeshek et. al., 1994*], acting as "online design libraries", collecting experience based design information. The effectiveness of such systems relies on an ability to present that information in a usable form to the designer. Such systems are useful for variant design but less useful for supplying radical solutions to novel problems.

Expert[38] and Knowledge based systems also perform the first role but also combine this with the role of performing design by inference from design "regulations". Such systems rely on the storage and interpretation of stored design knowledge or "rules" to suggest design direction or infer design solutions. Examples of such design systems include [*Cleland et. al., 1994*] for the development of configurations for made to

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36 *"There is a widely held belief that current CAD does not support the whole design process, particularly the early conceptual stages.... In particular the notion of co-operative interaction between computer and human has yet to realise it's full potential."*[*Candy & Edmonds, 1996*]

37 From [*Domeshek et. al., 1994*] *"At its core, Case Based Reasoning claims that the basis of expertise is experience, and that the first line of attack of any new problem is to seek applicable lessons in old situations."*

38 *"An expert system can be defined as an intelligent computer program that utilises knowledge and inference procedures to solve problems"* [*Welsh et. al., 1990*].

order artefacts, the development of container ship designs [*Welsh et. al., 1990*] and QUAESTOR [*van Hees, 1992, 1997*] for naval ship design, as detailed in Section 4.3. Such systems rely on the existence of valid design rules to infer appropriate decisions.

Decision Support Systems

Decision Support Systems implement the role of designer as decision maker to further the development of a design. Such systems often have an underlying mathematical nature, attempting to allow the designer to concentrate on obtaining valid design decisions. Example systems include the "Decision Support Problem" or "Decision Based Design" models of Mistree [*Mistree et. al., 1990*]. [*Koch et. al., 1995*] demonstrated the application of such systems for heat exchanger design while Simpson [*Simpson et. al, 1997, Simpson, 1997*] demonstrated similar systems for design of aircraft and design for mass customisation[39]. Such decision support systems provide methods of classifying the decisions to be made in the design process and allowing different decision making techniques to be implemented. The ability to apply similar methods to all design problems lead to Peplinski and Mistree [*Peplinski & Mistree, 1997*] suggesting the decision based approach as a unified foundation for design tools. The advantages of such tools when applied to naval design are detailed in Chapter 4.

2.7 SALIENT POINTS OF CHAPTER 2

This chapter has presented the complex inter relationships that exist between design processes and design artefacts. Effective design processes must exist in order for the design solution to emerge with the design characteristics required. Thus the study of design methodology is considered important. The discussion has focused on the definition of the designer's task as being the genesis, synthesis and analysis of the design artefact. The designer must possess many skills in order to effectively perform design. These include the creativity required to propose unusual solutions, the need to communicate with the wider design community and an ability to perform effective decision making. The provision of these features in a design process has been considered important and worthy of investigation to improve the methods used.

It has been noted that design has been portrayed as a sequential and iterative process, searching for a solution, viewed as a spiral [*Evans, 1959*]. However it has also been noted the sequential part of this descriptive model may not be considered a valid

39 An approach to performing design for families of related products, such as light aircraft, where many variants on a theme may be developed.

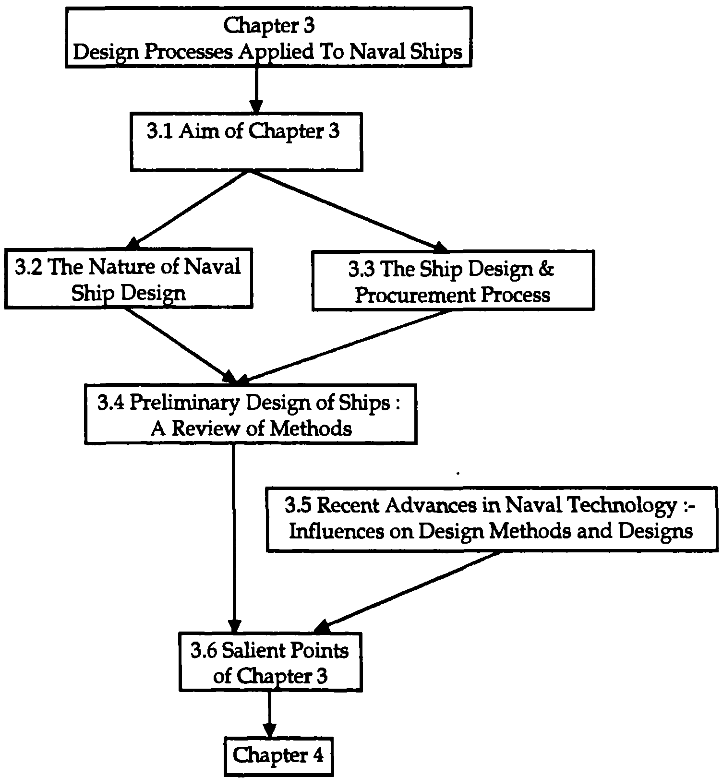
representation of modern CAD based design processes.

The order of the design search has been considered as important in defining which solution emerges from the design process. Definitions of design, leading to a description of a creative process leading from initial ideas as to a requirement, through a valid requirement and initial solution, to a final solution via the stages of conceptual design, embodiment design and detailed design have been developed. While the nature of such stages vary with technology, environment and design complexity, a common theme of the importance of architectural layout or configuration issues has emerged as important, particularly for design artefacts, where the complexity of requirements and solution are such as to render impractical an attempt to detail an optimal solution. The importance of the preliminary design stages in defining the final solution has also been emphasised. The development of computer technology has affected the nature of design. The styles of computer design aids and computer based designers have been presented.

All these issues can be considered as important when applied to the complex activity that is the design of naval ships at the preliminary stage. That topic is the subject of the following chapter.

3. DESIGN PROCESSES APPLIED TO NAVAL SHIPS

Figure 3-1 Chapter 3 Schematic



From Benadetto Brin to Kaiser Wilhelm II:

"The ship which your majesty has designed would be the mightiest, most terrible, and also the loveliest battleship ever seen. It would have a speed which has not yet been attained, its armour would surpass that of anything now afloat, its masts would be the highest in the world, its guns would out-range any others. And the inner appointments are so well arranged that for the whole crew, from the Captain down to the cabin boy, it would be a pleasure to serve in her. This wonderful vessel has only one fault; if she were put into the water she would sink like a lump of lead!"[Reprinted in Bryson, 1984]

3.1 AIM OF CHAPTER 3

Naval design is considered distinct from most other design processes due to the particular impact of the design artefact on the design process. In particular the constraints of the marine environment, a lack of design prototypes and the risk associated with new designs leads to a stylised design procedure. While naval design procedures follow the broad patterns of design discussed in Chapter 2, the implementation is often different. This chapter discusses the nature of naval ship design and the issues which enforce the implementation of different naval design methods. Section 3.2 places naval ship design within warship procurement programmes, detailing the importance of preliminary design methods to the procurement process [Section 3.3]. Current methods of preliminary ship design are detailed [Section 3.4], using a representative design procedure.

Current methods of preliminary ship design are deemed insufficient to perform the holistic synthesis required by modern naval technology. The impact of modern technology on emergent ship designs is detailed in Section 3.5. The chapter is summarised in Section 3.6. Although this chapter focuses on the application to naval ship designs deals, much of the discussion is relevant to marine design processes in general.

3.2 The Nature of Naval Ship Design

"Ship Design is Engineering's Greatest Compromise" [Purvis, 1974]

Types and Features of Naval Ships

The design methodology developed within this thesis is not specific to any particular naval design style or hull type. This section details the forms of ship design currently under consideration for future naval requirements, to express the importance of considering more than one solution to a design problem.

The most common form of ship design is the monohull, a single hull displacement bourne form. Monohulls of all sizes are in use in navies from small glass reinforced plastic minesweepers [*Harris, 1980*] through escort designs [*Purvis, 1974, Thomas & Easton, 1993*] to large Aircraft Carriers [*St Denis, 1966, Honnor & Andrews, 1980*]. New design programmes for such ships often still consider the monohull as the only design type considered [as in *Eddison & Groom, 1997, Downs & Ellis, 1997*], or the most likely design replacement [as in *Betts, 1996*]. Examples of different types of monohull design features include the use of stern docks [*Downs & Ellis, 1997*], flare [*Burcher, 1980, Thomas & Easton, 1993*] and stealth designs [*Gilligan, 1996, Bergman et. al., 1995*]. Design methods must recognise this variety of design type and style. Other less conventional design types may have advantages for specific design requirements and must be considered alongside monohull designs to allow those advantages to emerge. Such designs can either be considered as Unconventional, when buoyancy is the source of lift, but the distribution of buoyancy is altered, or advanced naval vehicles, when other forms of lift are introduced, such as Hydrofoils.

The most researched form of unconventional hullform is the SWATH[40] [*Betts et. al., 1987*]. SWATH has found uses in applications where there is an enhanced requirement for its seakeeping performance, which is comparable to monohulls of much greater size [*Andrews, 1994b*, comparing designs produced by *Kennel et. al., 1985*]. The SWATH configuration has not been widely adopted due its extreme sensitivity to weight changes, larger size for a given payload and increased resistance at higher speeds [*Foxwell, 1998*]. The Trimaran[41] concept is considered to maintain a seakeeping performance advantage over the monohull, but in addition[42] the long length decreases high speed resistance [*Zhang, 1997*], while providing a large area of useful space [*Andrews & Bayliss, 1997*].

Both of the above forms will, given current development plans, have demonstrated their perceived advantages by the early part of the 21st century[43]. Therefore they must figure strongly within design study programmes for subsequent ship procurement. Other forms of hull design exist which are less understood and more uncertain in benefits[44]. However given that Trimaran research only began in earnest in 1989 [in *Bastisch & Peters, 1989*], such design types should be studied. An example is the HYSWAS[45] [*Meyer, 1989*] with its single cylindrical submerged hull and dynamic lift.

3.2.1 The Marine Design Environment

Section 3.2's initial quotation forms a sanitised version of the oft used *"ships are different"* statement [*Brown, 1995b*]. This section expands these statements and introduces current design and procurement methods that apply the issues of Chapter 2 to the marine environment.

That ships "sail" in the marine environment is the first feature that makes them

40 SWATH : A Small Waterplane Area Twin Hull design. A SWATH form has two essentially cylindrical hulls located below the waterline. Two thin vertical struts join the two hulls to a large rectangular cross structure in which the majority of ships compartments are located.

41 A Trimaran is a three hulled vessel. This thesis generally considers the Trimaran variant whereby two small outriggers or side hulls are attached to a main hull by a structure.

42 The Trimaran concept was introduced by [*Pattison & Zhang, 1994*] and is under development by academic [*Zhang, 1997, Andrews & Zhang, 1996, Chan et. al., 1997*] and naval authorities [*Eddison & Summers, 1995, Betts, 1996*]. The Trimaran uses the inertia provided by two small transversely separated side hulls to allow the large central hull to be reduced in beam and increased in length in comparison with monohull designs.

43 Broadbent & Short [*Broadbent & Short, 1997*] detail the likely trials programme for a Trimaran Demonstrator and its role in the wider Trimaran development programme.

44 The focus of unconventional design research changes with time. Currently Trimaran has the opportunity to demonstrate its advantages. In recent history the Hydrofoil and Air Cushion vehicles have similarly held procurement authority's attention, but failed to capitalise on their strengths and demonstrate a worthwhile advantage. Such designs must not be forgotten, and the lessons of their failures remembered within design methods.

45 HYSWAS: A Hydroplane Small Waterplane Area Single Hull design.

"different" from other design artefacts. The ship operates at the interface between two mediums, air and water and must satisfy the requirements of both. The marine environment is highly corrosive, requiring "heavy" engineering, influencing design style. The ship design must float, hence the displacement and weight of the vessel must balance in all conditions throughout a long design life in which the ship's material state will change greatly[46]. The ship is affected by gravity waves, which affect its ability to float, structural loading, the motion of the vessel in six degrees of freedom and the speed at which the ship moves[47]. Analytical difficulties in estimating the performance of ship designs, caused by the nature of the sea has led to ship design being a conservative profession in which safe but imprecise standards are evolved based on simplifying assumptions and limited practical data [*e.g. Sarchin & Goldberg, 1962, Chalmers, 1993*]. The designer often attempts to guarantee the "satisficing" of minimum requirements rather than predicting exact performance levels. As analytical capabilities improve the simplifications of previous methods are removed[48]. However even modern methods contain gross simplifications, for example the slamming correction of Clarke [*Clarke, 1986*]. Other conservative features of naval design result in the use of design and contingency margins[49], converting uncertainty into a general conservative approach to design. To a certain extent a commercial marine design also incorporates such features, but the emphasis on cost and economic returns as the prime design consideration, the larger number of designs produced, the reduced system complexity and the rule based nature of design to classification standards such as Lloyds [*Lloyds, 1998*] allows the features of a design to be more certain prior to construction.

Most design programmes include a test stage in which a design prototype is tested thoroughly, sometimes to destruction. This allows more adventurous design

46 NES 109 [*NES 109, 1990*] recognises that a warship's displacement may grow by 5% over 10 years, while the vertical centre of gravity may climb by 3% in the same period purely due to non attributable growth.

47 This leads to four of the "S"s of Andrews and Browns "S^5" concept Stability, Strength, Seakeeping and Speed [*Brown & Andrews, 1980*]. The four S's above, along with "Style", show the major topics of study of the naval architect, related to the demands of the ship. Stability is the term given to the broad topic of ships hydrostatic and hydrodynamic performance, regarding capsize, flooding and safety. Seakeeping is the study of the motion of ships in rough weather, particularly for effects on crew comfort and operational effectiveness. Speed and Strength are self explanatory.

48 For example, in 1866 Rankine [*Rankine, 1866*] presented a simple bending moment calculation based on displacement and length. Current, more complex, methods [*Chalmers, 1989*] use the probability of bending moment exceedance during a ship's design life.

49 [*Andrews, 1984*] considers three types of design margins, usually employed as weight and/or VCG allowances. Board margin being that required for unforeseen upgrades to capability, Growth margin being that for uncontrolled changes to the ships condition such as additional layers of paint. Design margin is used to consider the uncertainties inherent in the design.

features to be employed with the knowledge that if unsuccessful they can be replaced[50]. This allows the incremental approval of a complete design. Such a prototype system is only feasible when the cost of prototypes can be absorbed amongst the production of many identical design examples[51]. Large marine designs are not subject to large scale production orders and are considered as being "made to order" [*Cleland et. al., 1994*]. This has several affects on the design of ships, particularly naval ships. First the cost and risk of a prototype ship, relative to the total programme cost is too great to justify. Similarly the time required to build the prototype, test it and implement design changes to the production model is too great. Hence ship classes do not generally have dedicated prototypes. This suggests that the first of class acts as the prototype, but without the ability to fail, that is always acceptable, if undesirable, in a dedicated prototype. This suggests that all design uncertainties must be solved prior to construction or rendered irrelevant by conservative design estimates. As a result the ability to propose and implement creative, radical ideas can be more difficult.

A modern naval ship is one of the most complex made to order design artefacts. It combines all issues associated with a floating engineering structure, the power generation requirements of a small power station, a complex integrated weapons system and a medium sized hotel. Each issue has complex and explicit demands. The integration of all four individual issues together within a cost and resource restricted ownership environment is much more difficult than the satisfaction of any one of the four issues. Full satisfaction of one requirement often leads to a reduction in capability for the other issues. The complexity of the naval ship, alongside the need for risk reduction in place of a prototype, the long service life and great financial commitment, has led to long, complex procurement programmes. Bryson [*Bryson, 1984*] suggests that the current procurement cycle can last 12 years from concept studies to operational capability. Within the cycle many different organisations[52] are required to specify requirements, scrutinise proposals and certify the design's suitability from a specific viewpoint. Therefore naval ship design is highly interactive. Every element of the design has effects on several other elements. This was shown by [*Brown, 1995a*] with his

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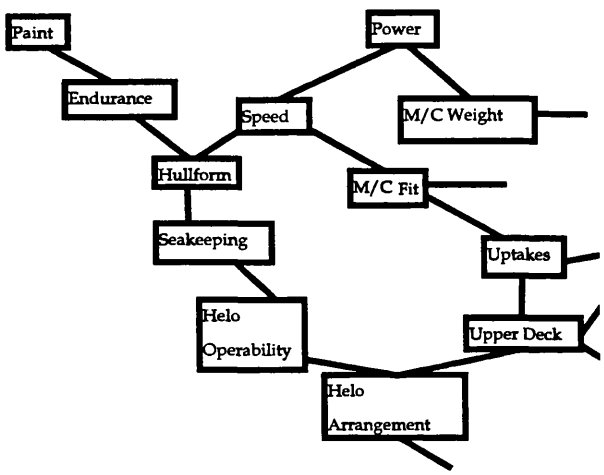
50 An example is the Eurofighter prototype program. The first prototype incorporates the aerodynamic structure of the new design with propulsion technology from older aircraft. The second prototype [DA2] adds specifically developed turbojet propulsion and combat systems [*Preview, 1998*].

51 For Eurofighter, several prototypes were built, while the total production run could exceed 629 aircraft [*The Times, 09/10/1997*]. Leopold [*Leopold, 1994*] argues that a similar approach should be possible for the United States Navy, albeit on a different scale.

52 Bryson states 25 in his figure 1, while Andrews [*Andrews, 1992*] suggests that 100 authorities are directly involved in the LPD(R) programme .

interaction mesh [Figure 3-2]. It is impractical to consider change in ships features and performance levels without noting the effect on other design issues. An example is the relationship between stability and speed[53].

Figure 3-2 The Interaction Mesh [Brown, 1995a]



As a result of the impact of each interaction on the overall design the process of developing a ship is iterative in nature. Each decision is confirmed or refuted at several points as design definition increases. The most common visualisation of this is the design spiral originally presented by Evans [*Evans, 1959*] for merchant ship design and modified by several authors including Andrews [*Andrews, 1984,* Figure 3-3 here]. Models of the ship design process are detailed further in Section 3.3.1.

Such models recognise the iterative nature of ship design but focus on the act of ship design as achieving a balance of weight and space. The historical importance of weight in the ship design is related to the dangers of unrestricted weight growth [and also centre of gravity rise] on the hydrostatic characteristics of a design. It is also due to the major design issues of ships produced by the first "educated"[54] naval architects. The impact of weight on these issues is important, affecting the safety of the vessel in ways which at the time could not be adequately expressed mathematically. The importance of weight still remains, partially for technical reasons and partially as a method of assessing the likely procurement costs but has been supplemented by a multitude of design issues as design requirements have altered.

The emphasis on weight and space leads to modern ship design methods in which the first stage is to assess the displacement and space provided by the ship design. The designer then assesses combinations of style and form that can be proposed at that displacement and volume.

53 This is a classic debate in which a long ship length, which generally improves maximum speed, is compromised by the need to provide beam. Beam is required to maintain adequate stability. Neither dimension is generally optimised due to adverse effects on the other. The impact of beam and length on a design was demonstrated in [*HMSO, 1988*].

54 Rydill [*Rydill, 1968*] suggests that the first scientific text of Naval Architecture, "*Traite du Naivre*" by Bouguer in 1746, concentrated on the flotation and hydrostatic stability of ships.

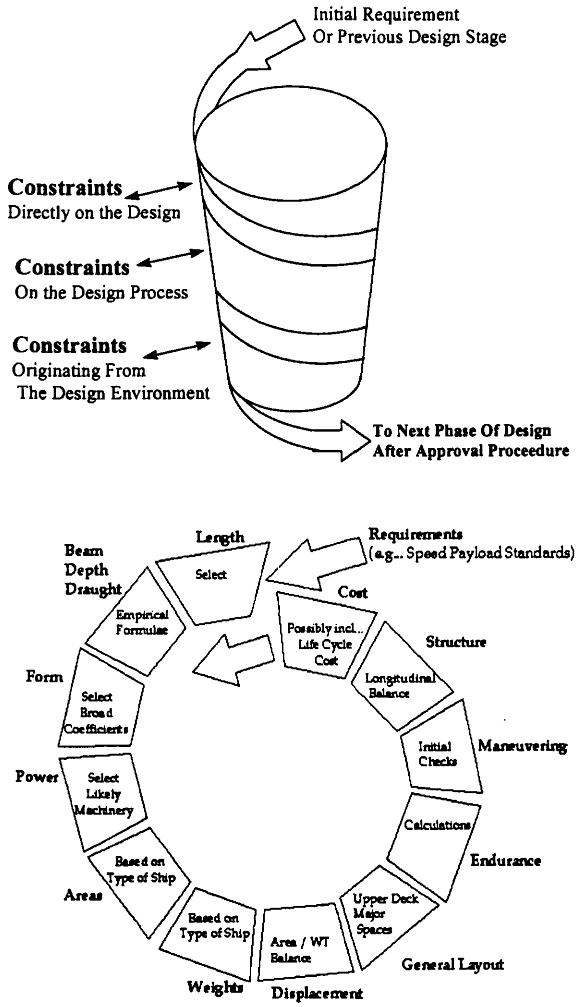


Figure 3-3 An Interpretation of the Ship Design Spiral [Andrews, 1984]

Such views of the ship design process can lead to the idea that the design of a complete naval design is essentially the definition of the hullform, an idea which may have had some credence in past times. In modern design exercises the achieving of a synergetic relationship between Float, Move, Fight and Infrastructures elements of the ship design is all important, in order to match the capabilities of the design to those demanded by the wider fleet. In subsequent sections the idea of naval ship design as hullform design will be replaced by the consideration of the design process as the fundamental link between the combat system engineer, the mechanical engineer and the naval ship designer.

3.2.2 Participants And Organisations In The Ship Design Process

The naval ship design task can be considered in relation to the customers (the operators[55]) and engineers (the design authority) for the specific aspects of the design. From the 25 interested parties of Bryson [*Bryson, 1984*] four major design participants can be detailed:-

- Operators.
- Naval Architects.
- Marine Engineers.
- Combat System Engineers.

The operators as a corporate body are the future "customers" for the design. Hence operators specify the role and requirements of the ship. As a result operators should be interested in all aspects of the ship design, particularly the relationship between the new ship design and the existing fleet with respect to standards, training and personnel issues, operational effectiveness and ship life. Naval Architects often are

55 The operators are represented in the design process by the operational requirements staff.

responsible for the ship as a whole and are often warship project managers [*Andrews, 1993*], as such they perform system engineering[56] tasks, ensuring that major items of equipment and the whole ship concept are delivered on time, within budget, with the specified performance. Similarly in commercial ship design the project manager is often a naval architect [*Warren, 1997*]. As such the naval architect is concerned mainly with the "S⁵" elements [*Brown & Andrews, 1980, see Footnote 47*] but has an interest in all aspects of the other three design participants responsibilities as design co-ordinator, due to the interactions between the ship and all other technical and operational issues.

Marine Engineers are responsible for the definition and provision of the Move[57] element of the ship design, particularly the development of propulsion systems and their integration into the ship design. Combat System Engineers define and procure all aspects of the weapon and sensor systems. From the above discussion, it is noted that the naval architect must be aware of all design issues, and communicate with all design participants. The primary method of achieving this throughout the ships procurement process is through the maintenance of the General Arrangement drawing and the weight and space estimates which represent the ship design during the design process.

Preliminary naval ship design is performed by different organisations in order to support specific elements of research, specific operational requirements or within the ship procurement programme. Preliminary design is undertaken by agencies such as technical and operational research establishments to apply specific design or operational ideas to a whole ship design for assessment of impact. Examples are experimental Trimaran hullform designs [*Andrews & Hall, 1995*] backed by example ship design studies [*Zhang, 1997*]. More detailed and holistic ship design investigations are performed in support of the procurement of specific ships. This is undertaken by three types of design team. The first design team is that belonging to the future owner of the ship, normally for naval ships a government design team. For British naval ships the design team historically belonged to the Defence Procurement Agency of the Ministry of Defence, or a direct ancestor [*Brown, 1983*]. Design teams are also provided by design consultants and by the shipyards. Design consultants provide contract naval architecture ship design expertise, and apply this expertise to specific conceptual

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56 Systems Engineering: A top-down integration of combat/weapon systems and [Hull and Machinery] systems into a total warship system. [*Tibbitts & Keane, 1995*]. "*a branch of engineering using esp. information theory, computer science, and facts from systems-analysis studies to design integrated operational systems for specific complexes*" [*Compton's, 1998*].

57 [*Brown & Andrews, 1980*] divided the contents of the naval ship into Float, Move and Fight to detail the importance of Fight issues on unit cost.

designs. Shipyard design teams may also perform a similar function but are more likely act as the initial point in the development of the detailed ship designs to be constructed within that shipyard. All the above design teams should use preliminary ship design methods to justify the result, whether that is a new operational role, new hullform shape or a new ship design.

3.3 THE SHIP DESIGN AND PROCUREMENT PROCESS

3.3.1 Models of Ship Design

The approach to design used by a design team can affect the emerging design from the entire process [*Simon, 1981*]. Discussed within this section are common descriptions of both ship design and procurement cycles. The design spiral is the most widely documented design model for ships, and other marine artefacts. Evans [*Evans, 1959*] presented the design spiral as a structural design model for merchant ships in which the progression from General Arrangement to form coefficients is detailed as an inward facing spiral. Snaith and Parker [*Snaith & Parker, 1972*] suggested an outward facing spiral suggesting a broadening of design issues and definition as well as the movement towards one solution. A further modification of the design spiral representation is the addition of design constraints as the third dimension by [*Andrews, 1984*]. This suggests that design is constrained by the design requirements, design process and design environments [See Figure 3-3].

Another interpretation of the ship design process was presented by Eames and Drummond [*Eames & Drummond, 1977*], with an inward facing design spiral starting from a basis ship. This is evolutionary or type ship design, similar to the variant design of [*Pahl & Beitz, 1984*]. This was presented to allow the demonstration of the Concept Exploration Model view of ship design, [detailed in Section 4.3.1]. Lamb [*Lamb, 1969*] and Watson and Gilfillan [*Watson & Gilfillan, 1977*] also present sequential models of the ship design process.

Much of the design spiral's popularity is based on ease of understanding and its use in design education, rather than specific features or design order. Particularly useful is the interaction between successive elements demonstrating the difficulties caused by the interactive nature of ship design. The influence of ship design models on ship design processes can be witnessed by initial sizing processes [Section 3.4] that sequentially and iteratively refine the ship design description towards a final solution.

Not all models of ship design are sequential, as detailed by [*Tan & Bligh, 1998*] who attempted to identify a concurrent computer aided approach to the identification of an "optimum" design. The chief benefit of this approach was that "the capability of the designer to design better products within a shorter period of time would be enhanced". However the definition of design time used by Tan and Bligh does not recognise those delays inherent in a complex ship preliminary design project that are not caused by computational capabilities, but are introduced by politics, commercial issues and other technical issues not directly related to the act of preliminary design. In the author's experience these delays are more significant to the preliminary design process than the "velocity" of computer aided preliminary design iterations.

3.3.2 Ship Procurement Processes

The design of a naval ship is one element of a vast procurement process. All elements of the process are important if the class of ship is to be provided on time, in sufficient numbers, with required capabilities, to meet requirements. This section considers ship design, particularly naval preliminary ship design in the context of the whole procurement cycle[58]. The example used relates to recent United Kingdom procurement strategy, although other practices are considered. Procurement strategies continually change and each procurement project implements the strategies in a slightly different form due to specific needs of the project and the particular state of industrial, fiscal and political situations.

A short discussion of procurement processes is necessary to detail the effects that changing the preliminary ship design process has on the entire procurement cycle. Most naval ship procurement programmes are initiated for one or more of the following reasons:-

- Replacement of an ageing ship class.
- A requirement to introduce a new combat system at sea to meet a new threat.
- Fulfilment of a newly conceived operational requirement or meeting a perceived threat.

This is not to suggest that the requirement for the warship is always known or understood [*Andrews, 1993*]. It is likely that a new design is postulated due to the end of a previous construction program. Initial requirements are dictated by both fleet, production, political and commercial pressures. A common initiation is a need to replace an old ship design while introducing the latest technology available for that

[58] A more comprehensive discussion of the design environment applicable to the British warship naval architect in the mid eighties was presented by [*Andrews, 1984*], which was used to develop the third dimension in Figure 3-3.

role. The stages of the ship procurement program are therefore often integrated with the development of new equipment[59].

Before the formal initiation of a new procurement programme, discussions as to the need for ships to be replaced, initial ideas of new threats and available systems are undertaken. The complete British naval ship procurement cycle of the 1980s and early 1990s has been detailed by [*Bryson, 1984, Pattison, 1989, Andrews, 1993*]. To coincide with these procurement phases several phases of the warship design process can be described, each with differing goals [*Pattison, 1989*] as shown in Table 3-1.

This thesis focuses on the use of design methods within Pattison's concept

Main Phase	Sub Phase	Aim
Research Phase	Engineering Research	To investigate new technologies
	Operational Research	To discover the design requirements
Concept Phase	Concept Exploration Concept Studies	To investigate types of ships to meet a requirement Focused design explorations of the possible and probable.
	Concept Design	Production of a Baseline concept design to allow preparation of a Staff Target
Feasibility		To increase the confidence and detail, while reducing the risk of the design
Detailed Design		To design the ship artefacts for production
Design Support		To support the operations of the warship while operational

Table 3-1 Warship Design Phases [Pattison, 1989]

studies, concept design and feasibility stages. Prior to the official start of a procurement programme is the commencement of a concept studies phase in which *"wide ranging concept studies are closely linked to the weapons proposals, major ship systems ... and initial thoughts on operational concepts."* [*Andrews, 1993*]. Not only do concept studies produce examples of possible design types and capabilities, the direction of research and development and operational requirements can be justified or altered from the results of design studies. As a result of the need to perform wide ranging studies, this stage of design is the most

59 This sometimes suggests that the ship procurement program is delayed to allow technology to mature, in other cases the time scale removes the ability to implement specific technology. This may result in modification of the design for later ships of the same class [*Bryson, 1984*]. Bryson linked a description of naval ship procurement to the major weapon system procurement cycle, demonstrating the importance of synchronising the design of the weapons system and the ship.

likely to investigate radical concepts, performing divergent design. It is here that the provision of wide ranging design tools and methods is important. If radical solutions to design problems are not considered at this early stage it is unlikely that they will emerge later in the procurement process and an opportunity is missed.

The influences on the technical description produced in the concept design were illustrated by [*Brown, 1986*]:-

- Role Definition.
- Identification
    - of constraints,
    - of risk area,
    - of characteristics,
    - of weapon system impact.
- Technical definition.
- Historical Experience.
- Standards.

Concept design focuses on the development of a Staff Target, a statement of the operational needs, linking cost, operational effectiveness and technical feasibility [*Andrews, 1994a*]. Concept design focuses on a few possible solutions. Brown [*Brown, 1986*] suggests that the philosophical styles of the early design stages are thus:-

- Concept Studies — Divergent
- Concept Design — Convergent

The results of technical and operational research programs add to the discussion, resulting in a compromise between technical aspects, cost and operational effectiveness [*Andrews, 1994a*]. From an increasing definition of requirements, potentially viable solutions emerge. A formal proposal advances specific design(s) to progress further to the feasibility stage.

The feasibility stage commences after endorsement of a Staff Target and leads to the preparation of the Staff Requirement. Its intention is to progress one [occasionally more] design concepts in definition, procurement issues[60], production issues, commercial issues and risk implications to the stage at which full design definition by a ship yard can occur. At the early stages, feasibility is a more focused and detailed conceptual design stage. Towards the end production and commercial issues are more dominant.

Traditionally the end of feasibility was the demarcation of customer and contractor involvement in the naval ship design process. Prior to feasibility the majority of design work was undertaken by customer based design teams. After feasibility the customer became an "intelligent customer", advising contractors with respect to

60 For example risk.

producing a design in line with contract requirements. Increasingly feasibility design contracts are performed on a competitive basis with several parallel studies being undertaken by different shipyards [as in *HMSO, 1993*].

The subsequent three stages act as the "procurement specification" [*Andrews, 1993*] in that one design is progressed in definition, while construction and commercial issues are developed to allow contractors to tender for construction contracts. A first of class construction contract is then placed. This includes all aspects of the detailed design of the ship to allow construction to commence, the construction task and even through life support issues [*Jackson, 1997*]. Design issues move from whole ship development to detailed design of systems, although concurrent engineering attempts to change this division of design types [see Section 3.5].

The procurement cycle described above is based on [*Andrews, 1993*] and details then current British procurement practices. Procurement cycles reflect the era and style of government that implements them[61], as demonstrated by American experiences [*Tibbitts et. al., 1988, 1993*]. Until recently modern cycles reflected the desire for a free market economy, with minimal government involvement. Here the customer acts as an "intelligent customer" sub contracting all aspects of design development[62]. Recent British developments attempt to utilise public-private partnerships with integrated project teams, combining both customer and (multiple) contractor employees working as one team. This and the progression to a concurrent engineering [*Tibbitts & Keane, 1995*] based approach to design is currently modifying procurement cycles and processes [as *Andrews, 1998*]. Andrews stated the intentions of concurrent engineering, summarised here as being:-

- A Continuing Interactive Dialogue with the customer.
- Integration of all interested parties as one team.
- Concurrency of Design, Manufacture and Support Processes.
- Universal use of Computers in all those processes, especially graphical representations.

Pan-European procurement cycles may reflect the current political desire for defence integration[63], by joint procurement programs which compromise features of each individual nation's procurement cycle in a search for commonality. Recent

61 Historic cycles reflected the ability of in house design teams to manage and perform design at all stages of the program. This is a system still employed by the French Director of Naval Construction [*Andrews, 1992*].

62 An example of this was followed by the "Collins" submarine project. Australian requirements and Swedish design expertise were forged into the Australian Submarine Corporation specifically for the development of one submarine class under government contract.

63 Defence integration is currently being further proposed by the introduction of a joint European procurement agency, OCCAR. [*Lidgett, 1998*]

examples are presented by [Common New Generation Frigate, *van Griethuysen & Juliot, 1996*, LCF 90, *Galle & Smit, 1996*]. The most ambitious example was the, now defunct, the eight nation NFR90 project [*Schaffer & Kloehn, 1991*]. Regardless of specific details the relationship between preliminary design stages and whole ship procurement remains similar and a need for effective preliminary design remains.

The Impact of Preliminary Design Stages

The previous discussion detailed preliminary ship design within the whole ship procurement cycle. One issue that might render the preliminary design stage less important is the emergence of designs from contractors that do not directly bare the parentage of the customer's preliminary designs. It might be argued that if competing contractors prepare designs without recourse to original concepts, why perform preliminary stage design at all? Time could be saved by continuing directly from requirement to a design and build contract.

This viewpoint is not considered feasible for the following reasons. Firstly preliminary stages exist to determine the form of the likely solution to a problem that is not precisely stated, and is itself under investigation. To refine the problem to a level of definition that is acceptable for contractual requirements it is necessary to judge what is achievable within financial and technical limitations. Andrews [*Andrews, 1990*] noted *"The essence of concept design is divergence and innovation in trying to ascertain what is the customers real requirement and how that can be tuned to what is technically realistic and affordable"*. As stated by Baker [*Baker, 1955*]:-

"So the chicken comes before the egg and the ship comes before the staff requirement"

"There are far more bad staff requirements than bad warship designs" [Preston, 1979]

Namely staff requirements would be infinitely complex and unachievable unless anchored to a method of achievement. Requirements are rarely expressed in total by an explicit and coherent statement. This is characterised by the problem description of Rittell and Weber [*Rittell & Weber, 1973*] as a *"Wicked Problem"*, in that the determination of the requirements is the major objective of preliminary design. The manner in which an individual designer selects, creates or produces his initial ideas of the overall design is fundamental to the end design. Particularly important is the identification of risk introduced by equipment under development, and sensitivity to design issues and requirements[64].

64 An example is the "cost" of an extra knot of maximum speed in ship size, engine requirements and other design features which increase program cost.

If a customer is to act "intelligent" he must be able to determine his own solution to the requirement in order to rule out proposals which are not suitable. Otherwise technical issues can cause programme schedules to be delayed, as debate occurs, as in the "short fat ship affair" [*HMSO, 1988*]. This requires a preliminary ship design description that is representative of a valid solution.

Even during detailed design stages, a contractor may still initiate a rapid preliminary design phase prior to detailed design, if the design to be produced differs notably from any that has been previously investigated. While specified from a very highly defined requirement, the initial stages of such a project rely heavily on conceptual methods allowing detailed design to be undertaken.

Throughout the ship procurement cycle design errors are inevitable. However the "cost" of error correction is not uniform with time. A comparison of cost with design stage [*Andrews, 1993*] shows the benefits of redressing errors and finalising requirements at the preliminary design stages. This is partially due to the ideas of cost implication and cost incurred. Costs incurred are those *which have actually been spent*. Preliminary design incurs few costs. Costs implied are those which given the current design *are programmed* to be incurred at a later date. Preliminary design stages imply the vast majority of the total warship cost. The likely cost, based on the concept ship design, is used for the assessment. Once costs have been implied it becomes expensive to change the design, particularly for systems with long development or research programs. [*Keane & Tibbetts, 1996*] suggested that the cost of change to a naval ship design during detailed design was 100 times the cost of the same change made during feasibility studies. This idea can be extended to the risk of project termination. An aim of the warship project manager is to keep the project alive[65] [*Andrews, 1993*]. This suggests that the preliminary design should be similar to the final design and hence designed using a methodology that allows the important issues of the final design to emerge quickly. If a project is reduced in resources the use of preliminary design methods is required to detail how far the requirements must be reduced to meet the reduced resources.

The role of preliminary design in assessing what can reasonably be achieved within budget is also important due to a need to consider radical and novel

[65] If procurement authorities base a long term financial commitment on the concept stage design features, the survival of the project becomes dependant on the final design (and its cost) resembling that of the concept design. Alternatively the success of the design in meeting its operational requirements may be hindered by artificially holding the price of the design to a pre-determined level.

configurations and ideas. Preliminary design investigations are required to detail whether such ideas are suitable for further research or development. Ship procurement never remains constant across time and changes to procurement methods for future ship designs are detailed in Section 3.5.

3.4 PRELIMINARY DESIGN OF NAVAL SHIPS : A REVIEW OF METHODS

> *"The Chief Constructor would go into the Assistant Constructor's room and request him to make a rough drawing, indicating the disposition of armour and the arrangement of guns and other things, and to make what we call preliminary calculations as to the weights of all the principal features and to consider the disposition of weights longitudinally to see that the vessel would float properly. The Assistant Constructor would also make an outline calculation of stability to see that the vessel would have sufficient stability to float properly."* [*Whiting, 1901 , recorded in Brown, 1983*]

Having defined why preliminary ship design is of importance it is necessary to consider the methods currently used to develop designs at this stage. To provide a preliminary naval ship design to meet operational requirements several alternate forms of design can be considered. Andrews [*Andrews, 1984*] suggested several approaches to naval design [Table 3-2].

The ship design methods, described in this thesis, predominately use the approaches of simple synthesis, broader synthesis and radical configuration. The use of type ship, evolutionary and historical design methods is considered largely redundant in modern procurement environments. This is due to the gap of up to thirty years

Design Approaches	Description[66]
Type Ship Design	Modification of a basis design, maintaining most of the original features to a new design requirement.
Evolutionary	Substantial modification of a basis design to a new requirement.
Historical	Assessment of holistic features by regression from historical data [*Miller, 1965*].
Simple Synthesis	Approximate initial sizing of weight and space followed by iteration to a balanced design.
Broader Synthesis	Synthesis considering wider design issues due to requirements exceeding design knowledge. In particular the introduction of configuration as an issue during synthesis.
Radical Configuration	Application of synthesis methods to new arrangements.
Radical Technology	Design following technical research and prototype development in untested technologies.

Table 3-2 Andrews' Design Approaches

66 This authors.

between the introduction of successive classes for the same role. Such infrequently performed design procedures, cannot be documented properly over time, and are inappropriate given large changes to operational and technological environments between designs. Radical technology is not considered in this thesis due to a reliance on the idea of the prototype and research driven design that require different design processes dependant on technology.

A Numerical Synthesis Method

The majority of current ship naval design methods are based on the use of numerical design procedures in a sequential investigation, using Andrews' simple synthesis approach. A typical procedure[67] is presented here. The design procedure consists of five stages:-

- Design Initiation
- Initial Sizing
- Parametric Survey
- General Arrangement Preparation
- Performance Analysis

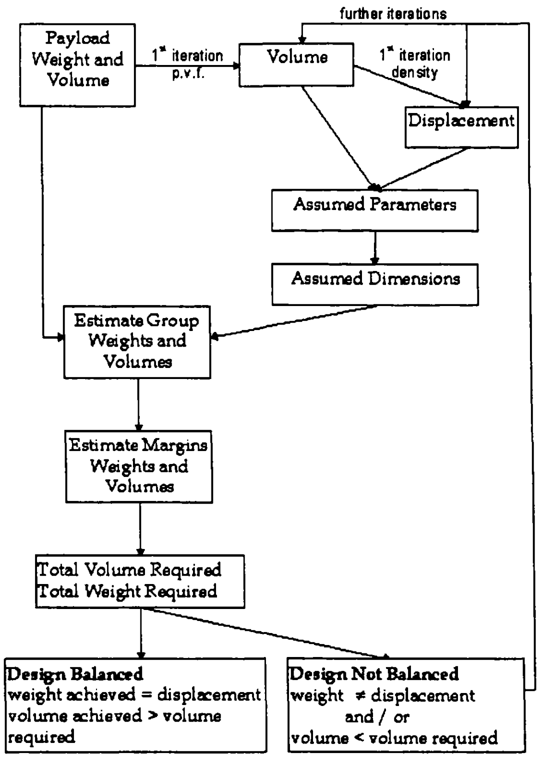


Figure 3-4 UCL Initial Sizing Procedure [B.Eng. 1994]

Similar procedures exist for Monohull, SWATH and Trimaran design types. A monohull procedure is detailed here. SWATH and Trimaran procedures differ primarily by the initial assumption of hullform and volume parameters assuming the relative size of the different portions of the design prior to a more detailed assessment.

Each stage of the procedure is undertaken sequentially. Design initiation starts the design procedure, specifying an initial assessment of the requirements based on the role that the concept is to meet, detailing known features of the ship design, in particular "payload" systems.

The initial sizing stage introduces the ship design by detailing demands for weight and space within the ship, allowing the designer to propose a hullform that meets those gross requirements. This process is iterative and is shown in Figure 3-4.

The sizing process is entered using historical data regarding the relationship between ship size and payload size, a payload volume factor. This allows an initial estimate of ship size to be assessed and using historical ship densities[68], a crude initial displacement detailed. "Weight groups" divide the contents of the ship into different weight types[69]. The weight and space requirements of each sub weight group are directly specified by the designer or calculated using regression algorithms. Such algorithms chart the change in demand of a design requirement with increasing ship size. Gross internal volume is commonly used as a size related scaling factor. Weight groups such as "Structural weight" are more accurately defined by relation to specific dimensions [as in *Chalmers, 1989*]. To facilitate this, a default hullform for the ship is defined using non dimensional characteristics, allowing dimensions to scale with overall size [*UCL, 1994a*]. An example is the use of a length displacement[70] ratio of seven to eight for standard escort designs. With a weight and space estimate prepared for all weight groups, it is possible to postulate the size of ship that provides sufficient buoyancy for the ship to float given weight demands and sufficient internal volume for all spatial demands. The new estimates are compared with initial estimates and the surplus or deficiency of supplied volume and displacement addressed.

This is the design balance and generally is not achieved using initial design estimates. This was graphically expressed by [*Andrews, 1984*]. Revised weight and space requirements iteratively refine estimates for displacement and space until the design balances. This is, normally, a process during which the design grows as weight and space demands are driven upwards, and systems increase in weight and space to meet requirements. This has obvious cost implications. It is at this stage that the complexity and interactive nature of naval ship design is most apparent, with multiple system changes being made by the designer to maintain design performance.

Although a preliminary ship design is output from the balanced initial sizing process, the majority of features of this hull are not defined as the designer has made

68 It is noted that the use of specific values of ships density and payload volume fraction are not important. These values are used to quickly move the design towards a final solution, which should be achieved regardless of starting point.

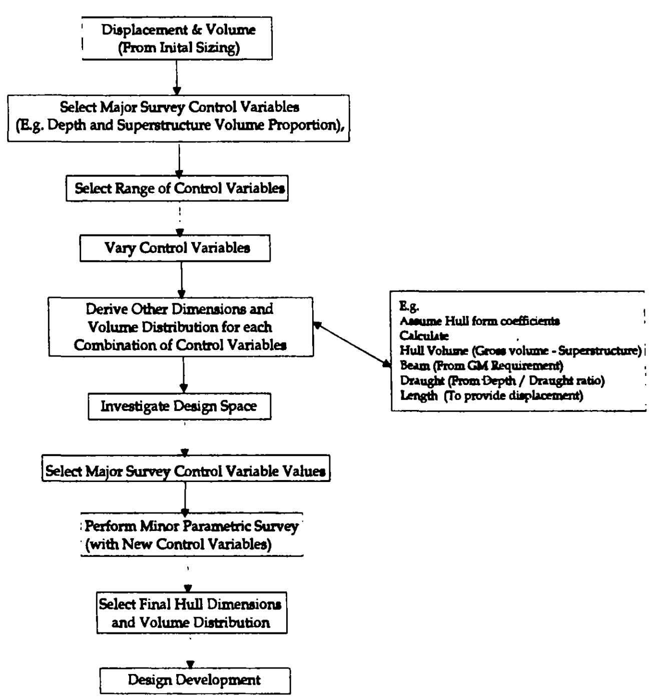
69 A discussion of weight and space groups was presented in [*Andrews, 1984, Andrews, 1992*]. The UCL weight group system is detailed as: *Group 1 Hull, Group 2 Complement, Group 3 Ships Services, Group 4 Propulsion, Group 5 Electrical, Group 6 Payload, Group 7 Variable.*

70 More correctly length to displacement$^{1/3}$ ratio, a measure of fineness in comparison to a cube of the same displacement.

several gross assumptions in defining the form of the design. In initial sizing the designer only finalises ship displacement, enclosed volume and individual weight group demands. The gross assumptions are re-assessed in a parametric survey. The parametric survey has appeared in several forms [for example *van Greithuysen, 1994, Bayliss et. al., 1998a*]. The survey provides a systematic search through a design solution space populated by hulls of equal displacement and volume. The survey finalises hull dimensions and form. The survey usually considers that a hull is *"made of rubber"* [*Brown, 1981*] and can be stretched (or compressed) to a degree, with changes resulting in other dimensions. Thus long thin hulls can be investigated alongside shorter fatter hulls for relative suitability.

This allows a designer to investigate conflicting problems of providing suitable seakeeping, stability and powering performance. In the survey postulated in [*UCL, 1994a*] a two stage [major and minor] survey is presented in which the impact of depth and superstructure proportion are assessed in the major survey, while detailed hull shape characteristics are considered in the minor survey. Each survey creates a range of designs, each providing the same stability [based on Metacentric height[71]] but with differing dimensions. The designer chooses a single satisficing design for further

Figure 3-5 UCL Parametric Survey Procedure



71 Metacentric height is often used as the stability measure at early design stages due to its ease of calculation. However such an assessment only provides a measure of initial stability, ignoring large angle stability which has been shown by [*Thompson et. al., 1998*] to be important.

development. A typical procedure is shown in Figure 3-5.

Following the parametric survey, the design is progressed by the use of a general arrangement drawing. Compartments and spaces are added to the hullform diagram changing the mathematical description to a fully configured definition. The location of all weights, spaces and structural elements are detailed and overall centres of gravity assessed. The introduction of system weight location allows the calculation of vertical centre of gravity and hence a stability analysis (for example intact GZ curve acceptability) for this aspect of the design.

This simple synthesis procedure is inadequate due to the use of a mathematical description of the design at the earliest stages, while configuration issues are ignored until the general arrangement stage. The configuration of a design should affect its gross characteristics. When the dimensions are fixed at the end of the Parametric survey the configuration has not been considered.

In turn this introduces other problems as the designer has to assume a configuration's impact on the design to allow an initial numerical description to progress. Such assumptions take little account of the desired design style and physical features. The introduction of more detailed design descriptions later in the process does not allow the designer to make design decisions with regard to this information. Instead the design descriptions only suggest whether the decisions made are acceptable at a later stage. A similar argument is placed on the detailed analysis of performance post the parametric survey. To analyse stability in sufficient detail, configuration information is required to allow the calculation of centres of gravity, and damaged stability using agreed criteria [e.g. *NES 109, 1990, Sarchin & Goldberg, 1962*]. As such information is unavailable at the earliest stages, regression data or simplified calculations are used. For commonly designed ship types this information may be reliable. An experienced ship designer will modify the design procedures to allow the investigation of configuration based issues when required, however such processes occur in an ad hoc manner and do not form part of the published theories of initial sizing. Formalising several of the unpublished heuristic rules of the designer is a side effect of the design sequence described later.

For radical or unconventional designs the assumption of relative size for the components of the design, such as hull length ratios, can lead to a final design which is over or under designed. The reliance on simplistic calculations or heuristic and regression based data leads to conservative design solutions resulting in difficulties when proposing genuinely attractive and novel solutions.

The distinction between initial sizing and the Parametric survey is made to render the design problem tractable by piece wise investigation and emergence of the design definition. However such an approach leads to several questionable assumptions. Firstly that the displacement suggested by initial sizing becomes *the* final displacement. If different initial hullform assumptions had been introduced the resulting displacement and volumes would have changed. Therefore the initial sizing stage design information is highly dependent on un-validated assumptions.

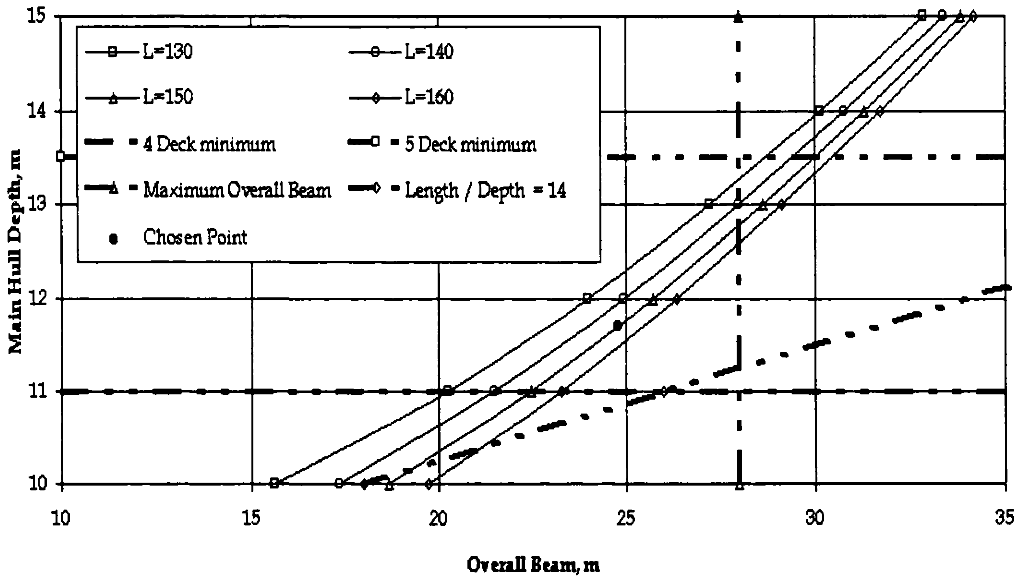
Transferring the volume and displacement definition to a Parametric survey perpetuates this assumption by considering that the resulting forms all infer the same demands on the hull, as they all share the same displacement and volume requirements. This was detailed by the author in [*Bayliss et. al., 1998a*]. An example given was the variation of structural weight with geometry. "Long thin" designs experience greater longitudinal bending moments than shorter beamier designs [*Chalmers, 1993*]. This requires greater structural weight assuming a constant structural style. Hence the longer design is heavier and displaces more than a less extreme form, all other issues being equal. This is not considered within a Parametric survey. Hence longer thinner designs may appear unduly favourable when selecting one hullform for further development.

A Parametric survey does not allow the full impact of configuration on the design forms considered. Instead simple constraints indicating the boundary between valid and invalid designs are developed. This may cause the design to be invalidated at a much later stage when configuration is considered fully.

The mathematical nature of the Parametric survey implies that the important issues at this stage of the preliminary design process are the specifics of choosing hullform coefficients to meet hydrodynamic performance requirements. Given that the preliminary stage attempts to define areas of risk, the absolute determination of hull coefficients is often not important provided the hullform is sufficiently investigated to illuminate risk laden areas. The decision making process during a parametric survey uses a design space such as Figure 3-6. This perpetuates the simplistic assumption of a continuous design space, which was suggested by [*Brown, 1986*] as being incorrect.

Subsequent to the parametric survey the designer develops a hullform, using manual [*Rawson & Tupper, 1994*] or automatic methods [*Wray, 1982, Birmingham & Smith, 1997, Peacock et. al, 1997*]. This allows design configuration to be developed. Few rigidly applied methodologies exist identifying the order in which compartments are added to the configuration. Those which have been produced for specific designs[72] or in

Figure 3-6 Example of a Trimaran Parametric Survey



general [such as *Brown, 1981*], logically suggest that the more important and demanding requirements for space on the ship design are met first. The definition of those compartments which are important and demanding does vary with designer and ship design with Brown ranking [*Brown, 1987*] the Galley and Magazines alongside the Operations Room as compartments to locate at an early stage of the configuration process[73]. Regardless of layout order the designer needs to consider configuration and compartment location as an iterative process.

It is noted that the issues of prioritisation of compartment location suggest that some compartments have greater claim to the more "valuable spaces" such as those on 2 deck and amidships spaces on lower and higher decks. If there is a need to ensure that these compartments are located in specific locations then the design decision making process should consider whether the design is capable of allowing such compartments to reside in suitable locations. Within numerical synthesis procedures, this can only

72 Notably the classified Type 23 Frigate layout methodology document produced by the MOD project team.

73 The Galley is chosen due to the large volume of space [Dining Hall, Food Stores] that must reside close to the Galley in order to form an efficient arrangement.

occur by the complete re-iteration of the initial sizing and Parametric survey stages post a general arrangement stage.

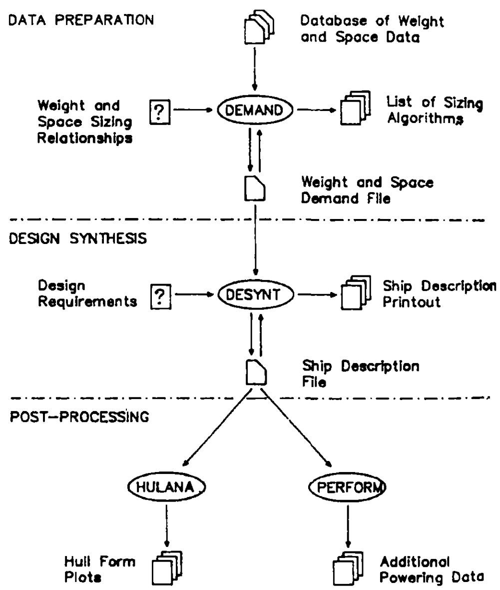
One role of a general arrangement stage is to allow a more accurate estimate of the centres of gravity of the ship design and the effect of configuration on design suitability. For example, the location of bulkheads and size of tanks, informing stability calculations [such as *NES 109, 1990*] and other analytical processes.

This shows the difficulty of incorporating information provided by analysis of the design into the design process. To accurately predict such features as seakeeping and damaged stability, knowledge of the configuration of the ship is necessary. Such information is only available after design synthesis. Therefore analysis of the ship design moves from the problem of providing a specific level of performance to the assessment of "whether a problem exists". In many cases this satisficing [*Simon, 1981*] approach is acceptable as exact performance levels are not necessary or able to be assessed, given the limitations of analytical methods. It is still necessary to meet certain levels of performance, for example maximum calm water speed, to satisfy requirements, and for these circumstances, given reliable methods, the failure to provide, or over provision of, performance, can lead to a design which is not satisficing or is overly expensive. To redevelop the design from first principles to reflect these failures given the time invested in preparation of the design is unreasonable. A more suitable method of achieving this would be to perform analysis at all stages of the design evolution, maximising the depth of such analyses. For powering assessment this is easily achieved but for other forms of analysis this cannot accurately proceed without the weight, space and configuration of the design being defined[74].

CONDES : A Computer Based Implementation of Sequential Numerical Ship Synthesis

A computer system based on similar design processes to those detailed above is CONDES [*Hyde & Andrews, 1992*]. CONDES is utilised, within the British Ministry of Defence, for preliminary design of naval ships. The methodology underlying CONDES [detailed in Figure 3-7] uses numerical design information to perform a numerical design balance. The naval ship database used contains detailed analysis of the features of current and recent British naval ships. Historic data for a specific system or a weight

Figure 3-7 CONDES Components [Hyde & Andrews, 1992]



group relevant to the new design's role, is used, by the designer, to develop suitable weight and space algorithms.

The design balance operates in a manner similar to the numerical synthesis approach detailed previously but includes stability and three spatial[75] requirements in the balance requirement.

The stability assessment is the provision of Metacentric height at different design vertical centres of gravity[76]. As CONDES is a numerical synthesis tool all internal and external configuration is performed separately. Hyde and Andrews suggested an improvement to the system:-

> *"A lot of time is spent .... doing checks outside CONDES ... to improve confidence...more rapid transfer of the concept design to .... Computer Aided Drafting packages (for layout investigations)".*[*Hyde & Andrews, 1992*]

This suggests that a weakness is the need to confirm externally, that the balanced volume and weight can subsequently be laid out practically after synthesis has been completed.

Design Methodologies For Unconventional Ships

The above discussion presented the use of a numerical design methodology in the development of naval monohull designs. Attempts[77] have been made to apply a modification of such a methodology to the design of unconventional forms. Unconventional naval multi-hull designs may be developed using procedures derived from monohull design, where similarities between the monohull and the unconventional design form allow. Trimaran is considered to be such a form and Zhang

74 For example damage stability can only be performed satisfactorily even in a quasi-static sense if major transverse bulkhead locations are defined. If more advanced analysis is to be performed, for example stability analysis is to be undertaken using a time domain strip theory program [such as FREDYN, *De Kat & Thomas, 1998*] more detailed information on the ships inertia is required.

75 Deck area overall, Tank deck volume, Machinery Space.

76 As no configuration is available at this stage, this is provided using regression data based on displacement, hull depth and superstructure volume. The resulting data can be found to be too restrictive when a design with an abnormal centre of gravity, for example, due to a heavy, high radar antenna, is under development.

77 The author developed a numerical sizing model involving a modified initial sizing stage and four stage parametric survey for naval Trimarans. This is detailed in [*Bayliss et. al., 1996*].

[*Zhang,1997*], Dicks [*Bayliss et. al., 1996*] and Eddison and Summers [*Summers & Eddison, 1995*] detailed numerical approaches to the initial sizing of Trimaran ships. These assume the Trimaran to be a monohull design with "extra design features". The extra features are initially heuristically assumed and subsequently re-assessed towards the end of preliminary design.

Trimaran ships are sensitive to the configuration of the three hulls and the cross structure due to these features impact on hydrodynamic performance [*Zhang, 1997, Cudmore, 1992, Cole, 1992*], structural arrangements [*Putnam, 1995*] and configuration [*Andrews & Bayliss, 1997*]. In particular the location, form and dimensions of the side hulls have been emphasised [*Zhang, 1997*]. These are normally defined by a need to provide sufficient damaged stability with low resistance. However it is also necessary to consider the impact of side hull position on cross structure location and hence on weather deck configuration. This cannot be achieved currently with satisfaction using a purely numerical design methodology.

At initial design stages, side hull characteristics are assumed from relationships based on previous designs [as detailed in *Bayliss et. al., 1996*]. A Parametric survey is performed using heuristic relationships for hydrodynamic issues and design constraints such as proposed by the author in [*Bayliss et. al., 1998a*]. Such a Parametric survey develops size and location relationships between the three hulls of a Trimaran and the gross size of superstructure and cross structure, being determined, removing many design alternatives from consideration prior to layout[78]. This leads to a situation in which ship designs are found to be inadequate after layout, when decisions have been taken, unless many iterations are undertaken. With the structural uncertainties of the Trimaran geometry and the impact that changes in structural configuration can have on a Trimaran's displacement [see *Putnam*[79], *1995*] the risk of initial estimates not resembling final features is great. Particularly important are issues of structural continuity for side hulls, main hull, cross structure and superstructure, which can only be monitored after structural arrangements have been developed.

When applied to the Trimaran, numerical initial sizing methods often lead a

78 This is necessary due to the lack of previously constructed Trimaran designs, but contradicts Chalmers [*Chalmers, 1989*] by estimating new design descriptions using untested ship design information.

79 Putnam redesigned a Trimaran's structure post design, to meet the requirements of [*Chalmers, 1989*], adding a cross structure double bottom, dramatically increasing structural weight. The revised structural arrangement has become commonplace in Trimaran design and has led to recent Trimaran designs having extra depth to maintain the air gap.[*E.g. Smith, 1996, Alder, 1997, Long, 1997*] or indirectly led to the replacement of the Cross structure by beams [*Rehman & Way, 1997*].

designer to ignore the implications of functionality and architecture on the overall ship design concept at the earliest decision making stages. Such implications may cause the design to be rejected completely at later stages.

Numerical design methods also assume that the dimensions of a naval ship are continuously scaleable. Brown insists [*Brown, 1986*] that there are discrete steps of ships size and capability relationships, in that there are areas of the design solution space, in which designs are "stable"[80], in terms of capability and size. In other areas designs are naturally unstable, leading to the formation of "natural" ship size ranges such as the corvette family. Such a change in the suitability of a design is responsible for the large increase in design displacement between the longest feasible three deck monohull design and the shortest feasible four deck design for the same requirement, once a structurally limiting length to depth ratio is reached. The addition of an extra passing deck above the machinery to reduce structural design problem "drives" many other design issues to larger solutions, each adding to design size and cost. Brown's concluding remark from his final paper [*Brown, 1995a*] also illuminates a seasoned designers understanding of the design process, which can be equated with a more general view of design.

> *"... the essential feature is the experience to understand the complicated interactions and discontinuities ...." [Brown, 1995a]*

With the Trimaran a continuously scaleable design space paradigm is even less applicable than for a monohull, due to the design requirements of such design features as air gaps, complex structural continuity and cross structure height. All of these control acceptable ranges of design features. Several designers[81] have suggested that the need to provide an air gap drove their designs to a limited number of alternative arrangements. Rehman and Way [*Rehman & Way, 1997*] found it impossible to meet air gap requirements simultaneously with other design issues for a corvette sized design and needed to completely remove the cross structure to eliminate the slamming load constraint, replacing the cross deck with three structural beams. Similarly the derivation of an acceptable superstructure configuration for Trimaran designs is complicated by a need to assure complex structural continuity requirements are met. Such requirements

80 Stability in this sense reflects the idea that at various points in the design solution space in which the relationship between design "size" and operational requirements is linear. At these points the design can be slightly stretched or extended to change features as desired. However a region exists in which the design cannot be considered satisfactory due to engineering limits on performance and to satisfy the engineering aspects a large increase in design "size" is required.

81 Based on conversations with the authors of [*Smith, 1996, Duggan, 1996, Alder, 1997, Long, 1997*].

limit possible superstructure volumes, particularly in the light of other Topside design issues such as Electromagnetic Interference [see Chapter 6 for a more detailed description] and cannot be considered thoroughly during a purely numerical synthesis stage.

The number of parameters to be considered in determining a Trimaran's hull configuration should force a designer to consider internal arrangement of the hulls and superstructure at the same time as overall dimensions. This is not compatible with a purely numerical synthesis approach.

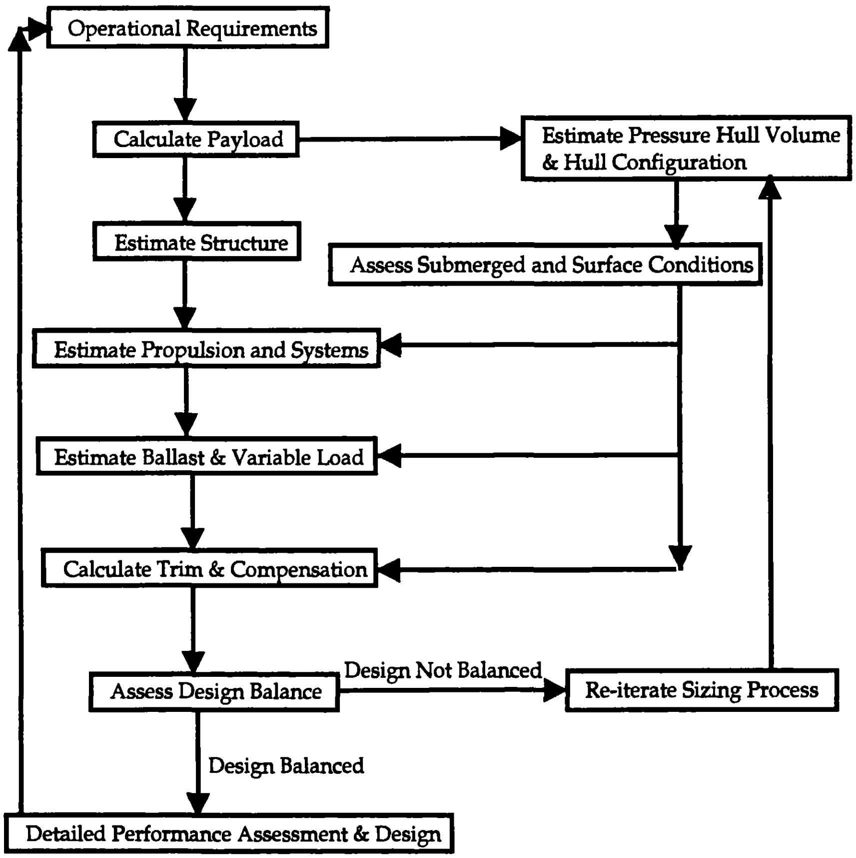
Similar arguments can be applied to the design of SWATH concept designs. However the degree of change from Monohull methods is greater than for Trimaran. Firstly a completely different geometry model is used with four important areas of the design, Hulls, Struts, Box Structure and Superstructure. An integrated parametric survey and initial sizing stage is often used due to the extreme sensitivity of the SWATH form to displacement and space. In particular the demands on space in the Box Structure can define the overall form of the design. Such issues cause the designer to consider more detailed hullform and strut design issues, particular numerical determination of space requirements for particular locations, before finalising the gross ship size.

A Submarine Design Methodology

The development of submarine concept designs is detailed regarding British practices in [*Burcher & Rydill, 1994*] and US procedures by [*Jackson, 1983*]. The initial sizing procedure used by Burcher & Rydill is iterative and based on the need to provide sufficient pressure hull volume to contain all internal systems and spaces of the design. The pressure hull must contain sufficient buoyancy to suit both submerged and surfaced conditions. The Burcher & Rydill submarine sizing process, summarised in Figure 3-8, is very evolutionary, utilising a type ship approach. The majority of the design description is evolved using scaling algorithms relating submarine characteristics to size. Concepts such as Reserve of Buoyancy are introduced to allow a mathematical definition of design style.

While focused on assuring that the all-important weight and buoyancy numerical design estimates balance, submarine sizing methods also require extra design information. Particularly important is the introduction of several aspects of configuration into the design. First pressure hull internal configuration is detailed by a

Figure 3-8 A Submarine Sizing Procedure [Simplified from Burcher & Rydill, 1994]



Flounder diagram[82] [*Burcher & Rydill, 1994*]. The Flounder diagram is a first attempt at space allocation and details initial estimates of bulkhead and conical pressure hull section locations. When these are known the pressure hull structural weight can be more accurately estimated.

A major reason for the introduction of configuration as a design issue, is the influence of system and compartment sizes on the total size of the design, as some submarines are driven to a final design solution by the amount and distribution of pressure hull volume. As a result the introduction of configuration information into the submarine design methodology is very important.

The external[83] configuration is developed to allow the definition of overall submarine form and assessment of hydrodynamic performance once main ballast tanks, fin and other features are introduced. The need to develop the internal configuration of submarines during design synthesis has resulted in the SUBCON system and the associated Building Block Design Methodology [*Andrews et. al., 1996*].

82 This is an allocation of compartments, modelled as volumes, to locations in the pressure hull, allowing internal spatial relationships to be defined.

83 In this case external means outside of the pressure hull, i.e. subject to full diving depth pressure.

3.5 Recent Advances in Naval Technology:- Influences on Design Methods and Designs

Part of the justification for developing new ship design methods and methodologies is that the designer must have tools that are capable of proposing design concepts to meet novel customer requirements and illuminate new areas of risk. Customer requirements are driven by the following issues:-

- Operational needs and likely scenarios;
- Technology; and
- The structure of the customer's procurement processes.

This section details current issues of note in these topics and assesses their impact on designs and design methods.

Novel Methods of Procurement and Design Management

In the papers [*Tibbitts et. al., 1988, 1993, Tibbitts & Keane, 1995, Betts, 1996, Andrews, 1994, 1998*] indications as to likely changes to the procurement process and structure of procurement teams are outlined. Such changes have implications for preliminary naval ship design. Tibbitts et. al. [*Tibbitts et. al., 1993*] suggest that Concurrent Engineering will feature strongly in the future design of ships. Tibbitts & Keane defined Concurrent Engineering as *"Integrated product and process development teams, collocated physically or electronically, employing a new design methodology to harness the true power of multi-functional teams.* [*Keane & Tibbetts, 1996*] defined concurrent engineering by three "truths" namely:-

1. *Design is the primary driver of quality, cost and time.*
2. *Need to leverage the power of design - earlier, broader and deeper.*
3. *Multi functional teams are the key to solving the total design equation.*

When applied to ship design the major benefits are considered faster product development and better designs. General benefits of concurrent engineering were quantified by [*Baum & Ramakrishnan, 1997*].

There is also a strong belief that multi disciplinary "Integrated Product Teams" [*Tibbitts & Keane, 1995*] are required to assure that all design issues are introduced at the start and influence the design concept. Such teams are also known as Integrated product and process development teams, a name suggesting that process development should be considered an important element in the design process. The integrated team allows the introduction of the influences of the end user, the constructors and *"process owners"*[84] [*Tibbitts & Keane, 1995*] allowing the *"total design equation"* to be viewed. Tibbitts

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84 Process owners can be considered as the personnel responsible for controlling how a particular element of the ship design process is performed.

and Keane suggest such design teams should be introduced at the earliest stages allowing broader [a more varied selection of different concepts] and deeper [a more detailed definition] design. These issues reflect the belief that the total ship design entity should be considered fully [including associated design processes] to ensure that the final ship design reflects the customer's wishes. Thus the requirement for the design will be more widely considered, with more detailed issues affecting what is possible and what is required. As a result the final solution is considered more likely to meet the final requirement.

Advances in Production Technology

With current financial restraints naval ship construction yards can only gain construction contracts on the basis of low initial price. Such low prices imply low cost that can only sensibly be achieved by a constant reduction in the personnel necessary for the production of ships[85]. Methods of producing the ship in fewer hours, using fewer people requires the adoption of advanced construction techniques. The major technological thrusts are a move towards pre-construction and pre-outfitting and an increasing use of computers for manufacture, design and planning.

Traditional methods of naval construction have revolved around the construction of the ship on the slipway. All ship systems and structure are added to the keel sequentially. After the ship is launched final outfitting occurs. This is expensive, in that the installation and setting to work of ships systems within the constraints of the ship are difficult and time consuming. There are also delays caused by sequencing. A more cost-effective solution is to construct and outfit ship elements in separate parts of the shipyard, delaying assembly of the ship as late as possible. This allows cheaper outfitting of ships systems. The separately constructed elements are known as modules, and an example is shown by [*Thomas & Easton, 1993*], *"From the outset the vessel was designed with large modular construction in mind"*. That paper also suggests the limitations on maximum module weight were provided by the capabilities of the shipyard. The experiences of the lead ship yard [*Fyfe, 1991*] suggest that the impact of including shipyard engineers at the early design stages benefited the design. These statements suggest that preliminary design methods should consider the broad aspects of potential module definition and design for production. This allows the cheapest construction techniques to be employed where other design features are not impaired. An important issue is the need to avoid constraining the design with respect to build issues.

Simulation Based Design

Simulation based design is the use of graphical real time computer based simulation of design artefacts to suggest whether a sub system design is acceptable within a total system. Jons [*Jons, 1994*] suggests that the development of a new system takes place in three "worlds":-

- The world of operation;
- The world of design; or
- The world of shipbuilding.

This was based on the premise that the design of a new artefact originates when a capability shortfall is identified leading to the formulation of new requirements. Jons suggested that the use of Virtual Reality techniques [*Angus, 1995*] can be used to perform the design act using a range of virtual prototypes *"unencumbered by the constraints of hardware"* [*Jons, 1994*]. Therefore the system allows the assessment of untested design features without the expense of detailed design, construction and analysis with potentially large savings in cost and time. The virtual prototype allows a designer to design, build test and operate a prototype without resorting to physical artefacts. To virtually simulate a design artefact with enough realism to justify any resulting design decisions two features must be provided:-

- A Virtual Prototype: *"Any software version of a (future) project capable of functioning properly and realistically in a responsive virtual environment"*, [*Jons, 1994*].
- A Virtual Environment: A physically responsive, visually realistic and accurate software model of the environment in which the design will operate.

Thus computer systems are required to provide the interface between a product model, containing an accurate representation of the design artefact and analytical tools to predict the response of the design artefact to external stimuli.

Practical applications of virtual prototypes include the development of anti tank missiles [*Jons, 1994*], the assessment of vehicle deck arrangements for ferries and landing ships [*Jons et. al., 1994, Edinberg et. al., 1996*] and naval airships [*Jons & Schaffer, 1995*]. A direct naval application has been developed by the Ministry of Defence, in assisting the safety management process and assessing the impact on human factors of proposed systems [*Woodrow et. al., 1998*].

The important application of simulation based design in the preliminary ship design stage is the development of constraints on a ship design to allow a system to

[85] This was particularly evident in the NAPNOC [No Acceptable Price No Contract] contract discussions for the LPD(R) design between the Ministry of Defence and GEC Marine [*Downs & Ellis, 1997*].

operate satisfactorily. The virtual prototype should be used to detail conflict between a ship design concept and the individual system, informing the designer as to the suitability of the whole ship design with respect to the individual system. Thus preliminary ship design methods should allow any design definition that is introduced by a virtual prototype to be used to inform the whole ship design process, requiring a form of ship design definition that integrates the numerical and physical design aspects. One suitable method for achieving this is to introduce architectural design information into the design description.

Stealth

Stealth technology is the generic name given to the methods of reducing a ship's Acoustic, Radar and Infra-Red signature. Recent naval ship design has moved from "un-stealthy" designs through semi-stealthy designs [Type 23 Frigate, *Thomas & Easton, 1993*], to designs with stealth as a core design issue [SMYGE 2000, *Bergman et. al., 1995*]. The requirement for stealth in ship designs continues to be debated[86].

Stealth impacts in two significant respects on the ship design. Firstly, in the provision of systems to reduce signatures. Examples include noise reduction systems fitted to the ship's hull and propellers, or heat reduction measures fitted to exhausts. These may have an impact on ship characteristics but are not normally of critical importance at the earliest stages. The second form of stealth impact is the effect of modifying the geometry of the ship structure in order to reduce Radar Cross Section.

For designs such as SMYGE 2000, [*Bergman et. al., 1995*], this can have a major impact on the space available in the superstructure and hull if extreme slopes are applied. The impact of this form of stealth on the whole design should inform the debate as to gross ship characteristics at the preliminary stage.

Performance and Safety

The impact of performance related issues on a ship design is a need to assure that the desired performance levels are met. Modern computers allow relatively accurate analysis of a ship design to be performed and should inform the preliminary design team as quickly as possible. The need to assure, at an early stage, that a ship will not emerge from the design process with inherent stability and safety problems is as

86 The requirement for absolute stealth is debated by [*Goddard et. al., 1996, Friedman, 1996, Graham, 1993*]. It is considered that a compromise between minimisation of a ships signature and the impact of stealth measures on the ships operational effectiveness must be drawn.

important than ever [see Footnote 21]. Although few naval ships have been lost recently at sea, many ships sail in restricted states or with limitations on operational capabilities due to stability related issues. The opportunity should be taken to assess the stability and other safety issues of the design early in the design process. This allows the design to evolve using design specific data and using fewer heuristic methods that may not be wholly applicable. The use of single measures of initial stability assessment alongside heuristic ratios of acceptable dimensions may not be applicable for a new role. An example is a submarine deployment ship [*Winstanley, 1997*], where stability at all stages of many different loading operations must be assured, requiring a reasonably detailed definition of tank and ballast systems. The early implementation of detailed analysis techniques for stability and structural issues rely heavily on the configuration of the ship design and such information should be provided in the design process.

Unconventional Ship Designs

The lack of naval design experience with unconventional ship designs introduces uncertainty and risk into the design process. With risk and uncertainty comes caution and an unwillingness to suggest radical solutions if satisficing evolutionary solutions can be found. This can be partially solved by research programs into the specific novel design features. Despite this a need exists to provide the designer with design tools allowing the development of unconventional designs alongside more evolutionary designs, so as to allow the fair comparison of the two against an operational requirement. This requires the provision of design methods that are compatible with the important design issues of unconventional forms. The important design issues of novel ship types can be considered to be of several types:-

- Issues related to the lack of design experience;
- Technology related issues; or
- Configuration related issues.

The first issue can only be mitigated by utilising conservative solutions for initial designs and learning from the successes and failures of the conservative solutions. Technology related issues can be solved by research programmes, for example structural design research. Configuration issues control the development of the design as a whole and can only be solved by careful consideration of the effect of configuration and other whole ship design issues, such as the S^5 issues, on each other as detailed in Section 3.4. Therefore it is considered important that configuration is dealt with through out the preliminary design of unconventional ships.

The important issues of propulsion system selection have changed widely with the introduction of new maintenance procedures, technology and environmental regulations to naval marine engineering[87]. Such changes may be beneficial in terms of a reduced marine engineering complement. Maintenance issues have also mandated the inclusion of system removal routes at the earliest design stages. For example, there is a need to provide large vertical access routes for Gas Turbines, which may influence superstructure location and size to facilitate equipment removal. The introduction of marine pollution legislation and it's application to naval vessels will influence the types of prime mover fitted, with "clean" gas turbines being preferred to diesels. This will render more difficult, the existing problems related to the impact on the ship design of voluminous gas turbine exhausts. Such exhausts require large spaces on passing decks, often causing unsuitable internal arrangements. The position of gas turbine inlets and exhausts also need to be considered at the earliest stages due to the impact of the hot exhaust on electrical antenna and also the inlets sensitivity to salt water. Such features requires configuration issues to be addressed early in the design process to avoid subsequent conflicts. Ship design studies by Smith [*Smith, 1996*], Spragg [*Spragg, 1995*], Duggan [*Duggan, 1996*] and Summers [*Summers & Eddison, 1995*] all attempted to reduce the impact of the large inlets and exhausts by various means of moving the prime mover location or re-routing ducts, introducing other major design problems in the process. [*Gregg & Bucknell, 1998*] demonstrated the difficulties of arranging satisfactorily the prime mover arrangement for a Trimaran frigate in comparison with a monohull of the same displacement, again noting the impact of systems on the hullform[88].

Propulsion systems have changed significantly through this century, both in prime mover type and power transmission method[89]. This has many implications on the ship concept design that must be considered when estimating the risk and financial implication of an Integrated Full Electric Propulsion solution [*Mattick, 1996*]. Some

87 The introduction of Integrated Logistics Support [*Jackson, 1997*] and increased emphasis on Availability, Reliability and Maintainability suggest that repair and maintenance of systems in situ is avoided.

88 It should be noted that a simple comparison of equivalence by displacement is not valid as the Trimaran and Monohull ships to perform the same function will not necessarily be of comparable displacement.

89 A typical British escort design of the mid seventies would include four gas turbines, two for cruise operations and two for boost operations, driving two gearboxes and two controllable pitch propellers. The modern IFEP solution is expected to use one or two high power gas turbine alternators with several low power gas turbine alternators [*Mattick, 1997, Henderson, 1997*]. All alternators would feed the ship's main electrical supply and the propellers would be driven by high power electrical motors.

issues from the ship designer's point of view are:-

- Increased weight and space requirements aft due to motor position;
- Fewer shaft induced restrictions on prime mover placement;
- Provision of Zone[90] based power generation for survivability;
- Fewer large machinery spaces close to amidships, with damage survivability implications;
- The impact of inlets and exhausts;
- Superstructure mounted power generation; and
- Removal routes.

These combine to give the designer much greater choice in arrangements but a greater responsibility to assess the subsequent impact on other design issues before deciding on gross ship characteristics.

Weapons and Sensor Technology

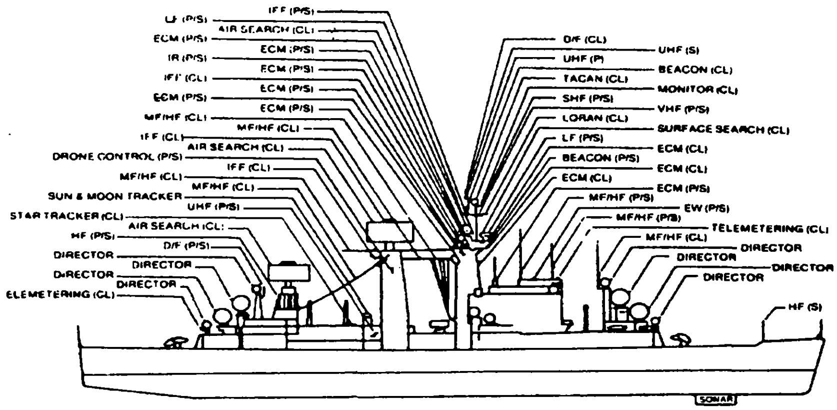
The style of naval ship designs continually changes to reflect the nature of propulsion and combat systems. This has been constant throughout history with notable examples being the initial disastrous introduction of turret systems on board H.M.S. Captain [*Hawkey, 1963*], the successful introduction of H.M.S. Dreadnought [*Massie, 1993*], through to the influence of missile technology on power projection[91]. Current issues in the development of weapons and sensor technology can be considered to affect ship designs as follows.

Since the second world war the growth of ship-borne Electrical and Electronic systems has been incessant [*Reuter et. al., 1979*]. The weight of electronics has multiplied by greater than a factor of two for destroyer designs while the number of antennae on a typical aircraft carrier has increased from less than 40 in 1950 to over 160 in 1974. [*Reuter et. al., 1979*]. The number of electrical systems employed on a naval ship design affects the vessel's design, due to the issues of radiation hazards [RADHAZ], poor system performance due to electromagnetic interference [EMI] and the physical impact of antennas on the overall configuration. This was detailed by [*Reuter et. al., 1979,* Figure 3-9].

90 A Zone is a series of co-located spaces on a ship that can be considered as self contained with respect to emergency and hotel service provision, and damage resistance measures.

91 Resulting in the now defunct concept of the Arsenal ship.

Figure 3-9 Typical Shipboard Antenna Arrangement [Reuter et. al., 1979]



Antennas and associated electrical systems impact on the whole ship design due to the need to provide antennas with a location on a mast or superstructure deckhouse at sufficient height and clearance for performance reasons, without overly affecting ship stability. Communications antennas may need to be of specific lengths [up to 25 m] and form to meet wavelength requirements [*Gates, 1987*]. Antennas will also need to be linked to control and processing units. Radar system processing units are often required to be located below or close to the radar antenna in order to minimise wave-guide runs. Such issues may drive ship configuration. [*Scott & Moak, 1994*] detail the enforced re-development of the aft end of the Flight IIA DDG 51 design to allow the AEGIS radar and helicopter hangar to co-exist, demonstrating the impact of the above issues on overall ship design issues. The extensive re-development was limited in scope due to the need to retain a fixed hull design.

It is necessary for the ship designer to consider the operations complex location as an important step in arranging a naval ship's internal layout [*Brown, 1987*]. This is due to a need to locate operations complex, associated computer spaces and communications spaces, together allowing efficient operation. Once the location of these spaces has been defined the layout of the ship design is much more constrained. If the location of the operations complex is under debate[92], the amount of superstructure required by the design [and hence amount of internal hull space] will change significantly with different options. Such decisions should be considered during the development of overall characteristics, influencing both hullform and superstructure arrangements, if a rational, balanced, design is to emerge.

92 Dependent on size, operational role and other design issues either a superstructure or hull mounted operations complex may be selected. With an unconventional design the choice of locations may be greater.

Advances in the use of modular ship designs[93], propulsion and weapons systems also force the designer to consider system form and its impact on the remainder of the design.

The above discussions have outlined current areas of interest and change in naval ship design. It is notable that a common thread appears to emerge, that of the interaction of the ship and individual systems. It can be noted the manifestation of the problems of this interaction can be viewed as a problem regarding the internal and external configuration of the ship design.

3.6 SALIENT POINTS OF CHAPTER 3

Chapter 3 has detailed the development of design methods specifically for application in the design environment. The chapter has focused on several issues, the nature of marine design, the naval ship procurement environment, current methods of preliminary design of ships and, finally, changes to naval issues that suggest that design methods and methodologies should adapt.

It has been noted that a modern ship procurement cycle is a complex process in which the preliminary design stages play a pivotal part in defining, the projects survival, growth to maturity, capital implications and inference of risk, but may not lead to an exact definition of the final design. It is noted that the designer must develop the preliminary design as if it is to be developed fully to production in order to ensure that the levels of risk, costs and validity of the requirement are established as possible. Thus it is still considered important to perform preliminary design, and to perform it using valid methods.

The most common form of preliminary ship synthesis systems have been noted as being based upon the concept of a numerically based ship synthesis, treating the ship and her systems and requirements as a set of numerical equations relating characteristics and gross size.

Modern trends in naval ship design have been noted and the impact of modern technology on the design has been developed. Major influences include the growth of electromagnetic issues on board ships, the development of radical and unconventional designs for specific roles and the movement away from a architecturally constrained

93 A modular design is one in which the basic hull design is developed to allow multiple different systems arrangements to be adopted dependent on requirements of the customer. Often this requires existing systems technology to be adopted and mounted in a package of a standard form. As a result innovative design and introduction of up to date technology is difficult. Modularity is discussed by [*Gates, 1987*].

propulsion arrangement to the relative freedom offered by the full electric propulsion concepts. All these issues would benefit from a further investigation of configuration related issues at the preliminary stage.

4. THE NEED FOR A NEW NAVAL SURFACE SHIP PRELIMINARY DESIGN METHODOLOGY

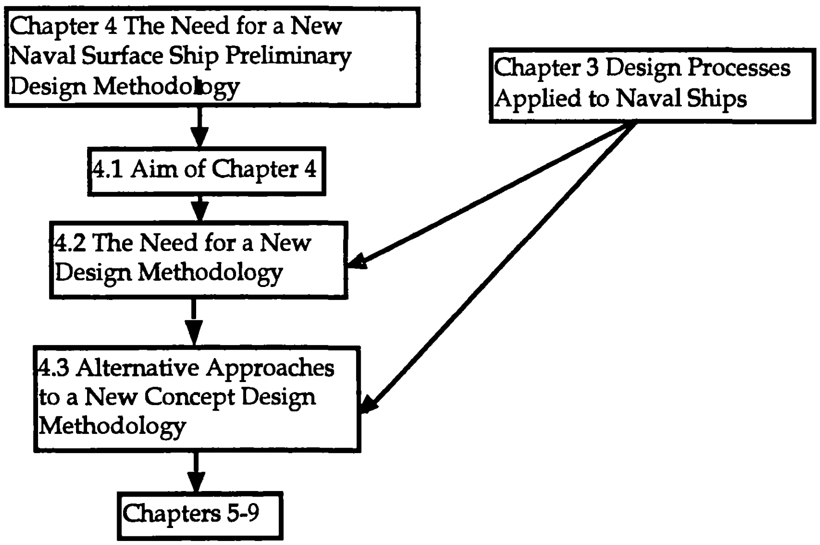


Figure 4-1 Chapter 4 Schematic

4.1 AIM OF CHAPTER 4

Chapter 2 suggested that design theory and specific design methodologies are important when detailing solutions to a design problem. Chapter 3 detailed the influence of design artefacts on naval ship procurement process and preliminary ship design.

It is considered that the preliminary stages of the ship design process are currently undertaken with design methodologies that do not fully reflect a naval ship designer's requirements. A requirement of the preliminary stages is to identify risk by development of a representative ship design. Preliminary stages also illuminate important technological and financial issues. Chapter 4 details the shortcomings of current design methodologies when applied to naval ship design [Section 4.2]. The deficiencies of current methodologies are used to illustrate an "ideal" design methodology [Section 4.2.1]. The ideal design methodology is used to compare and contrast alternate new ship design methodologies [Section 4.3]. The choice of a design methodology to be developed in Part two is illustrated. The result of these discussions is the definition of the Surface Ship Building Block Design methodology, demonstrated fully in Part two.

4.2 THE NEED FOR A NEW PRELIMINARY DESIGN METHODOLOGY

Three forms of justification for the development of a new design methodology for naval surface ships can be developed. These are those related to unsatisfactory elements of current design processes, those related to forthcoming modifications to the type of ship under development and the introduction of elements of design theory and research into the design process with a view to the improvement of the design process. This section details all three forms of justification.

Limitations of Numerical Synthesis and Methods

> *"Theorists interested in optimisation have been too willing to accept the legacy of ... mathematicians who painted a clean world of quadratic objective functions ...The real world of search is fraught with discontinuities and vast multi modal, noisy search spaces"* [*Goldberg, 1989*]

It is impractical to consider all aspects of a ship design to be definable by mathematics. Often a numerical description of a system or design feature does not describe fully all-important issues. An example is the need for structural continuity in a ship design. The continuity of a ship's structure cannot be described mathematically in a manner that assists the designer to grasp its suitability. Conversely a practising naval architect has an in built grasp of "poor" structural arrangements and given a crude sketch of the proposed arrangement can identify likely problem areas. Features such as structural continuity can and should change overall design characteristics and thus should be considered before design dimensions are finalised.

A mathematical design culture exists [such as *Bell et. al, 1991*] encouraging designers to ignore or delay consideration of non mathematical issues until after major decisions have been made. Thus numerical ship synthesis models deal with dimensions, but not arrangements, while deriving gross ship characteristics. It is considered that the ship designer should constantly be aware of the configuration of the current concept design using graphical representations. This allows a designer to consider those design issues that are far better or perhaps only described visually and take action as necessary.

Current naval ship design methods, based on numerical synthesis, often require a designer to perform external design tasks in addition to the main synthesis in order to develop a valid design solution. For example the constraints imposed by layout are not integrated within current synthesis tools and only emerge as a result of additional arrangement studies. Thus configuration issues can only be assessed once a numerical balance has been obtained, and can therefore only inform the next design iteration.

While suitable designs do emerge from this process, a more efficient decision making method would integrate configuration into the synthesis and allow such influences to directly affect the form of the design at each iteration as design decisions are made. This would permit any constraints on layout to drive dimensions rather than simply assessing, post synthesis, whether the design is feasible. The data handling required by a tool embracing both numerical and layout aspects is sufficiently complex to benefit from a computer based implementation.

Numerical synthesis procedures, by their nature, act as 'Black Box' design procedures in which the designer does not have full control of the emerging design in the midst of each synthesis iteration. Here a designer can best affect the emerging design by improving on previous iterations and changing inputs to the synthesis accordingly. A more appropriate system would allow the designer's creativity and experience[94] to directly influence the direction of design evolution.

Numerical design definitions do not adequately describe modern features, such as complex combat and propulsion systems, which can affect gross ship size, cost and risk by their configuration as well as by their weight and space demands. Whilst the designer can consider such issues outside an automated synthesis method, he is unable to affect the results once the synthesis iteration has started. It is considered that to fully inform the procurement process, the functionality and configuration of the design should influence its gross size within the synthesis.

The traditional numerical approach to the initial sizing stage assumes that the design space is a continuous entity, using fixed relationships between hull dimensions and a continuous range of valid displacements. In reality not all the hull dimensions and ratios can be considered continuous variables. For example as depth increases a point will exist at which a four deck solution is more appropriate than three decks. This was detailed by Brown [*Brown, 1994*].

From the author's viewpoint, there are combinations of dimensions that are unacceptable (unstable) in arrangement due to combinations of depth, length, numbers of passing decks, superstructure arrangements and many other issues. The acceptance of an unstable solution during preliminary design can hide the risk of a subsequent rapid increase in ship size due to a small design change. Such risk is detrimental to the management of ship procurement.

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94 The importance of such experience was noted by [*Brown, 1994*] "*The starting point is the designers experience - and if he lacks experience he should not be in the team*".

[*Brown, 1994*] noted the anticipated utility of the SUBCON [*Andrews et. al., 1996*] approach, prior to that systems commissioning, in identifying the impact of the important linear, spatial and other design constraints. Brown's approach to surface ship design, noting the importance of non-linearity's and stressing caution in parametric design systems as geometric issues become more important suggests similar claims can be made for surface ship design systems operating on an architectural approach.

The current emphasis on logistics support analysis [for example the Astute class submarine, *Jackson, 1997*], designing with long term service issues in mind, requires system design issues to be developed on a wider basis than purely minimum weight and cost. This requires preliminary design methods to introduce a more comprehensive definition.

Design Generators

Another justification for a new design methodology is the concept of the design generator, proposed by [*Darke, 1979*] from discussions with building architects. Prior to a more detailed definition [Chapter 6] the design generator concept is based on the suggestion [*Andrews, 1984*] that each modern naval ship design has a specific design feature or demanding requirement that is considered of great importance and the key in the genesis of a new design. The design generator reduces the size of the valid solution space to those solutions reflecting a certain range of style, configuration, and often most importantly, requirements for gross size. The design generator is often related to one of the operational requirements of the ship design. The design generator usually affects the configuration of the design, through the relative location of elements of the ship. To provide a design concept that meets the requirements of the design generator, it is important that the impact of the design generator on the emerging ship design is a fundamental aspect of the ship synthesis. This ensures that all design alternatives considered are capable of meeting the principal requirements.

Current ship design methodologies do not easily allow the features of an emerging preliminary design, to be driven by the design generator. Recognition of the generator's requirements is not possible until the general arrangement stages by which time gross ship characteristics have been defined. This leads to repetition of the design stages. A new design methodology is required allowing the generation of the ship design to encompass the requirements of the design generator before selection of key design features such as length and gross form parameters. The importance in the eyes of a seasoned designer, of the design generator of modern escorts, topside design was implied by [*Brown, 1994*] who suggested that the starting point of a design should be a sketch of the upper deck, leading to Figure 6-3.

Needs of New Technology

Historic examples of the influence of the introduction of technology on ship designs include the changes in ship arrangements resulting from the move from steam to gas turbine propulsion[95]. A modern ship design should not solely be defined by a simple balance of weight, space, and numerical assessments of service requirements. Functional issues must be considered throughout a design process, assuring that the resulting ship design is fully capable of operating as desired.

The specific needs of new technology can be often be considered by introducing the configuration of the total ship at an early stage of the synthesis [*Andrews, 1984*]. More complex issues of new technology such as the effect of sloped superstructure on the radar cross section can be rendered amenable by application of both analytical and configuration based design approaches.

New requirements also demand the consideration of the different forms of monohull and unconventional designs that can be proposed. It is likely that one or more unconventional design types will be "in competition" with the conventional monohull form for a specific naval ship requirements with the monohull design being generally considered as the default solution. In such cases the unconventional design must demonstrate that, without doubt, once all additional risks have been considered, it is more suited to the particular operational requirement, in order to be selected as the chosen design form. Unconventional ship types have many different characteristics and as a result introduce subtly different design issues and foci [*Bayliss et. al., 1998a*]. While all are consistent in the need to balance weight and space, many unconventional designs are sensitive to design configuration [*Bayliss et. al., 1998a*]. This is due to the fact that unconventional design types have widely differing hullforms and as a result the configuration of the design is affected by the differing distribution of space in the design. Again the complex design problems introduced are likely to be amenable once a designer's experience and analytical expertise is applied to configuration and gross ship characteristics simultaneously. Previously the majority of methods used to develop

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95 Changes to marine propulsion affect more than the shape and size of the engine room. Changes to complementing regimes, the introduction of different inlet and exhaust requirements, different electrical generation requirements and changes to the operation of the vessel are all affected.

unconventional forms have been evolutionary ones, based on monohull design methods with additional features as required for the specific unconventional form in question. Examples of such methods are detailed for Trimaran design [*Summers & Eddison, 1995*] and HYSWAS design [*Selfridge, 1996*]. The disadvantage of such methods has generally been the strict adherence to monohull criteria, algorithms and methods that have not been adapted to take into account the differences between hull configurations. The application of an evolutionary design method without change to a different design problem may lead to a conservative approach, with application of additional margins to mitigate the risks associated with uncertainty. Consequently an unconventional design may be penalised unfairly in comparison with the more familiar monohull concept.

A new design methodology is required to allow a designer to recognise the differing design drivers of each type of unconventional design, using similar design methods for each type. In particular for multi hulls, those design driving features of each design are more likely to be defined by configuration of the different hulls. By using a common methodology across design types, capable of dealing with the important issues of all designs the overall task becomes more widely understood. In particular insight into design features of unconventional ships with respect to value for money, would be provided.

Concurrent Engineering

The influence of computers in ship design is considered all pervasive [*Gallin, 1973*]. The ability of modern computers to present graphical information has allowed shipyards and ship design agencies to consider the use of product models[96] and simulation based techniques [see Section 3.5] to impact on the design process. There is pressure to address, much more extensively, production issues within the preliminary stages of ship procurement.

A major aim of the modern ship design process is to employ a concurrent engineering approach to reduce the length and cost of the procurement program [*Baum & Ramakrishnan, 1997*]. Thus a new ship design methodology should allow computers, using simulation based [*Jons et. al., 1994*] and production design/product model techniques [*Baum & Ramakrishnan, 1997, Foster, 1998*], to supply information at a stage at which it can significantly inform the design process. Introducing traditionally "down stream" information "up stream" is considered to allow more rapid and lower risk development. Such issues as this lead Andrews to state [in *Andrews, 1998*] that concurrent engineering requires more emphasis on preliminary design stages. More emphasis can be detailed in two forms, firstly applying more resources to ensure that the design process is effective, and secondly providing an information rich design environment and design description. This information should be provided by numerical and graphical representations of aspects of the design. To make full use of the hybrid information the design methodology should itself be based on both methods for describing the design artefact, developing spatial as well as numerical design issues fully.

Introduction of Configuration

As just suggested, the early introduction of configuration issues into a design is necessary to develop the primary generator of the design concept, and to meet the needs of new technology (i.e. concurrent engineering).

It is also considered that irrespective of these important issues all naval designs should utilise configuration within the design process long before the solidification of the gross ship characteristics. The specific attributes of the contents of the ship design place many localised requirements on the ship design, dictating the form of the whole ship. For example minimum acceptable engine room arrangements should be considered before final selection of a ship's beam and depth. Therefore a design methodology should allow the designer to consider if overall ship design characteristics are compatible with individual system requirements. This is currently not achieved due to the difficulty of manipulating such issues as equipment location, access routes and subdivision in a numerically dominated synthesis[97]. Conversely a simple graphical illustration of such issues often allows the designer to assess areas of the ship in which the local configuration is not compatible with the overall numerical description of a ship design. A designer can then assess whether gross ship characteristics should be changed.

4.2.1 Features of an "Ideal" Naval Design Methodology

The previous discussion detailed aspects of preliminary naval ship design that

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96 A Product Model is defined by [Baum & Ramakrishnan, 1997] as "*the integration of .. geometric and non geometric database information*".

97 See [*Andrews, 1984*] for a numerical example.

are not presently suitably addressed in synthesis before the solidification of a ship design's gross characteristics. Alternative methodologies for improving the preliminary design process are presented in Section 4.3. To select one methodology to develop further, this section considers the features that are desired of a theoretically "ideal" design methodology. The scope of the ideal design methodology can be specified simply by the following statement:-

- The ideal design methodology should be capable of designing to an equal standard of development monohulls naval ship designs, and naval unconventional hullform designs, using all relevant design issues at the preliminary stage.

The nature of the ideal methodology should allow a freeform approach to design focusing on the synthesis act as the main creative act of preliminary ship design. The data description formats used should not prescribe the types of synthesis and analysis that can be performed. The ideal methodology should allow a designer to perform decision making tasks as necessary, providing access to design information in all major technology areas. The methodology should support analytical, creative, financial and production based techniques to assess design suitability, against an emerging requirement.

A necessary feature of the ideal design methodology is the need to replicate the capabilities of current methods of preliminary ship design. Therefore the ideal methodology should be implemented within the practical constraints of a ship design team, able to be used by practising ship designers. For example, data associated with the ideal methodology will be maintained by a naval architect and not require specialist support.

The ideal methodology is intended to be independent of the mechanics of implementing the enshrined concepts, with the focus being on providing a broad, widely understood design approach. While it may be beneficial to develop specific computer systems to implement the methodology the most important aspects of the methodology must be capable of being performed manually.

The ideal design methodology should notably allow the introduction of configuration and geometric information into the design process at a time that allows the designer to use these influences to examine their effect on gross ship characteristics.

4.3 ALTERNATIVE APPROACHES TO A NEW PRELIMINARY DESIGN METHODOLOGY

Several modern developments in ship design methodologies are documented within this section, justifying the further development of one design methodology to meet the requirements of Section 4.2. The developments considered are concept exploration models, optimisation approaches, decision making approaches, artificial intelligence and configuration based approaches. These are assessed, noting the requirements of the ideal design methodology.

4.3.1 Concept Exploration Models

A Concept Exploration Model [CEM] uses the rapid analytical abilities of the computer to allow a designer to explore a broad design space. The concept exploration model has been applied to monohull naval ships by [*Eames & Drummond, 1977*], to SWATH naval ships by [*Nethercote & Schmitke, 1981*] and to commercial designs [*Georgescu et. al., 1990, Daman et. al., 1997*]. Nethercote and Schmitke [*Nethercote & Schmitke, 1981*] defined the task of the concept exploration model as being *"to explore a wide range of ship options in the opening phase of the design process....to conduct a parametric design and operational studies."*

In this task the concept exploration model replaces the Parametric survey [Section 3.4] in the design process[98]. The model input is a mathematical vector describing ship design characteristics and requirements, (including performance targets and constraints on the design solution space). The concept exploration model includes data and algorithms used to scale design features from initial inputs. The output of the model is an array of designs with different attributes. The designer manually chooses one design to develop further.

An advantage of the CEM approach, when applied within the range of applicability of the design information, is an ability to investigate the effect of hull geometry on ship performance and suitability. When a novel design requirement is under investigation the ability to consider the change in design suitability with design features is considered important [*Eames, 1981*]. However such an approach can only be used when design data permits a wide ranging study. [*Fulford, 1981*] argued that the extension of the SWATH CEM to large SWATH designs demonstrated this limitation.

The amount of merchant ship design information available and relatively limited design freedom suggests the application of the CEM concept to commercial ships is more justifiable then an application to naval design. This is particularly true when economic criteria are used to distinguish between the effectiveness of each commercial design, due to the single performance function [profit] that can ultimately be derived if all design issues are fully investigated.

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98 This can be seen by the use of the SWATH's displacement as the initial input in [*Nethercote & Schmitke, 1981*]. A more "preliminary" ship design system would be expected to derive displacement from the initial requirements.

A disadvantage of the CEM concept is a need to provide a specific scaling \ sizing model for each ship type. Other disadvantages include the reliance on extrapolation of design data across a large design solution space, assuming a continuous design space is valid, and the reliance on numerical measures of requirement satisfaction. Configuration issues are not considered, past an initial assumption of design style and hull type, which is assumed constant across the design space. As a result the designer compares alternative designs without considering the effect of changes to dimensions on overall or local configuration issues or the validity of design algorithms. The SWATH CEM model of [*Nethercote & Schmitke, 1981*] even omits to balance the spatial demands of the individual concepts, and hence cannot be considered to provide a truly balanced design. This suggests that comparison of individual designs would be attempted without consideration of the spatial characteristics of the designs. There is also the dilemma of how to achieve the initial start point of the search which requires a genesis stage by itself. Such simplifications rule out the CEM approach as the basis of a new design methodology.

4.3.2 Optimisation Based Approaches

Concept Exploration Models and Optimisation models share several characteristics but differ in the output. A CEM attempts to provide a wide variety of designs for consideration by the designer while optimisation approaches attempt to reduce this number of designs to one, that design solution considered optimal. Optimisation based design methodologies represent an attempt to define the preliminary ship design process as one in which all issues and requirements can be described in purely numerical form. The decision making task is wholly assigned to a computer. Optimisation systems have been proposed for both naval [*Keane et. al., 1990*] and merchant [*Ray & Sha, 1994*] ship design applications. Optimisation is also employed in support of expert system based methods [*Duffy & MacCallum, 1989*] and decision making methods. The popularity of the optimisation approach is due to the strengths of the modern computer, compared with the weaknesses of the human designer, in the area of repetitive calculations and data retention.

An optimisation based approach to ship design [using *Keane et. al., 1990* as an example] replaces the Parametric survey stage with an "optimiser". The optimiser manipulates a vector of input variables so that the maximum value of an output variable [the objective function[99]] is achieved. The optimiser uses a mathematical optimisation technique such as "Hooke and Jeeves" [*Keane et. al., 1990*] to perform the search for the maximum value of the objective function. [*Keane et. al., 1990*] describes its operation as follows:-

- "An Arbitrary starting point is selected…at which the objective function …is evaluated.
- An exploratory search is begun by increasing [the first input variable] by a predetermined step length. If this improves the value of [the objective function] it is retained. If not a corresponding reduction is made. If both fail no change is made. A similar exploration is made for [the second input variable] and so on. The final result of such an exploratory search is called a base point.
- A pattern move is made by changing each variable from the last base point an amount equal to the difference between the new and previous base point…
- If the pattern move fails to improve [the objective function], it is cancelled and replaced by a new search…
- The iteration continues until an exploratory search fails to locate a better point…. The step length is then reduced ….. and the search repeated."

The naval architecture content of such methods is the provision of relationships linking inputs to outputs and hence to the objective function, and the selection of constraints on the resulting design. The information content consists of several types of design information:-

- Design requirements and constraints, e.g. a desired maximum speed.
- Input variables and acceptable ranges of those input variables. e.g. an initial payload volume.
- Relationships between input variables and other design description variables. e.g. length to beam ratio.
- Relationships between design description variables and overall design performance (often using standard analytical tools).
- Formation of the objective function.

All information is processed in a mathematical form. An example would be the assessment of the impact of on hullform properties, selecting one performance variable[100] to optimise. Multi-variable input vectors, in which many hullform variables are modified independently, can be proposed. A five variable example was demonstrated by [*Keane et. al, 1990*].

Keane also demonstrated a single objective function based on the need to minimise resistance for a naval ship. The use of single objective functions based on one area of design performance is not a suitable method of defining the optimum ship as an operational requirement cannot be stated as one value to maximise. The use of multiple objective function optimisation methods such as those used in the design of ships structures using fuzzy methods [*Xu & Yu, 1995*[101]] are more applicable.

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99 The input variables are features of the ship design concept (normally hullform parameters), while the objective function is a performance measurement describing the "fitness" of the ship concept.

100 E.g. resistance in calm water.

101 This paper utilised the concept of the fuzzy set to allow minimisation of both hatch cover weight and deflection under load.

Optimisation systems are usefully employed in some merchant design studies, in which the objective function of the design [the maximisation of profit], and the constraints on operation and design are understood and can be fully expressed in mathematical terms. As a result the scope for innovation is deliberately reduced. Thus the use of optimisation methods to assess the hullform dimensions of a new container ship design derived from a well-documented parent design to maximise profit is considered valid. In this specific example the designer may be able to express all relevant design data in numerical terms, extrapolated from a parent design suitable for society classification. The optimisation tool thus searches for favourable "distortions" from the parent form. In this case the optimisation tool can fulfil the need to perform a divergent search of the design space before converging on the design solution, finding the optimum solution, that solution providing the highest value of the objective function.

The application to a naval design in which the "objective" function could be specified directly from a firm operational requirement might also be acceptable. However such simplistic and rigidly defined naval scenarios are unlikely to occur. To define naval requirements to allow definition of a valid objective function leads to highly specialised designs which generally have not proven as successful as more general purpose designs[102].

Even the "simplest" naval vessels perform multiple roles and operate under multiple scenarios in which individual features of the design may be more or less important.

The need to provide a valid objective function representative of the requirement is the greatest barrier to the use of optimisation of naval designs at the preliminary stage. This discussion can be devolved into four separate issues. Firstly the concept design stage should not finalise with absolute accuracy the physical features of the new ship design. Instead it develops the relationship between an emerging operational requirement, the likely features of ship to meet that requirement and the related risk and financial implications. These inform the naval staff of the potential capabilities of the fleet and how much those capabilities may cost, to allow the formalisation of the requirement. In this case the accuracy of hullform attributes is less important than often suggested and time spent, for example, decreasing resistance by a small percentage, is

102 [*Brown, 1993*] suggests that general purpose designs have proven more useful due to the increased design margins included at design, while specialised designs are likely to be expensive or unable to withstand a major modification if operational requirements change during the ships life.

not effective. More important is the need to assess areas in which changes to ship features can affect the whole procurement program. This cannot be achieved solely by numerical means.

A second issue is that the concept designer informs the naval staff as to the performance they can reasonably expect from the final design, refining the initial estimate of a requirement. Hence performance targets will, probably, not be known with certainty. The importance placed on meeting a performance target at the expense of other targets is generally unknown. This is particularly important for multiple criteria optimisation methods where the final optimum design is a compromise between separate, competing, criteria. This assumes that all performance and stylistic constraints on the design can be specified in both numerical form and relative importance, the third issue.

Ship configuration cannot be expressed readily in such a form as the complex mathematical descriptions of circulation [in *Andrews, 1984, Cort & Hills, 1987*] show. A ship design emerging from an optimisation routine is the optimal arrangement *of those features and requirements that can be and have been specified numerically*. If the design has a primary generator [*Darke, 1979*] defining the satisfaction of a major design requirement that cannot be modelled mathematically, this is not considered by the optimisation routine and hence not automatically satisfied. To identify the constraints induced by the design generator applicable to a specific design, configuration of the ship during synthesis is required.

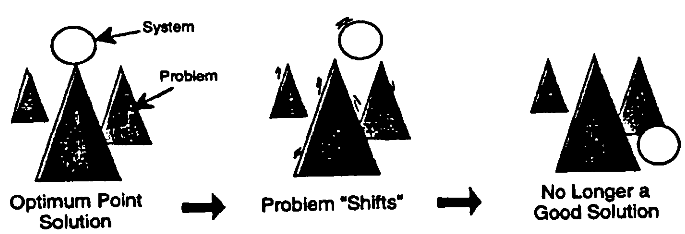
The inability to model many design generators leads to the use of optimisation routines as methods of defining hullform parameters and dimension for a previously defined gross ship size. This assumes that concept ship design is solely hullform design, and that the important issues at concept level are hull coefficients, dimensions and weight and space, and the meeting of hydrodynamic performance targets. The naval ship designer is responsible for more than the form of the hull and considers all issues affecting the ship. Hullform style affects overall ship features as does configuration and *all* issues need to be addressed to a degree before decisions are taken.

The most important issue however is that naval requirements are evolved alongside the design that is intended to meet them and hence the objective function would be continuously changing in a real procurement programme, even if it was possible to specify precisely at any one point in time.

Optimisation tools do not allow the designer to interrupt the design synthesis to introduce a radical concept. With an optimisation based synthesis (using a computer) the designer loses control of the task until results are produced.

A final issue regarding optimisation is that it is not uncommon for the design concept and final design to differ widely in displacement as a result of post concept stage changes to the design. Optimisation routines do not generally include a penalty for designs that are particularly sensitive to change. Thus the design that appears to be an attractive option at the concept stage may not appear so attractive when the design subsequently develops. This is detailed graphically by [*Simpson et. al, 1998*] reproduced here as Figure 4-2.

Figure 4-2 Potential Pitfalls of Optimisation [Simpson et. al., 1998]



4.3.3 Decision Making Based Approaches

Chapter 2 considered design to be a process of decision making using emerging data followed by reinforcement of those decisions. In marine design processes two forms of decision based design approach have been advanced. One form follows the work of Mistree [Decision based Design]. The other uses Multiple Criteria Decision Making, as advanced by Sen.

Decision Based Design applies systems engineering principles to the design process. System Engineering utilises the idea that the important issues of engineering systems are the interfaces between design elements. The introduction of decision making support into design should allow a designer to create better designs by making better design decisions.

In [*Smith, 1992*] a Decision Based Design process is described as consisting of a Meta design phase and a computer based design phase. Meta design is the design of the design process, *"partitioning the design process into a set of decisions and planning the sequence in which these decisions will be made"* [*Mistree et. al., 1990*]. Meta design applied to Decision based Design transforms the design problem into a series of Decision Support Problem Technique models. Each model details the progression of a design task from statement to solution. The model presents all aspects of the design process. Representations are assembled to form a complete design process [Figure 4-3]. The most important aspects are the three decision task types (Selection[103], Preliminary Selection, Compromise). The cornerstone of the technique is the Compromise Decision Support Problem. Compromise Decision Support suggests a solution to individual design decision problems based on design requirements, using goal programming techniques. [*Lyons & Mistree, 1985*] defined the formulation of such a problem in terms of variables, constraints, bounds and objectives. Using information in these forms the compromise decision can be stated as follows [*Lyons & Mistree, 1985*]:-

- Given
    - an initial design;
    - requirements that need to be satisfied by the design for feasibility;
    - goals of the design - these need to be achieved as far as possible; and
    - relevant assumptions.
- Find
    - value of the system variables;
    - value of the deviation variables (which indicate the extent to which the goals are achieved).
- Satisfy
    - the system constraints (must be satisfied for feasibility);
    - the goal constraints (to be achieved as far as possible);
    - the bounds.
- Minimise
    - the difference between the required and the estimated performance of the design.

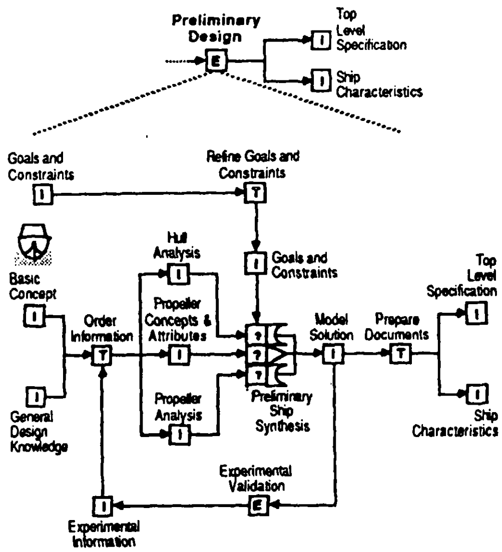
It can be seen from the above discussion that a compromise decision is heavily influenced by the optimisation issues detailed previously, notably in the definition of deviation functions. As discussed previously, this approach is not considered advisable where complex design requirements are under consideration.

The use of compromise based methods has been demonstrated in the development of cargo vessels [*Lyons & Mistree, 1985*]. The development of top level naval ship specifications was advanced by [*Smith, 1992*] developing multiple, feasible, alternatives and then reducing the range of allowable ship characteristics. The development of a specific naval design was presented by [*Mistree et. al 1990*]. The naval design concept was modelled in two design phases, conceptual and preliminary design.

103 Selection and Preliminary Selection decision making require a final (selection) or initial (preliminary selection) decision as to the type of solution by the designer, employing creativity, judgement, intuition and experience.

Mistree's preliminary design template increases the amount of design definition and analysis for the hull form and propeller. Compromise decisions are made after each analysis stage. The input to the preliminary stage is the basic concept and general design knowledge. The outputs are gross ship characteristics and a top level specification of requirements. This is as shown in Figure 4-3. The design problem can be specified using the format from above as:-

Figure 4-3 A model of the preliminary design event [Mistree et. al, 1990]



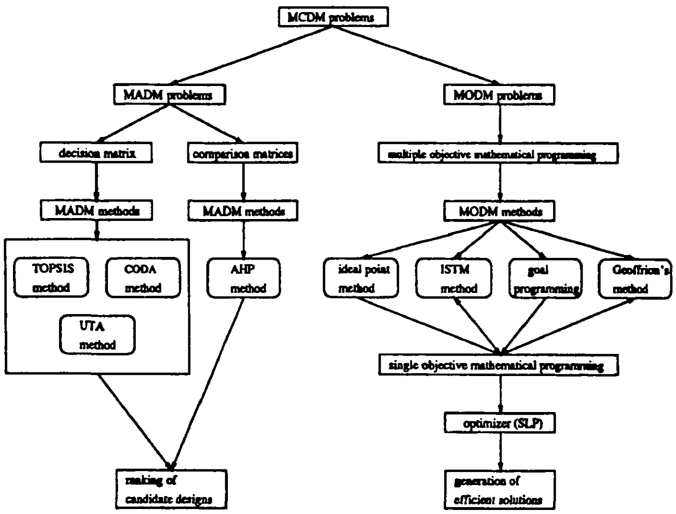
- Given Naval Operational Requirements.
- Find Principal Ship Dimensions;
  Form Coefficients.
- Satisfy Spatial Balance;
  Stability Requirements.;
  Seakeeping Requirements;
  Form Constraints;
  System Bounds;
  System Goals.
- Minimise The deviation function (of performance).

Although the processes used are based on design decisions, the underlying design data for each compromise decision support problem is similar to the mathematical formulation of concept exploration models. Numerical information forms the majority of the data used to form decisions. Using a selection based decision making method does allow the designer greater control over the evolution of a design, as the need to select specific systems and design features based on performance indicators prevents an automatic assumption that a design space is continuous. The use of decision support techniques for hullform design is detailed in [*Peacock et. al., 1997*].

A second design methodology, that advances the role of decision making in the development of a design solution, is Multiple Criteria Decision Making [MCDM]. Multiple Criteria Decision Making methods can be sub-divided for use with two separate problem types, the development of alternative designs [a multiple objective decision making problem (MODM)] and the selection of one from a range existing designs [a multiple attribute decision making problem (MADM)].

Two design tasks can be achieved using these methods, first the synthesis of a design, secondly, the selection of one solution from a range of potential solutions. This is illustrated by the integrated support environment [*Sen et. al., 1993* presented here as Figure 4-4].

Figure 4-4 A Conceptual Framework of Integrated Multiple Criteria Decision Support Environment [Sen et. al., 1993]



The methods used to perform the decision making processes use ranking of design objectives (MODM problems) or attributes (MADM problems) to select the design features that most influence the solution.

[*Sen, 1991*] notes three methods of ranking design features: weighting, prioritising and efficient solution methods. Weighting attempts to assess the relative importance of disparate quantities numerically to allow compromise decisions to be made. Prioritisation uses evidence that human beings take decisions by prioritising the issues. In this case the attributes and objectives of the design task are ranked in order of importance. Both methods are controversial due to the subjective nature of the weighting or ranking system, its influence on the result and the difficulty of formulating acceptable weights or ranks for disparate quantities[104]. Several MODM procedures use efficient solution methods to allow multiple objectives to be manipulated mathematically using goal programming techniques. These minimise deviation of the design performance from design objectives. In [*Sen et. al., 1993*] the interactive step trade off method allows the designer to perform trade off analyses in semi-submersible offshore design.

The method begins with a designer postulating an initial design solution and deciding whether to improve, maintain or sacrifice the performance of that design solution, regarding each design objective. The designer's response is used to adjust the design solution to a new design point. Related to the design of a semi submersible [*Sen et. al., 1993]* these objectives were:-

- Maximisation of payload.
- Maximise allowable centre of gravity given stability constraints.
- Minimise construction costs.

104 For example both Andrews [*Andrews, 1994a*] and Brown [*Brown, 1995a*] suggest the methods used are flawed, but disagree on whether they have a use. Andrews apparently suggesting not, while Brown recommends not rejecting a useful tool because it is imperfect.

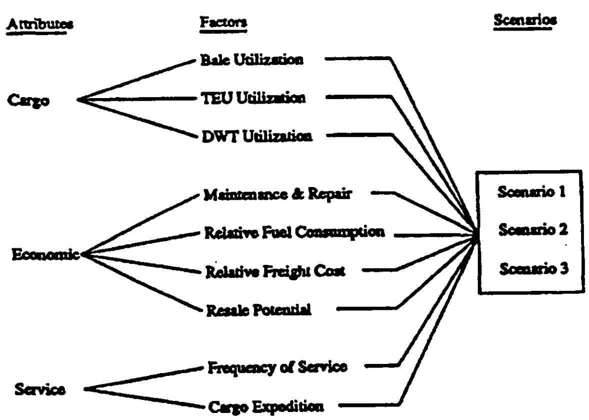
MADM procedures do not require the synthesis of designs, hence efficient solution methods are not applicable [*Sen, 1991*]. Instead design selection tasks use complex procedures for rationalising the weighting[105] process, with the characteristics of the ideal design emerging, allowing the designer to assess which of several candidate designs fully meets the requirements. The general process can be considered as:-

- Several alternate solutions to a design problem are postulated.
- The factors that relate the overall satisfaction of requirements to physical features of the ship design are noted in a hierarchy.
- The importance of each of level of the hierarchy is assessed (for example using the Analytic Hierarchy Process, [*Saaty 1980*]).
- The contribution of each ship design feature to the total ship performance is ascertained.
- The highest scoring design is the most suitable.

The application of such methods to ship design has been demonstrated by the selection of the type of commercial ship to meet specified requirements [*Sen, 1990*]. Other demonstrations include the development of retro-fit options [*Yang & Sen, 1993*] and the selection of one from three similar ship designs [*Sen & Yang, 1994*]. An example of the hierarchy from global features through specific performance attributes to candidate designs was presented by [*Sen & Yang, 1994,* here as Figure 4-5].

The applicability of multiple criteria based methods to a new ship design methodology depends on context. The use of design selection techniques (MADM) is considered valid in merchant design programmes where a relationship between "success" of the design and specific design features can be stated with clarity, by such methods as required freight rates[106] [*Fisher, 1973*]. When applied to the naval design problem, where a method of measuring the success of the design is not so readily related to physical features, this concept is less attractive[107]. As a methodology to be applied alongside the designer's own judgements, confirming previously made decisions or providing reasons to reassess a decision, the methods are suitable.

Figure 4-5 A Hierarchy of Factors [Sen & Yang, 1994]



105 Several methods have been used, Evidential Reasoning [*Yang & Sen, 1994*], Dempster Schaffer theory [*Sen & Yang, 1994*] and the Analytic Hierarchy Process [*Sen, 1991, Saaty 1980*].

106 The required freight rate is a measure of the amount of economic activity required by a specific ship design in order to break even, as a result the most profitable design for a given route can be identified.

The synthesis of a naval design solely by reference to objectives using MODM, is considered inappropriate as goal programming techniques are necessary to synthesise ship design features in MODM. The need to use weighting or prioritising approaches is also very suspect for the definition of naval ship designs as not all naval requirements can be so specified.

4.3.4 Artificial Intelligence Based Approaches

Two techniques simulating artificially the intelligence of the designer exist. These allow the computer to aid, or replace, the designer in the development of conceptual ship designs. The first paradigm uses the artificial intelligence methods of Expert \Knowledge Based Systems [*Turban, 1992*] to store design information, allowing either automatic or interactive design synthesis. A second group of techniques mimic biological processes to map the relationship between the features of the design and their performance. The biological processes modelled using computers are Genetic Algorithms [*Goldberg, 1989*] and Artificial Neural Networks [*Lippmann, 1987*].

Expert and Knowledge Based approaches to ship design are considered natural candidates for use as synthesis methods, due to their ability to include non numerical issues within the design decision making process. This allows more creative influences to enter the design process. In this section their implementation in marine design is discussed.

Most implementations of Expert Systems in a marine design environment assist designers to use in built knowledge to perform design. An example is Gorton's preliminary design tool. A tool was described [*Gorton, 1991*] for the selection of naval systems. The tool uses its internal "expert system" knowledge to infer suitable combinations of systems and complete ship designs to be assessed as a complete mission capable system using "measures of effectiveness". The tool would allow the designer to modify design rules to suit particular scenarios or allow the expert system to develop the design. The output from the system would not be a full concept ship design description. Instead a detailed specification of systems required to perform the operational role would be prepared.

Calisal and McGreer [*Calisal & McGreer, 1991*] used knowledge of an existing style of fishing vessel, government legislation and classification society rules to allow a designer to develop evolutionary fishing vessel designs. The system provides expert

107 An example is the need to subjectively weight the importance given to naval accommodation standards and the

knowledge based on design experience in the selection of principal dimensions, performance assessment and equipment selection. A weight balance module completed the design process. Calisal and McGreer express one potential problem of expert systems with the statement that an equally satisfactory design could have been more easily achieved by a conventional design spiral approach.

INCODES[108] [*Welsh & Hills, 1991, Welsh et. al., 1990*] allows the development of container ship designs using an Expert system. Data within the system belongs to one of the following types of information.

- Domain Knowledge — Knowledge about sub-systems and components.
- Constraint Knowledge — Constraints applied by standards and regulations.
- Procedural Knowledge — Knowledge of the design process.
- Analysis Algorithms — Knowledge of how to evaluate proposal designs.
- Proposal Knowledge — The current representation of the ship design.

INCODES allows the complex problem of container ship design with variable weight containers to be assessed, instead of the constant weight containers that conventional design processes generally assume. The system assesses the principal dimensions of a design that meets the container carriage requirements using rules derived from type ship information. Other rules are "fired" sequentially according to current dimensions, increasing design definition. Rules also define the configuration of the vessel regarding approximate location of major systems, tank arrangements and container locations. This provides an advantage over numerical design methods in that the configuration of the design is considered, albeit only at the simplistic level required for the arrangement of possible container loads. [*Welsh et. al., 1990*] note the importance of visualising the current design solution at all stages of design.

[*Hills et. al.,1993*] developed an "expert critic" within a computer aided layout tool to identify suitable compartment arrangements for marine systems. [*Cleland et. al., 1994*] detail the development of that research for domain independent made to order artefacts, while [*Guenov et. al., 1994*] explores the addition of cost estimating and product models.

The system detailed by [*Hills et. al., 1993*] links the features of optimisation tools [in this case simulated annealing] detailed previously with the advantages of the expert system. The simulated annealing element developed candidate solutions, while the knowledge based system assessed the solutions for validity against stored design knowledge. When applied to internal configuration development in domains where

number of helicopters carried. The exact relationship between the two is difficult to ascertain.

108 INCODES : Intelligent Concept Design System

valid and comprehensive domain specific and generic knowledge can be detailed, the approach employed by [*Hills et. al., 1993*] is considered to have merit. However this system is employed solely to develop internal arrangements. It is considered that the step change in complexity that would result from an integration of preliminary development of gross characteristics alongside the complexity of the internal arrangement system could rely heavily on the development of optimum gross characteristics using an optimisation or similar approach.

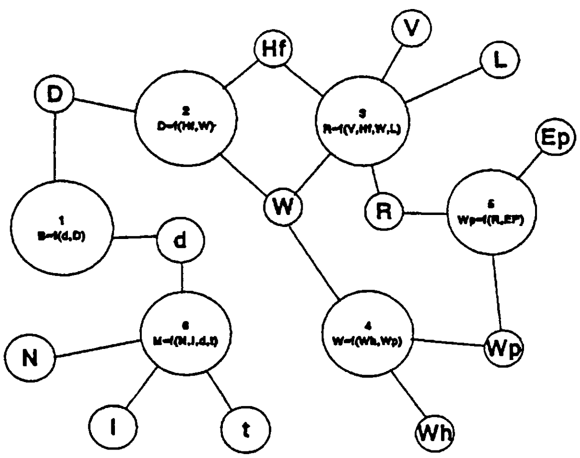
An interesting observation [made in both *Cleland et. al., 1994, Hills et. al., 1993*] is that practical experience with computer automated layout development across several design domains suggests that the designer is required to revise the computer generated solution to provide an elegant solution.

QUAESTOR is a knowledge based naval design system [*van Hees, 1992, 1997*]. Application to the conceptual design of a remote controlled mine sweeper drone was detailed by [*Wolff & Zuiddam, 1993, Wolff, 1994*]. The application to propeller design was detailed by [*van Hees, 1992*]. QUAESTOR assumes a naval design description contains the following information [*van Hees, 1992*]:-

- Mathematical Relationships.
- Constraints.
- Parameter Expression (a ratio description method).
- Parameters.

A designer maps individual elements of design knowledge such as algorithms or rules to a template. The template allows the designer to perform synthesis, making decisions and receiving based on current design information feedback [*Wolff & Zuiddam, 1993*]. This allows the results of designs decisions to affect other design issues, with the changes progressing through the template, triggering design rules, developing a solution. A typical template is detailed in Figure 4-6.

Figure 4-6 A Typical QUAESTOR Template [Wolff & Zuiddam, 1993]



The order of calculation and knowledge capture is not fixed. Hence the design process employed is not rigidly sequential. The system requests information and proposes relations as necessary to form a system that can be solved. For the Minesweeper example [*Wolff & Zuiddam, 1993*] the designer supplies a magnetic performance figure to be achieved and asks for the assessment of cost of a design to achieve that performance. Trade off studies are performed on absolute performance and on specific design features such as hull structure thickness [*Wolff, 1994*].

The use of the designer to construct or modify the template suggests that any "Black Box" effects are avoided by the incorporation of meta design. Other advantages of the QUAESTOR approach include an ability to develop templates for specific ship types and re-use design knowledge. However it is considered unlikely that the underlying knowledge required in order to develop a genuinely valid specific template for each design type is available. If more generalised data is used the advantages of modelling each design as a different template may be reduced.

The use of expert and knowledge based systems aid the ship designer in specific preliminary design tasks, by replacing the more traditional sequential design spiral with a free-form iterative approach. The advantages of design knowledge retention and inference of overall ships features from specific features, provide a good synthesis approach providing reliable design rules are used. However a difficulty exists in the assessment of the reliability of the rules prior to synthesis. The ability to model design rules in a non mathematical form and to assess the impact of configuration on the design, provides an open design method, especially when compared with optimisation routines.

Disadvantages include the need for the designer to create valid rule bases for each specific type of design and an inability to create radical new designs for which current rules are inapplicable. This is particularly relevant for designs that are not designed to classification society rules, for example Lloyds [*Lloyds, 1998*]. Such rules specify in detail many merchant ship design features. Naval regulations are not so specifically stated[109] and allow much greater variation between designs and greater designer freedom. Thus as a concept design methodology for naval ships based on an Expert system concept is not currently desirable.

Genetic Algorithms and Neural Networks

Genetic Algorithms are the computer based application of evolutionary selection theories to problem solving. Their use in ship synthesis is at an evolutionary stage. Marine applications include merchant ship sizing [*Sommersel, 1997*] and the design of optimised merchant ship structures [*Okada & Neki, 1992*]. The application to ship structural design demonstrated the development of a steel hatch cover from five independent variables and one dependant variable, resulting in the minimisation of hatch cover weight. Design was performed automatically, without recourse to the designer after problem specification, by multiple iterations, in which each genotype[110] is subject to the following processes:-

- Recombination.
- Mutation.
- Natural Selection (based on fulfilment of a "fitness" function[111]).

The final genotype when decoded represents the most "fit" (lowest weight) design.

Applied to supply ship design by Sommersel [*Sommersel, 1997*] the fitness function was not a single criterion. Instead target values for 50 criteria were postulated. These were weighted in order of importance and a penalty function evolved detailing the degree of requirement satisfaction. The geometry model and design style was specified by Sommersel along with outline features of each of nine spatial zones that formed the ship. This allowed the introduction of numerical values for local space utilisation (areas for cargo, tank volumes etc.) to be assessed and included alongside overall dimensions within the evaluation criteria.

The application of Genetic Algorithms to ship design closely resembles the optimisation tools detailed in Section 4.3.2. The similarities include the production of an initial design description vector, the use of iterative search mechanisms to develop new design data, followed by numerical evaluation of the "fitness" of the design description. As a result the disadvantages of using Genetic Algorithms for surface ship design are

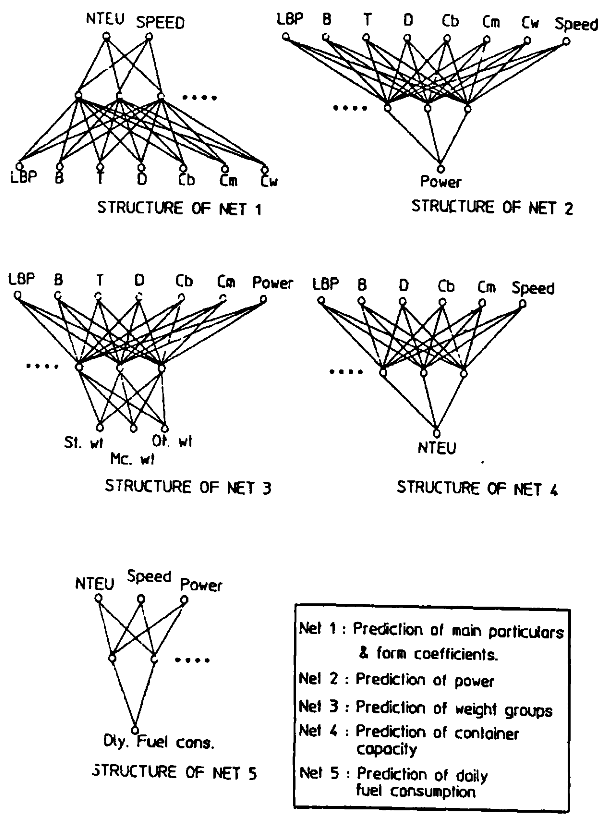
109 Currently this is a definitive statement but may alter as quasi-classification society rules for naval ships such as being proposed by Det Norske Veritas and Lloyds are introduced.

110 A Genotype is the description of the design artefact in a coded form.

111 The fitness function performs a similar role to the objective function in optimisation methods and suffers from the same dis-advantages.

similar to those specified in Section 4.3.2[112].

Figure 4-7 Overall Structure of a Neural Network Ship Design Model [Sha et. al., 1992]



Neural Networks [*Lippmann, 1987*] simulate the mechanisms by which it is believed the brain operates. Using computer analogues of the elements of the brain a neural network is trained, by example, to recognise patterns between input and output data. Two applications of Neural Networks in the marine design community are, firstly assessment of the roll damping characteristics of a ship, reducing the need for complex analytical predictions [*Haddara & Hinchey, 1994*]. Secondly Sha et. al. [*Sha et. al., 1992*] presented a container ship design system based on the development of five separate networks each developing a specific aspect of the design. Each net is trained from existing ship data.

The five nets contribute to an initial estimate of all major (numerical) design characteristics that are refined using design constraints and a non linear solver. The structure of the system is shown in Figure 4-7.

An advantage of neural networks is the ability to model situations for which input data is "noisy[113]" or in which there are many complex interactions between design issues. Such systems are not really considered suitable for naval ship design as a large database of existing designs is required to train the network to recognise patterns. The slow rate of introduction of new naval ship classes prevents modern technology influences being used to train such a naval design synthesis network, to allow

112 Similar methodologies to Genetic Algorithms have been demonstrated in the use of Simulated Annealing [*Ingber, 1993*] based on the cooling of metal alloys, and Evolution Strategies applied to multi objective optimisation [*Jang & Shin, 1997*]. Both systems share similar advantages and disadvantages, differing in the detail of the search mechanisms and population derivation techniques.

113 Noisy data is that which is incomplete, imprecise, or unclear (fuzzy).

prediction of the likely characteristics of a new design. Conversely sufficient numbers of commercial container ship designs exist to enable commercial design systems to be trained. Hansen [*Hansen, 1997*] suggests that only six commercial examples[114] are required to present a system capable of modelling that design style. The neural network is not capable of modelling design issues that cannot be modelled with numerical data. The Neural Network acts as a "Black Box" [*Jones, 1970*] as it's internal workings are hidden from the designer and have no physical relation to the design[115].

4.3.5 Configuration Based Approaches

The importance of configuration, layout or spatial approaches was stressed by [*Guenov et. al., 1994*] *"Spatial Engineering is ... an activity of fundamental importance when designing complex, multi-system made to order products"*. This view was based on a need to consider practical design considerations such as structural integrity and life cycle costs in the design process. Configuration based approaches to preliminary ship design can be classified into two forms.

In the first approach configuration plays a subsidiary role in the main synthesis and is further considered with regard to improving the arrangement or form of the vessel. An example of the first type of approach was presented by [*Carlson & Fireman, 1987*].

The second form of configuration based approaches are derived from the research of Andrews [*Andrews, 1984*] in which a need for a holistic synthesis including both numerical and graphical synthesis styles was expressed. The practical implementation of configuration based approaches to naval design is proposed [Figure 5-3] and developed further in [*Andrews, 1994, Andrews et. al., 1996, Andrews & Dicks, 1997*] as the Building Block methodology.

An application of configuration based design to naval vessels was detailed by [*Carlson & Fireman, 1987*]. This details a "General Arrangement Design System" [GADS] for use in preliminary and detailed design stages, after gross ship characteristics have been developed. The methodology behind GADS aims to improve the ship arrangement process by the following strategies [*Carlson & Fireman, 1987*]:-

> "Reducing the time necessary to develop a general arrangement..."
> "Eliminate design data inconsistency ...."
> "Allow real time arrangement analyses ..."

114 In this case all six designs are from the same ship yard and hence likely to show a specific design style.

115 [*Hansen, 1997*] criticises the work of [*Husted & Nørksov, 1997*] as a "black box" regression /interpolation model, when applied to Marine Design.

The mode of operation of GADS is that of a *"Computer Aided, not computerised interactive design system"* [*Carlson & Fireman, 1987*]. To meet this requirement a general arrangement methodology was produced, summarised here:-

- Identify and understand the ship design requirements.
- Estimate functional space requirements.
- Define the major internal subdivision and superstructure envelope.
- Locate the major passages and accesses.
- Assign functions to zones of the ship.
- Define boundaries of functions by bulkheads.
- Calculate compartment spatial requirements.
- Define equipment removal routes.
- Prepare general arrangement drawings.
- Prepare space utilisation report.
- Circulate drawings, receive comments and iterate.

This methodology is considered to be successful in terms of achieving the above aims. In comparison with the methods derived by [*Andrews et. al., 1996*] for holistic ship synthesis, it is limited in scope. This is due to the exclusion of the impact of ship configuration on gross ship characteristics. The inability to modify the ship design characteristics from consideration of the configuration removes this design methodology from consideration for a new preliminary design methodology. Other approaches to configuration based design methodologies concerning merchant practices have been produced by [*Han et. al., 1994, Kang et. al., 1994, Lee et. al. 1991, Levander, 1991*]. The lesser importance assigned to the arrangement of compartments by [*Han et. al., 1994*] suggests the influence of configuration of the ship design in Han's BASCON system was mainly the visualisation of hullform design features with a view to the designer accepting or rejecting the hullform. The methods of evolving the ship were similar to numerical design methodologies, with the designer adding to the numerical description by use of his creativity and experience through the visual medium.

[*Kang et. al., 1994*] demonstrated a similar system based on three separate design tools for concept design, hullform design and compartment design, allied to a common three dimensional geometry model. The separate and sequential nature of the three tools suggests that the definition of gross ship characteristics is performed before further development of the hullform and internal arrangement.

The above design methodologies succeed in a limited introduction of configuration issues within the design methodology. However the requirements for a new design methodology detailed in Section 4.2 require features that none of the above methodologies fully satisfy notably the ability to influence internal and external arrangements before design dimension selection. Only Han [*Han et. al., 1994*] attempted to introduce this approach. One unsatisfied feature is the lack of a comprehensive synthesis approach dealing with the functional aspects of systems and their influence on the whole design. Another is a perceived inability to deal with radical design forms in their published form.

Levander's system based approach to cruise liner design [*Levander, 1991*], while not specifically noting configuration as the basic method of design noted that all liner design issues can be considered as either part of the "Hotel Function" or the "Ship Function". Levander's design approach, while not explicitly architectural in nature considered the spatial requirements of the passenger as paramount and attempted to design the ship about the satisfaction of the passenger. For example Levander noted the difference between traditional ship design approaches, in which the hull is developed first, and his approach where the mission description leads to a economically feasible design via a functional description and technically feasible alternatives. Levander illustrates the influence of the percentage of outside cabins on the form of the vessel at the system description level. Levander's extreme case leads to a Trimaran form. The summary of the system description of Levander is noted as being areas and volumes, but due to the influence of style on spatial characteristics it is considered that there must be an architectural component even though there is not a complete design arrangement. Following the finalisation of the system description, weights, costs and a full design description are sequentially introduced. While applicable to cruise ships, the direct application of Levander's approach to naval ship design is not considered useful. This is due to its reliance on the economic aspects of passenger carriage which can be considered at the early stages as purely a hotel function problem, ignoring the remainder of the ship description until later.

Many of the elements of Levander's description are relevant, for example the introduction of a hierarchical description of the ship as a system based on function, or the start point of design as being consideration of the mission may be directly relevant to naval ship design. These features when applied to a naval ship would allow illustration of the preliminary design issues of cost, technology and requirements.

Methods of introducing configuration into naval ship design were proposed by Andrews[116]. Andrews [*Andrews, 1981a*] discussed then current approaches to ship design and concluded that attempts to synthesise the design of naval ships using numerical methods neglected the ability of the designer to interpret non numerical

116 In papers between 1981-1998.

design requirements, and to design creatively. Given the increasing complexity of the design environment, Andrews recommended that *"A solution seems to lie in a combination of ...an approach to form selection that explores the disposition of space concurrently with form selection ..."*. The solution was considered to be an application of Computer Aided Architectural Design to the naval ship design process. This integrates the development of gross design characteristics with configuration, allowing layout issues to affect the features of the emerging design. This was justified on the basis that all space within a naval hull is not equally valuable. Numerical balancing of space is not sufficient to assure that a ship is capable of meeting the requirements of systems and functional issues. At the time of publication the limitation of the physical implementation of the recommendations of Andrews were those caused by the lack of suitable computer based design tools.

Andrews' theories progressed to include the stage at which architecture was integrated into the ship synthesis [*Andrews, 1986*]. This paper suggested that the sequential synthesis [*Andrews, 1984,* here as Figure 4-8] which typified then current preliminary warship design process should be replaced by an integrated or holistic synthesis in which the primary generator [*Darke, 1979*] and the designer's idiosyncratic stamp [*Daley, 1983*] were allowed for. The resulting concept design method included spatial and stylistic influences, as a holistic synthesis [Figure 4-9]. Figure 4-8 can be

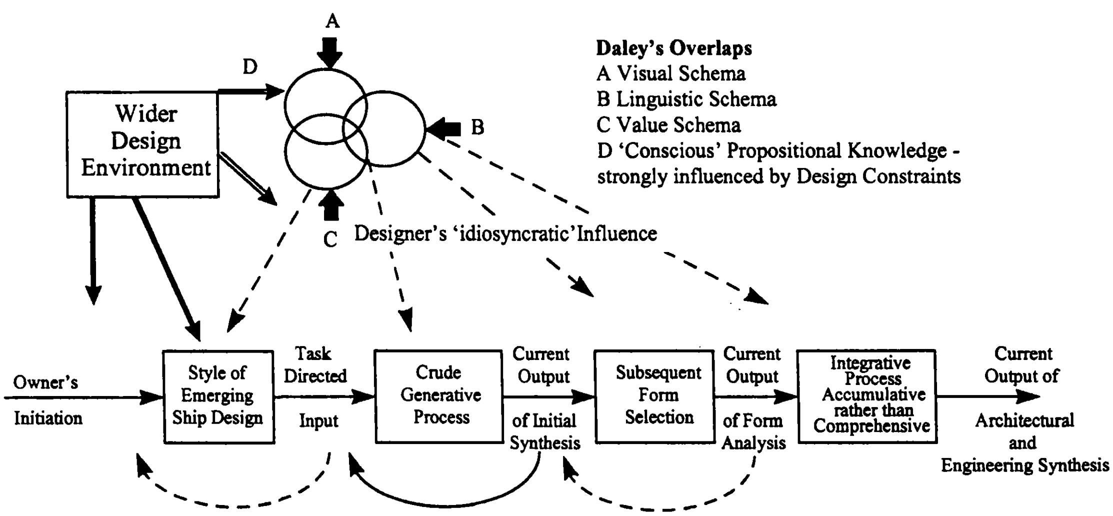


Figure 4-8 A Summary Representation of Current Sequential Synthesis in Ship Design [Andrews, 1984]

used to represent the design processed detailed in Section 3.4 where a simple initial sizing is followed by an assessment of the design geometry in a parametric survey and a final general arrangement stage. However each stage is undertaken with incomplete knowledge and must often be re-iterated, "accumulative" rather than "comprehensive" process. It can also be seen that while the designer's own influence is noted in all design stages, his input into later stages is limited by the nature of the initial synthesis. A comprehensive synthesis was the main aim of the approach noted in Figure 4-9, with all influences affecting one synthesis stage in which all influences, whether related to the task, the nature of naval ships or the designer's own creativity could be allowed to affect the output of the synthesis. It should be noted that this synthesis approach also retains the feedback, iterative loop to allow the emergence of both a solution and an updated requirement.

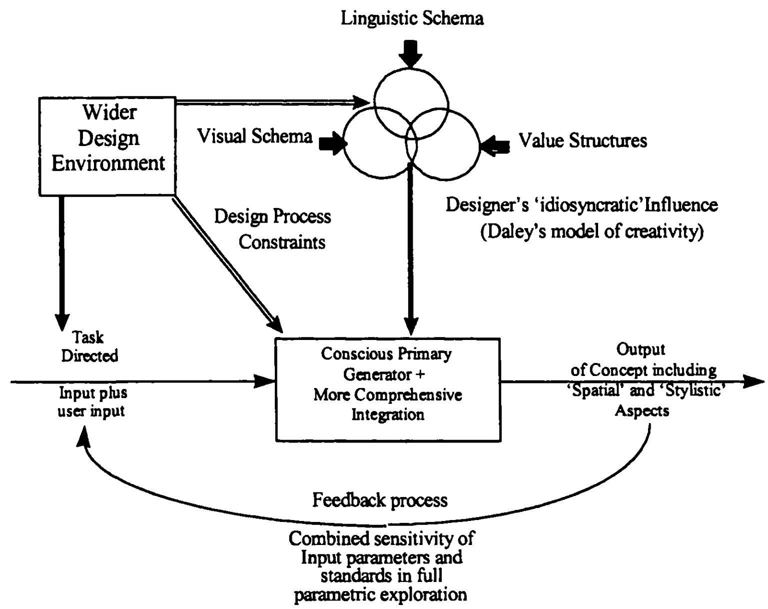
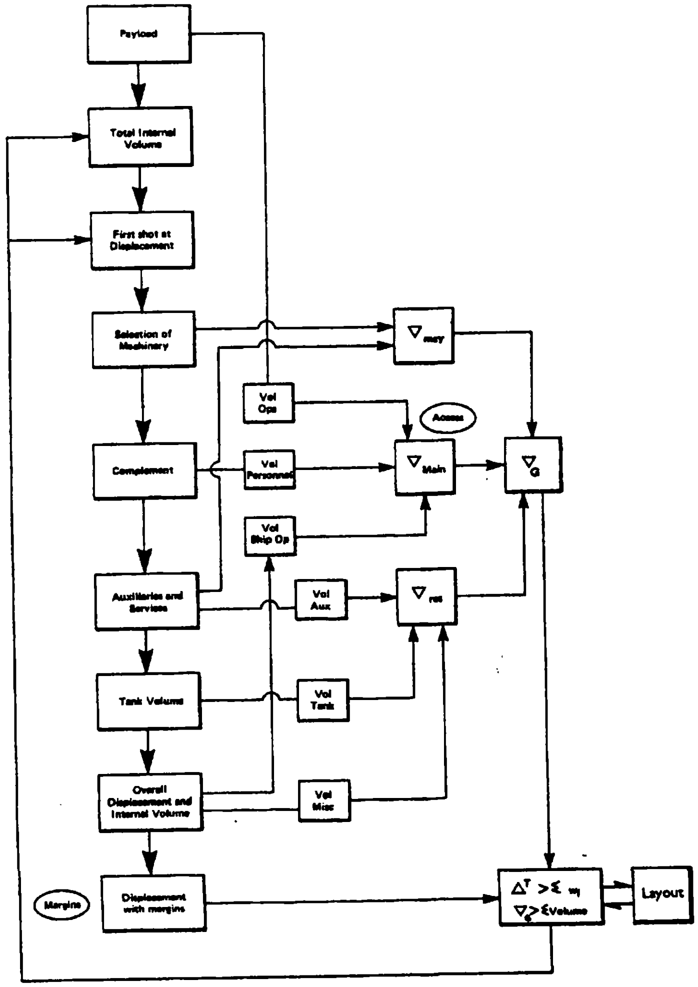


Figure 4-9 A Holistic Approach to a Fully Integrated Ship Synthesis [Andrews, 1986]

The holistic approach advanced by Andrews was partially implemented in two forms. The first was a modification to the initial ship synthesis with spatial disposition located at the end of each sizing cycle, before feedback [Figure 4-10]. The second implementation was the use of compartment adjacency information in the specification of ship arrangements. Following the development of the holistic synthesis [Figure 4-9] of Andrews, an application [*Andrews, 1993, 1994, 1998*] is the use of a configuration based methodology in which all design elements and influences are used to develop both the gross characteristics of the vessel and its configuration. The ship design is detailed using graphical representations of ship functions as "Building Blocks". This allows a designer to use the locations of Building Blocks to develop the design in an iterative manner. Numerical, functional and configuration issues can be addressed at all stages of design. This allows the designer to consider all design issues as required and hence develop the design in a manner suited to the specific design requirements. The

Figure 4-10 Introduction of Spatial Tools to Initial Ship Synthesis [Andrews,1986]



ability to place Building Blocks on the CAD system allows a designer to fully visualise and control the design synthesis, avoiding the problems of Black Box design methods.

The types of design developed to be developed are extensive, given suitable sufficient design information, as most design issues can be represented graphically or numerically.

Andrews [*Andrews, 1998*] noted the complexity of modern ship design, the current moves to a concurrent engineering approach and the increased capabilities of computers and suggested the Building Block approach as a recommended approach to naval ship preliminary design and to all complex design problems.

4.3.6 Comparison of Alternative Approaches

Many of the design methods and methodologies detailed in this section, but not all, share similar characteristics. Notable shared characteristics are the use of wholly numerical methods of design description and the use of optimisation or similar methods to solve a set of "design equations". Other shared characteristics include the use of methods that are not visible to the designer, Black Box methods. Such issues suggest the use of these methodologies within the constraints applied by naval design, is disadvantageous. The naval ship design space is not a continuous space [*Brown 1995a*] as many design features such as deck numbers are discrete. A small change in requirement may lead to a large change in overall solution size, if the designer is forced, for example, to change the number of decks. A mathematical description of the ship design process that does not recognise this is misleading. Many features that render the ship design space discontinuous are related to configuration, for example the number of passing decks and superstructure style. These cannot be readily identified using mathematical means.

The representation of designs by complex mathematical relationships based on particular ship types reduces the applicability of design methods to unconventional forms. The algorithms used become specific to each ship type. Optimisation, neural nets and genetic algorithms do not allow the designer to readily add creativity or judgement within a design iteration. Similarly the reliance of neural networks on algorithms that are not related to physical data is not useful in this respect.

A more open methodology is required capable of investigating specific attributes, but not reliant on methods and data from type ships. The need for open design methods rejects the use of single or multiple evaluation functions, objective function, weightings and rankings. Such methods rely on the designer specifying, in detail, the relative importance of every aspect of performance. Specifying all requirements precisely, along with their relative importance, mathematically, is impractical. Given that naval ship designs are driven by ship configuration, none of the mathematically based design methodologies allow the designer to creatively investigate the configuration.

Expert systems offer some of those features required for a new design methodology, as non mathematical descriptions can be used to describe design features. However when applied to naval designs, the nature of the rule base and an inability to deal thoroughly with configuration related issues or unconventional designs, does not suggest it's adoption as the core of a new methodology.

Decision making methods are both attractive and flawed for use within a new design methodology. They allow a designer to perform the meta design task before each new style of ship design ensuring that the design task is fully considered before commencement. However compromise decisions or weighting assumptions are made by optimisation or goal seeking methods. When optimisation is based on a small design issue independent of other considerations this is acceptable but decision making by optimisation is not sensible when a multitude of design issues are pertinent.

This suggests that the only suitable design methodology is not based on the automated solution of algorithms and should not be opaque to the designer. A suitable methodology must include the ability to consider the configuration of the design when design decisions are taken. One approach meets these requirements, a configuration based approach derived from Andrews' research, with its implicit use of system and configuration issues alongside numerical data at all decision making stages. The most useful and wide ranging methodology to implement the ideas of Andrews, regarding integrated naval ship design, is the Building Block Methodology. The Building Block methodology forms the basis of the Surface ship design methodology described in this thesis.

This chapter has highlighted the shortcomings inherent in current design methods resulting from the separate consideration of numerical or spatial design descriptions. There is a need to integrate both aspects into a single process, with the aim of ensuring that the design presented by the project team to appraise both risk and financial aspects properly reflects both these aspects, allowing the final requirement to emerge. Failure to do so can result in design issues remaining hidden until later in the design process with significant consequences. Thus the following problem statement is proposed:-

> *"A new design methodology is required which will introduce the elements of configuration and functionality into preliminary ship synthesis giving equal emphasis alongside numerical balance. This will facilitate a proper appraisal of risk, technical and financial design issues.*
> *Such a methodology is required to be supported by a comprehensive and integrated preliminary design computer system capable of aiding the designer in the synthesis process."*

In Part two a Building Block design methodology is demonstrated suitable for naval surface ships of both monohull and unconventional form, with a view to solving the above problem statement.

Part 1 Conclusions

The first part has developed the concept that the design processes that are currently in use for naval ship preliminary design do not allow the designer to add all necessary design influences into the design at a stage at which they can affect the resulting ship design's gross and localised characteristics. Thus a new design methodology, the Building Block methodology adopted for surface ship use, is proposed for discussion in Part two.

Part 2 Evolution of a New Design Methodology

Part two develops and demonstrates the Building Block design methodology, that Part one argued is the most suitable methodology for modern naval preliminary ship design. Part two outlines the Building Block design methodology and its application to Surface Ships. Chapter 5 considers all aspects of the design methodology and details, with the aid of a simplified example, how a design is developed using the methodology.

An important concept in the development of a ship using the Building Block design methodology is the recognition of the role of Darke's primary generator, which provides a key to the designer making choices in both initial synthesis and downstream. The importance of this concept to the methodology leads to a detailed definition of the concept and consideration of the apparent design generators of recent ship designs. This is detailed in Chapter 6.

Chapters 7 and 8 detail the application of the new design methodology to several types of modern ship design notably a monohull escort, a landing ship for tanks, a Trimaran escort design and several SWATH escort designs. These chapters detail the advantages of the design methodology over current numerical synthesis methods. Part three of the thesis concludes the discussion of Parts one and two and develops areas for further discussion and development.

5. A CONFIGURATION BASED SHIP DESIGN METHODOLOGY

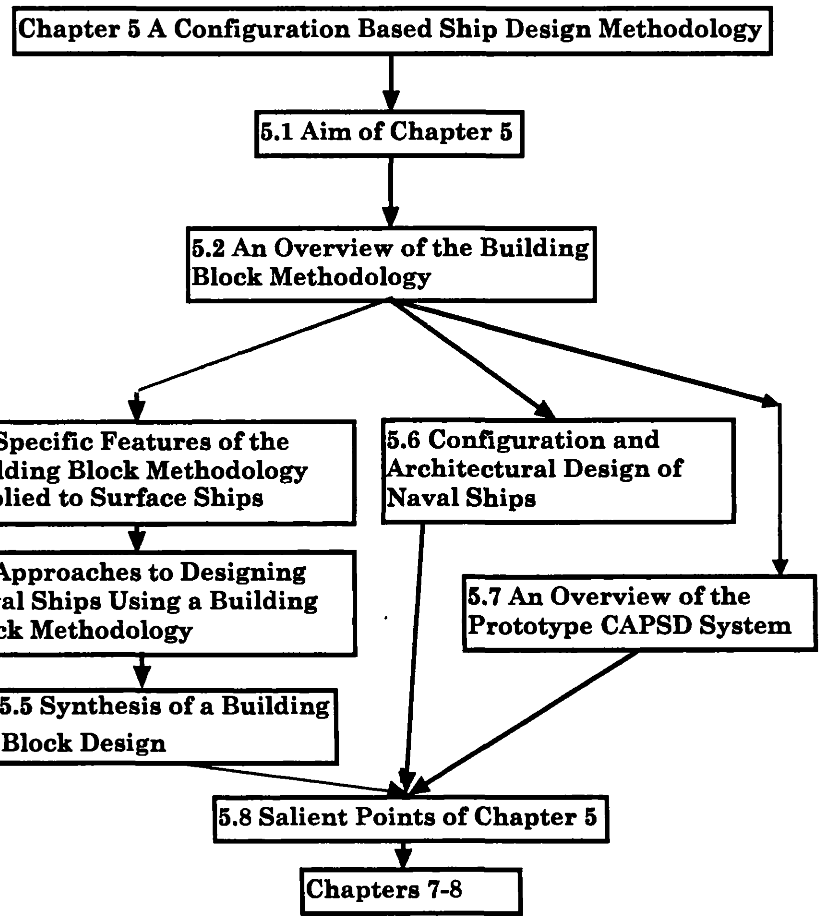


Figure 5-1 Chapter 5 Schematic

5.1 AIM OF CHAPTER 5

The requirement for a new surface ship design methodology to improve current preliminary ship design methods was detailed in Part one. This chapter details the basis for the new Building Block design methodology. The new methodology for preliminary ship design incorporates configuration and functional issues concurrently with definition of weight and space. The Building Block design methodology uses the definition of the contents of the ship description as "Building Blocks" each linked to a function or system of the ship design. The chapter provides an overview of the new design methodology [Section 5.2] and proposes its application in the current ship procurement process [Section 5.2.1]. The surface ship Building Block methodology is developed in Section 5.3. The methods used in the surface ship methodology are expanded in Sections 5.4-5.6. Appendix B.1 similarly details the submarine design variant of the Building Block design methodology, defined by Andrews [*Andrews et. al., 1996*], used by the author for an example design [*Dicks & Spragg, 1995*, summarised in Appendix B.2]

To implement the Building Block design methodology as a prototypical CAPSD system, the role of the computer in design is investigated in Section 5.7. The discussion leads to the requirement for computer aided but not computer dominated design. A description of the prototype computer system is presented although the associated ship design examples are not detailed until Section 7.2.

5.2 An Overview of the Building Block Design Methodology

The following statements outline the philosophy of the Building Block design methodology. These statements can be represented by Figure 5-2.

- A need for a new conceptual design is conceived and an idea of the likely design style to meet that requirement suggested.
- Drawing on novel ideas or historical data a series of Building Blocks are defined. Each Building Block contains geometric and technical attributes regarding the functions of that block.
- A design space is generated and Building Blocks configured as required (or desired) within the design space.
- Overall balance, and design performance are investigated using simple and flexible algorithms and as necessary, using analysis programs.
- Features of the design such as size and configuration are then manipulated until the designer is satisfied.
- Decomposition of the building blocks to greater levels of detail is undertaken, as necessary to increase confidence in the design solution.

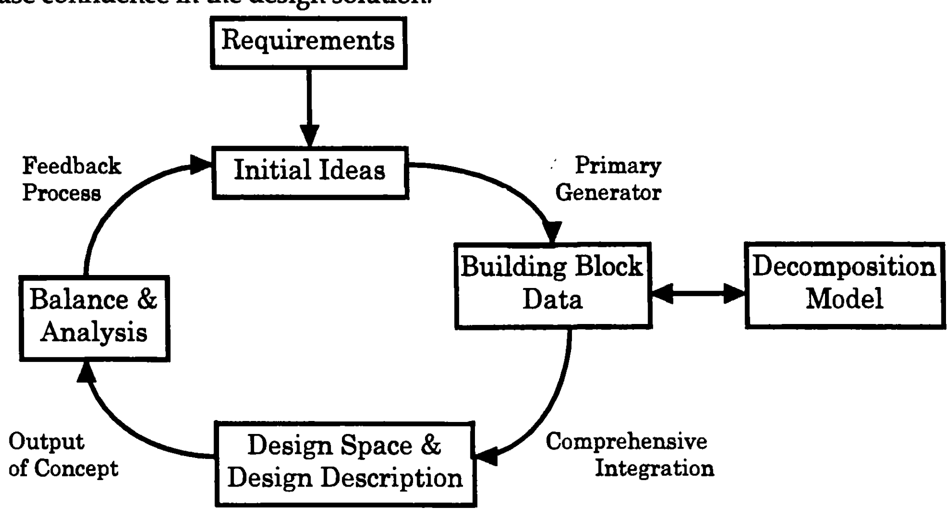


Figure 5-2 Overall Features of the Building Block Methodology

This methodology is fully compatible with the holistic approach to naval ship design presented by Andrews [*Andrews, 1986*], shown in [Figure 4-9] and discussed in

Section 4.3.5. It provides all advantages arising from an early inclusion of configuration issues into ship design.

The methodology relies on the designer making decisions based on all design issues. The results of these decisions become visible, affecting all ship design characteristics, not only those features that can be manipulated using mathematics. This is necessary to avoid the problems of numerical synthesis methods as detailed in Section 4.2. Not all information is available at a suitable level of detail and certainty at all stages of the design. Hence initial decisions must be re-affirmed by iterative design techniques. This requires the ability to change design representations as the design evolves. Other Building Block methodology features include:-

- An 'open' or 'Glass Box' approach to design allowing the designer to incorporate his experience and judgement in the process, rather than relying on a 'Black Box' system which has usually been produced by someone else and may be opaque in its assumptions and limitations.
- The methodology and resulting computer based systems are 'soft', so that the structure and processes used can be readily updated and improved algorithms or even different modelling features readily incorporated.
- Allowances for design margins and specifically access can be made as part of the particular design evolution, rather than using default values based on possibly inappropriate historic data values which may not reflect the actual configuration being designed [*Andrews, 1987*].

5.2.1 Applications of the Building Block Methodology in Naval Design

The first use of a Building Block style description of a naval ship was presented by [*Andrews, 1984,* Figure 5-3] as a method of applying that author's holistic synthesis to architectural arrangement in a warship. This later developed to include a submarine specific methodology implemented by SUBCON [*Andrews et. al, 1996, Dicks & Spragg, 1995*] as detailed in Appendix B. The submarine implementation of the Building Block methodology is represented as a descriptive design methodology by Figure 5-4.

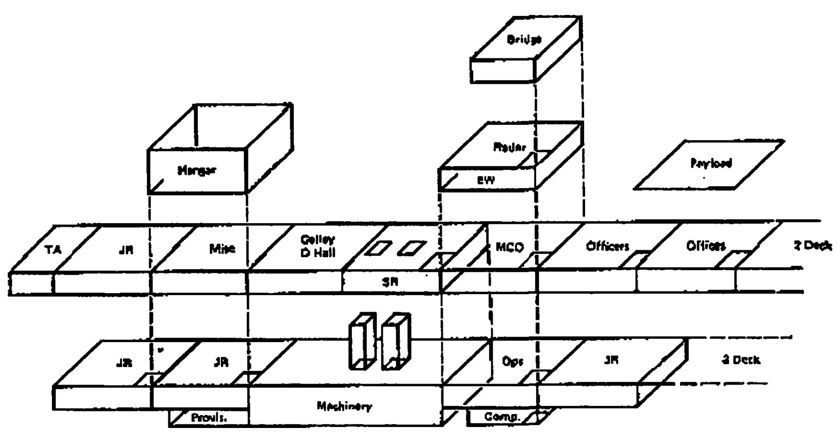


Figure 5-3 How a Holistic Synthesis might be achieved [Andrews, 1984]

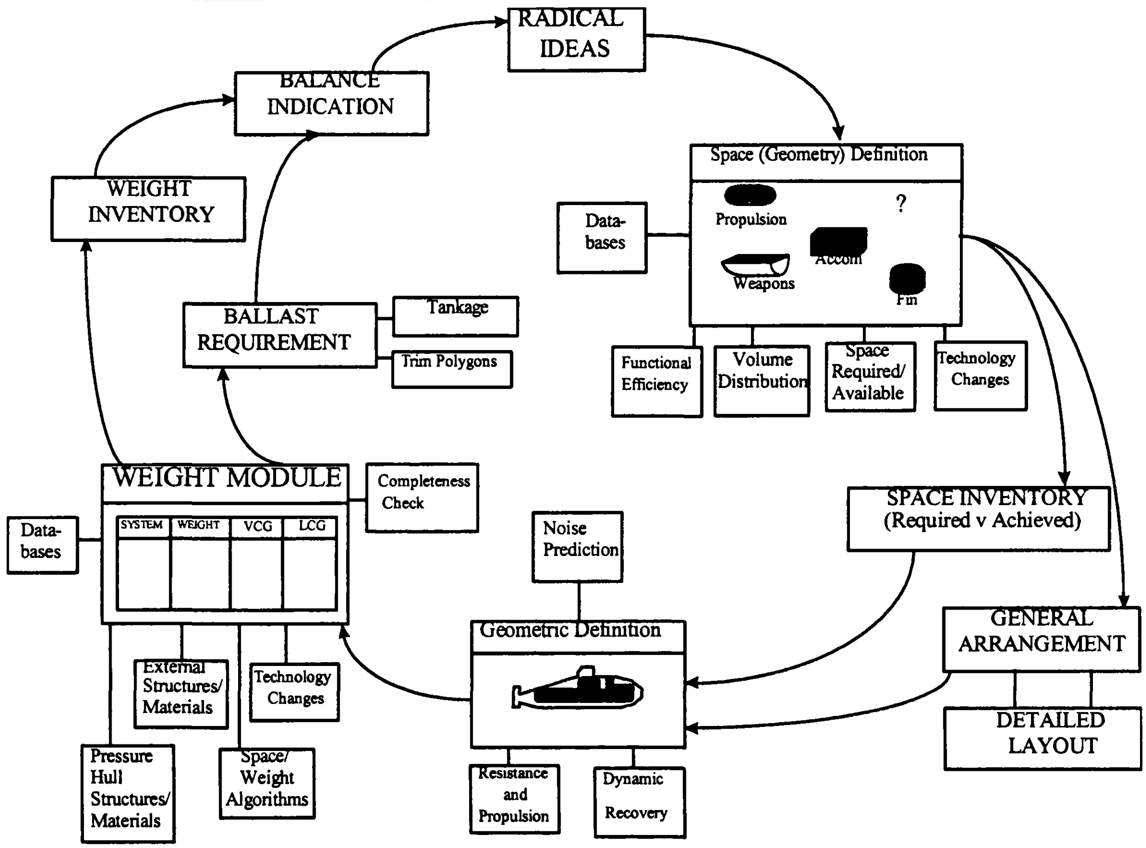


Figure 5-4 Submarine Building Block Design Methodology [Andrews et. al., 1996]

The SUBCON suite of computer programs and associated Submarine Building Block methodology are applied to the development of modern submarine designs. A major role is the development of "radical" designs[117]. Previous methods of submarine synthesis [*Jackson, 1983, Burcher & Rydill, 1994*] have not explicitly provided an ability to model the impact of novel design features comprehensively. An example of the type of radical design is that presented by Houley [*Houley, 1993*]. The features of the Building Block submarine design methodology reflect this, as demonstrated in Appendix B. Similarly a major role of the Surface Ship Building Block methodology is intended to be the development of unconventional or radical designs, aiming to notify the design team of the true impact of the newly introduced hullform or technology on the design.

A new design methodology proposed for use within the naval surface ship preliminary design community that must be capable of existing within the constraints detailed in Section 3.5. This section places the Building Block methodology within the

[117] Several British and American submarines have effectively been evolutions of a previous design with small changes, due to the cost and technological constraints on the design programme. Changing technological and strategic situations suggest that future submarines may need to be radically different in arrangement and capabilities [*Emery, 1995 Houley, 1993*].

context of current and future procurement programme styles. Firstly, the application of the methodology within the Concept-Feasibility-Detailed Design [*Bryson, 1984*] process is examined.

The Building Block design methodology can be utilised within all preliminary design stages of a sequential ship procurement program. In preliminary design stages the flexible nature of the methodology allows a designer to utilise design configuration and functional issues to effect changes on overall ship characteristics. This impacts on the design information available to the design team. An advantage of the Building Block methodology is the flexibility to include all data types. As a result the Building Block methodology supplants existing processes used in preliminary stages of the design process such as numerical initial sizing.

Potential applications of the methodology at the detailed design stage are limited as the design methodology does not have a useful role once the major features, and characteristics of the design have been formulated. At this stage the remaining tasks are directly related to the production of the vessel. However interaction is necessary between computer systems implementing the Building Block methodology and detailed design product models [*Foster, 1998*], anticipating the downstream sharing of data from the conceptual design. Similarly the concurrent procurement environments envisaged by [*Tibbitts & Keane, 1995*] suggest that the Building Block methodology should be able to utilise detailed design and production information. In turn the methodology could provide sufficient description to enable design activities, such as Simulation Based Design [*Jons et. al., 1994*] at an early stage. This allows construction and configuration based compatibility issues to influence the design at an early stage. The methodology is not appropriate to detailed design, but detailed design tasks may influence the design model. In a concurrent engineering regime, the shipyards product model may include the conceptual Building Block model as one its core components.

5.2.2 Definition of a Building Block

The Building Block is the fundamental element of the new surface ship design methodology. A Building Block contains all information required to perform a particular function within the broader ship design. With multiple Building Blocks, each representing different functions, all important design characteristics can be represented both graphical and numerically. The ship design can be considered to be at the head of a functional hierarchy of Building Blocks.

Examples of typical Submarine Building Blocks were presented in [*Andrews et.*

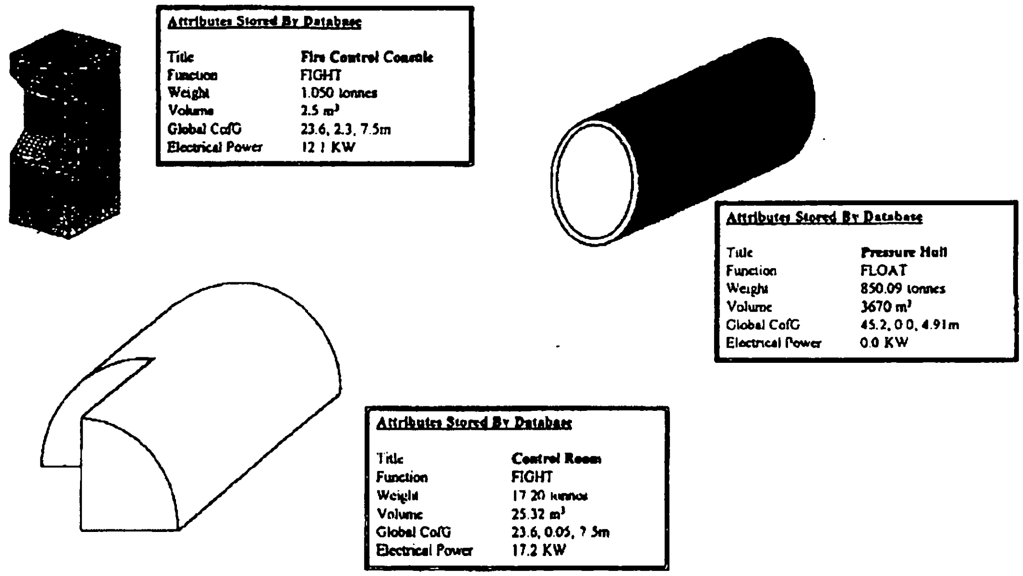


Figure 5-5 Typical Submarine Building Blocks [Andrews et al, 1996]

al., 1996, Figure 5-5]. The data contained in a single Building Block description can consist of four types:-

- Numerical Data : Fixed data regarding the function of the Building Block. E.g. Cooling Water requirement.
- Parametric Data : Data that is dependant on other Building Blocks for its magnitude. E.g. Structural weight.
- Geometric Data : The geometric form of the Building Block.
- Descriptive Data : Such as designer notices, functional details.

Building Blocks are graphically defined by the spatial requirements but other forms of design information necessary to perform the function are included as integral parts of the Building Block description. Such issues include weight, performance related issues (e.g. speed) and requirement related issues (e.g. low Radar Cross Section). The requirements of one Building Block often specify the required performance of another Building Block, acting as constraints. Alternatively a summary of all requirements for a certain function can be provided based on the total requirements of other building blocks. The functional requirements of each Building Block are estimated using data based upon production capabilities, ship design databases, designer estimates and judgement or analysis based estimates of performance. Each source is used as appropriate, the designer taking care to apply design margins as appropriate on a functional basis [see Section 5.4.4].

At the earliest stages of ship design it is impractical, due to complexity, to detail the ship design in terms of every individual function or space. A less detailed description is required, allowing important design features and trends to emerge and the design to evolve towards a solution. A functional hierarchy approach is used, with different detail levels providing a logical path from the least significant function to the whole ship. The functional hierarchy used is based on four functional groups but varies in detail between design types and between individual designs. This topic is detailed further in Section 5.4.2.

A Building Block present in all Building Block designs is the Master Building Block. This is the highest level of Building Block and contains data representing the features and characteristics of the overall ship design. This information is required for the assessment of overall performance of the ship concept.

Functional Group Title	Major Elements
Float	Structure, Trim and Ballast, Mooring
Move	Propulsion and Manoeuvring
Fight	Weapon Stowage and Launch, Sonar, Radar Command, Control and Communications
Infrastructure	Accommodation, Logistics, "Hotel" Services

Table 5-1 Functional Group Contents

A Functional Breakdown and the Functional Group Concept

A cornerstone of the methodology is the use of a functional breakdown to define the relationships between Building Blocks and assisting in innovation. The specific functional breakdown used in the surface ship methodology is based on the concept of functional groups. Each functional group contains a loose hierarchy of Building Blocks detailing specific aspects of the functions of that functional group. Four functional groups have been defined to encompass the functions of a naval design, demonstrated here:-

- Float : The functions of the vessel that allow it to float, without motion.
- Move : All aspects of the vessel controlling the forward and lateral motions of the vessel.
- Fight : The functions of the vessel that enable it to exist, protect itself and project offensive power in a military environment.
- Infrastructure : All functions of the vessel that do not contribute directly to the above functions but contribute to providing the support and "hotel" services for the vessel's complement.

The functional group concept supports the comparison of the relative proportions of weight, volume and cost required to perform the Float, Move, Fight and Infrastructure tasks. This allows a designer to modify the design when capabilities are not suitably balanced or when the impact of meeting the requirements of one functional group is found to be prohibitive. Example contents of each functional group are shown in Table 5-1. A functional hierarchy links the broadest and most specific features of the

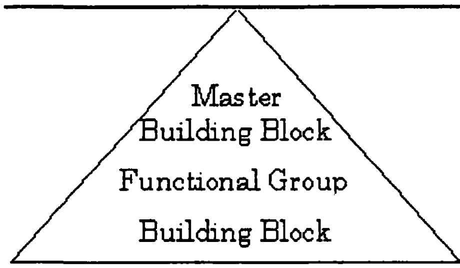


Figure 5-6 A Basic Functional Hierarchy

design [Figure 5-6].

A relationship between the whole ship entity and individual Building Blocks is required to allow a ship design to progress. This takes the form of a functional hierarchy of varying levels of design information.

The concept of abstract functional hierarchical decomposition of the design task and design artefact was detailed by [*Ulrich & Eppinger, 1995*]. The work of Ulrich and Eppinger is focused on the application of functional decomposition in mechanical systems design. Ulrich and Eppinger recommend the use of functional hierarchies to produce individual sub-tasks from the overall design task. A single design feature can then satisfy each sub task. The remaining design process is to integrate the individual design features to form a total solution. The definition of sub tasks is an application of Suh's independence axiom [*Suh, 1990*], which states that all requirements should be independent of each other. It is not considered that such an approach is completely valid for complex design artefacts such as a naval ship where many functional requirements are inseparable. However the idea of a functional hierarchy relating design elements is a useful method of relating the different levels of design definition required during the synthesis process.

Current ship design methodologies use the decomposition of the concept design into hierarchical groups based on discipline type, rather than function. Weight groups are used since they provide the basis for cost[118]. At the preliminary ship design level the use of weight based methods for scaling ship designs can lead to underlying design issues to be lost. In the Building Block methodology, function based hierarchies are implemented, allowing cause and effect relationships between functions and ship characteristics to be investigated.

Preliminary naval ship design methods cannot follow the rigid functional hierarchies, based on catalogue design methods, described by Ulrich & Eppinger, due to the inter-related and multi disciplinary nature of many design features. The definition of a ship at the concept stage is based on the definition of the spaces, weights and systems necessary to allow that function to be performed, rather than the development of a mechanical mechanism. Thus in Building Block design, the functional decomposition model uses the assignment of space required to perform a function, as

118 Several different weight group descriptions are detailed in [*Andrews, 1984, Ferreiro & Stonehouse, 1993*].

its primary descriptor[119].

An important feature of the functional hierarchy, is that while its levels are permanently defined, the numbers of elements at each level are defined separately for each specific design. Hence the form of the functional hierarchy will vary across different designs, as the role of the vessel and the functions change. This provides greater flexibility than the weight group system allowing individual elements to be investigated. It also has an apparent disadvantage, making comparison between designs more difficult. However such comparisons often mask the complexities that the Building Block methodology is intended to expose.

The methodology promotes openness due to a reliance on the designer performing design tasks in a freeform manner. Openness allows the designer to modify design processes [Meta design] as necessary for each design using a designers creative influences and the task directed constraints to form a iterative design process suitable for the comprehensive synthesis of a design in accordance with Figure 4-9. An example of the openness inherent in the methodology is the method of design entrance, and an example focusing on submarine design is presented here. Practical applications of the submarine design methodology [*Dicks & Spragg, 1995,* Appendix B] have considered entering the design by using an initial sizing routine[120] or a simple assumption of pressure hull section and form. Using a low definition design model an estimate of the minimum size of submarine to meet the operational requirements can be postulated. A selection of a small number of Building Blocks, each representing several functions residing inside the pressure hull, is used to define the requirements for space.

Constraints on internal space are applied by the pressure hull form forcing the designer to evolve the design configuration until internal spatial relationships between individual Building Blocks are satisfied. This provides a minimum length pressure hull and an incomplete design, the starting point for more detailed design iterations. In other situations such as surface ship design, other methods of entering the iterative design synthesis can be used as necessary.

An advantage of the Building Block methodology is the inclusion of functional and configuration characteristics at the earliest stages ensuring that the designer is

119 A similar approach was used by [*Levander, 1991*] for cruise liner design, although only two functional groups [Ship and Hotel] were used for that application.

120 This less suitable method of entering the ship design has been used at the earliest stages for design procedures such as that detailed in Appendix B. The use of numerical initial sizing to size the minimum size design space introduces the possibility of preventing a cheaper, functionally suitable design from being discovered.

aware of the impact of such issues on the whole design. The designer's control over design evolution is also a strength of the methodology. For example if initial assumptions prove to be misguided, the designer controls the removal of the assumption and the subsequent re-iteration of the design.

5.2.3 Generalised Design Stages

In this section a broad outline of the design phases undertaken in a generic Building Block design is developed.

Entering the Design Process

The entry point to the design methodology is a need for a specific concept to be designed. The conditions necessary for this to occur are as follows:-

- A initial estimate of likely requirements for a particular design.
- Initial ideas regarding the style of design, complementing and procurement methods.
- Estimates of the features and requirements of major systems.
- A method of entering the design process.

An initial indication of the requirements of the perceived role is necessary to allow the definition of a target for the concept ship design to achieve. The initial indication provides a focus for design activity, but will progress alongside the actual ship design concept. Initial ideas are qualitative aspects of the ship design (necessary or desired) considered likely meet the initial perception of the role of the vessel. These can be as diverse as the style of ship structure and superstructure arrangements or initial concepts regarding the relative position of major equipment items. In particular, wider issues may be considered, influencing design style.

It is essential, for a methodology using configuration at its core, that the major ship systems are specified in terms of design requirements and features. Similarly initial estimates of performance requirements are required to allow initial investigations into systems and standards that would allow the design to perform as required.

An important feature of the initial part of the Building Block design methodology is the method of initiating the design modelling process, providing the first design description to be iterated to solution. Unlike numerical based design methods, the iteration of the design to convergence cannot be undertaken almost instantaneously[121]. Because of the time taken for each configuration iteration in a Building Block design, it is important to provide a valid starting point for the ship design.

Experience[122] suggests that the method of design initiation is different between the submarine and surface ship implementations of the Building Block methodology. A submarine design is entered by preparing representations of all internal design features at a low level of decomposition. The surface ship methodology only introduces the major features and design generators [*Darke, 1979*] of the design to produce a feasible design space at the initial stages. These features are described in detail in this section and Section 5.3, the concept of the design generator is fully detailed in Chapter 6.

Assembly of a Design

The assembly of a design description is the synthesis stage of the Building Block Methodology. It is also the first occasion at which the ship concept exists as a whole. This is greatly benefited by, but does not mandate, the provision of a computer aided design system with graphical capabilities. Assembly is undertaken at several different levels of detail, using different functional hierarchies levels, as the design description becomes more developed. The output from this stage of the design methodology is a ship description that can be assessed for suitability in comparison with emerging requirements and refined as necessary.

Assessment of the Design

The assessment of the ship design description has several aims. Firstly to assess the design as a whole with respect to meeting the requirements. This is achieved by comparison of space, displacement, and function provision against requirements, a balancing task. Other aspects of the balancing task include assessing the performance of the vessel in such areas as the maximum speed requirement, stability and seakeeping, using analysis tools.

Similar tasks are used in conjunction with the assembly task, identifying areas of ship design that could be refined by altering the functionality provided by a Building Block. An example would be assessing the cruising range requirement and altering the volume of the Fuel Building Block to rectify deficiencies. A large change in volume might result in changing a compartment's location or major structural arrangements. This provides cause and effect relationships between functionality and whole design characteristics, informing the designer of the need for further iterations or changes.

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121 The rapid iterative nature of numerical methods is not advantageous as the designer does not control the direction of design evolution and has to use over simplistic assumptions.

122 From the author's designs detailed in [*Andrews, et. al., 1996*] and [*Andrews & Dicks, 1997*].

Decomposing the Design

At the end of the initial design synthesis iteration, the information available is suitable for broad consideration of spatial disposition within the hull against requirements. It is not sufficiently detailed to assure that specific requirements can be met. Hence the design definition must be decomposed to a greater level of detail. This requires each function to be divided into the specific spaces required to fulfil the needs of that function.

At each decomposition stage, constraints on the design increase in number, as the number of Building Blocks increases. The configuration constraints on Building Blocks become more specific. This often increases the design size. Several levels of decomposition are used to evolve the design to greater levels of definition without submerging the designer in detail at too early a stage, as detailed in Table 5-2.

Design Stage Iteration	Number of Building Blocks
1	10
2	40
3	109
4	140

Table 5-2 Increase of a Building Block Design's Definition with Design Stage [Dicks & Spragg, 1995]

At each design iteration, the designer re-assesses requirements for each Building Block. The size and features of such Building Blocks as motors, fuel and tank capacity change relatively frequently throughout a design evolution as design issues and characteristics change. As the design description becomes more detailed, the methods used to prepare the Building Block functional demands change from simple estimates based on gross size to analytical methods. At all design stages, analysis of design performance is performed as frequently as possible, allowing the results to affect design features, changing the direction of design evolution. An example is the Hull Building Block. At the earliest stages Building Block attributes are estimated from previous similar designs. After initial dimensions and form are known analytical techniques[123] can be used to estimate the structural characteristics of the hull and a refined assessment of the solution's characteristics obtained.

5.3 Application Of The Building Block Methodology To Surface Ships

Both applications of the Building Block methodology to submarines and surface ship, utilise many of the same concepts. However there are several differences caused

123 See Faulkner [*Faulkner, 1983*] for submarines or Chalmers [*Chalmers, 1989*] for surface ships.

by the nature of the design artefact.

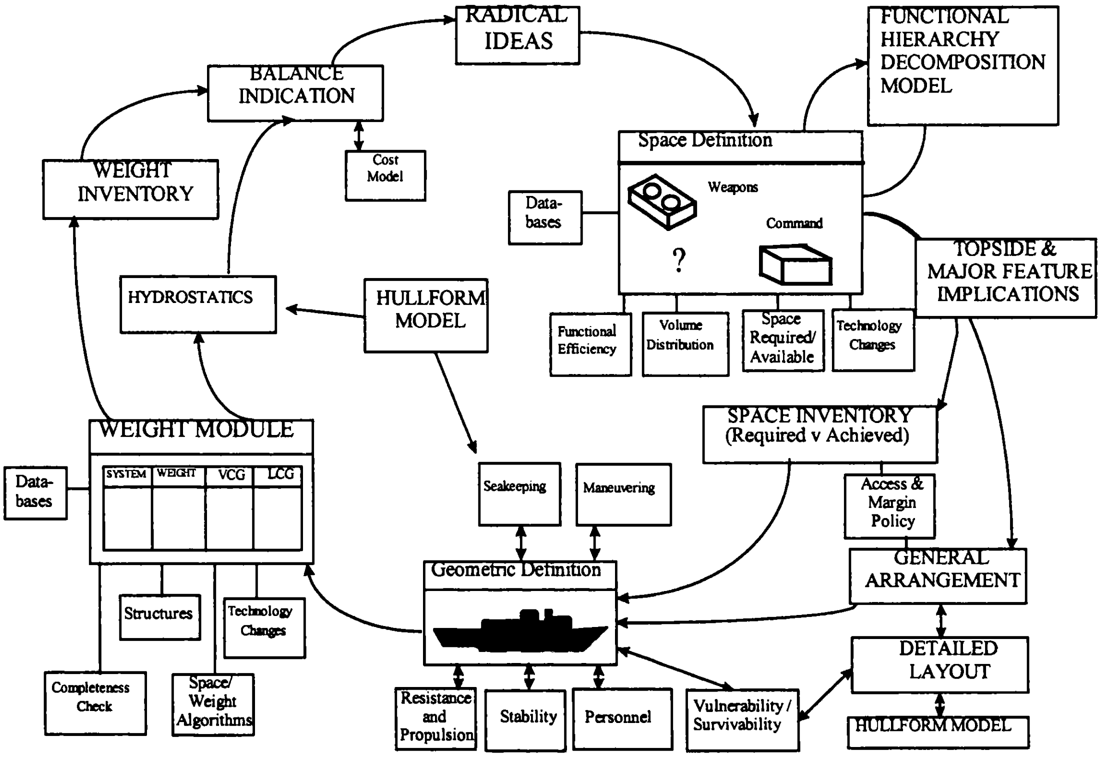


Figure 5-7 Building Block Design Methodology Applied To Surface Ships

The differences between the submarine and surface ship variants of the Building Block methodology are due to the differences in design issues and considerations between submarines and surface warships. The discussion of the application to surface ship focuses on the method of commencing the design evolution, performing the initial design stages and the functional hierarchy used. In particular a formal functional hierarchy is created at the start of the surface ship design process. The total surface ship design methodology is presented as a descriptive design methodology in Figure 5-7. An overview of design phases undertaken when using the methodology is presented as Table 5-3.

Design Preparation
Major Feature Design Stage
Multiple Level Building Block Based Design Stages
General Arrangement Stage

Table 5-3 Surface Ship Building Block Design Phases

The Design Preparation stage considers the style of the design to be created. The Major Feature design stage develops the design model for the first iteration, providing initial estimates of minimum dimensions based on configuration of major design features. The Building Block design stages allow the synthesis of the functional Building Blocks into a model of the total ship concept. In the final, General Arrangement, stage the designer replaces Functional Building Blocks with compartments, spaces and structural elements.

The submarine design methodology uses the geometry of the pressure hull to enter the modelling stages easily. The initial task of the modelling stages is the development of a pressure hull configuration and size that is likely to meet design requirements. The pressure hull is often of a simple form, that can be simply modelled. A surface ship hullform does not provide the same simple mechanism for entering a design, due to its complex form. Hence other methods of entering the design are required. These should enable the designer to reduce the design space to be searched for a valid design concept. The method employed uses a simplified modelling process, introducing the major design issues that define the style and minimum size of the design (the design generator), without resorting to complex design modelling. For surface ships complete design modelling requires large numbers of Building Blocks and a complex hull description to be prepared.

The simplest method of entrance would be to perform a rapid numerical synthesis resulting in estimates of design displacement and total enclosed space. However many design assumptions regarding the hullform style would need to be made, without assessing the validity of those assumptions, providing a procedure no better in several respects than current numerical design methods, and would follow the sequential synthesis detailed in Figure 4-8. As a result this method is not recommended or used in the example designs.

A more suitable method applies the approach of the design generator [*Darkes, 1979, Andrews, 1984*]. The development of this concept is detailed in Chapter 6. If the design space of possible solutions can be reduced by the assessment of a design generator's demands, it is logical to use those demands to provide a starting point for the full design model. This approach is applied during the Major Feature Design stage, which requires three decisions to be made before beginning:-

- The designer's assessment of the likely design generator of the concept design.
- The design features to be associated with satisficing [*Simon, 1981*] the design generator.
- Design style and other project issues, detailed in the Design Preparation stage, which may affect the design generator.

Using this information, and graphical representations of the design generator's constraints, the designer postulates an initial workspace of arbitrary dimensions on which to place design elements representing the design generator. The initial arrangement is unlikely to be suitable as constraints on configuration, or functional requirements will be broken. The workspace is modified in dimensions and design elements re-located. This occurs until design intent and all constraints are met, conflicts resolved and the design generator capable of functioning as desired. The dimensions specified as a result are the minimum for the design generator to be satisfied in that configuration. Types of design generator are detailed in Chapter 6. In the example [Table 5-4] it is assumed that the design generator for a typical Frigate is the integration of all Topside equipment elements. The Major Feature design stage fulfils the same role as Levander's system design stage [*Levander, 1991*] in which the functional requirements of a cruise liner design are related to an indication of likely design requirements without a full design being developed.

A conceptual naval Frigate design is created using the Building Block methodology. The design generator is likely to be the integration of all the elements located on or above the weather deck of the vessel, "topside design". The basis for proving the suitability of the topside design is as follows:-

- Helicopter Landing Pad
- Helicopter Hangar
- Exhausts and Inlets for the Prime Movers
- Weapons and sensors
- Bridge position

The design space is the length and beam of the weather deck. The minimum length and beam that allows the topside elements to function correctly are the minimum sizes of those ship dimensions, purely from the design generators point of view.

The initial dimensions are chosen arbitrarily as 80-m long and 10 m maximum beam. A ship like plan form is applied to assume the approximate distribution of space on the weather deck. Geometric representations of the topside design elements are applied to the weather deck with additional information in the form of geometric representations of the following design constraints:-

- Physical dimensions and form
- Minimum access dimensions
- Missile Efflux dispersal zones
- Heuristic design rules[124]
- Electromagnetic Interference exclusion zones
- Structural continuity
- Engine exhaust routes.

124 Heuristic rules are experience based design rules. They are particularly used in the assumption of locations for compartments whose locations are constrained by the motions of the vessel. An example is the location of the bridge no further forward than 1/3 of the length from the bow to prevent excessive acceleration [*Brown, 1987*]. Where possible they should be replaced by analytical assessments in later design iterations.

The resulting arrangement of equipment items breaks several constraints and these can not be resolved until the length of the weather deck is 105 m and the beam is 14 m. Thus the input to the first Building Block modelling stage is a partially defined layout of the upper deck of length 105 m and 14 m beam.

Table 5-4 Simplified Example of a Major Feature Design Stage

During this stage other design elements may be introduced due to their impact on the design generator. An example is the height of an engine compartment giving the minimum number of decks below the main passing deck. All known constraints are included in the major feature design stage description thereby reducing the range of alternative designs. Care is necessary to avoid over constraining the design space with unnecessary constraints. For example artificially introducing restrictions on antenna length where careful design or use of a folded antenna could suffice.

Evolution of Building Blocks

Following the development of the minimum design space the functional hierarchy for the complete design is developed using the four functional groups previously detailed. This is a form of meta design [*Smith, 1992*], designing the design process by consideration of the range of functions to be provided and modelled at each design stage. Table 5-1 indicates some typical contents of each functional group.

The methods used to develop the functional requirements of each Building Block vary with the function being provided, for example:-

- Directly specified and fixed data [for example from equipment data sheets].
- Scaled requirements from overall size characteristics [functional scaling algorithms from regression analysis of previous design [*UCL, 1994a*].
- Scaled requirements from local characteristics [for example Engine room area scaled by a fixed length x beam].
- Heuristic and historical data.
- Analytically derived data.

At earlier design stages when low level modelling is employed, the contents of multiple Building Blocks of related functions are summated together to form a Super Building Block. Characteristics of Building Blocks are detailed further in Section 5.4.1

A Surface Ship Functional Hierarchy Decomposition Model

The use of Super Building Blocks is introduced for surface ship design by the need to perform wide ranging studies at early design stages. This is followed by confirmation at greater levels of detail. The functional hierarchy from whole design to individual item of modelled equipment is demonstrated in Figure 5-8. The highest level of this pyramid, is the Master Building Block. Each Functional group contains a small number of Super Building Blocks, each the summation of a small number of Building Blocks. The impact of the Super Building Block concept on the design stages undertaken within a design evolution is detailed in Table 5-5.

A Parametric Survey for Building Blocks

Unlike a modern submarine[125], a surface ship has many combinations of hullform. It is necessary at the preliminary stage to consider the more important features of the hullform and the effect that form has on performance and design characteristics. In numerical design techniques this is undertaken by a wide ranging Parametric Survey procedure [such as *van Griethuysen, 1994,* see Section 3.4]. Such a wide ranging survey is not recommended within the Building Block design methodology, due to the introduction of additional functional and architectural constraints on the design solution space. The Building Block methodology, despite using those design issues to focus the feasible design space, still requires the assessment of the relative merits of different hull styles. Thus a hullform selection method is incorporated in the design processes. This is detailed further in Section 5.4.8.

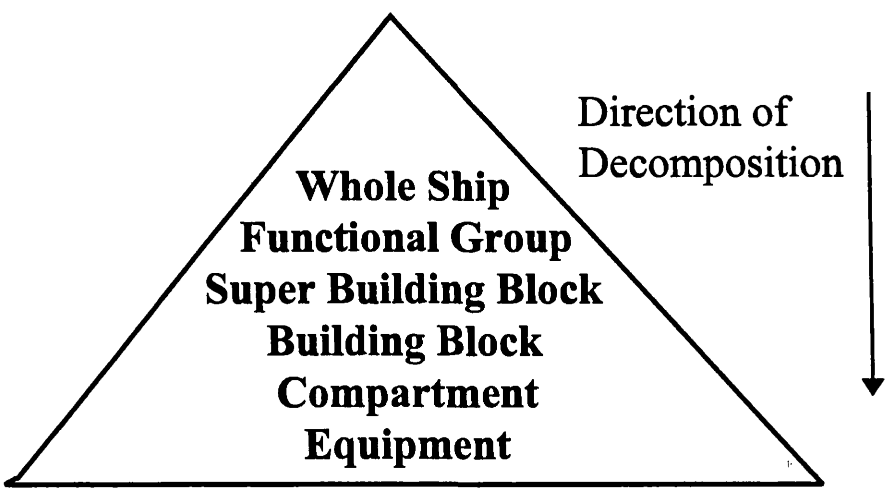


Figure 5-8 Surface Ship Functional Hierarchy

In Section 5.4 methods used to develop Building Block models of surface ship designs are detailed further. Those issues which have not been detailed in the discussion thus far are the inclusion of survivability and vulnerability considerations, the introduction of complex hullform, the use of access and other methods to model the configuration of the design concept.

125 Modern submarines have a relatively standard hullform, the tear drop form with limited change between designs other than that dictated by missile tubes and other extraordinary features.

Design Preparation
Selection of Design Style
Iterative Major Feature Design Stage
Topside Design Space Creation
Weapons and Sensor Placement
Engine and Machinery Compartment Placement
Aircraft Systems Sizing and Placement
Superstructure Sizing and Placement
Iterative Super Building Block Based Design Stage
Composition of Functional Hierarchy
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 Building Block
Iterative Building Block Based Design Stage
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 Building Block
Iterative General Arrangement Stage

Table 5-5 Typical Design Stages for a Surface Ship Building Block Design

5.4 Approaches to Designing Naval Ships Using a Building Block Methodology

Section 5.4 provides further detail on the definition of the Building Block Methodology beyond that already given in Sections 5.2 and 5.3. This section focuses on the Building Block as the ship description model used during the synthesis stages of a Building Block design. In particular it focuses on the definition of techniques and methods applied through the concept of the Building Block.

The first three sub sections initially describe the features of Building Blocks at each level of detail (i.e. Master Building Block, the Super Building Block, the Building Block representations). These sections differentiate between functional groups and the definition of functional hierarchies. Methods of defining the location of design elements within the functional hierarchy are detailed alongside examples of the behaviour of different Building Blocks. Details are given of methods of data collection for Building Blocks. Margin and access policies for use in the initial design stages are subtly different in Building Block processes from those used in traditional synthesis approaches and are defined in Section 5.4.4.

A problem is raised by the introduction of marine engineering data in to Building Block representations at the earliest stages when multiple alternatives, or uncertain requirements are presented. The introduction of marine and combat system

Building Blocks into the design process is presented in Section 5.4.6 and compared with current approaches.

A Building Block model, while considering all design issues equally, must maintain the naval architect's concern for the representation of hydrodynamic performance. Section 5.4.8 introduces the hullform into the Building Block description. This section also details the need for a decision making system to allow comparison and then selection of alternative hullforms.

5.4.1 Definitions of Surface Ship Building Block Design Elements

Master Building Block

A Master Building Block is the repository for two forms of design definition, firstly a summary of overall requirements assessed from all defined Building Blocks (e.g. total ship weight) and secondly data which cannot be assigned to an individual Building Block (e.g. ship length). Every design will have one Master Building Block. Information contained in the Master Building Block is used both in analytical routines and to record a ship's gross requirements and characteristics. The information to be held in a typical monohull Master Building Block is shown below.

Overall Design Features

- Displacement (in several loading conditions)
- Ship Structural Weight
- Enclosed Volume
- Superstructure Volume
- Hull Volume (enclosed volume - superstructure volume)
- Length (waterline and upper deck)
- Beam (waterline and upper deck)
- Draught (in each condition)
- Depth to Upper deck
- Hullform Coefficients (e.g. C_P, C_M, C_W, C_B)
- Centres of Gravity (summation of individual Building Blocks)
- Centre of Buoyancy (from hullform data)
- Water-plane Second Moment of Area (from hullform data)
- Ships Complement
- Accommodation provision
- Air Conditioning Systems provision
- Chilled Water Systems provision
- Electrical Generation provision
- Speed, fuel endurance and stores endurance provision
- Stability performance
- Seakeeping performance

Achieved Performance

- Achieved Speed and Endurance characteristics (from analysis code)
- Achieved stability characteristics (Metacentric height, and GZ curve data for specified conditions, from external analysis)

- Ship motion data (from external analysis)
- Cost (from summation of Building Blocks), if applicable / practical.

Overall Design Requirements

- Air Conditioning Systems requirements
- Chilled Water Systems requirements
- Electrical Generation requirements
- Speed, fuel endurance and stores endurance requirements
- Stability requirements
- Seakeeping requirements

Overall Margins

- Board Margin (percentage and value)
- Growth Margin (percentage and value)
- Overall Design Margin (if applicable)

When considering margins it is important to carefully control how they are applied. The Master Building Block contains only the margins that are applied to the ship as a whole these, normally, being the Board and Growth margins. Individual design margins are applied to the Building Blocks associated with the uncertainty.

For unconventional hullform models extra design data is required in the Master Building Block to define, for example, the dimensions of extra hulls, the change in geometry model, and the volume of cross structure.

Functional Building Blocks

A Building Block is a 'container' for all design information regarding a single function within the ship design. With multiple Building Blocks, each representing a different function, all important design issues are described both graphically and alpha-numerically. Designs are developed by placing Building Blocks on the 'drawing board'. A fully defined Building Block contains the following information:-

Position in Functional Hierarchy

- Building Block Title / ID No
- Component Compartment and Equipment Names
- Super Building Block Membership
- Functional Group Membership

Form and Location Definition

- Geometry and Dimensions
- Local Centres of Gravity
- Design Centres of Gravity
- Volume provided
- Area provided
- Zone
- Superstructure or Hull location

Constraints

- Required Adjacencies (to other Building Blocks)
- Restricted Adjacencies (to other Building Blocks)

- Separations (from other Building Blocks)
- Minimum Dimensions

Functional Characteristics[126]

- Volume required by each component compartment and overall Building Block
- Area required by each component compartment and overall Building Block
- Dimensions required by overall Building Block
- Weight, including additional Structural Weight if appropriate
- Design Margins
- Access Margins
- Supplied or Required Complement
- Supplied or Required Services
- Electromagnetic Data
- Radar Cross Section and other signature data
- System Cost, if available

Super Building Blocks

A Super Building Block is a high level Building Block containing design information necessary to detail the provision of a group of related functions. It is used to avoid over complexity during early design stages when few design features are fixed. A Super Building Block is the summation of the requirements of several Building Blocks. For example, consider the provision of officers accommodation in a frigate. The functional spaces of the accommodation can be considered as being:-

- Officers Cabins
- Wardroom
- Wardroom Annexes
- CO's Accommodation
- Washrooms & Heads.

During early design stages it is unnecessary to represent many functions as individual Building Blocks providing sufficient volume and weight allowance is made and the blocks are co-located, consequently five Building Blocks are merged to form one Super Building Block with an additional allowance for inter-block access. Once the design has progressed to a point where large changes in characteristics with each iteration are unlikely, individual Building Blocks are introduced, by separating each Super Building Block to its constituent parts. Hence the detail of the design definition can be improved.

Specific requirements dictate that some Super Building Block representations are more thoroughly defined initially [e.g. the provision of separate fore and aft tracker systems]. Another example is the use of a split Super Building Block in which several locations for the same function are provided and the total space provided must be that

126 Where applicable this should include the scaling algorithm as well as the currently indicated requirement.

required[127].

Functional Hierarchies

An important feature of the functional hierarchy is that while its levels of detail [e.g. Super Building Block, Building Block] are defined permanently, the numbers of elements at each level are defined specifically for each design. Hence functional hierarchies vary across designs as ship functions vary. This provides greater flexibility than a weight group system, allowing individual components to be investigated in more detail where required, leading to novel rather than evolutionary solutions. However it has the disadvantage of making comparison between designs more difficult. An example of flexibility is the ability to change the functional hierarchy to reflect the nature of the electrical supply and propulsion arrangements. In a COGOG ship the propulsion system is a member of the MOVE functional group while electrical supply is provided to support the ship's infrastructure, hence is a member of the INFRASTRUCTURE group. For an IFEP [*Mattick, 1996*] design the majority of electrical supply is devoted to the propulsion system and hence the whole of the electrical generation and distribution system is best considered part of the MOVE functional group. In the proposed system documented in [*Dicks, 1998,* Appendix A] the levels of the functional hierarchy are assigned different portions of a numerical code to distinguish between Building Blocks on a CAD model as follows:-

- Master Building Block: no code
- Functional Group: first digit
    - 1=FLOAT, 2=MOVE, 3=FIGHT, 4= INFRASTRUCTURE
- Super Building Block: second and third digits
- Building Block: four and fifth digits
    - i.e. 20304 is the fourth Building Block of the third Super Building Block of the MOVE functional Group

Additional levels are added for compartment and equipment level definitions.

It is necessary for a Building Block designer to consider, at the earliest stages, relationships between Building Blocks. Such relationships are considered in terms of constraints on separation or adjacency between Building Blocks. These are generally detailed in the following terms:-

- Building Blocks that need to be adjacent (vertically or horizontally).
- Building Blocks that need to be closely located.
- Building Blocks that need specific separation distances between them (either maximum, minimum or exact).
- Building Blocks that require to be widely separated.

127 E.g. stores spaces that are not location specific but require a gross capacity.

- Building Blocks that must be located in specific positions.

In planning the layout of a Building Block model it is useful to define with a non dimensional configuration style definition [as used in architectural design by *Hillier et. al., 1984,* see Section 5.6] in which such constraints are illustrated graphically. Such a model allows the introduction of architectural relationships between spaces and permissible superstructure arrangements. Introduced before Super Building Blocks are defined, such a model can assist in making sensible choices for these blocks. Particularly useful is the identification of Building Blocks with enforced constraints dictated by their location, relative to specific hull features and superstructure. From such constraints permissible layout styles arise, a possible example being a need to locate a Command and Control Building Block in the superstructure to meet the constraints imposed by a certain communications antenna.

The design data required to perform ship design using a Building Block methodology does not differ in substance from that required to perform the initial sizing through general arrangement stages of a numerical sizing methodology. The differences are the stage of introduction of the design data. System data is used widely in the specification of MOVE and FIGHT functional Building Blocks, due to the reliance of those Building Blocks on the form and requirements of systems. An example is the specification of the volume of a Prime Mover Building Block based on the size of the prime mover in addition to access and maintenance spaces. Specifications from other Building Blocks may be used to specify requirements for many INFRASTRUCTURE Building Blocks. For example, the provision of accommodation may be linked to the size of the complement required to fulfil other Building Block demands. Where such information is not available it may be necessary to use regression algorithms based on previous ship designs to estimate functional requirements.

Conversion of existing algorithms from a weight group based approach to a Functional Building Block system was necessary for the example designs detailed in Chapters 7 and 8. The summation of individual functional data elements for weight, space and other requirements form the Building Block requirement. The reliance on modified weight group data should be reduced as Building Block designs become more common.

5.4.2 The Functional Group Concept Applied to Surface Ships

The concept of the functional group is derived from the consideration of the Naval ship in FLOAT, MOVE, FIGHT [*Brown & Andrews, 1980*] terms, suggesting the dominance of the FIGHT function in defining the procurement cost of a naval ship. It has a parallel in the cruise liner world [demonstrated by *Levander, 1991*]. The use of a functional group concept, for both the Submarine and Surface ship Building Block methodology, allows the full implications of changes to design features to emerge.

It is essential at the earliest design stages, when comparative ship design studies are being prepared from baseline designs, that the full "cost" of an additional or subtracted capability is noted. Traditional weight group based estimates do not facilitate easily such insights as the elements of a specific function or capability are located amongst many different weight groups. The precise portion of a weight group allocated to that function is often hidden. The most obvious current example is the merging of the boundaries of Propulsion and Electrical weight groups caused by an IFEP solution. More important in the earliest stages of design, than an accurate weight group breakdown, is the need to distinguish elements of similar systems required to support one function or another.

By dividing the ship's capabilities into three groups based on functions, the separation of similar functions for different purposes can be managed. However it is noted that the functional group concept, as implemented in the Building Block methodology makes recourse to a fourth functional group. The INFRASTRUCTURE group is required because of the impracticality of defining all ship functions as a member of one of three functional groups. Many functions do not divide neatly into the first three groups detailed in Table 5-6. For example commissariat spaces are used by all a ship's complement. It is considered impractical and unrealistic to divide the functional requirements of each commissariat space into three as the requirements need to be provided as a whole. Therefore the use of the functional group for INFRASTRUCTURE has been adopted.

In design examples [Section 7.2] the attributes of Building Blocks in each functional group differ. The four different functional groups do not evolve in the same manner and the general trends shown in Table 5-6 have been noted.

The FIGHT and MOVE groups have the characteristics of directly defined requirements and limited configuration choices driving the design to limited numbers of acceptable architectural arrangements. The FLOAT and INFRASTRUCTURE groups are derived to a significant degree as a result of the FIGHT and MOVE groups. To this extent they can be seen as dependant on, rather than drivers of, the ship design. They are also often determined directly from choice of "gross ship characteristics" and

Functional Group	Method of Estimation of Requirements for a Building Block	Flexibility of Building Block Configuration
FLOAT	Scaled from Master Building Block (Regression algorithms)	Medium
MOVE	Derived from performance data. Fixed equipment sizes	Low
FIGHT	Derived from operational requirements. Fixed equipment sizes	Low
INFRA-STRUCTURE	Scaled from Master Building Block (Regression Algorithms) and other functional group requirements	High

Table 5-6 Functional Group Attributes

operational requirements. As in all such considerations these categorisations of the groups cannot be applied too rigidly[128] but a useful consideration of the trends is shown in Figure 5-9.

5.4.3 Composition and Decomposition of Building Block Hierarchies

The creation of a functional hierarchy is a design task occurring prior to the first Super Building Block design stage, after the Major Feature Design stage[129], referring to Table 5-3. The aim is to develop a relationship between design model elements at different detail levels to allow the transition from an initial broad level of design description to the compartment level description. The creation of a functional hierarchy is undertaken alongside development of the contents of Building Blocks.

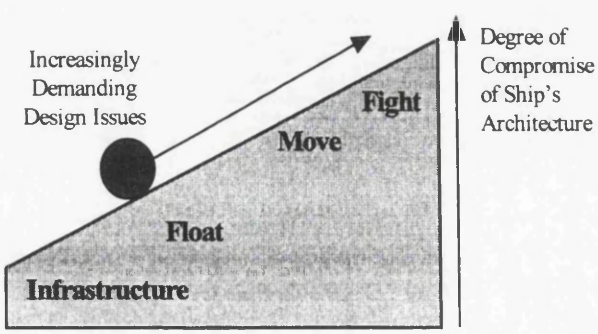


Figure 5-9 Behaviour of Functional Groups

A functional hierarchy is specified so that initial design stages use a few Super Building Blocks, but each is related to the compartment level descriptions desired later. The compartment level description is influenced by a designer's stylistic intent and the architectural considerations of

128 Technologies such as the all electric ship and vertical launch missile silos provide the ship designer with more architectural options.

129 The information gleaned from the Major Feature Design stage influences the functional hierarchy extensively.

naval ship configuration. If the designer intends a system to be split over two separate locations, to reduce vulnerability or increase coverage, this should be reflected in the functional hierarchy. This is due to the difficulty of developing a meaningful description in which one block represents two physically separate elements. Configuration specifies the arrangement of the functional hierarchy, particularly for the FLOAT and MOVE groups, as these are often dependant on configuration for effectiveness or acceptability.

Another issue affecting the composition of the functional hierarchy is the type of technology involved in the design. Functions can change location in the functional hierarchy dependant on ship systems and technology. For example the use of electric propulsion is best considered as a single entity electrical generation function. As a result it is best considered as a member of the MOVE functional group rather than the INFRASTRUCTURE functional group.

When attempting to assign a multi purpose element of ship's structure to a specific place in the functional hierarchy it is necessary to assign such functions to the Building Block that they are driven by in design form. E.g. for a mast required to support a small light navigation radar and a demanding multi function radar the masts requirements would be part of the multi function radar's Building Block. The ability to add structural weight to specific equipment items as part of Building Blocks is important in order to allow the true impact of design features on the whole design to be assessed, where possible.

In the submarine design detailed in Appendix B, a formal functional hierarchy was not considered prior to design commencement and instead evolved as a result of design decisions taken in the design process. This is an inadequate design process due to an inability to relate constraints on the Building Blocks, provided by smaller compartments, to the size and relationships of the Building Blocks. A more applicable approach for both submarine and surface ships is to develop an initial functional hierarchy prior to design synthesis.

The form of hierarchy functional used is considered important. Mistree [*Mistree et. al., 1990*], discussing hierarchies of decisions support problems suggested that a purely hierarchical representation promotes ordered and directed relationships between design elements, while a heterarchical representation of the design acts in the opposite sense. This approach can be considered applicable to the hierarchy of Building Blocks where sensible decisions as to the numbers and arrangement of the functional hierarchy must be made if the resulting hierarchy is to assist the designer in clarifying the design problem. An example of a typical hierarchical Building Block functional hierarchy is detailed in Figure 5-13 while the functional hierarchies developed for the research designs are detailed in Appendices E and F.

Because of the freeform nature of a functional hierarchy it is difficult to compare similar Building Blocks from different designs, due to the likelihood of superficially similar Building Blocks containing slightly different systems. This is not problematical due, to the undesirability of comparing one concept design with another unless they are both developed for the same or similar requirements, due to the danger of extrapolating from unproven "paper" design data [*Chalmers, 1993*]. It is assumed that all designs focused on meeting one requirement will apply similar functional hierarchies to aid comparisons between designs, where practical. It may prove necessary once design work is complete to construct a weight group based breakdown of the design, allowing cost estimation to be achieved using the methods of Top down or Bottom up forecasting as advocated by Pugh [*Pugh, 1993*]. Pugh suggests that in many cases a functional approach to costing linking provision of a design performance to the system cost may prove more useful and accurate than a slavish adoption of weight as the cost scaling factor. The example designs detailed in Chapter 7 and 8 suggest that a functional breakdown is a suitable method suitable for examination of design properties in mid design and the true impact of each system on gross ship characteristics, and hence cost, may be obtained. Thus if the current shortfalls in an ability to cost by function[130] can be removed, function scaled costing algorithms may aid the designer.

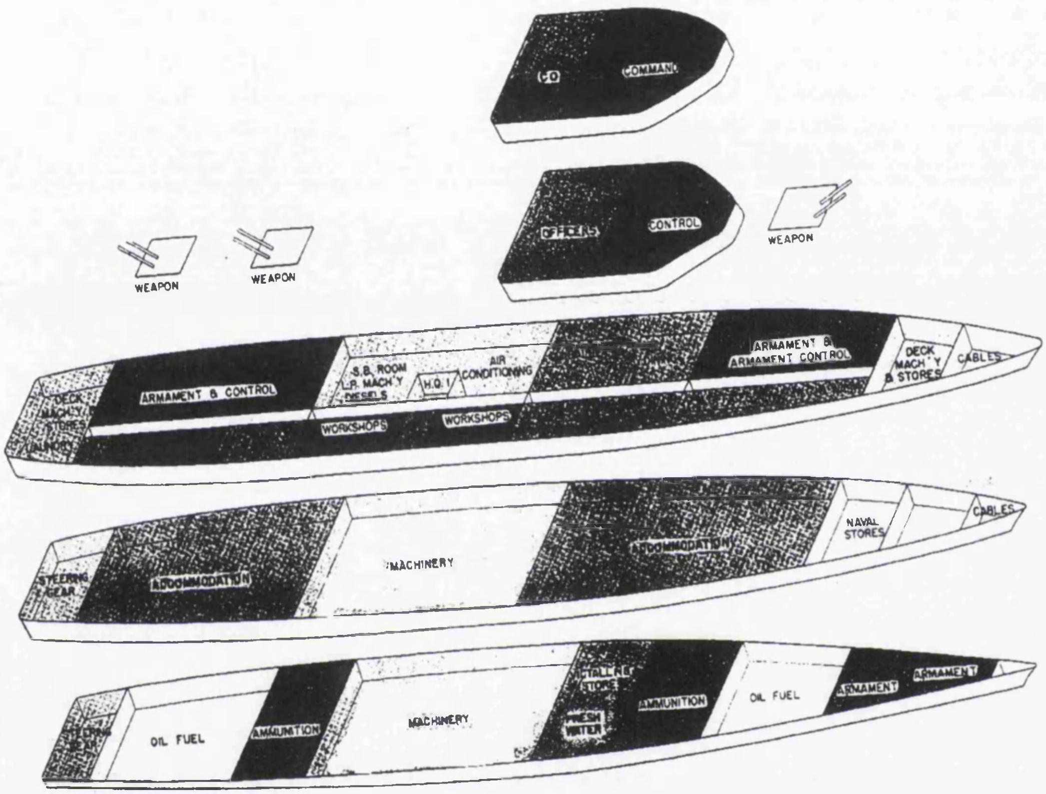
Baker's Stylised Layout for Naval Ships

The block based nature of naval ships is also advanced by the suggestion of Baker [*Baker, 1957*] that a stylised naval ship layout is required. Such a stylised layout emerges from the need to consider *"military characteristics"* as a priority, leading to a reduction in the potential combinations of layout. Such a stylised layout was required by Baker to manage the overall logic of ship design layouts in an era of rapid evolution of different classes. Although procurement rates have changed, the approach is still considered valid. Baker's layout [Figure 5-10] shows that in general certain related

130 [*Dicks, 1997*] suggested that while the theoretical approaches to costing suggest that a functional approach applied in conjunction with the Building Block would provide a suitable method of addressing the relationship between ship design cost and operational capabilities, the lack of functional cost relationships would hinder the practical introduction of such methods.

functions[131] of escort ships generally reside in specific locations. Therefore it is valid at the earliest design stages to treat those functions as a whole, rather than as individual compartments in order to perform gross ship synthesis, providing constraints raised by individual spaces or functions are introduced.

Figure 5-10 A Stylised Destroyer Layout [Baker, 1957]



A concern with the representation of ship designs as collections of Building Blocks, from which design decisions can be made, has been the ability to compare Building Block arrangements with actual ship configurations. Another issue is the degree to which a function represented by one Building Block can still be considered to reside in the same location with the same requirements, when arranged at a compartment level. By assessment of an existing ship's general arrangement it is obvious that a compartment level general arrangement has several spaces arranged specifically to utilise space effectively and not to maintain the elements of one function in one location. The degree to which this occurs is important as it is considered undesirable to derive ship dimensions on the configuration of a design at the Building Block level of representation, if that representation cannot realistically be decomposed

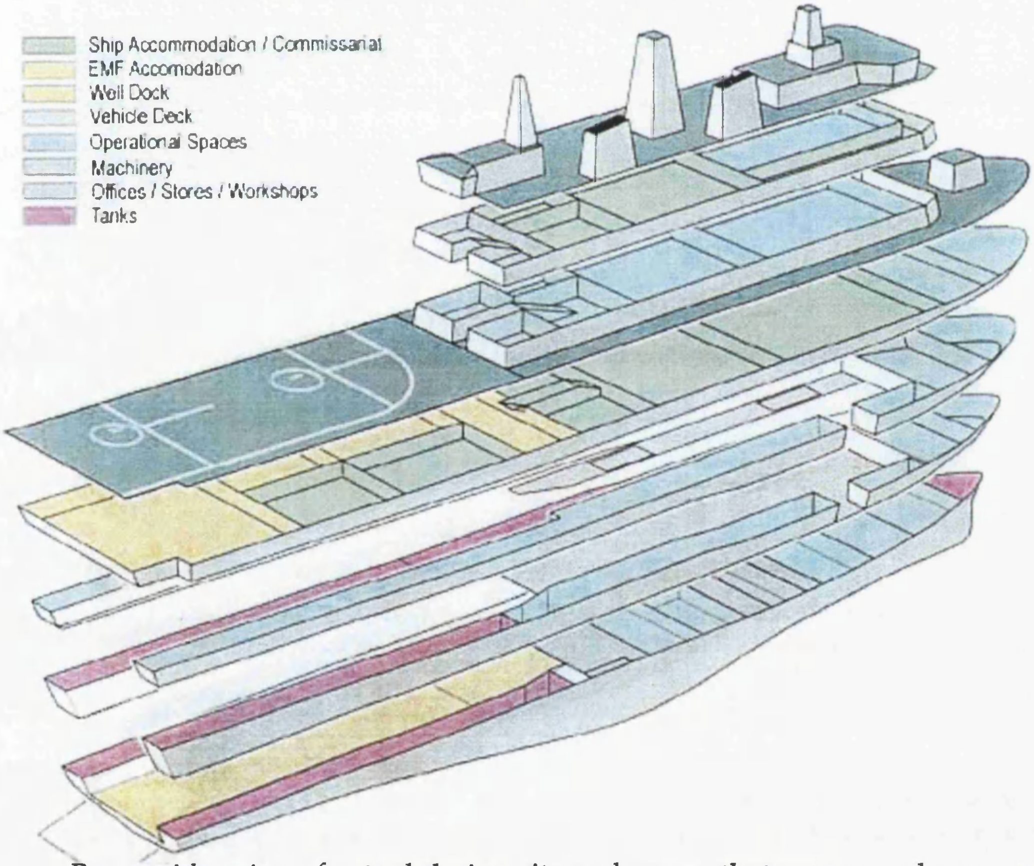
131 For example Escort ships of Baker's era always had central machinery spaces and the main armament directly forward of the bridge.

to a compartment level. It is considered that this is not an obstacle to the use of the Building Block approach for the following reasons:-

- The natural building block like nature of naval ship design arrangements, as illustrated by Baker and Figure 5-11.
- The desire to strive towards a more logical layout [*Baker, 1957*].

It is often the case that those spaces separated from the majority of a function can be considered as being of two types. The first type is large, demanding spaces, located separately for functional reasons[132]. This is addressed by consideration of functional issues prior to definition of the functional hierarchy and the provision of separate Building Blocks. A second type of separated function is the provision of small, undemanding spaces separated from the majority of similar functions. Such spaces do not generally affect the configuration and dimensions of the ship design and are often located where possible or convenient.

***Figure 5-11 LPD(R) Arrangement* [*Downs & Ellis, 1997*]**



By consideration of actual designs it can be seen that many modern naval ship designs are naturally arranged in blocks of similar function spaces due to the impact of system requirements on acceptable architectural solutions. This was partially illustrated by Andrews [*Andrews, 1984*] for escorts with the definition of machinery space and residual spaces. The development of Amphibious assault ships [*Downs & Ellis, 1997,* Figure 5-11, *Hudson & Rawlinson, 1997*] provides further evidence of the block based nature of large naval ships in which large areas of specific functionality can be detailed, for instance accommodation spaces or prime movers spaces. An earlier example was provided by Leopold & Reuter [*Leopold & Reuter, 1971*] who, while advancing a optimisation based approach to selecting the most suitable design alternative, used the off-load requirements of a fast deployment ship to inform the design.

To investigate the concept of the functional group, the functional hierarchy and the location of similar functions together as one Building Block, to an actual design, a commercially developed naval ship design, FF-21 [*Afanasieff & Mabry, 1995*], and a naval staff developed dual purpose design, HMY Britannia [*Shepherd, 1953*] were modelled. The procedure was as follows:-

- Identify all compartments from general arrangement drawings.
- Assign each compartment to a Functional Group.
- Identify Functional Building Blocks that could realistically have been used to develop the final arrangement.
- Prepare Functional Hierarchy from Master Building Block downwards.

Figure C.5 details the ability to describe a ship design's layout in Building Block terms. These Blocks and the hierarchy can be seen to be representative of the co-location of similar functions throughout the design. If the complex configuration of an actual ship's spaces can generally be described in Building Block terms, it is possible to describe a preliminary ship design in Building Block terms.

5.4.4 Definition of Margin, Survivability and Access Policies for the Building Block Methodology

In all ship design processes, margins are applied in addition to minimum requirements, to cover uncertainty, change and unforeseen events. Four margins may be applied:-

- Design: Applied individually to cover uncertainty of design estimates. This margin should be used in the period prior to construction.
- Board: Applied on a whole ship basis to cover changes in role and additional equipment and systems that result from changed requirements.
- Growth: Applied to the whole ship to allow for weight changes due to unplanned accretion of weight.
- Access: Extra space requirements to allow access to ship compartments[133].

The design margin to be applied depends on the form of technology inherent in each weight group. Typically values are detailed in [*UCL, 1994a*].

132 Such an example includes the mandatory separation of spaces for forward and aft radar tracker offices.

The method of introducing margins into the surface ship methodology has been specified, especially with respect to the use of access allowances. It is normal within a Building Block design to apply design margins to each functional Building Block. As a result Building Blocks are larger and more demanding than the minimum specified requirement. The percentage design margin applied is considered from the range of those detailed in [*UCL, 1994a*] with variations dependant on the type of technology inherent in the Building Block. An example would be the application of a large design margin to a new IFEP electrical motor Building Block. The uncertainty associated with new electrical technology, can easily translate into large increases in design weight. Older technology Building Blocks would be considered to have a smaller margin requirement.

Growth [and any design margins based on whole ship issues such as hydrodynamic performance] are generally applied to the Master Building Block due to the nature of such margins, which cannot be allocated to specific Building Blocks and are empirical in nature. Board Margins are applied to the design as a whole through the Master Building Block if necessary but should be applied to specific equipment items as necessary given specific identifiable requirements, for example "Fit to Receive" items.

When considering access allowances within the Building Block methodology it is important to note the influence of function, location and access type[134] on the amount of access required. Access can be assigned as part of the Building Block or separately from the Building Blocks as specific access runs. At the earliest design stages, for many designs, it is unwise to consider the actual access passages present as the gross features of the ship are not finalised. At this stage access allowances are added as numerical estimates of extra space required to provide access within the Building Block. Building Blocks likely to have main passageways running within are allocated larger amounts of access space. Other Building Blocks have a lesser access allowance.

Where a design's features are likely to be heavily influenced by the distribution and arrangement of access, for example with landing ships, it is considered appropriate to model major access routes at the earliest design stages. Amounts are defined by the designer but are generally in the region of those detailed in Table 5-7.

133 Access is not strictly a margin but is treated similarly by most design methods. Unlike "true margins" it is necessary to consider the absolute location as well as magnitude. [*Andrews, 1987*] demonstrated this aspect of access.

134 Access can be either main passageways or spurs and change in requirements accordingly.

	Brown, 1987	FF-21	Light ASW Frigate	Trimaran ASW
Deck	%	%	%	%
03	10	5	7	N/A
02	10	10	5.5	10
01	10	15.5	16	11
1	15	13	23	11
2	20-25	20	26	21.5
3	5	8	8	8
4	5	4.5	10	4.5

Table 5-7 Variation of Access With Vertical Location

As the design description moves from Super Building Blocks with broad allocation of space, through Building Blocks, onto compartment level descriptions, it is necessary to consider the space available once major passageways have been allocated. Major access route allowances are removed from within Building Block descriptions and implemented as separate geometrically and numerically defined passageways.

To assess the amount of access required by Building Blocks in different locations of the ship, classified and unclassified ship design general arrangements were examined. As can be seen they are similar to generic figures published by [*Brown, 1987*]. The vertical distribution of access in terms of percentages of deck area utilised for access was calculated. The classified ship design results are not presented here but the results were similar to those prepared for the unclassified designs below:-

- FF-21 Frigate Commercial Design [*Afanasieff & Mabry, 1995*]
- Light ASW Frigate Student Design [*Spragg, 1995*]
- Trimaran ASW Frigate Student Design [*Smith, 1996*]

The large superstructure access variation's are caused by variation of superstructure style, whether continuous or discrete deckhouses are present. Higher superstructure decks have very little access requirements. Allowances used in the Building Block designs are based on Table 5-7 with variations allowed dependant on the type of technology and longitudinal position.

5.4.5 Introduction of Survivability and Susceptibility Considerations into the Building Block Design Methodology

A cornerstone of the new design methodology was detailed previously as the use of Baker's ideas regarding co-location of similar functions [*Baker, 1957*].

In [*Brown, 1990*] Brown suggested that where the design of a warship to withstand the pressures of battle damage was concerned the design maxim "*concentrate duplicate separate*" should be employed.

Two such opposing views of the configuration of a naval design cause a dichotomy due to the desire to minimise the number of Building Blocks to be located at the earliest stages without over simplifying the design problem, causing design decisions to be based upon unrealistic data. It is necessary to consider the types of design function which will be affected by the introduction of susceptibility and survivability considerations.

A first category is active susceptibility reduction measures. Such items include such active decoys as Chaff systems and Towed decoys. In a Building Block design process these are treated identically to other systems. The second category is passive susceptibility reduction measures, including the use of signature reducing agents such as mountings, insulation and shaping. In general these agents are inextricably linked to another system, for example the resilient mounts attached to vibrating machinery. Such systems will generally be arranged so that it is impractical to add the reduction measure to a Building Block model as a separate entity. Such elements should be applied to the Building Block of the isolated machinery or structure as additional demands to the overall Building Block requirements.

All ship features necessary to keep the ship afloat and operational under battle damage are dealt with separately. The primary concern is the derivation and implementation of a zoning and citadel policy. Adoption of zoning is a key design decision, placing constraints upon other design characteristics, and should be reflected in the design. For every stage of the Building Block Design process it is necessary to review zoning arrangements to ensure the current design is compatible with the zoning philosophy. Items placed in the ship design model representing the zoning plan are as follows:-

- Definitions of Zone boundaries and extents of Citadel systems as deemed necessary.
- Escape routes.
- The (duplicated) equipment to be located in each Zone.

In the CAPSD system detailed in Section 5.7 these elements are detailed by an overlay showing location of zone boundaries and systems. This overlay provides information regarding weight and volume demands of the same zone based equipment. The zone layer is not fully added to the functional hierarchy as all systems assigned to the zone model will already have an assigned location in the functional hierarchy.

5.4.6 Introduction of Marine Engineering

Marine engineering considerations require the designer to consider simultaneously the implications of the type of propulsion system to be used, its impact on the ship design as power supplied for hydrodynamic use or electrical generation use, and the need for space and other internal considerations within the design. The types of plant to be developed within the design is dependant on the technology available and thus follows the procedures detailed by [*Plumb, 1987*] without regard to the type of design methodology.

The impact of propulsion arrangements on the design in question will depend on the design methodology in use. Differentiating between the advantages of systems such as COGOG and IFEP at the earliest design stages should not be a question of solely assessing system specific issues such as power generation and specific fuel consumption, but should also illuminate the interaction between gross ship characteristics and propulsion system. Certain combinations of propulsion plant and ships styles are more favourable when combined, notably IFEP and Trimaran or Nuclear Power and Super-Aircraft Carriers or submarines. Such a favourable combination is difficult to assess prior to the consolidation of design dimensions. The importance of marine engineering issues to the size of the emerging design was detailed by [*Ferreiro & Stonehouse, 1993*]. Ferreiro and Stonehouse suggested that one of the major reasons for the difference in size between equivalent British and American ship designs was due to the difference in Diesel Generator sizes between the two nations, driven by each countries available Diesel Generator rotation speed. The impact of propulsions systems on ship internal characteristics can be considered to manifest itself by:-

- Specification of hull dimensions / Location of large spaces within the hull.
- Location of ducts, maintenance routes/open access spaces.

The first of these specifies minimum dimensions and constraints on the hullform geometry, to provide a space suitable for locating, operating and maintaining a large Prime Mover. The second is the need to provide services and inlet and exhaust routes for the Prime Movers, which interfere with the access and usability of space on decks above the Prime Mover. These features are fully represented in the Building Block methodology as such constraints can be represented graphically as well as numerically. As a result the designer is well informed and can control the use of space in those areas. An inability to perceive the utility of a given propulsion system and ship combination can lead to arrangements that are not feasible and may need to be redeveloped in a new design.

Practical modelling of Marine Engineering systems in a Building Block methodology requires that the designer particularly considers the following issues within the Functional Building Blocks:-

- Space requirements for the physical plant.
- Access/ Maintenance / Air flow requirements for the plant.
- Gross sizes and location of fuel tanks.

Such issues are modelled within a Building Block by specifying gross volume, weight and system requirements numerically and the occupied space geometrically. The geometric model may also include major system components such as gearboxes and Prime Movers as geometric elements within machinery spaces.

5.4.7 Advantages of the Building Block Design Methods with Regard to Analysis

An advantage of the Building Block Design Methodology is the ability to perform design analysis at earlier stages of the design evolution, thus using analytical results in place of empirical or estimated data. This has been proven by the ability to model Building Block designs at all stages with the correct centre of gravity of the concept at that stage in the design, rather than using an estimate for the ratio of centre of gravity to hull depth [as in *UCL, 1994a* and CONDES, *Hyde & Andrews, 1992*]. This is more useful than empirical data, as it introduces the design in question rather than regression analysis of several previous designs. Similar arguments apply to the ability to predict seakeeping at an early level if design issues require it.

To analyse the design further, it is important to consider the effect of the fluids in the tanks. These effects can only accurately be considered if the position of structural divisions are known so that individual tank free surfaces can be assessed. At the Super Building Block stage, a designer is only aware of tank extents and can only estimate the effects of subdivision on the stability of the vessel. The designer has to decide whether an accurate calculation of stability is sufficiently important to demand the subdivision of the Super Building Block. This adds to the workload of the designer but allows the inclusion of full damaged stability analysis at the earliest design stages and hence the ability to use stability constraints arising from damage requirements to inform the design. Design analyses, which solely rely on overall ship characteristics such as powering calculations, are unaffected.

5.4.8 Introduction of Hullform Characteristics

Introducing a hullform into a Building Block design raises two contradictory views of the Building Block process. A hullform forces a designer to place Building Blocks within hull constraints. Thus the freedom to explore radical ship designs is lost. With a hullform the designer has to sub optimise within the constraints of the current hull. Alternatively a hullform allows the designer to assess the hydrostatics and other performance characteristics of the design. Early introduction of a hullform enables analysis to inform design characteristics.

Both views are partially correct and hence a compromise view is suggested. The hullform is introduced after the major feature design stage based on those dimensions specified by that stage. This form is not allowed to initially constrain Building Block location initially. At the end of the first iteration it is likely that there will be large amounts of empty space or more likely, Building Blocks will overlap the hullform or remain un-placed or undersized due to a lack of space. As the design evolves, hullform and Building Blocks coalesce and the design is fully balanced only at the end of the Building Block design process. At each intervening stage the designer uses the discrepancy between hull and Building Block requirements, performance and the designer's judgement to move the design towards a balance. This approach is analogous to Levander's approach [*Levander, 1991*] of describing the ship's Hotel requirements prior to assessing its reality. Several hull definitions are likely to be applied before design balance. This implies quick design methods such as those available within automatic hull development tools.

The level of hullform definition required is not considered to be as detailed as provided by Computer Aided Ship Design systems such as GODDESS [*Barratt et. al, 1994*]. The definition need only be sufficiently detailed to allow the designer to assess the amount of space within specific regions or to provide information for analytical tools such as GODDESS.

A Building Block Parametric Survey

A major feature of preliminary ship design is the need to compare different hullforms for impact on hydrodynamic performance and overall design suitability. However it is often overstated in conceptual ship design literature. An advantage of the Building Block methodology is that it does not regard ship design as purely hull design, but regards the ship as a whole, informing the four-way debate between Naval Architects, Marine Engineers, Combat System Engineers and Operator-Customers. However it is still necessary to select a sensible hullform design. An example is the need to assure that the bow ramp of a landing ship for tanks and the hullform resistance characteristics are compatible.

Given that in each design iteration of the Building Block methodology only one hull design is defined, it is unlikely that the initial design chosen is suitable. It will be necessary to perform a search for alternative, more suitable hull styles for later iterations. The search advanced here is not a traditional major parametric survey [*van Griethuysen, 1994*] as not all dimensions are freely variable. The search is performed after each design iteration with the range of considered variants decreased at each design stage as more solid information emerges. The process used is as follows:-

- The Master Building Block description is used as the Baseline design description.
- Constrained dimensions are defined.
- Hullform characteristics to be varied are detailed along with constraints on form.
- Building Blocks that vary with gross ship features are introduced.
- A systematic variation of hullform coefficients produces a matrix of possible forms.
- Analysis of potential performance suggests which hullform is selected.

Each geometry in the matrix meets all constrained dimensions, the constraints on form and is re-balanced to ensure that system requirements and current hullform are compatible[135]. The designer selects one form to apply to the next iteration of the Building Block design.

This section has detailed in detail the conceptual ideas and features of the Building Block design methodology for surface ships. In particular the ideas regarding the introduction of different forms of the Building Block concept at different stages of the ship design process, notably Super Building Blocks when design dimension information is scarce and Building Blocks when design dimensions are more certain, have been detailed. The introduction of the marine engineering, survivability, margin and access issues, hullform determination methods and functional groups has been introduced. Example designs detailing the practical application of all such issues are detailed in Section 5.5 and Chapter 7.

5.5 SYNTHESIS OF A BUILDING BLOCK DESIGN

This section outlines the procedures involved in the Building Block methodology. It makes use of an example design, which has been restricted in scope to aid clarity, in that it consists of only ten Building Blocks. This example design cannot represent a real naval ship design, rather it illustrates the procedures used in placing and modifying blocks, auditing designs, etc.

Design Preparation

The requirement is to provide a naval ship consisting of the following functions, with adequate stability, and a specified maximum speed:-

135 An example is the increase in structural weight for longer thinner designs demonstrated by the candidate in [*Bayliss et. al., 1996*].

Bridge	
Dimensions	Fixed from previous practice
Desired location	Above 1 Deck forward of amidships
Constraints on location	
Must maintain a clear view of wings and forward of bow to 1.5 times ship length	
To reduce unpleasant motions the bridge should be located no further forward than 1/3 of ship length from the bow.	
Engine Inlets / Outlets	
Dimensions	Fixed from engine supplier
Desired location	On centreline on 1 and 01 Deck
Constraints on location	
Inlets must be shielded from extreme green seas	
Exhausts should not interfere with Sensors, Weapons, Bridge or Helo Flight Deck. (assume separations required)	
Sensors	
Dimensions	Specified from equipment data
Desired location	On 01 Deck, one forward, one aft
Constraints on location	
360 degree coverage	
Sensors separated by a minimum distance	
Sensors out of Engine exhaust flow	
One sensor close to Weapons to reduce vulnerability	
Forward sensor no further forward than 15 % of length from the bow for seakeeping reasons.	
Access	
Dimensions	Minimum width specified by designer
Desired location	Port and Starboard, along entire length
Constraint on location	
Must be at extreme breadth	
Mooring	
Dimensions	Minimum length (from previous designs) Full ship beam at longitudinal location
Desired location	Bow
Constraint on location	
Must be at Bow	
Weapon System	
Dimensions	Minimum dimensions specified by equipment
Desired location	Aft of Bridge on 1 deck
Constraints	
Must be full width at longitudinal location (excluding access)	
Co-located with one sensor	
Must avoid Engine Exhaust	
Maximise coverage.	
Flight Deck	
Dimensions	Length and width specified by helicopter type
Desired location	Aft on 1 deck
Constraints	
Must be aft most design element	
minimum beam aft specified by flight deck	

Table 5-8 Example Design Functional Requirements

- Hull, Mooring
- Bridge, Engines, Fuel
- 1x Weapon System "A", 2x Sensor "B" (Fwd and Aft) for Weapons system "A", A Flight Deck
- Accommodation, Commissariat

It is assumed that the superstructure must be small in order to maximise the length of the design, to reduce resistance and improve seakeeping. Furthermore a small superstructure will reduce radar cross section and VCG. The sensors will need to be arranged to avoid engine efflux and provide 100% coverage, suggesting an arrangement with sensors fore and aft.

Major Feature Design Stage

Previous ships with similar requirements have been driven by the upper deck arrangement of weapons and sensors [*Brown, 1987*]. As a result the Major Feature Design stage in this case focuses on the definition of a minimum length and beam that will allow the weapons and sensors to operate. This involves the following considerations:-

- The bridge position and visibility of the bow from the bridge.
- The engine inlets and exhaust position and their relation to the sensors.
- The separation between the two sets of sensors.
- Access around the upper deck.
- Bow mooring arrangements.
- Weapon system with efflux and launcher clearances.
- The minimum length requirement for the flight deck.
- Ship motion on equipment performance and ship operability.

The major feature design stage starts by developing functional descriptions of the elements listed above, as noted in Table 5-8.

To locate all these elements to meet the constraints, a plan of 1 Deck of arbitrary beam and length is used to place them in the following order:-

a) Locate mooring space and mark as unusable by other design elements. (Figure 5-12-(1)).
b) Locate flight deck at stern (Figure 5-12-(2)).
c) Mark width required for access on each beam through ship length.
d) Add design aids as planes:-
   - A vertical plane at L/3 from the bow (maximum forward location of bridge for seakeeping reasons)
   - A vertical plane at 0.15L from the bow (maximum forward location of combat system elements leaving space for line handling reasons and green sea shipment)
   - An angled plane through the bow and a point 1.5 L ahead of the design. (for bridge visibility) (Figure 5-12-(3)).
e) Assume engines are located approximately amidships[136]. Add exhaust and inlet representations. (Figure 5-12-(4)).
f) Place aft sensor system aft of the exhaust, with required separation, on 01 deck or higher for RADHAZ reasons. (Figure 5-12-(5)).
g) Place weapons system so that the forward bulkhead is continuous with aft edge of exhaust. assess aft sensor and weapons system location compatibility. (Figure 5-12-(6)).

136 A valid assumption for a "classical" COGOG design. If an IFEP solution was under consideration such an assumption would not be made.

h) Place bridge so that aft bulkhead is continuous with forward edge of inlet. Raise in height until bridge is above angled plane. (Figure 5-12-(7)).
i) Locate forward sensor longitudinally ahead of bridge on 01 deck (raised to remove green sea effects). Assure sensor does not impair bridge visibility. (Figure 5-12-(8))
j) At this stage all topside design elements have been placed. (The placement of some elements on 01 deck presumes that additional compartments will subsequently be added on 1 deck). The design length and beam can be re-assessed by consideration of constraints not met and excessive space allocations. The design arrangement is then modified until the minimum size of design meeting all constraints is found. (Figure 5-12-(9)).

From this sequence the minimum length and beam values can now be included in the Master Building Block. It is also necessary to assume both an initial estimate of minimum depth [to allow an initial hullform to be developed] and an overall volume for those scaling algorithms which are volume dependant[137].

In this example, minimum heights for the engine room, the assumed single passing deck and a practical double bottom provides the minimum depth. A first

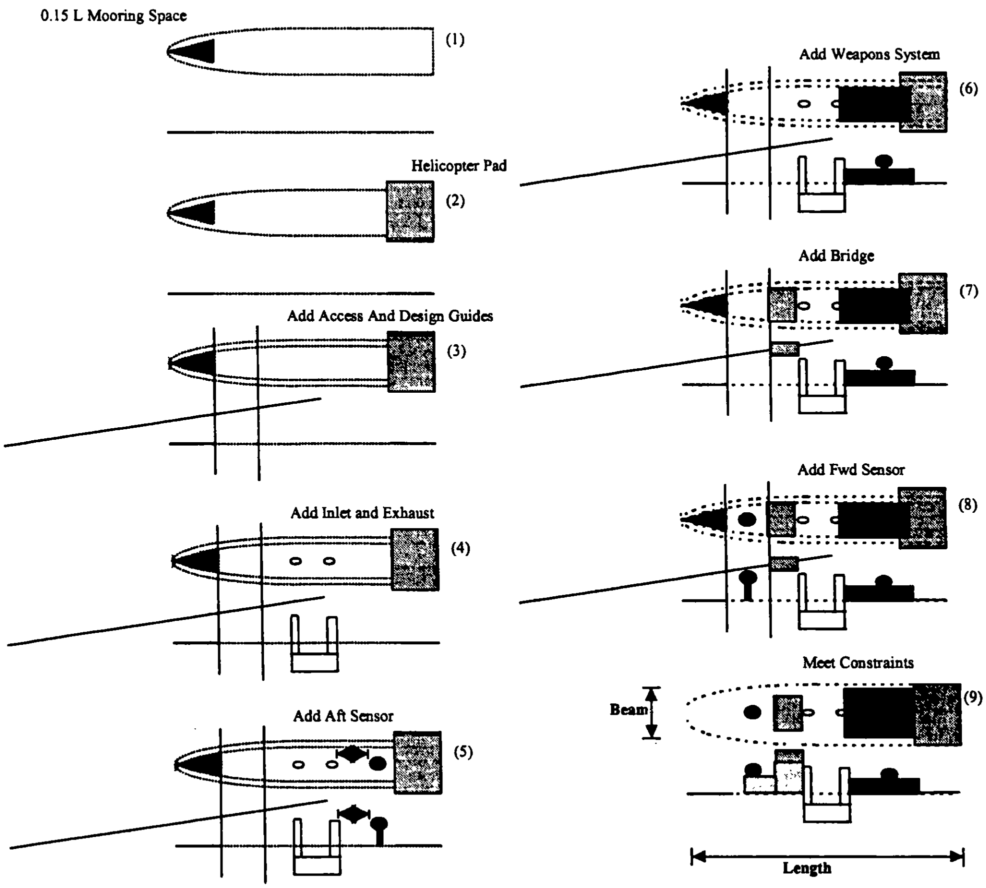


Figure 5-12 Topside Evolution Sketches

estimate of the draught is obtained using the depth and an assumed freeboard. Hullform coefficients at this stage are chosen based on previous successful designs. Values that will produce the smallest feasible ship are assumed initially for unknown

137 For example air conditioning requirements.

dimensions. These will generally be revised later in the design.

Super Building Block and Building Block Design Stages

At this point a ship design barely exists. Only a few minimum dimensions have been assessed, others having been estimated on the basis of imprecise information. The task of the Super and Building Block stages is to model all major functions of the design to assess which features require replacing by more realistic values.

In order to start the Building Block stages, an assessment of the functional hierarchy of features must be made so the designer can:-

- Assign of all ship spaces and systems to a functional group based on the major function of that space or system.
- Develop a spatially and functionally acceptable representation of the ship design at more detailed stages.
- Establish a logical relationship between the simplistic and complex levels.

To do this the designer divides the spaces and systems in to functionally related groups. In the absence of specific data information to the contrary it is sensible to assume that functionally related spaces would be located together. Groups of functionally related Building Blocks are assessed to identify whether they can be grouped to form one Super Building Block. Every element to be modelled by Building Blocks has a location in the Super Building Block level description. This may lead to Super Building Blocks that due to their functional and location demands in latter stages decompose to Building Blocks with identical features. Experience from the designs of Chapters 7 and 8 suggest that the important issue is not to keep the number of Super Building Blocks at a minimum. Rather it is important to have sufficient Super Building Blocks for the ship design arrangement to remain indicative of that required at the end of the design process. For the design example detailed above the functions detailed in Table 5-9 are considered.

Functional Group	FLOAT	MOVE	FIGHT	INFRA
Function	Hull Mooring	Bridge Engines Fuel	Weapon System A Sensor B (2) Flight Deck	Accom. Commissariat

Table 5-9 Assignment of Example Functions and Spaces to Functional Groups

Whilst in this basic example the allocation of function to representative Building Blocks is clearly simpler than it is likely to be for a real design, it is illustrative of the principles that will apply in any design. The two functions in the FLOAT group are assigned as Building Blocks, however it is impractical to consider combining the two as one geometric entity in a Super Building Block. In this case the Super Building Blocks in the FLOAT Functional Group translate to Building Blocks on a one to one basis. The MOVE group issues are similar, consequently there are three Super Building Blocks and Super Building Blocks (Bridge, Fuel, Engines). In the FIGHT group it is desirable for one of the Weapon Systems and one of the Sensors to be co-located. Therefore at the Super Building Block Level two Super Building Blocks can be defined (Weapons & Sensor Aft, Sensor Forward). These are in addition to the Flight deck SBB. In this example infrastructure group functions are volume dependent, and both Accommodation and Commissariat functions are to be co-located. It follows one Super Building Block (Accommodation and Commissariat) should be formed from two Building Blocks (Accommodation, Commissariat) with additional allowances for access. The functional hierarchy that results is shown in Figure 5-13.

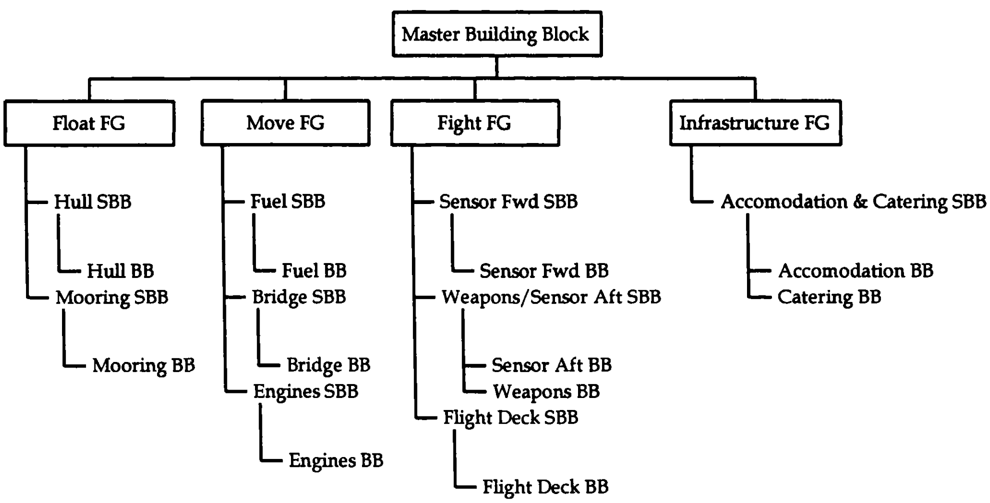


Figure 5-13 Functional Hierarchy of an Example Design

Having identified the Super Building Blocks and Building Blocks it is necessary to relate how the size and features of these change with the ship size. This is summarised in Table 5-10 for Building Blocks. Super Building Block requirements are the summation of constituent Building Blocks with additional margins for access where appropriate.

Building Block	Functional Definition Method
Hull 10101	Scaled using regression algorithms from Master Building Block dimensions plus extras for small items (e.g. degaussing)
Mooring 10102	Scaled from numbers of Anchors / gross steps related to ship size

Fuel 20101	Estimated from engine power initially and likely endurance Calculated from analysis after first iteration
Bridge 20201	Fixed from previous similar designs
Engines 20301	Specified system (could be replaced if insufficient)
Sensor Fwd & Aft 30101, 30201	Specified systems
Weapon Aft, 30202	Specified system
Flight Deck 30301	Specified from aircraft constraints and additional structure estimate or calculation
Accommodation 30101	Scaled using regression algorithms from Master Building Block complement and enclosed volume
Commissariat 30102	Scaled using regression algorithms from Master Building Block complement and MBB stores endurance.

Table 5-10 Building Block Functional Definitions

Individual Building Blocks are assigned design and access margins at this stage to cover design uncertainties and access requirements based on preferred location[138]. Board and Growth margins are applied to the Master Building Block. At this stage modelling begins using the full ship Building Block model[139]. Assuming standard deck head height spacing, representative decks are added. The first modelling stage is to recreate, using the relevant Super Building Blocks, the arrangement of the major features developed previously. To this, bulkheads should be added to assure structural continuity. For the example, the following Super Building Blocks are located, with additional bulkheads, Figure 5-14 shows the model at this stage with:-

- Bridge SBB
- Flight Deck SBB
- Weapons / Sensors Aft SBB
- Sensors Fwd SBB
- Bridge Superstructure Block Forward Bulkhead
- Bridge Superstructure Aft / Engine inlet Bulkhead
- Weapons / Sensors / Engine Exhaust Bulkhead
- Weapons / Sensors Aft Bulkhead

138 Those blocks to be positioned on 2 deck will require greater access than those elsewhere.

139 The previous Major Feature (topside) model is different from the full Building Block model.

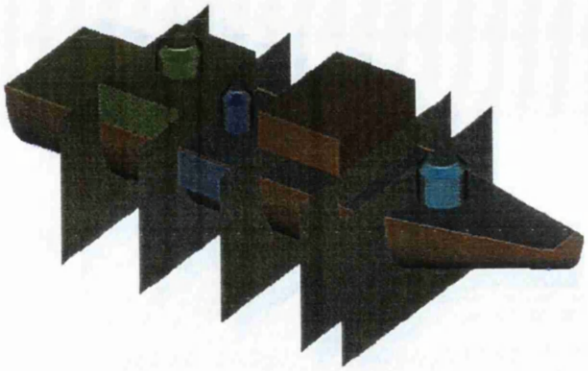


Figure 5-14 Location of Topside SBBs and Selected Transverse Bulkheads, within Representative Hull

The permissible locations of the engine inlet and exhaust bulkheads define the location of the Engine Super Building Block. The Fuel Tank Super Building Block is added to the double bottom. The Mooring Super Building Block (which includes chain lockers etc.) is added at the bow, on 2 Deck.

This leaves the Accommodation & Commissariat Super Building Block which can be located forward and aft of the Engine Super Building Block. The requirements of this Block are met provided the volume requirements are met, there being no specific adjacency requirements to consider. Therefore the SBB is divided and placed in available spaces as required. At this stage each Building Block is represented within the hull (see Figure 5-15). Auditing the design revealed the following issues:-

- The overall weight is greater than the overall displacement.
- The hull volume is not sufficient to meet the gross requirements for space.
- The superstructure is not supporting the Bridge SBB at the required height.
- Space in the double bottom is not sufficient for the initially estimated fuel capacity.
- The curvature of the hull does not allow the Engine Block to be mounted within the hull properly.
- The Accommodation / Commissariat SBB has insufficient volume.

An initial performance estimate suggested that both the achieved maximum speed and cruise speed were insufficient to meet requirements. Therefore the prime mover installation has been up-rated and the fuel requirement revised. The initial stability was also considered unsatisfactory. The following changes to the design dimensions were therefore considered necessary:-

- An increase in beam to meet displacement, stability and engine space requirements.
- An increase in draught to meet displacement requirements.
- An increase in depth to allow the double bottom height to increase, increasing fuel stowage space.
- Hull coefficients revised to provide a more suitable form based on Parametric exploration of options.
- Extra superstructure is added to support the Bridge Super Building Block.

The changes made were intended to meet the new requirements given the current performance. A hullform with the new dimensions was generated (using the weight and space required and design discrepancies at the end of the last iteration as drivers) to replace the existing hullform. Those blocks whose requirements have altered, or were never satisfactorily met, were removed and updated. The major feature arrangement was checked for validity given subsequent changes to design dimensions and necessary changes were made. A new layout cycle was then undertaken. The major change in layout introduced was the addition of a third portion to the Accommodation/Commissariat Super Building Block in the superstructure to support the Bridge Super Building Block.

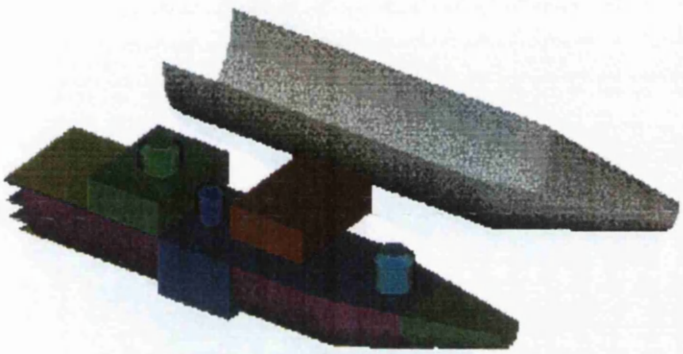


Figure 5-15 First Full layout of SBBs (Hull removed for Clarity)

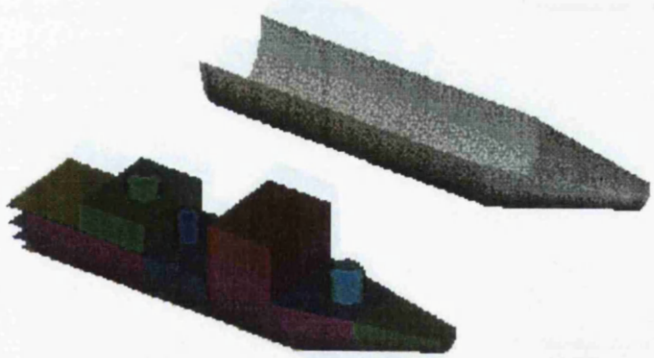


Figure 5-16 Revised Layout of SBBs

At the end of this iteration the hullform and internal arrangement were considered to be much more satisfactory (see Figure 5-16) with just small discrepancies in the following issues:-

- Displacement
- Stability

These discrepancies were not considered sufficient to justify a third iteration at the Super Building Block level. The most sensible additional change to the design, that of a slight increase in beam could be applied at the Building Block level. The old hullform was replaced with a new hullform and the Super Building Blocks replaced by their component Building Blocks. Changes made to the locations of Building Blocks satisfied the increased number of constraints on the design, notably the movement of the Commissariat SBB block so that it could be located in between two bulkheads. Major access requirements were removed from individual Building Blocks and applied on the main passing deck. This caused a major re-examination of the Accommodation and Commissariat Building Blocks as the entire Commissariat block could not be located on the same portion of the passing deck as required. Consequently some of the Accommodation was also moved.

At this stage the balance between provision of features and requirements was considered acceptable and the design dimensions finalised. A final analysis of the design indicated performance in line with requirements. Individual Building Blocks could then be decomposed to their constituent spaces and systems and a full general arrangement produced. Several minor changes to the overall arrangement were made to meet the specific spatial requirements of individual compartments.

In more realistic Building Block design processes the following changes would be apparent. Firstly on average a Super Building Block is likely to be composed of three Building Blocks. Hence more changes than are suggested in this example would occur at the Building Block level, although gross size changes would be less than at the Super Building Block level. Finally more design iterations would be required to actually balance the design.

5.6 Architectural Design of Naval Ships

It has been suggested in Chapter 4 that the architecture of a naval design is an important consideration in the development of the preliminary design. This section details architectural design issues within naval ship design. The types of compartment and space to be located within the hull are described alongside other important warship architecture concepts. This section also details the implementation of compartment location selection techniques both in the building architecture field and the naval design field. This is used to develop a concept of spatial maps detailing relationships between compartments and spaces. Such relationships can be used to plan both the layout of naval ships, and also aid the development of suitable functional Building Blocks and Super Building Blocks.

The Architecture of a Warship: Important Concepts

The example of a relationship between dimensions and features of the Assault Ships and the internal arrangement of the ship [see Section 5.4] shows that it is important to consider internal arrangements of the warship at the same time as gross ship characteristics are being evolved. In part the link between internal ship architecture and design features can be satisfied by the development of the Building Block design methodology. However there is a need to develop complete general arrangement level internal arrangements of using a methodology that assesses the relationships between spaces. Within the Building Block methodology this aids the definition of which functions can be considered as part of the same functional Building Block. If applied to other design methodologies such as numerical synthesis the relationships between spaces can be used on a non dimensional level to assess the desired arrangement of spaces prior to the placement of compartment representations on a General Arrangement diagram. This avoids the designer deciding "as required" the order in which the elements are allotted space and location, a method which only provides a suitable layout by chance. It is considered that spatial relationships such as requirements for adjacency or separation between two compartments define a layout's suitability as well as the consideration of access routes and the major constraints placed upon the layout by structural and survivability considerations.

This section provides an architectural methodology broadly applicable to warships that allows the designer to consider the issues associated with layout in a clear and comprehensive manner, focusing on relationships between layout elements. The methodology does not attempt to provide optimum layouts, if such a thing can be defined, or to automate layout processes as it is considered such methods do not really allow the designer to exert the creative control over a design required. It must be noted that a ship is a multi role system with the layout being required to facilitate operations both during peacetime and wartime without major changes. Thus layout optimisation would be solely for the requirements for one particular role (i.e. peacetime convenience, or wartime survivability), and the treatment of the architectural form as a mathematical problem would also require the optimisation to treat the success or failure of the layout in numerical terms.

It is intended that output from the architectural design methodology is a 'satisficing' layout, one which meets all requirements but does not profess to be the optimal layout. The architectural methodology is demonstrated by application to a monohull frigate. While not a formal part of the Building Block methodology, the architectural design methodology forms a useful tool when performing Building Block design.

The spaces and compartments of a warship are considered to be composed of design elements which can be decomposed into one of five groups. These five groups are defined below:-

- **Type 1 External Demand Spaces** Spaces devoted to systems or functions which interface directly with entities which are not part of the whole ship system. These must be located in positions so that the interaction can occur and thus are very important to locate towards the start of the internal configuration process. E.g. the Bridge :- the visual interaction between the ship and the sea.

- **Type 2 External Demand Associated Spaces** These spaces are provided on the basis that the Interface spaces would not be able to exist without them, thus generally they are located to meet a constraint between the interface and associated spaces minimising the distance between them. E.g. the chart room, without which the bridge would not be fully effective.
- **Type 3 Internal Demand Spaces** Spaces which require careful consideration to configuration both in terms of overall size and location but are not placed to allow interaction with elements that are not part of the ship. E.g. Galley.
- **Type 4 Internal Demand Associated Spaces** These spaces must be positioned in order to allow access from themselves to and from the Internal Demand spaces. They may or may not be demanding by themselves in terms of size but their approximate location will be determined by the location of the Internal Demand space. E.g. Junior Rates Dining Hall.
- **Type 5 Flexible Spaces** The least demanding spaces which are only difficult to configure in terms of dimension rather than in location, and therefore generally located towards the end of the configuration process and in space unassigned to more demanding and important requirements. E.g. Naval Stores.

The treatment of each groups is slightly different with regard to the major problems of layout processes, resolving the inevitable conflicts between adjacency of compartments, access, position of structural and zone elements and the numerical size requirements for compartments. Other similar descriptions may be equally valid provided they note the distinction between elements that affect the design layout and those that are affected by other design elements.

Selected Architectural Design Methods

In considering the role of architecture in naval ships several lessons can be learned from the architectural design community. Several researchers [*Hillier et. al., 1984, Steadman, 1983*] have suggested the use of symbolic configuration maps to allow the designer [and historian] to assess the nature of design layouts. This involves the decomposition of the components of a building or village into individual rooms, represented as point sources regardless of size. Relationships between rooms are shown by lines representing access points. From such "non dimensional" maps the original design considerations, driving the layout, can be investigated. In the paper [*Hillier et. al., 1984*] the trends in the design of seventeenth century farmhouses were detailed.

A view is taken that the use of such non dimensional maps of layout, removing the implications of size from consideration of the layout's suitability, is a useful concept for clarifying interactions between spatial elements. However the approach of [*Hillier et. al., 1984*], in which the non dimensional map is analysed numerically and conclusions drawn as to the effectiveness of the layout, is not considered to be wholly valid when the layout in question is a multiple purpose complex arrangement such as that for a warship. In [*Hillier et. al., 1984*] a doctor's surgery is examined in terms of the "integration[140]" of the spatial arrangement from both the doctor's and patient's point of view. For each point of view a numerical value is calculated for the integration, a lower value of which suggests a more integrated design. This technique does not suggest a method of dealing with the problem of improving layouts from the doctors and the patients viewpoint at the same time, other than by trial and error.

The recommended course for assessing a naval design's configuration, is to develop non dimensional spatial arrangements, prior to preparation of a general arrangement diagram. However mathematical techniques are not recommended for defining a warships layout's success.

The manner in which the designer derives the internal arrangement of the warship concept design influences the style of the design and its suitability for the task for which it was defined. A design methodology for the internal arrangement of a warship could consist of the following stages:-

- Suggest items to be located.
- Investigate relationships between items.
- Locate critical items.
- Investigate placement of less critical items.
- Evaluate complete design configuration for suitability.
- Iterate configuration as required.

When placing compartments a designer must ensure that all compartments are located in a position where they can fulfil their own role without preventing other compartments from fulfilling their own requirements. Problems arise when a compromise is required, due to a lack of sufficient space in an area of the ship in which two spaces would ideally be located. At this stage the designer must choose which compartment must have its functionality compromised to allow the other to function, or in an interactive synthesis such as the Building Block methodology, whether more space in that area is permissible. Part of the problem of developing an internal layout methodology is to formalise methods of decision making and produce a hierarchy of compartments so that those compartments that have greatest influence on design style have their requirements investigated at an earlier stage. The description of the compartment as being a member of one of five groups was evolved as a result of considering those compartments that interact with the outside environment should generally be considered at an earlier stage and higher priority than those interacting solely within the ship artefact. The major considerations in the naval architectural

140 Integration is defined by [*Hillier & Penn, 1994*] with respect to a street map of London. *"By this we can assign an integration value to each line in the system reflecting its mean depth from all other lines in the system.... how much movement passes down each line is very strongly influenced by its integration value... "*.

design methodology are as follows:-

- Numerical spatial demands must be met.
- Structural arrangements must both influence and be influenced by the layout.
- Watertight subdivision must both influence and be influenced by the layout.
- Personnel circulation issues (ease of passage and length of major routes).
- Attraction and repulsion between design elements should be incorporated as a design issue.
- Vulnerability concerns such as zoning and separation should be considered at the earliest stages.

The Need for a Unconventional Hullform based Architectural layout methodology

A common theme of this thesis is the need to consider layout at the same time as the definition of design dimensions. This is considered especially true for unconventional designs. If the designer is not using an integrated conceptual design methodology, such as the Building Block methodology, there is still a need to consider the requirements of compartment and other features that define an unconventional design's layout. It is difficult to produce an internal arrangement for a Trimaran, for example, given geometric and structural constraints, that meets all functional requirements. This coupled with a need to revise traditional arrangements for spaces such as the officers accommodation spaces, to make use of the different distribution of space within the Trimaran hull suggests that simply evolving a modified monohull architectural arrangement process is not suitable for the Trimaran. When considering such a concept as the SWATH or the HYSWAS the designer needs to depart from a post synthesis layout approach completely and consider carefully the functional requirements and their affect on architecture, due to the completely different distribution of space.

Analysis of Existing Design Arrangements

Following the development of the notion that spatial elements of a warship can be considered to be members of one of five groups, it is suggested that it is a useful approach in developing new designs. Prior to this the application of this concept to existing design arrangements will be considered. Non dimensional maps will be produced of two existing designs, using the assumption that the two existing designs must meet all realistic layout requirements as they are in existence. Security implications dictated the types of design investigated. Two designs for which complete and unclassified, realistic data was available were the following:-

- FF-21 Multi Mission Frigate [*Afanaskieff & Mabry, 1995*]
- H.M.Y. Britannia [*Shepherd, 1953*]

These two designs show a wide variety in internal arrangement due to the complete difference in design style, the role[141], the types of space present, and design bureau responsible.

There are three aims to the study, firstly to consider whether the hypothesis of the five types of compartment actually has a role to play in the layout of ship designs. Secondly to assess which of the groups of associated compartments was considered to most strongly influence the remaining groups of compartments and therefore the order in which the compartments should have been sited. It was expected that this order would be commensurate with the proposed decomposition of the elements into the five types. The final aim was to assess the types of compartment in the ship and the relations between them whilst detailing the Building Blocks which would have been created to model these designs had the design been modelled using the Building Block methodology.

Firstly the compartments in each design were listed and the reason for their given location assessed, to assign them to one of the five types of compartment detailed previously. Examples are given in Table 5-11.

Compartments were added to a non dimensional map, all compartments were

Compartment / Equipment	Hierarchy Level	Spatial Characteristic
Forward CIWS System	1	Forward of Bridge with clear arcs. Therefore required to be located with respect to external environment
Forward CIWS Magazine	2	Must be located immediately below the Forward CIWS System
Main Gun Magazine	2	Must be located vertically below but separated from the Main Gun
Officers Cabins	3	Located separately from Ratings thoroughfares to provide "officers only" area. Therefore position important relative to other ships compartments, not relative to external environment.
Officers WC	4	Located Near to Officers Cabins
Storeroom	5	Location relatively unimportant provided access is reasonable.

Table 5-11 Examples of Compartments with Configuration Requirements

141 It should be noted that while Britannia was generally used as a royal yacht, the general arrangement was also developed to allow the role of hospital ship to be performed without major change, by the Ministry of Defence and hence shows military thinking in its arrangement. In this thesis Britannia was analysed in her normal condition.

represented as single points regardless of size. The non dimensional map shows relative locations of all the compartments of the design both in terms of longitudinal and vertical position. Transverse position was considered of secondary importance. The non dimensional map was analysed for patterns of compartments, whose locations were influenced by each other. Figures showing the compartment spatial arrangement are shown in Appendix C. The final addition to the non dimensional maps assessed which groups of functions were sufficiently closely packed to be represented as one building block should this design be produced using the Building Block design methodology.

Analysis of the Non Dimensional Arrangements

In Appendices C-3 and C-4 the FF-21 arrangement can be seen to show an arrangement with the superstructure space and the central portion of the main hull dominated by Group 1 compartments. Almost all Group 1 compartments are immediately adjacent to a related space in Group 2. This reinforces the hypothesis that the Group 1 compartments should be located first in the design process followed by the Group 2 compartments which "rely" on them. The engine rooms, inlets and outlets dominate the central portion of the main hull. Figure C.4 shows the relative positions of Group 3-5 compartments on the non dimensional map. It can be seen that the spaces available to these compartments are limited to those in which there are no Group 1 and 2 compartments. There are more isolated compartments in Groups 3 and 4, further away from functionally linked compartments. Exceptions to this include the galley and related spaces, and the officer's accommodation. The separation of the Group 3 and 4 compartments is due to the fact that many of these compartments are multiple instances of the same type of compartment.

It is considered that should a designer design these ships, the key to designing a satisfactory layout would be the positioning of Group 1 and 2 compartments. Anticipating the designer's choice of Building Blocks, for use in the development of an FF-21 like design using a Building Block methodology, the Building Blocks which would have resulted are clearly visible, as shown in Figure C.5.

The Royal Yacht design shows similar domination of superstructure and main hull spaces by the Group 1 and 2 compartments, although Group 1 compartments in this case include the Banqueting facilities, which are required to be easily accessible by visiting dignitaries and the Royal party. The vast majority of compartments are Groups 3 and 4, generally accommodation and living spaces for royal aides, ship's complement and ship's Royal Marine contingent. The link between the Group 3 and 4 compartments adjacencies is much greater than on the FF-21 design, due to the number of cabins and bathroom's/WC's, allowing most cabins to have washing facilities. The lowest two hull decks contain the vast majority of compartment's in Group 5, those whose location is relatively unimportant.

The layouts of two designs analysed were influenced by the spatial relationships between compartments. In the FF21 design, the topside arrangement of weapons and sensors effectively defined space available inside the hull and superstructure for other compartments. The role of the ship and the types of compartment to be fitted in the design drive the layout style. It appears feasible to use the requirements to meet all the functional, positional and adjacency demand of compartments to generate a non dimensional arrangement that meets all the specified architectural design requirements.

5.6.1 Development of a New Layout Methodology

Using the analysis of existing ship designs just described, a new layout methodology can be implemented such that the architectural issues within the general arrangement stages of traditional design approaches and within all design stages of a Building Block design methodology are considered. The methodology relies on the definition by a designer of suitable spatial relationships. It is considered that the most suitable method of considering the adjacency requirements does not involve any mathematical measures of distance between compartments, rather those compartments with specific demands for other compartment are specified by the following statements:-

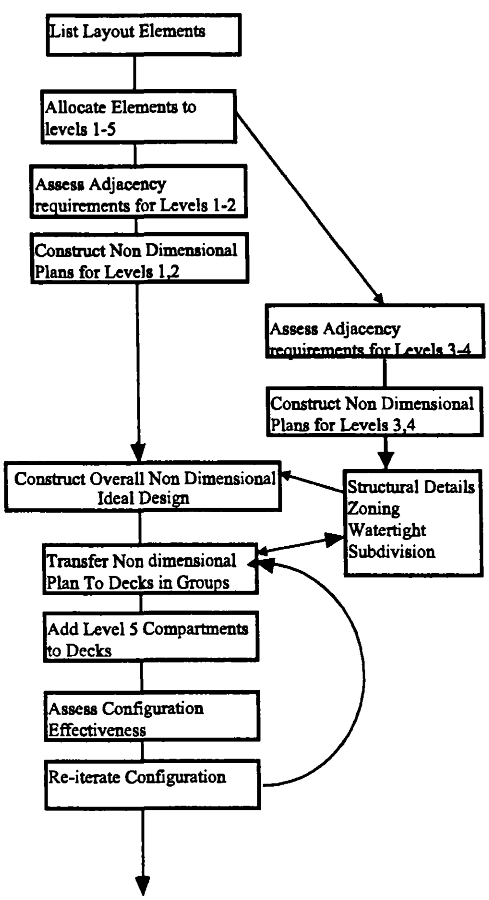


Figure 5-17 Internal Layout Methodology

- Next to — Immediately adjacent to a compartment.
- Near to — In the region of, but not necessarily next to a compartment.
- Separated from — Not in the near vicinity of a certain compartment.

Each constraints is applied to compartments with extra detail specifying the direction of the constraints[142]. The layout methodology is detailed in Figure 5-17.

Application of the New layout Methodology to Monohull designs

It is necessary to demonstrate the development of a monohull layout to prove the new layout methodology. The method chosen is to demonstrate the re-development of a layout for a typical escort warship design, whose major features and design issues were known. The procedure was to select a design, measure the existing compartment areas, volumes and hull shape, and develop a new arrangement of compartments using the new internal arrangement design methodology. The problems of obtaining unclassified, realistic data was encountered, and a student monohull escort design [*Alder, 1996*] was selected with origins in real designs. It was assumed that the compartments as placed by Alder on his general arrangement diagrams were of the desired size. The compartments to be placed were assigned to the five groups listed previously. Requirements for adjacency between individual compartments were assessed. This led to the development of isolated groups of compartments represented as non dimensional elements, equivalent in many respects to the Building Blocks used during the Building Block design process. Such groups generally have one or two compartments that drive the location of all the compartments in that group. Examples of such groups are shown in Figure C.1. The groups were placed on a non dimensional map. Without considering the feasibility in terms of available space, this allows the designer to place a group of compartments where they would ideally be located, suggesting an arrangement that meets the requirements for the overall functionality of the design. The final stage was to modify the functionally ideal but practically invalid arrangement into one in which correctly sized compartments are located, with suitable access. The space desired in several locations was greater than the space available and the arrangement was re-arranged becoming less satisfactory in terms of the functionality and adjacency relationships between the compartments but more practical in that the compartments were of the desired size.

The final re-development of the Alder general arrangement is presented in Figure C.2. The majority of the requirements for adjacency have been met. The most noticeable changes from the original design concern the location of the operations and communications groups. On the non dimensional map these are placed below the main mast assembly, on a main hull deck (3 Deck). When these elements were placed in the

142 i.e. next to but vertically above or separated longitudinally.

corresponding position on the general arrangement diagram there is not enough space to locate all compartments with the required space, bulkheads separation and access routes. Thus both groups were moved to a deck (01 Deck) where requirements could be met. This has the advantage of shortening the distance between the communications offices and antenna, but at the cost of moving the operations room above the waterline which was felt to be acceptable but not desirable. The final general arrangement is considered successful, in that the layout meets all the adjacency requirements originally defined.

A major problem when applying the layout methodology to unconventional forms is the need to consider the transverse direction as a major layout characteristic. The designer would need to investigate the requirements for particular hulls or areas, such as cross structure. This suggests modifying the layout methodology to utilise "three dimensional" non dimensional maps of the proposed layout in preference to the two dimensional profile view currently utilised.

Application of the Architectural Methodology within the Building Block methodology

Appendix C demonstrates a link between requirements for adjacency of individual compartments and a proposed Building Block arrangement. The Building Blocks are those proposed for use if the same design was to be created using the Building Block design methodology .

It is proposed that, at the stage at which a designer subsumes individual functional requirements into Super Building Blocks, the designer should consider the configuration requirements of that Super Building Block using a non dimensional map. The prediction of relative locations of individual parts of a Building Block enables a designer to assess whether numerical spatial requirements will be affected by location within that Building Block.

5.7 AN OVERVIEW OF THE PROTOTYPE CAPSD SYSTEM

5.7.1 The Role of Computers in the Building Block Methodology

"Ship Design without the computer is no longer imaginable" [Gallin, 1973]

The above statement is true, given that the need to affirm the potential performance of new designs before the use of expensive model testing mandates the use of computers to analyse performance. Examples of the beneficial use of computers in design, include the almost instantaneous calculation of seakeeping properties and the use of two dimensional drafting techniques on a computer. Both implement procedures previously performed by hand. Generally there is a great increase in rapidity without any reduction in calculation accuracy, or even the ability to calculate using methods too mathematically intensive to model by hand. The use of computers allows re-use and modification of designs as well as simple rectification of errors to be undertaken, saving time and money. It is impractical to argue that the use of computers has adversely affected the performance of analysis tasks, other than the loss of manual skills amongst computer operators. The benefits of using the ship design computer system to support the ship designer in performing design are not so clear.

However using a computer to perform design, using methods without a manual analogue, has produced controversy and the computer may not provide a suitable host. The ways in which a designer can use computers can be thought of as representing two styles of design, based on the technological complexity and capabilities of the computer. These are:-

- The use of the computer as a design assistant (analogous to 4th Generation Systems)
- The use of the computer as a designer (analogous to 5th Generation Systems)

The first case[143] is considered generally successful at performing real design tasks, while the second case is considered as un-obtained. The beneficial effect of using a computer as a design assistant is due to the relative strengths of a computer when compared to the human mind. Such strengths include the speed and accuracy of data retrieval and transformation. However the computer is only able to transform data accurately if the mechanism for the transformation is rigidly defined.

The weaknesses of the computer are related to a lack of inherent creativity, intelligence and self directed thought. The computer, even with the aid of complex Artificial Intelligence techniques such as Neural Networks [*Lippmann, 1987*] or Expert/Knowledge based systems cannot pass the Turing test[144] [*Turing, 1950*] and other tests of a cognitive nature. Self directed thought includes the creativity required for a designer to perform the design task well.

The computer is unable to replace the designer satisfactorily for wide ranging

143 The fourth generation design computers were the first computer systems to move from a mathematical treatment of design to the use of design as a graphically based task. The next step, the 5th generation computers, evolved from the rigid numerical implementation of design to the use of artificial intelligence in design [*Andrews, 1981b*].

144 "*The Turing Test, measures the performance of a machine against a human being. The machine and a human are placed in two rooms. A third person, designated the interrogator, is in a room apart from both the machine and the human.... The task of the interrogator is to distinguish between the human and the computer on the basis of questions she may put to both of them over the terminals....If the interrogator cannot distinguish the machine from the human then, Turing argues, the machine may be assumed to be intelligent.*" Definition of the Turing Test from Brunel University. Internet reference "http://www.brunel.ac.uk/depts/AI/alife/al-ttest.htm".

creative design exercises. Purcell & Gero [*Purcell & Gero, 1996*] attributed the "demise" of the computer as designer to the ill defined nature of the design problem. This has conversely led to the intelligent design assistant computer system and the use of case based reasoning [as in *Domeshek et. al., 1994*].

In ship design the use of optimisation methods [*Keane et. al., 1990*], Expert systems [*Duffy & MacCallum, 1989, Gorton, 1991, van Hees, 1992*] and Neural Networks [*Sha. et. al., 1992*] attempt to utilise the computer to perform initial sizing. These ship design tools utilise limited design knowledge or mathematical optimisation, focusing on a small range of possible ship designs. In that range the systems are capable of sizing ship concepts provided that the important design issues are compatible with the underlying system data. When creating solutions to novel requirements such systems are considered incapable of forming a valid solution without specific modification.

Hence a first requirement of a prototype CAPSD system for the Building Block methodology is to use the computer as a design assistant, presenting information, performing precise calculations, and performing repetitive tasks for the designer. This allows the designer to concentrate on the design to be created, applying creativity to that design, making decisions to suit the particular issues relevant to that specific design's.

System Element	Program
Overall System Kernel	SMS (Submarine Modelling System)
Solid Modelling CAD System	Intergraph EMS
Relational Database Management System	Oracle
Building Block to NES Weight Group Conversion System	Microsoft Excel
Analysis Tools	SUBDRAG[145] SUBDRIVS[146] MNSTRL[147]

Table 5-12 SUBCON Computer Aided Design System Components [Summarised from Andrews et. al., 1996]

A second requirement of the Building Block design prototype system is to act as a "Glass Box" system rather than as a "Black Box" [*Jones, 1970*] system in line with view of Pattison [*Pattison, 1994, see Section 2.3*]. The contents of a "Glass Box" system should remain visible and open to modification by the designer to avoid the problems of "hard wired" systems in which design data and algorithms are utilised without regard for their validity.

[145]SUBDRAG is a modified version of the DERA tool PBDRAG, used for submarine resistance and power requirement prediction.

[146]SUBDRIVS is a DERA Derivative prediction tool for submarine manoeuvring analysis.

[147]MNSTRL synthesises a minimum weight pressure hull structure using the methods detailed by [*Faulkner 1983*].

5.7.2 Requirements of a Prototype CAPSD System

The computer aided design system used to develop and demonstrate the methodology, is of a prototypical nature, capable of rapid reconfiguration and flexible operation. Such features allow a designer to concentrate on the application of the design methodology, rather than the development of individual system components. Thus the complexity of computer development programs including the generation of industrial quality computer programs was avoided. The prototype system was constructed from existing components, to enable flexible and rapid development. The major tasks to be performed by the prototype system were as follows:-

- Collection, storage and modification of the "Design Description" as Super Building Blocks, Building Blocks, Compartments and System elements. This was to be in such a form to allow the designer to alter the structure of the design description if different design requirements or hull types required.
- Display of the three dimensional geometry of the design description as Super Building Blocks, Building Blocks and Systems. This was to allow the designer to model and manipulate the configuration of the concept ship design.
- Manipulation of the functional, numerical and geometric information of design elements in three dimensions.
- Transfer and update the data descriptions when the design changes.
- Storage of whole ship design attributes such as complement and physical overall dimensions as the Master Building Block.
- Provision of separate models for the major feature and topside design phases.
- Analysis of the design in major performance areas.
- Preparation of physical output of numerical and geometric design definitions.
- Storage of design decisions for later reference.

5.7.3 Components of a Prototype CAPSD System

The requirements of the CASPD system prototype are analogous to those of the SUBCON suite [see *Andrews et. al., 1996* for a description], given that they share an underlying methodology. For the initial prototype system, each element of SUBCON was assessed and analogous computer programs introduced.

System Element	Program
Wireframe CAD System	Autocad release 12
Topside and Major Feature Modelling System	Autocad release 12 with Advanced Modelling Extensions
Data Storage Spreadsheet	Excel
Hullform Generation	HULLFORM, Autocad release 12
Analysis Tools	HYDSTAT, TGRESIST, S64PE, POWERING for GODDESS, Excel

Table 5-13 CAPSD System 1 Components

The SUBCON system, demonstrated in Table 5-12, was used in the development of Submarine Building Block design methods and the design is detailed by [*Dicks & Spragg, 1995*] and summarised in Appendix B.

Two versions of the prototype surface ship design system were prepared. CAPSD system 1, consists of the elements detailed in Table 5-13. System 1 was used on all the design studies detailed in Section 7.2, except for the two SWATH designs and the Landing Ship Tank [LST] design. System 2's capabilities are described in Section 5.7.4.

Using a solid modelling CAD system, the second generation CAPSD system 2 was evolved. Differences between the two systems are shown in Table 5-14. CASPD system 2 was used in the development of the two SWATH design examples [Section 7.2.6] and the Landing Ship Tank design [Section 7.2.5]. In the following sections the functionality of the individual components of CAPSD systems 1 and 2 is described.

5.7.4 Description of the CAPSD Systems

To introduce configuration and functionality at the earliest stages of ship design, it is necessary to produce a graphical model of the ship concept. This must be synchronised with an alpha-numerical model definition stored in a database [as in SUBCON] or in a spreadsheet [as in CAPSD systems 1 and 2]. The graphical model details the configuration of the ship with sufficient accuracy and versatility to allow

System Element	CAPSD 1 Program	CAPSD 2 Program
Wireframe or Solid Modelling CAD System	Autocad 12 (Wireframe modelling features only)	Autodesk Mechanical Desktop 1.2 (solid modelling)
Topside and Major Feature Modelling System	Autocad 12 with Advanced Modelling Extensions	Autodesk Mechanical Desktop 1.2
Hullform Generation	HULLFORM Autocad 12	HULLFORM AutoSurf
Naval Architecture Extensions	CAESAR (Wireframe)	Not Applicable

Table 5-14 CAPSD System 2 modifications

design decisions to be made using geometric as well as numerical information. Practically this suggests a three dimensional approach to modelling. Several three dimensional CAD modelling approaches currently exist. Firstly, Wireframe based methods in which the three dimensional entities are modelled by lines connecting those vertices defining the three dimensional form. For more complex forms the use of constructive solid geometry is preferred. Constructive Solid Geometry uses the rapid definition of regular forms as solid models, these are formed into more complex entities using "parts" and "features" attached as parametric design descriptions. A "part" is the basis of the constructive solid model and consists of a three dimensional solid model defined from basic parametric dimensions and constraints[148]. After a solid has been formed, dimensions and features may be edited by varying the parameter values. By adding "features" to the base part the solid model is increased in complexity. A "feature" can be a Boolean operation [e.g. union of two parts] or a modification [e.g. a countersunk hole]. The resulting solid geometry is stored as the sum of the operations that created it, allowing features to be modified or reused without invalidating the model. Complex forms can be created from which the solid properties, mass, volume, inertia and centres of gravity can be calculated.

A further method of three dimensional modelling is surface modelling. This models a three dimensional entity as a thin surface of varying shape and form. Typical methods used, include the Bezier description method [described in *Yamaguchi, 1988*] and the B Spline description method in its uniform and non uniform forms [as used by *Peacock et. al., 1997*]. Such methods are often used as the description method of ship hullforms for stability analysis tools.

In CAPSD system 1 the three dimensional description method is a wireframe method, due to the use of CAESAR[149]. As a result the hullform description method was limited to deck based descriptions. The hull is defined as a two dimensional polyline entity at each deck height. CAPSD system 2 benefits from the integrated surface and constructive solid modelling of Autodesk Mechanical Desktop, allowing much more complex forms to be modelled easily.

The Functionality of CAESAR

CAESAR was developed as an extension of the research at University College London into spatially based synthesis of ship concepts. The original tools to implement the research of Andrews [*Andrews, 1984*] included the deck layout tool ROSTRA [*Lloyd, 1983*]. ROSTRA provides a tool to aid development of naval ship internal configurations from the point at which the hullform is known. ROSTRA operates in the plan view of the ship design. Unlike the standalone tool, ROSTRA, CAESAR only implements the necessary additions to an existing CAD system [Autocad]. The major functions of

148 A simple constraint could be enforcing the parallel condition or concentricity between two elements.

149 "Computer Aided Engineering of Ship Arrangements", a design program written and documented by Zhang at UCL. [*Zhang, 1994*]

CAESAR are:-

- Design space creation
- Compartment initiation and demand capture
- Compartment placement
- Compartment manipulation
- Compartment and design auditing

The deck edge at each deck height is input using hullform geometry data from the HULLFORM program [*Wray, 1982*] as a series of data points through which Autocad polylines are placed. This defines the boundary of space on each deck. The compartment initiation and demand capture functions allow the designer to add compartment descriptions to the ship description. The descriptions have the following elements:-

- Weight group number
- Short and long compartment name description
- Required volume
- Required deck area
- Number of vertical decks.

Thus the ship is specified as a series of compartment spatial demands. CAESAR extensions add three dimensional wireframe representations to each compartment. The designer assigns dimensions to the representation, and places the compartment in the ship model. The compartment can be audited and manipulated spatially. In CAPSD system 1, CAESAR allows the designer to place different CAD elements on the representative deck. When used with the Building Block methodology for surface ships, all layout elements in the Super Building Block, Building Block and General Arrangement stages are stored as "CAESAR wireframe compartments".

CAESAR is only suitable for modelling compartments of simplistic form. It is not truly suitable for modelling tanks and other complex shapes. The deck based view of a ship provides problems for surface ship design as design issues of the vertical dimension, particularly those associated with structural continuity are complex. These problems, added to the primitive hullform definition, require a more capable method, able to create and manage complex tank and hull surfaces. One solution is Autodesk's Mechanical Desktop 1.2 system[150]. The modelling capabilities of Mechanical Desktop allow a designer to consider in detail the assignment of space in complex forms. Parametric modelling methods allow the designer to change the overall dimensions of the base part until the characteristics of the Building Block are acceptable.

[150]Autodesk Mechanical Desktop 1.2 extends the functionality of Autocad release 13 with the addition of the parts based constructive solid geometry modeller "DESIGNER", the surface modeller "AUTOSURF" and an assembly modeller. The assembly modeller allows individual solid models to be attached to visualise an assembly of components.

Hullform Modelling Systems

A major difference between the requirements for prototype systems 1 and 2 and the SUBCON system [Table 5-12] is a need to consider hullforms that are not constrained by a cylindrical submarine pressure hull. Modern naval surface ship designs have complex hullforms, for example hullform flare [as in *Burcher 1980*]. Manual development of such hulls is complex and time consuming. To undertake rapid evolution of ship design concepts, where hullforms change with each design iteration, it is necessary to invoke an automatic hullform generation tool, generally distorting a parent form[151] to new dimensions.

The hullforms are exported as body plans to the CAD modelling tools of CASPD system 1 and 2. The hullforms do not meet all downstream requirements for fairness but do provide sufficient representation of the space available. This was acceptable due to the nature of the analysis tools. None of the CAPSD system analysis tools directly utilise the CAD hull definition itself[152].

Description of the Data Storage Tools

The change in data storage mechanism, from the relational database management system used in SUBCON [*Andrews et. al, 1996*] to a spreadsheet, is the largest deviation from the SUBCON system to the surface ship CAPSD systems. This was due to the closed nature of database systems. At the earliest stages of the Building Block Design methodology's evolution, methods of operation and data storage requirements were not certain. An ability to modify the structure of Building Block data storage was essential to the evolution of the methodology. "Excel" is a three dimensional spreadsheet based on the worksheet concept. Each worksheet acts as the repository for a different part of the ship description. The exact arrangement of worksheets changes as the design type changes. In general the following worksheets are utilised:-

- Master Building Block Summary, Master Building Block Detail
- Weight and Space summary including Margin Policy
- Complement Breakdown
- Equipment Database
- Float Functional Group

151 The capturing of design intent without using parent forms is under development. Peacock et. al [*Peacock et al., 1997*] suggest the use of a decision support approach with a B Spline curve description method to generate control points meeting form and style requirements. Birmingham and Smith [*Birmingham & Smith, 1997*] suggest a method using optimisation techniques. These tools do not currently meet the requirements for robustness and ease of use. Thus it is necessary to utilise parent based existing technology such as the UCL HULLFORM program [*Wray, 1982*].

152 Tools such as HYDSTAT use Simpson's rules [*Rawson & Tupper, 1994*] to assess hullform characteristics.

- Move Functional Group
- Fight Functional Group
- Infrastructure Functional Group
- Stability Assessment
- Performance Assessment

The first four of these worksheets contain aspects of the ship description that describe the Master Building Block. The summary worksheet provides the most commonly used descriptions of the design, while the detail worksheet contains all the ship dimensions and overall features. The weight and space summary provide the repository for the design's overall weight, space, centres of gravity, Growth and Board margin policies. The complement breakdown allows complement dependant functions to be assessed.

The subsequent four worksheets contain Building Block design information regarding all elements of the ship. Each worksheet represents one Functional Group. The stability worksheet also acts as a repository for the results of external stability analysis tools such as HYDSTAT. The performance analysis worksheet contains simple performance assessment measures such as the natural frequencies of the SWATH designs in Heave, Pitch and Roll or basic resistance calculations. A single spreadsheet file contains all non geometric information regarding one design. The spreadsheet mimics the idea of Stroustrop [*Stroustrop, 1997*] in the use of object oriented data management[153], without the inflexibility and overheads of a formal database system.

The spreadsheet solution is unable to synchronise automatically the geometric description of the Building Block design, in the CAD model, with the numerical and functional data elements. As CAPSD systems 1 and 2 are system prototypes, demonstrating a methodology rather than specific integrated computer aided systems, it is acceptable to use the designer to transfer and synchronise data.

The analysis programs of CAPSD systems 1 and 2 act as surrogates for more extensive and complex tools, which are intended to be available in a commercial implementation of the Building Block design methodology [see Appendix A]. The emphasis is not on analysing all possible conditions or the suitability of the design to meet the operational requirement. Instead it is to quickly provide indications of performance, enabling the designer to make informed design decisions. Thus the following representative design tools were used amongst the various design examples demonstrated in Section 7.2.

- Stability Assessment
    - HYDSTAT
    - Simple Metacentric height calculations for Monohulls *[Rawson & Tupper,1994]*
    - Simple Metacentric height calculations for Trimarans [*Bayliss et. al., 1996*]
    - Simple Metacentric height calculations for SWATHS [*UCL,1993*]
- Seakeeping Assessment
    - Natural frequency calculations for SWATHS [*M.Sc. 1993*]
    - Design rules for monohulls [*UCL, 1994a*]
- Hydrodynamic Resistance & Powering Estimates
    - POWERING for GODDESS release 15[154]
    - POWSPD for GODDESS release 14
    - Series 64 [*Yeh, 1965*]
    - Taylor Gertler [*Gertler, 1954*]
    - Preliminary SWATH resistance methods [*Illyas & Papalos, 1996, Efthyvoulides & Russell, 1997*]
    - Chapman

This section has defined the components of the prototype CAPSD system 1 and 2 used to demonstrate the use of the surface ship Building Block design methodology. Many system capabilities were analogous to those of the SUBCON system. Emphasis was placed on flexibility and openness instead of the automatic updating of different design elements, that is the core of the SUBCON system. The core of the proposed SURFCON system is detailed in Appendix A.

5.8 SALIENT POINTS OF CHAPTER 5

Chapter 5 has discussed major features of the Building Block design methodology. Each Building Block represents a function of the ship design allowing the designer to investigate configuration, numerical and functional design issues. The designer uses a graphically based computer aided design system backed by data storage facility. The methodology has been placed within the concept and feasibility stages of the sequential design processes. The methodology is not intended to perform design at the detailed design stage [*Andrews, 1998*], but can contribute information to that stage. The major features of the methodology include a need to enter the design in a controlled manner, allowing the design generator to define the starting point of the design modelling process. A feature is the functional breakdown of the design description from overall design to the lowest level of equipment. This introduces the concept of the Master Building Block, the four Functional Groups of Float, Move, Fight and Infrastructure and the Super Building Block concept. A detailed description of the

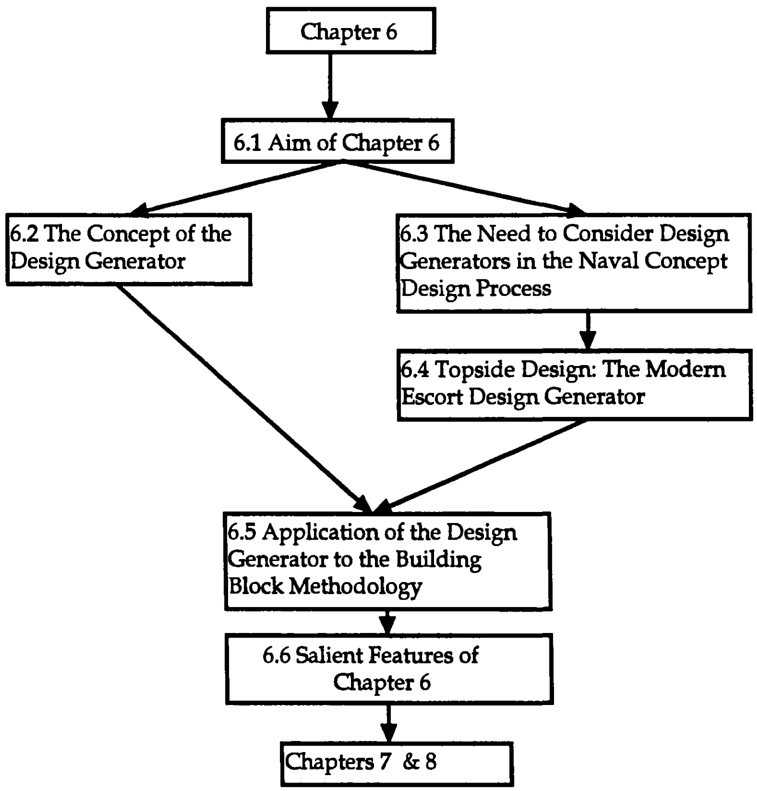
153 Object Oriented Programming is a method currently used for modern computer developments in which the programming code is developed from reusable objects containing both data and methods, using the properties of polymorphism, encapsulation and inheritance. [*Stroustrop, 1997*]

154 POWERING for GODDESS supplies ten different resistance prediction and four propeller design methods. Methods used within this thesis include Taylor Gertler [*Gertler, 1954*].

design concepts employed in the design methodology was presented and illustrated by a design example. The need for computer systems to perform as assistants to the designer, rather than as artificially intelligent designers, was emphasised. The components of the prototype CAPSD systems were described in some detail.

6. THE IMPACT OF DESIGN GENERATORS ON WHOLE SHIP DESIGN

Figure 6-1 Chapter 6 Schematic



6.1 AIM OF CHAPTER 6

The importance of configuration in the design of a naval surface ship has been argued. Most surface ships have a function that directs the design towards a certain configuration style and size of solution, despite other design issues. This feature, known as the primary or design generator [*Darke, 1979*] exists across the spectrum of ship design types.

The design generator is important to the Building Block design methodology. The implicit solution of a design generator's requirements is one of the most important advantages of the holistic configuration based approach to design synthesis not found in purely numerical methods. It also demands the integration of configuration and functional issues within the earliest decision making stages of the synthesis of a naval ship.

Chapter 6 commences with a discussion of the design generator concept [Section 6.2] and an outline of the importance of the design generator in producing naval ship design configuration [Section 6.3]. The design examples illustrate how the design generator has influenced the final design and its major characteristics.

The most common naval ship design generator is the satisfaction of weather deck design issues. The study of this, Topside Integration, is used extensively in Building Block Escort designs as a method of initially investigating the major features of escort designs. Topside Integration is detailed in Section 6.4. Section 6.5 details the use of the design generator as the major focus of the Major Feature design stage within the Building Block design methodology, with reference to design examples and design methods. Section 6.6 summarises the chapter.

6.2 THE CONCEPT OF THE DESIGN GENERATOR

The design generator concept is developed from parallels between the experiences of practical architectural designers and naval ship designers. The design generator is derived from the key or primary generator. This was presented by Darke [*Darke, 1979*] as a generator-conjecture-analysis model of design for application by practical designers in architectural situations. This was summarised by Andrews [*Andrews, 1984*].

> *"The primary generator, is 'the group of related concepts' or objectives that generate a solution. The architects' approaches were typified by the 'use of a few simple objectives to reach an initial concept' this small group being the means of reducing the variety of potential solutions to the yet imperfectly understood problem.*
>
> *The detailed requirements are then capable of being clarified 'as the conjecture is tested to see how far they can be met'."*

This followed Hillier's [*Hillier, 1972*] suggestion that *"conjectures of approximate solutions should come early on"* suggesting that before the start of decision making, the principal form of the design solution should be proposed. These discussions suggest that ship design is not the only design environment in which the designer subconsciously uses the concept of the design generator. A designer will use the design generator to select the initial estimate of design characteristics, removing from consideration design developments that are not compatible with the generator.

The act of design never constrains the resulting design artefact to one valid solution [*Simon, 1975b*]. The design methodology used and order of search suggest which of several valid solutions will be "discovered" and used. Therefore it is suggested that if the design generator is important in defining successful solutions then the satisfaction of the design generator should be the initial step in the development of a design solution.

When applied to naval ships the primary or design generator, is a link between the features of the final ship design and the most important of the initial operational and design requirements that specify those features. The design generator informs subsequent design decisions. When applied to unconventional ships, the concept of the design generator is more important. Satisfaction of such designs' generators removes from contention many potential forms, placing the relationship between size and location of hulls and superstructure detailed in much greater focus as in the Trimaran Escort design [see Section 8.2].

In ship design, the designer may consider the design as being defined by a design driver, a feature of the design that is controlling the design form. The concept of the design generator is subtlety different from that of the design driver in importance, relationship with operational requirement and the mechanism by which problems are solved. The design generator is of importance to the whole design as it prescribes design features necessary to meet operational requirements. For example aircraft related design features are the design generator of Aircraft carriers. The manifestation of design problems regarding the generator is often in the form of conflicting configuration requirements.

Design drivers vary in manifestation more often within the same design type. They can be thought of as features that prevent the design from progressing further in a given, favourable, direction. Such features may or may not be directly related to the operational requirement. Often a design driver is of a "strict naval architecture nature". That is hydrodynamic performance or structural design. A typical example is the "driving" of small Trimaran designs upwards in depth to provide a reasonable air gap below the cross structure [as in *Bayliss et. al, 1997*]. Another example is the reduction in main hull length for fast ship designs caused by a need to provide a large beam for adequate stability, or the increase in structural weight with diving depth for submarines. In particular the structural weight of a design is often a design driver, restraining a design's growth in a given, desirable, direction. Structural design is never considered as a design generator. Structure follows rather than defines the position of the concept in the overall design space. Design drivers are used to confirm or reject specific attributes of an evolved design, particularly with regard to more extreme designs. The design generator is fundamental to the identification of the design space in which the final solution resides.

The design generator concept was also raised by Broadbent [*Broadbent, 1996*][155]. Broadbent suggested a historical movement in the manifestation of the design generator. Broadbent suggested the movement from weight driven designs up to and including World War 2, where mass resulting from armour and armaments were all important, through the volume driven designs of the early electronics era, on to the current designs which Broadbent suggests are linear dimension driven. Broadbent also noted that there are many "Micro Drivers", those features such as individual systems which affect the design configuration by adding additional constraints. Broadbent predicted the future impact of the design generator in the design process, noting the establishment of the formal Topside design committee in the Project Horizon programme and suggesting that *"naval architects, marine engineers and combat system engineers will have to work much more closely together; this requires understanding of each others constraints and problems"*. It is proposed here that this is best facilitated using a system such as the proposed SURFCON tool [Appendix A] implementing the Building Block methodology.

6.3 THE NEED TO CONSIDER DESIGN GENERATORS IN THE CONCEPT SHIP DESIGN PROCESS

6.3.1 Examples of Design Generators

Having discussed the conceptual idea of the design generator, it is appropriate to suggest typical features of ship designs that act as the design generator.

Aircraft Carrier Design Generators

> *"The design of a carrier is dominated by the dimensions of the Flight Deck and the Hangar.... These dimensions are determined by the layout of equipment required for flying off and landing on the aircraft together with the space for stowage of aircraft and the facilities for their maintenance". [Chapman, 1960]*

Throughout the development of the Aircraft Carrier from the first purpose built designs to modern "super" carriers, design size and features have been dictated by the demands placed on the ship by the need to shelter and support organically a carrier air wing. This demonstrates the proposed link between ship design features, the design generator and operational requirements. A carrier air wing requires the following features which define the minimum size design:-

155 Broadbent did not distinguish between Design Generators and Design Drivers, calling both "Macro Drivers".

- Flight deck
- Hangar and engineering spaces
- Stores, fuel and magazines
- Air wing complement and associated facilities

The first two of these features can be considered to be design generators. The latter two are demanding requirements but do not enforce a specific direction of design growth. The Flight Deck and Hangar Deck are considered as design generators as they suggest sizes for specific features of the ship, such as length or beam, without which a design is impractical. Which of the two acts as the design generator for a specific design requirement depends on the nature and number of embarked aircraft. This is due to the nature of the flight deck and the hangar arrangements. A hangar grows in demands almost linearly with number of aircraft, albeit with configuration changing. Changes in hangar requirements arise as the number of aircraft carried becomes too great in ship impact in the current configuration. Such changes with number of aircraft carried are detailed by the multi variant design studies presented by *[Eddison & Groom, 1997, Webb et. al., 1997, Menon & Scheele, 1997]*. [*Menon & Scheele, 1997*] noted the effect of number of aircraft on hangar space, by the investigation of threshold points. Beyond these points single deck two lane or single deck three lane hangar arrangements were unattractive due to their impact on the whole ship. Double hangar designs were required, greatly impacting on acceptable design depths due to the requirement for extra hangar height. This informs the previous suggestion that the idea of warship design being part of a continuous design space is not valid for large designs.

The domination of the hangar on the remainder of a design has been detailed both for historic [*Chapman, 1960*] and modern aircraft carriers [*Eddison & Groom, 1997*]. The hangar affects the remainder of ship arrangements due to the impact on structural continuity, access and prime mover locations. Meeting a Prime Mover's requirements can suggest the investigation of the IFEP system mounted in the superstructure of a carrier [as in *Eddison & Groom, 1997*].

Flight deck arrangements are dependent on the type of aircraft, the landing / take off arrangements, the lifts, parking spaces and superstructure arrangements. Landing arrangements depend on the size of aircraft and its safe landing speed, the number of arrester wires and emergency barriers[156]. Such features are detailed graphically in [*St Denis, 1966*]. Spacing between arrester wires is a function of landing speed. The nature of the angled flight deck depends on sortie rates and the operational

156 Assuming conventional landing arrangements.

importance of simultaneous landing and take-off. Such issues are inextricably linked to the air wing concept of operations emerging from operational analysis and should be used to inform that debate.

Take off arrangements depend on anticipated sortie rates, dictating the number of catapults or launching space required[157]. The propulsion plant dictates the types and size of catapult systems that are feasible[158].

Parking and movement of aircraft on the flight deck also acts as part of the flight deck design generator as it is desirable to park aircraft without interfering with ongoing flight operations. This may dictate a wider flight deck to allow access to lifts without encroaching on the runway. The location and number of lifts, whether centre or waist mounted, interfere with flight operations and ships characteristics. Superstructure affects the flight deck arrangement due to the need to provide a useful island structure with space allocated to controlling both vessel and air operations. This places the superstructure close to amidships on the starboard of the design, making access arrangements to forward parking spaces difficult.

Consideration of aircraft carrier designs suggests that their design space is not one in which size is continually scaleable. Rather a number of essential design issues, derived from aircraft operational requirements place the design in a small design space with relatively few alternative options. This suggests that the first step in developing an aircraft carrier concept should be to perform investigations into the required flight deck and hangar characteristics. The designer should investigate which feature has the more onerous requirements, and use the design generator to prepare minimum dimensions for the design. This would place the ship design in the middle of the relevant range of the design space. Although applied subsequently to a numerical synthesis, a student study [*Menon & Scheele, 1997*] applied this method successfully after previous numerical synthesis studies failed to suggest a valid solution to the design problem.

Amphibious Assault and Vehicle Transport Ship Design Generators

The design generator of most Amphibious Assault ships is the requirement to

157 For non catapult designs the take off arrangements are dictated by the ramp assisted take off envelope.

158 One reason for the predominance of nuclear powered aircraft carriers is the ability to provide almost limitless amounts of steam for the steam powered catapults. The change in size between CTOL and STOVL carriers of similar size in [*Eddison & Groom, 1997*] is partly due to the need to provide catapults in the CTOL designs. The requirements of a CTOL system suggest a minimum size of 35-40000 tonnes [*Eddison & Groom, 1997*] for modern fleet carriers. As size increases the impact of launching arrangements on the design decreases as shown by [*Webb et. al., 1997*] where 40 aircraft CTOL and STOVL designs are only slightly different in dimensions and size [STOVL's displacement 65000 tonnes, CTOL 69000 tonnes].

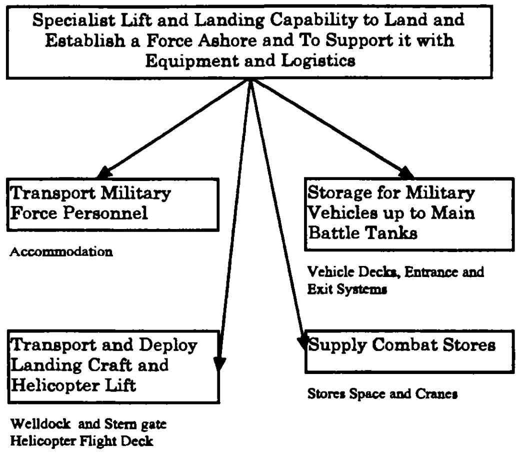


Figure 6-2 Relationship between Core Functions and Major Characteristics

store, transport and maintain military vehicles.

Regardless of the type of vehicle embarked, the operational requirement specifies several core functions and successful provision of such functions is the aim of the vessel and can be linked to the final ship characteristics.

In Figure 6-2 a relationship between the core functions of a new LPD design and its major design characteristics is drawn [derived from *Downs & Ellis,1997*]. The major characteristics derived from the core function of the vessel can be seen as those which have had a great impact on the final design of the vessel [with reference to figure 2, *Downs & Ellis, 1997*].

A particular case of the core function defining the design generator of a design, hence defining the overall design is felt to be the development of comparable Amphibious ships for the French and Royal Navies. The Royal Navy design (LPD(R)) is of such beam as to allow entrance of the LCAC air cushion vehicle into the dock as a result of the operational requirement demanding this capability. The beam, in turn, affects all other design issues. The French design was not required to operate the LCAC vehicle and is not so constrained [*Ferreiro, 1995*].

It is postulated that in the case of transportation vessels such as assault ships the design generator is most likely to be the requirements of those vehicles to be transported and supported. The application of the design generator to vehicle carrying ships is demonstrated in the development of the LST design [Section 7.4.3].

Frigate & Destroyer Design Generators

The purpose of modern Frigate and Destroyer designs can be considered to be the requirement to mount specific military weapon and or sensor systems, transport those systems to an operating area and allow use of such systems as appropriate. Types of weapon system mounted include helicopters, missiles and guns. Sensor systems are generally communications, radar or sonar. The majority of these systems impact on or above the weather deck of the escort design. The design generator of a modern escort design is provision of a suitable topside arrangement so that the combat systems can operate without mutual or external interference. A common manifestation of the topside design problem is a requirement for a minimum design length. Evidence for the nature of the Frigate / Destroyer ship design generator is provided by [*Purvis, 1974*] reporting on Royal Navy warship design practice since the Second World War. This also provides the scope of the topside integration problem:-

> *"The main parameter in such 'space orientated' designs is weather deck length which imposes a limitation on the weapon fit because of the inevitable compromises that have to be made to achieve satisfactory solutions involving:-*
>
> *1) the anchor arrangements*
>
> *2) the swept circles, firing arc and blast and efflux restrictions of the armament on the structure*
>
> *3) the bearing arcs of the bridge and look-out positions*
>
> *4) the swept arcs of navigational aids, guidance and control sensors for weapons the interference restrictions on siting of radio and radar aerials relative to the ship's structure, the funnels and funnel efflux*
>
> *5) the downtakes and uptakes to the machinery compartments and ventilation openings*
>
> *6) the boat arrangements*
>
> *7) the replenishment and embarkation arrangements*
>
> *8) the hangar and flight deck arrangements and the landing restriction for the helicopter if fitted*
>
> *9) the funnel smoke clearance." [Purvis, 1974]*

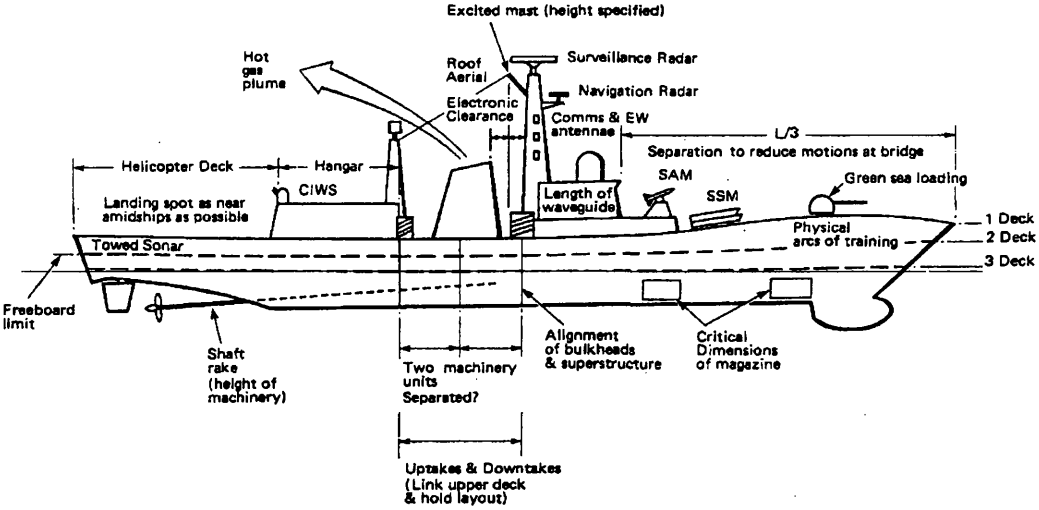
Confirmation of the truth of this statement for modern designs is the selection of a waterline length of 133m for the NFR 90 design [*Schaffer & Kloehn, 1991*] showing correlation with the minimum topside length detailed in that paper [reproduced here as Table 6-1]. A generic form was presented by [*Brown, 1987,* Figure 6-3 here].

Description	Minimum Length (m)
Mooring Area and Flight Deck	27
Hangar and Support Spaces	20
Torpedo Magazine	5
Machinery Spaces	25
Forward Superstructure Block	25
Forward VLS Launcher	10
Medium Calibre Gun area	10
Anchoring and Bow	10
Total	132

Table 6-1 NFR90 Minimum Topside Length [Schaffer & Kloehn, 1991]

The development of the various iterations of the Type 23 design [*Bryson, 1984*] demonstrate the influence of topside equipment, with design length increasing from 100 m to 123 m as system requirements increased. An alternative design,"S90" was considered [*Bryson, 1984*] to have inadequate length due to the topside requirements. This and other features of the Type 23 and S90 designs lead to a disagreement, the "short fat ship" affair [*HMSO, 1988*]. Ferreiro and Stonehouse [*Ferreiro & Stonehouse, 1993*] note the impact of

Figure 6-3 Critical Dimensions & Separations [Brown, 1987]



topside length on escort design dimensions during a comparative British American design study.

The impact of topside length demands can be seen in the rejection of radical concepts in superstructure configuration. In particular the advantageous amidships helicopter position[159] *[Brown, 1991a, Spragg, 1995*] has never been practically achieved, partially due to the compression of the forward mounted system elements that would result.

Length is not the sole dimension dictated by topside arrangements. In many cases this gives a minimum upper deck beam. In particular, flight decks and hangar space dictate the beam at 1 deck by a need to provide a minimum clear space with flight deck access. The style and gross size of superstructure is driven by the design generator. An example of this is the demand placed by Sea Slug missile stowage on the County Class destroyer [*Brown, 1983*] and the arrangement of the Aft SPY radar arrays/helicopters and Vertical Launch Silos on the Flight IIA DDG51 design [*Scott & Moak, 1994*][160].

Small Ship Design Generators

Design generators of smaller warships designs can be considered as two categories, performance driven and system driven. The first category arises due to a

[159] The central helicopter hangar and flight deck potentially allows the operability of the helicopter in rough weather to be increased due to less extreme motions. [*Barratt, 1984, Andrews & Bayliss, 1997*]

[160] Flight IIA has been extensively redeveloped due to the changing form of the topside design generator as the operational requirement added a helicopter hangar to the Flight II design, and the hangars interference with the coverage of the aft SPY radar array.

mismatch between the volume of hull required for the spatial requirements and the hydrodynamic performance expected from the design. Because of the effect of gross size on seakeeping, small ship designs often have difficulty in achieving adequate seakeeping performance. The design generator of such small designs may be the provision of adequate seakeeping, demanding increases in dimensions above and beyond those needed to contain all the desired equipment and compartments in a suitable arrangement. An example of this is the Castle class [*Marshall & Brown, 1978*] where the ship is much larger than the minimum size to carry the operational equipment.

Unconventional Designs

When dealing with unconventional designs such as Trimarans or SWATHs, it is suggested that the previous forms of design generator detailed for monohull designs are applicable to unconventional hullform fulfilling the same role. The major change is the addition of extra constraints forcing a designer to consider the geometry of the unconventional form with respect to the generator. The experiences of using the Topside design generator to define the initial design space of Trimaran and SWATH designs are detailed in Chapter 8. Example design generators from recent student Trimaran designs are shown in Table 6-2.

Trimaran Designs	**Design Generator**
ASW Trimaran [*Alder, 1997*]	Double EH101 Hangar
Trimaran LPH [*Mateus & Whatley 1995*] Small Aircraft Carrier [*Cudmore & Best 1992*]	Hangar Position and Structural Arrangements
ASW Trimaran [*Smith, 1996*]	Superstructure Mounted Prime Mover and Resulting Topside Conflicts
Trimaran Royal Yacht [*Long, 1997*]	Royal Compartment Arrangements

Table 6-2 Unconventional Ship Design Generators

6.3.2 Use of Design Generators within Current Design Methodologies

The design generators detailed in Section 6.3.1 have not been applied to current ship design methodologies in a manner that has allowed them to explicitly influence the form of the ship design that has emerged for each iteration. This is due to the configuration or performance related nature of the generators and the difficulty of applying such information in a numerical ship synthesis design methodology. The design generator is often only utilised after numerical synthesis when a designer "lays out" the design in a general arrangement diagram. At this stage the dimensions and form of the hull are fixed for that iteration. Any changes to the design resulting from the interaction of fixed hull and design generator lead to a complete new iteration of the numerical synthesis.

The constraint of this approach depends on the nature of the ship being designed. For a modern escort design it is likely that a second numerical synthesis with more detailed assessment of hull features will provide a suitable design to meet the design generator's requirements. However such a design procedure will be an unfocused search for a suitable solution.

For complex problems such as those provided by Aircraft Carriers, a numerical synthesis will not satisfice the design generator. The measurement of weight and space and overall ship dimensions does not guarantee that the requirements of the design generator can be met. One of the central themes of this thesis is that the configuration should be used to inform the decision making process.

In design studies, in which the design generator is not incorporated sufficiently early in the design process potentially major design problems can emerge. In research and student designs a complete failure to meet operational requirements can occur. In actual design studies such problems rarely survive through to the constructed ship design due to the long degree of gestation of modern designs. It is more likely that funding and programme decisions will be made on the basis of a conceptual design that is inadequate at meeting an emerging requirement. This, while not dangerous in terms of engineering design, is likely to cause procurement programme difficulties. The design will escalate in cost as unforeseen issues are resolved in the latter stages of design. As an aim of concept design is to illuminate risk inherent in the design by detailing the form of the likely solution this is undesirable

Examples of the impact of changes to the design generator requirements include the radical rethink of topside arrangements in the design of Alder [*Alder, 1997*], implemented after major hull dimensions had been determined and unable to influence those dimensions. Another example is the problem of mounting Gas Turbines in the superstructure of several Trimaran designs [*Duggan, 1996, Smith, 1996*] which leads to major problems with ship configuration.

Student design examples have been quoted as the short time scale in which they were prepared allows mistakes made to become obvious unlike real design studies where there are multiple stage design processes. Constructed ship designs follow a convoluted path in which shortfalls are rectified later in the design cycle.

6.4 TOPSIDE DESIGN: THE MODERN ESCORT SHIP DESIGN GENERATOR

In this section the various facets of Topside integration are detailed. The major considerations impacting on the preliminary design stages are as follows:-

- Ship Handling Aspects[161]
- Equipment Separation
    - For physical reasons
    - For electromagnetic compatibility reasons
- Access
- Signature Reduction
- Ship Motion and Aerodynamic Related Aspects
- Arcs of Fire

All weapons and sensors have requirements for separation from other ship elements. These can be due to the physical size of the equipment items, for example the space swept by a rotating system, or the clear area required by launch efflux [*Gates, 1987*]. Solution of such design issues relies on the provision of suitable information for each system by the system manufacturer.

With the increasing number of electromagnetic emitters [*Reuter et. al, 1979*] and receivers on the modern naval ship, it is necessary to consider the separation between two systems whose electromagnetic signatures interfere. Methods for assessing compatibility between two closely related emitters are complex [*Li et. al., 1988*].

The complexity and time required for such methods is incompatible with the limited design descriptions available at initial design stages. Such methods are not practical in considering EMI issues at the earliest stages of design, affecting the whole design [as recommended by *Orem, 1987*] due to their complex requirements. Alternative simpler methods based on Frequency Spectrum Utilisation Charts [*Juras & Cebulski, 1992*] and Source/Victim matrices are used, responding to previous design's incompatibility issues. RADHAZ[162] introduces a requirement to position emitters carefully with regard to the effect of the electromagnetic emissions on the human body.

Signature reduction, when applied to topside design introduces the concept of using the topside design to reduce signatures, notably Infra-Red and Radar. Reduction measures include altering geometry, structural materials and equipment location. Taken to extremes, designs such as Sea Shadow [*Chatterton & Paquette, 1994*] and Sea

161 Ship handling aspects are those systems and spaces required to be on the weather deck of a naval vessel to perform seamanship tasks. The most prominent requirement are the need to provide high points for Replenishment at Sea systems, and mooring issues. There is also a need to consider access routes, to facilitate these tasks.

162 RADHAZ : Radiation Hazard.

Wraith [*Gilligan, 1996*] result and the reduction methods interfere with many other design issues, affecting design size. In both areas three design analysis methods exist to allow reductions to be achieved:-

- Experience based and Stylistic Design Rules
- Simple Analytical Assessment of the Design
- Complex Analytical Assessment of the Design

The design rule approach is useful at the earliest stage of ship design as it allows impact of signature reduction measures on the whole ship design to be assessed. Such measures do not provide feedback for the designer on the achievement of signature targets. Analytical measures in both simple and complex form attempt to provide accurate numerical signature levels [*Nicholas & Stratton, 1996*] allowing the designer to achieve targets. However the complexity and time required for the calculation does not allow the designer to respond in real time to the results of the analysis. To allow a designer to calculate a comparative Radar Cross Section for variations of a single design, simple analytical procedures based on RCS formulae for simple geometries are used. Examples are presented by [*Way, 1997, Guerreiro, 1994*].

Ship motion affects topside design by ship operability considerations and the safety and comfort of the ships complement. Heuristic or analytical measures of acceleration based on seakeeping prediction methods can be used to identify suitable locations for compartments and equipment items. An example analysis was presented by [*Spragg, 1995, Andrews & Bayliss, 1997*], defining the operational advantages of a central helicopter flight deck.

Arcs of Fire analysis details the physical coverage of the weapons system. It includes coverage by sensors and limitations on operability caused by the motion of the vessel in extreme conditions. Modern methods often involve simulated missile engagements, producing a probability of engagement success as in [*Calvano & Riedel, 1996, Mangulis, 1979*]. Such assessments allow the analysis of alternate configurations for suitability [as in *MIT, 1982*]. A disadvantage is the subjective nature of the scenarios envisaged.

The identification of a suitable topside design is often undertaken almost in isolation from the remainder of ship synthesis. The confirmation or rejection of properties is undertaken after the development of the design.

Juras & Cebulski [*Juras & Cebulski, 1992*] described a post ship design model of topside development. The topside design is modelled using a pre-defined ship envelope, detailed analytical calculations are performed and the design is either accepted or modified as necessary. This approach is utilised is due to the amount of information required by accurate analytical tools. A more integrated method would modify analytical routines to allow instantaneous assistance to a designer, with lesser accuracy. This would allow design suggestions to be modelled and modified, with the design generator's impact on the entire ship concept noted. To achieve this it is deemed sufficient that the designer should be furnished with simple, instantaneous calculations or rules, allowing incorporation of results into improved design configurations. An example would be the approximate assessment of Radar Cross Section based on arrangements of flat plates [as in *Way, 1997*]. The RCS signature calculated would not be precise, but sufficient for comparative assessment.

6.5 Application of the Design Generator within the Building Block Methodology

> *"The initial concept is either based on a previous design or requires a dominant issue or feature on which the designer can base his creative thrust....." [Andrews, 1984]*

This statement suggests that the method of producing design concepts, for which previous designs are not considered suitable for use as a basis ship, requires the dominant issue of the design to be evaluated at an early stage. This is compatible with the need for a Building Block designer to enter a design process without resorting to the historical assumptions of a numerical synthesis. It is also compatible with a need to consider at each stage the suitability of configuration. An important case is the consideration of the degree to which operational requirements are met. The naval design that does not satisfice the design generator with regard to configuration does not meet design requirements. Therefore the design methodology should implicitly demand the satisfaction of the design generator at all stages.

The use of the design generator to start the Building Block design evolution is known as the Major Feature Design stage. The Major Feature Design stage models the impact of the design generator, as the first stage of graphical design modelling in a Building Block process.

The entrance to a Major Feature Design stage is the provision of a desired design style, an operational requirement and the assumption of a design generator. Modelling at the Major Feature Design stage requires the postulation of an arbitrary sized design space in which relevant design elements are placed with all requirements and constraints modelled, either as graphical or numerical entities. The designer arranges system elements, expanding or reducing the design space until stylistic and design generator requirements are satisfied. The output of the task is a feasible arrangement of systems, a set of the minimum ship dimensions and features required. This data is used to enter the Super Building Block design stage, reducing dramatically the number of ship designs that can be considered as acceptable. The methods used within the design examples [Chapters 7 and 8] suggest a three dimensional model of major features is required, allowing full consideration of that designs requirements.

Design	Design Generator	Modelling Method
Building Block Monohull	Topside Design	2D Autocad r 12
Building Block Trimaran	Topside Design	3D Autocad r 12 AME
Small Combatants 1-5	Topside Design	3D Autocad r 12 AME
LST	Vehicle Deck Arrangements	3D Autodesk Mechanical Desktop
SWATH 1,2	Topside Design	3D Autodesk Mechanical Desktop

Table 6-3 Major Feature Stage Design Generators

Two features are important in selecting the design generator. Firstly the type of design generator should not vary greatly with ship type. A designer can assume a generator based on the operational and technical requirements of the new design and design generators of similar designs. Thus the designer of an aircraft carrier would select the flight deck if his design was to carry small amounts of aircraft or the hangar if the design was to carry large amounts of aircraft. Secondly the penalty for an incorrect assumption should not be severe, rather the design will take longer to synthesise.

Modelling at the major feature stage is undertaken before decomposition of the design into Super Building Blocks. Hence the major feature model used does not feature in the functional hierarchy detailed in Figure 5-8. Each element contributing to the satisficing of assumed design generator is modelled. Heuristic rules are used when more appropriate analytical measures such as strip theory based seakeeping are unusable due to a lack of information. In the example designs described in Section 7.2, the Major Feature Design stages uses the design generators and modelling methods of Table 6-3. The two dimensional method used in the Building Block Monohull is not completely successful due to the need for separate plan and profile views to detail all design information. Three dimensional methods are more successful in allowing suitable investigation of the properties of the design.

6.5.1 Topside Driven Building Block Designs

The Major Feature Design stage for escorts utilises the output of a Topside research program [that detailed in *Bayliss, 1997, Andrews & Bayliss, 1998*]. This provides a seamless bi-directional relationship [*Bayliss, 1997*] between a Topside model and the whole ship design. This allows consideration of the Escort ship design generators at the earliest design stages, maintaining suitability for subsequent design iterations.

The application of Topside Integration within the Building Block research program neglects accurate analytical measurement of signatures and seakeeping, due to the complexity of analysis. The complexity is not justified for example designs and the research presented here considers these features with analysis based on general principles and heuristic rules. Typically a topside model consists of the following elements:-

- Design Space (Deck) Representation
- Superstructure Blocks
- Physical Equipment Definitions
- Geometric representations of clearance and separation requirements
- Geometric representation of Heuristic rule boundaries

Rule	Definition	Aim
Bridge Location	The Bridge should be located no further forward than 1/3 ships length, from the bow.	To provide acceptable motions on the bridge
Bridge Visibility	The Bridge should be mounted at such a height to allow clear visibility of the position in the water approximately 1.5 ship lengths forward for the bow.	To provide safe visibility from the bridge

Table 6-4 Examples of Heuristic Rules

The use of heuristic rules is a necessary but undesirable feature, with attendant dangers of applying general rules to specific designs cases. The designer judges the rule applicability in each design instance. Examples of such rules are demonstrated in Table 6-4.

6.5.2 Non Topside Derived Building Block Designs

The LST design [Section 7.4.3] demonstrates an ability to develop non topside dominated designs using a Building Block methodology. In this case the design generator is the vehicle deck and all aspects of the motion of the vehicles onto and off the vehicle deck. The methods used are similar to those used in Topside models, except that all geometric representations are based solely on physical size or separation. The elements modelled were as follows:-

- Vehicles
- Vehicle Separation

- Deck
- Vehicle Deck Boundary

The first two elements define the dimensions of the vehicle deck boundary and the vehicle deck, defining minimum dimensions for the whole ship design. The Vehicle Deck models are shown in Appendix E.27. The methods used are equally applicable to other design generators such as aircraft. Taken to a greater level of detail and requirement satisfaction, simulation based design [*Jons et. al, 1994*] offer's potential employment at the Major Feature design stage. Further detail on each specific Major Feature Design stages is presented alongside the definition of the complete design in Chapters 7 and 8.

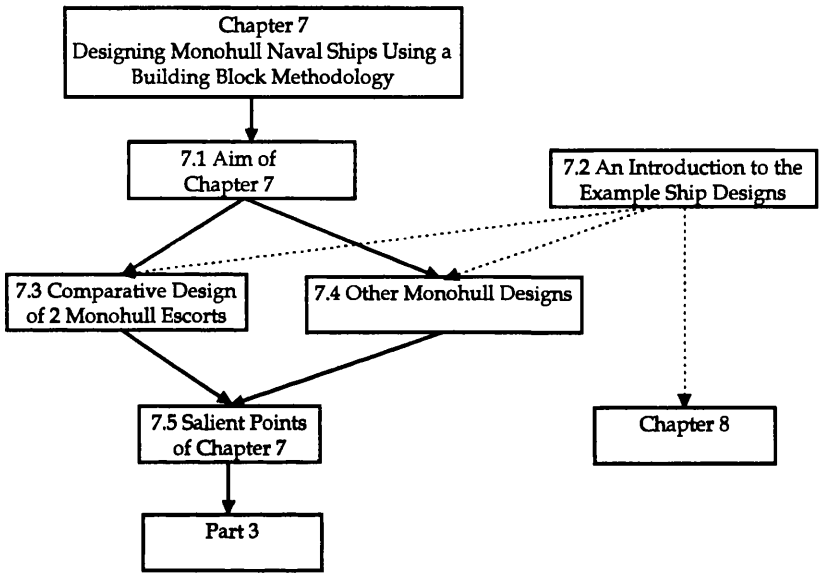
6.6 SALIENT POINTS OF CHAPTER 6

Chapter 6 has detailed the concept of the design generator, when applied to naval ship design. The design generator is derived from the primary generator concept of [*Darke, 1979*] used in architectural design methods. When applied to naval ship design the influence of the design generator concept determines the part of a design space that a successful concept design will inhabit. Different ship designs have different design generators due to the influence of operational and design requirements on design configuration. The variation of design generator with ship type has been detailed. Topside design was described as the design generator of Escort designs.

Because of the importance of the design generator, the Building Block design methodology uses the concept of the generator as its first "Major Feature Design" stage. This reduces the design space to be searched to include only those designs that meet both operational and designer's requirements. Subsequent to this discussion, Chapters 7 and 8 detail the development of example designs using the Building Block Design methodology and in particular the concept of the design generator.

7. DESIGNING MONOHULL NAVAL SHIPS USING A BUILDING BLOCK METHODOLOGY

Figure 7-1 Chapter 7 Schematic



7.1 AIM OF CHAPTER 7

A Building Block methodology to be used by a naval ship designer has been detailed conceptually in Chapters 5 and 6. Chapter 7 details the application of such a methodology to Monohull naval ship designs. In particular Section 7.3 outlines the development of two Escort designs to identical design requirements, one using a numerical initial sizing procedure and the other using the Building Block methodology. This demonstrates the advantages of the Building Block methodology. Section 7.2 details the operational requirement of these designs and the other example designs.

Further monohull designs have been developed, each demonstrating the application of the new design methodology to different design requirements and types of vessels. A series of small combatant designs are outlined in Section 7.4.1. The conversion of Building Block designs from one design requirement to subtly different requirements is shown together with the ability to model the design generator and specific design issues relevant to small naval designs. Several Building Block techniques were first introduced into the methodology as part of the small combatant series, including survivability issues, hullform assessment and decision making techniques.

The Building Block methodology is ideally suited to modelling the design generator and features of larger "vehicle carrying" designs, given the importance of configuration in sizing such designs [as detailed in Chapter 6]. The development of an LST design is detailed in Section 7.4.3.

7.2 AN INTRODUCTION TO THE EXAMPLE SHIP DESIGNS

In Chapters 7 and 8 issues associated with the Building Block design methodology are demonstrated by design examples. Each example focuses on the development of one or more naval ships to meet a specified, simplified operational requirement. This section presents the requirements, simplifications and characteristics of those individual ship designs, designated by the following terms:-

- The Numerical Synthesis Monohull Escort Frigate Design "Traditional Escort"
- The Building Block Monohull Escort Frigate Design "Building Block Escort"
- The Building Block Trimaran Escort Frigate Design "Trimaran Escort"
- Building Block Small Combatant Monohull Designs "Small Combatants 1 - 4"
- The Building Block Landing Ship Tank Design "LST"
- The Building Block SWATH Escort Frigate Designs "SWATH 1 and SWATH 2"

General arrangement and Building Block models are presented in Appendices E and F.

7.2.1 The Traditional Monohull Escort Design

Design Aim

The aim of the "Traditional Escort" and "Building Block Escort" designs is to create two comparable designs, synthesised using two different design methodologies. Footnote 14 suggests that comparisons between two naval ship designs is an emotive issue. By creating two designs to identical operational requirements, containing identical major systems, differences between the two methodologies can be examined. The discussion relating to the features of the two designs is presented in Section 7.3. The design of the Traditional Escort used a design methodology typical of the numerical design methods described in Chapter 3. The UCL naval ship synthesis model and data presented in [*UCL, 1994a*, see Section 3.4] was employed, avoiding intellectual property and security classification problems. The UCL synthesis model and methodology was employed rigidly. When applied to the design of unconventional hullforms and more difficult monohull designs the UCL synthesis is adapted to meet specific needs [such as undertaken by *Menon & Scheele, 1997*]. Such variations are no longer representative of published synthesis models and are excluded from consideration here.

The design evolved using numerical synthesis is a general purpose escort frigate. This scenario is chosen for two reasons. Firstly a need to undertake a design in an area in which design experience is common. Secondly to allow the Building Block design methodology for surface ships to demonstrate its advantages and disadvantages compared with the numerical synthesis model when applied to the type of naval ship for which a numerical synthesis is developed most frequently, due to the large database of previous designs.

Traditional Monohull Escort Operational Requirement

The operational requirement, the initial demonstration of the style of ship design required, was specified by the designer. The escort design is designed to perform anti-submarine, anti-surface and point defence tasks to a reasonable level of competence in each task, without specialisation. The operational requirement in terms of demand performance levels were as follows:-

- Design maximum speed (calm water, 6 months out of dock) 30 knots
- Design stability (solid metacentric height in the deep condition) 2 m
- Stores endurance 30 days

Several simplifications to the operational requirement are necessary for the Building Block monohull escort due to the evolutionary nature of that methodology. As the traditional design is to be comparable with the Building Block design it was necessary to apply identical simplifications to both designs. The simplifications are discussed further below.

The marine engineering aspects of the ship design process are simplified compared with commonly used procedures [such as *Plumb 1987*]. In concept ship designs directed at a specific outline staff requirement, the propulsion arrangement is not specified directly at the start of the concept ship design process. Rather alternate propulsion system concepts, such as COGOG, CODLAG [*Eaton & Mattick, 1993*] or IFEP [*Mattick, 1996*] are investigated with regard to meeting requirements, alongside their impact on the ship. Several concept propulsion systems would be considered for each concept ship design requirement. Variants of each concept could exist, each with different power ratings.

In the design examples, the location of the "optimum" marine engineering solution for the given operational requirement is not a desired output. Interest lies in the impact of marine engineering on the design. Thus particular marine engineering systems are specified as inputs to the design. Similarly, to simplify the calculation of the ships fuel load an amount of fuel was specified for this first requirement and was based on specified electrical and prime mover power output.

Minor equipment items, those comprising the majority of the ship description are not specified directly, but scaled from gross ship size. Scaling algorithms are always controversial due to the simplifications they impose on compartment size as ship's size varies. A simplification adopted for the example designs is that the UCL ship scaling algorithms are considered valid for all ship designs considered here.

To reduce design complexity, zoning and survivability enhancements [*Gates, 1987*] are not considered. This reduces the need to provide separated and duplicated equipment items and compartments, simplifying the design description.

Major Equipment Items

The major combat system elements are specified from the UCL ship design database [*UCL, 1994a*]. The systems data used is representative of actual equipment items, avoiding classification problems. The combat system elements are specified below:-

- Anti Submarine Warfare
    - 1 "Kestrel" ASW helicopter
    - 1 Helicopter Landing Spot
    - 1 Hangar with full organic capability for one helicopter
    - 2 Shipborne Torpedo Systems
    - 1 Hull mounted Sonar outfit "A"
- Point Defence (Anti Air Warfare)
    - 1 Surveillance Radar "G"
    - "ESM1" Electronic Surveillance System
    - 1 Double headed Sea Trace SAM system consisting of 2 Tracker Radar's, and 2 six missile launchers fed from deep magazine of 40 missiles
    - 2 Chaff Decoy launchers.
- Anti Surface Warfare
    - 4 "Hornet" Surface to Surface Missile launchers
    - 2 40mm gun mountings
- Command, Control and Communications Systems
    - Command System "A"
    - Communications fit "1"
    - Navigation Radar "C"

The propulsion system components are as follows:-

- Propulsion Prime Mover System
    - COGOG Arrangement
    - 2 x Boost Gas Turbines "UCL Olympus"
    - 2 x Cruise Gas Turbines "UCL Tyne"
    - 1 Gearbox (4 Input, 2 output shafts)
    - 2 Controllable Pitch Propellers driven by two shafts.
- Electrical Generation System
    - 4 1Mw Diesel Generators

The remainder of systems and compartments are scaled from UCL ship design algorithms [*UCL, 1994a*]. The structural weight algorithm used is derived from

Dimension	
Displacement (Deep) Tonnes	4166
Total Enclosed Volume m³	13228
Length (between perpendiculars) m	122.8
Beam (waterline) m	15.7
Draught m	4.22
Depth m	8.8
Number of Hull Decks	3 Decks + DB

Table 7-1 Developed Traditional Monohull Design Characteristics

regression analysis of recent naval ship designs. Several alternate formulations have been proposed [*Brown, 1995a*]. It has been argued that the importance of the differences between formulations is limited [*Usher & Dorey, 1981*]. For the purposes of this thesis the UCL structural weight estimation algorithm is considered valid. The features of the complete traditional monohull escort design are as shown in Table 7-1.

7.2.2 The Building Block Monohull Escort Design

Design Aim

The Building Block monohull escort design allows the Building Block design methodology to be compared with a traditional design methodology as applied to the Traditional monohull design [Section 7.2.1]. The design simplifications are identical to those detailed in Section 7.2.1.

The Building Block design methodology used to derive the Building Block Escort is detailed in Chapter 5. In this case, the major feature stage used to develop the minimum feasible design space, is based on the minimum length and beam weather deck needed to allow a feasible topside arrangement. Following the definition of a minimum sized design space, the design was developed at the Super Building Block level of detail (4 iterations), the Building Block level of detail (3 iterations) and one general arrangement level iteration.

Dimension	
Displacement (Deep) Tonnes	4386
Total Enclosed Volume m³	12098
Length (between perpendiculars) m	126
Beam (waterline) m	15
Draught m	4.53
Depth m	9
Number of Hull Decks	3 Decks + DB

Table 7-2 Final Design Characteristics of the Building Block Monohull

The major features of the Building Block escort design are broadly similar to those of the Traditional Escort design, with two superstructure deck houses and the central prime mover complex. In detail, the designs are different and a discussion is presented in Section 7.3. The major features of the Building Block Escort are shown in Table 7-2.

7.2.3 The Trimaran Escort Design

Design Aim

The development of unconventional naval vessels is possibly the most challenging preliminary design task a naval designer encounters. This, alongside the increasing emphasis on vessels such as Trimaran and SWATH, suggests it is necessary to develop such concepts with a Building Block methodology if that methodology is to be considered capable of supplanting current synthesis methods, particularly considering the nature of unconventional designs, as described in Section 8.1.2.

A Trimaran Escort design, developed using an implementation of the Building Block methodology is presented. This design identifies methods of using the Building Block methodology for the preliminary design of unconventional vessels. The Trimaran Escort design is not completely comparable with the previous monohull Escort designs but is designed to fulfil an operational role for which Trimaran designs are more suited. The operational requirement is an Anti Submarine warfare focused implementation of the escort requirement demonstrated in Section 7.2.1. This allows investigation of the problems and benefits of the Trimaran form when adding a second organic helicopter. The problems associated with configuration of a double hangar and single flight deck on the aft quartile of the cross structure, is a unique Trimaran capability[163] for escort ships and hence a unique design problem. The slender main hull of a Trimaran is not ideally suited to the implementation of a twin shaft propulsive arrangement [as noted by *Gregg & Bucknell, 1998*]. This introduces constraints on the development of high speed Trimaran naval designs[164]. The use of one main shaft reduces propulsion system survivability, unless side hull propulsion is introduced.

The combination of IFEP [*Mattick, 1996*] and Trimaran leads to a much more suitable propulsion arrangement due to the ability to locate Prime movers in many different locations[165]. The flexibility in locating the Gas Turbine systems has major implications on the remainder of the ship. The Trimaran design shows the importance

163 Given current constraints on escort costs and the size of modern helicopters.

164 There is a limit to the amount of mechanical power that can be used to propel the ship via one propeller given other limitations on propeller dimensions.

165 Recent designs by [*Smith 1996, Rose, 1996, Alder 1997, Henderson, 1997, Way 1997, Hall, 1997*] have demonstrated the potential for the IFEP-Trimaran combination.

of system location on superstructure and hull arrangements. This is investigated by comparison of main hull and superstructure mounted Gas Turbines. For the Trimaran Escort design an IFEP propulsion system derived from [*Rose, 1996*] is used.

The majority of major systems are identical to those specified for the Monohull Escort designs. In Table 7-3 differences between the Monohull and Trimaran escort equipment fits are presented.

System	Monohull Escorts	Trimaran Escort
Sea Trace System	2 x 6 Cell Launchers 40 Cell Deep Magazine	4 x 8 Cell Vertical Launch Silos
Prime Mover System	2 22Mw Boost Gas Turbines 2 4Mw Cruise Gas Turbines 1 Gearbox 2 Shafts 2 Propellers	1 21MW ICR Gas Turbine 4 2 MW Diesel Generators 20 MW + 6 MW PMM[166] Electric Motor 26 MW PWM Inverters 1 Shaft, 1 Propeller, 2 1 MW Azipods
Kestrel ASW Helicopter System	1 Helicopter 1 Flight Deck Spot 1 Organic Helicopter	2 Helicopters 1 Flight Deck Spot 2 Organic Helicopters
Electrical Generation	4 1 MW Diesel Generators	Prime Mover System [IFEP]

Table 7-3 Trimaran Escort Major Equipment Changes

Final Design Characteristics and Major Design Features

The design simplifications utilised in the development of the Trimaran Escort design are those of Section 7.2.1. The final Trimaran design characteristics are shown in Table 7-4.

7.2.4 Small Combatant Designs 1 -5

Design Aim

Each of the five small combatant designs investigates a specific aspect of the Building Block methodology. The designs share common operational requirements and propulsion system. Each design has a slightly different combat system implementation. A major design aim is to investigate methods of redeveloping Building Block concept descriptions after a change in requirements. Small Combatant 1 also acts as an example

166 PMM Permanent Magnet Motor.

of application of the methodology to small naval designs. Small Combatants 2 and 3 are re-developments of Small Combatant 1 with different systems and different Building Block arrangements. Small Combatant 2 was modified from the Small Combatant 1 design description at the Super Building Block level of detail. Small Combatant 3 was a complete re-design from the Major Feature Design stage. The rapidity and suitability of the two methods of redevelopment are compared and contrasted in Section 7.4.2. Small Combatant 4 undertakes a greater degree of change from the parent design [Small Combatant 2] by reduced complementing levels and a less capable combat system. Small Combatant 5 shows the application of hullform decision making methods within the Building Block methodology in place of the Parametric survey procedure utilised in numerical design methodologies [such as *van Griethuysen, 1994*]. Small Combatant 5 includes vulnerability considerations in the design process by including zoning.

Dimension	
Displacement (Deep)	4246 Tonnes
Total Enclosed Volume	15180 m^3
Side Hull Disp. Ratio[167]	3.5 %
Overall Beam	25 m
Air Gap[168]	3.45 m
Cross Structure Height[169]	3.2 m
Main Hull Dimensions	
Length BP	145 m
Beam (waterline)	10 m
Draught	5.45 m
Depth	12.1 m
Number of Hull Decks	4 + DB
Side Hull Dimensions	
Length	55.1 m
Beam	2 m
Draught	2.92 m

Table 7-4 Trimaran Escort Major Features

The role of the Small Combatant designs is that of offshore patrol vessels. Unlike Escort designs, support to an organic helicopter is not required. This eliminates one of the difficult topside integration issues, allowing other design issues to dictate the design decisions. Each design is fitted with one of several point defence systems [CIWS or Sea Swan], and Surface to Surface Missiles or a Medium calibre gun for anti surface duties. The common equipment fitted to the small combatant designs were as follows:-

- Prime Mover & Diesel Generator Fit [adapted from *Kramer & Shahid, 1991*]
    - 2 x Diesel Propulsion Motors @ 3.5 MW each
    - 2 x Gearboxes, 2 x Shaft, 2 x Propeller
    - 2 x Diesel Generators @ 0.5 MW
- Weapons & Sensors [from *UCL, 1994*]

167 Side Hull Displacement Ratio = Displacement of one side hull / Deep Displacement.

168 Air Gap is the distance from the underside of the Cross Structure to the deep waterline.

169 Cross Structure Height is the total deck height of cross structure decks added to the cross structure double bottom structure height.

- Communications System 3
- Command System A (modified)
- ESM 1Antenna
- Navigation Radar "C"
- Surveillance Radar "E"
- 2 x 40 mm Gun
- 2 x Chaff Decoy Launcher

The alternative systems of the five designs are as shown in Table 7-5 :-

Design	Flight Deck	76 mm Gun	CIWS1 System	Sea Swan Launcher	Frog SSM	Complement
1	X	√	X	√	√(4)	96
2	X	√	√(2)	X	√(4)	97
3	√	X	X	√	√(8)	94
4,5	X	√	√(1)	X	X	71

Table 7-5 Small Combatant 1-5 Combat Systems

The Sea Swan Launcher is a low capability point defence missile system. CIWS1 is a radar controlled cannon based point defence system. Frog is a Surface to Surface Missile System. The complements of the five designs vary with combat systems. Designs 4 and 5 are complemented to a reduced manning standard.

Design Simplifications

The major simplification in the design of the Small Combatant designs was the specification of the propulsion fit prior to design. The propulsion system is a representative small naval ship system [derived from *Kramer & Shahid, 1991*]. The propulsion system consists of two large diesel engines each supplying one gearbox. Each gearbox transmits power through a shaft to a fixed pitch propeller.

The Small Combatant designs present design problems typical of small naval vessels. Many of the functions of larger designs are not part of the ship description or

Dimension Design	1	2	3	4	5
Displacement (Deep) T	1884	1884	1877	1736	1815
Total Enclosed Volume m^3	5095	4983	5004	4536	4689
Length BP m	82	82	87	80	81
Beam WL m	11.8	11.8	11.4	11.5	11.67
Draught m	3.8	3.8	3.85	3.8	3.9
Depth m	7.3	7.3	7.3	7.3	7.3
Number of Hull Decks	2 + DB	2 + DB	2 + DB	2 + DB	2 + DB

Table 7-6 Small Combatant Major Dimensions

are coalesced into joint functions. The design fuel requirement varied with cruise speed power estimate.

Final Design Characteristics and Major Design Features

Due to the small size and lack of a helicopter hangar, the Small Combatant was a single superstructure deckhouse design. The weapons are forward or on top of the superstructure. A major design issue is the split level 3 deck. This structurally undesirable feature was necessary to accommodate the large engine room arrangement, fuel load and access through a two deck design.

This example of the need to consider in three dimensions the configuration of the concept design led to the decision to move to the solid modelling system, described in Section 5.7.4, due to the inability of CAESAR to model split level decks. The Landing Ship Tank design details the use of solid modelling methods.

7.2.5 Landing Ship Tank

Design Aim

The Landing Ship Tank tests the proposition of Chapter 6 that the "design drivers" of transport[170] ship designs, are the storage and dis-embarkation of the transported item. The arrangement of the vehicle deck was considered to be the design generator.

The LST's operational requirement is to transport a squadron of 15 Main Battle Tanks[171] and a troop of 4 Reconnaissance Vehicles. A secondary requirement is for the vehicle deck to be able to carry 20 infantry fighting vehicles. The vehicles embark and disembark through a single bow ramp[172]. The LST carries four assault landing craft and supplies the assault force with liquid and ammunition stores. Two 25 tonne capacity cranes are fitted for this purpose. The ship is fitted with a [*NES 106, 1993*] Class B Hospital facility. Landing facilities for a "Wizard" [*UCL, 1994a*] helicopter are provided. The design provides accommodation for 300 infantry in addition to the ships complement of 80. The operational range is 7000nm at 15 knots. The ship design was

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170 Transport ships include Assault Ships and Aircraft Carriers. Those ships which transport a smaller element into the operating area and then deploy and support that smaller element.

171 Based on unclassified dimensions of the Challenger 2 Design [*Internet reference "http://www.army.mod.uk"*]. Similarly "Scimitar" acted as the template for the UCL reconnaissance vehicle. "Warrior" was the template for the infantry fighting vehicles of the secondary payload.

172 Single ramp operation was enforced to ensure that the design evolved separately from the Royal Fleet Auxiliary's existing Landing Ship Logistic design.

designed to have a maximum speed of 18 knots and a stores endurance of 60 days. The specified major weapons systems are the two point defence systems ["CIWS1"], an amphibious task force Command, Control and Communications system, and main propulsion system arrangement consisting of 2 medium speed diesel propulsion units driving 2 fixed pitch propellers.

Design Simplifications

The LST design study did not investigate the impact of survivability and is not zoned. The embarked military force is accommodated to naval standards. The propulsion system was fixed prior to design and not permitted to change throughout the design. As the design specifically investigates the earliest stages of the design methodology when applied using a solid modelling approach, the design was not completed to the level of decomposition of the Escort designs just outlined. The design procedure was halted at the end of the Building Block stage, rather than at the end of the General Arrangement stage.

Final Design Characteristics and Major Design Features

Table 7-7 shows the LST design at the end of the Building Block design stages. Major features of the LST design, include the large [90 m long] vehicle deck dominating No 2 and No 3 decks. Both cranes and the LCVP craft are located forward of the main superstructure. Forward of these is a small deckhouse for deck stores and the forward CIWS1 system. The main superstructure contains operations complexes, the primary hospital facilities, some of the officers accommodation and the aft CIWS system. Aft of the superstructure is the flight deck. Further details of the design are discussed in Section 7.4.3.

Dimension	
Displacement (Deep) Tonne	6286
Total Enclosed Volume m^3	18327
Length BP m	111.5
Beam WL m	17.32
Draught m	5.26
Depth m	11.5
Number of Hull Decks	4 + DB

Table 7-7 Landing Ship Tank Building Block Stage Characteristics

7.2.6 Building Block SWATH Escort Designs

Design Aim

The two Building Block SWATH design studies are analogous to the Trimaran Escort design described in Section 7.2.3. They were produced to show that the Building Block design methodology could be used for SWATH studies. The CAPSD 2 prototype

Dimension Design	1	2
Displacement Deep Tonnes	4453	4825
Volume Internal m^3	18728	19764
Length Box m	100	105
Beam Box m	28	28
Box Height m	3.2	3.5
Air Gap m	6	6
Length Struts m	87	87
Width Struts m	2.75	3.00
Length Hull m	110	112
Hull Diameters m	4.45 x 5.5	4.60 x 5.65
Displacement Proportion	0.77	0.77

Table 7-8 SWATH Escorts 1 and 2 Major Characteristics

system was used. The first design, SWATH Escort 1, is identical in operational requirement and systems to the Trimaran Escort design except for two 13 MW Electric motors mounted in each hull, rather than the Trimaran's 20 MW and 6 MW motors. It is thus possible to assess and compare the Trimaran Escort and SWATH Escort 1 designs, noting changes in performance.

SWATH Escort 2, is a re-development of SWATH Escort 1, with increased propulsion power to achieve 28 knots maximum speed. The Building Block design methodologies utility in investigating propulsion plant selection was thus investigated.

Major Equipment Items

The major equipment items and minor scaling algorithms employed in the SWATH Escort designs are those used in the Trimaran Escort design. The electric motor solution employed in the Trimaran Escort relies on supplying the main propulsive power through a single high power shaft. This is impractical for a SWATH design requiring identical propulsion trains in each hull. Using motor feature scaling algorithms derived from [*Rose, 1996*] a representative 13 MW propulsion train was developed for SWATH Escort 1. SWATH Escort 2 was developed with a 21 MW propulsion train in each hull, the extra power supplied by a second 21 MW Gas Turbine.

Design Simplifications

The SWATH escort designs were developed to the Building Block stage. The development of a suitable hullform for SWATH's is a numerically intensive task relying on analytical tools and a degree of design skill not readily available within the CAPSD 2 system. Hence the underwater hullform was modelled to assess an approximate power requirement, while concentrating on the impact of hullform on system location. The final features of the SWATH Escort Designs are as shown in Table 7-8.

7.3 Comparative Design of two Monohull Escorts

The requirements of both monohull escort designs were detailed in Section 7.2. This section details the definition, and comparison of both designs, identifying differences between the effectiveness of the two design methodologies, by changes to the resulting design concept.

7.3.1 Design of a Monohull Escort using a Traditional Numerical Design Procedure

A traditional numerical design procedure was represented by the UCL design procedures documented in Section 3.4. These were followed, without allowing the designer to interject additional design stages as might occur when the methodology was implemented by a skilled and creative designer. The designer assessed displacement and volume requirements in an initial sizing stage and developed hullform dimensions in the Parametric Survey stage. The Traditional Escort design's compartment and systems were then configured within the previously defined hull. One complete iteration of this procedure was undertaken. Further complete design cycles would be required in actual studies to implement the knowledge gained as a result of the configuration of the first design.

Initially requirements for weight, space (volume, area and minimum dimensions) and ships services were clarified. A geometric model represented the ship after first initial sizing iteration[173]. From the geometry model dimensions and enclosed volume, requirements for area, volume and weight for ship systems were estimated. Design Growth Margin and Board Margin were applied. Iteration of volume and weight requirements was undertaken with the ship design expanding in dimensions and requirements until a balance was achieved. The design parameters were as Table 7-9, after assuming a hullform of (M)=7 [as recommended in *B.Eng., 1994*]. As the design altered in gross size the hullform changed in dimension, maintaining the same hullform parameters.

A parametric survey was undertaken, defining a compromise between maximising length to minimise resistance, altering depth and superstructure proportion, while maintaining sufficient beam to meet stability requirements. As the

[173] This model, which consists of hull scaling formulae and assumptions of hull coefficients, gives the initial dimensions of the ship design.

Dimension/ Feature	Value
Length BP m	111.7
Beam m	15.33
Draught m	4.7
Depth m	9.2
Superstructure Proportion	0.275
Weight tonnes	4166
Volume m³	13228

Table 7-9 Initial Monohull Traditional Design Parameters

design was required to meet a speed of thirty knots it was considered that, subject to other constraints, the design should have a high and L/D values. The major parametric survey constraints were as follows:-

- B/T < 4 To avoid a short curve range and also to avoid a large surface area.
- 5 < (M) <9 Marking the approximate boundaries of the design lane between poor resistance and poor seakeeping performance [*B.Eng., 1994*].
- L/D <14 The upper limit for reasonable structural weight. [*B.Eng. 1994*]

The selected design style had two superstructure blocks facilitating separate hanger and operations/bridge deckhouses, without a superstructure passing deck. This allowed a relatively low superstructure fraction and longer hull length. The feasibility of specific superstructure proportions was not investigated at this stage, a typical limit on superstructure proportion (0.2) was assumed. The design point chosen (L/D = 13.9) represents an extreme case. Given hullform depth and volume as constant the form characteristics were varied in a minor parametric survey. The characteristics of the design at this stage were as in Table 7-10.

To allow a 'long, low' style of design, compromise had to be accepted, both in double bottom height and number of passing decks. Although internal layout was not explicitly considered, at least three main hull decks were required to provide a main passing deck above the main machinery block. A decision was required as to whether a second passing deck was required. The parametric survey showed that this was not practical, as a ship of reduced length and greater depth, with poor resistance characteristics would result. The decision with regard to double bottom height ensured a suitable double bottom height for access and maintenance (based on traditional limits), without compromising high speed performance greatly.

Dimension/ Feature	Value
Length BP m	122.8
Beam m	15.7
Draught m	4.22
Depth m	8.8
Superstructure Proportion	0.2
Number of Decks	3
Deck head height m	2.5
Double Bottom Height m	1.3

Table 7-10 Developed Monohull Traditional Design Parameters

Following definition of major hull dimensions and characteristics a faired hullform was defined using the UCL HULLFORM program [*Wray, 1982*]. Tank top and other decks were created. Using CAESAR, compartments and system spaces were entered in to a compartment data file and placed on the deck plans [see Appendix D.]. The final General Arrangement drawing is shown in Appendix E.1.

7.3.2 Design of a Monohull Escort using a Building Block Based Procedure

The design procedure used to model the Building Block Monohull Escort was based on that in Section 5.5. Simplifications as previously detailed were implemented. The design style chosen was again a long hull with minimal superstructure. The superstructure was to be located as two separate structures, one designed about the bridge and forward weapons complex, the aft structure solely meeting Hangar and Aft Tracker requirements.

Major Feature Design Stage

Chapter 6.4 suggests that for most modern escorts, the design generator is the arrangement of the design's topside. Prior to the Building Block design stages, the minimum design dimensions were considered to be defined the design features given in Table 7-11.

Design Dimension / Feature	Dimension Driver (Main)	Dimension Driver (Subsidiary)
Overall Design Generator and Length	Topside Design and Arrangements	
Beam	Stability	Engine Room Width
Depth / Number of Internal Decks	Engine Room Height	Double Bottom Height, Number of Access Decks, Freeboard
Superstructure Arrangement	Bridge/ Fwd Tracker & Hanger	Masts & Exhausts

Table 7-11 Monohull Escort Design Drivers

To define topside length and hence a minimum design space, it is necessary to consider combat system equipment and the permissible separations between aerials and antennas[174]. Having suggested a design style, a warship form of an arbitrary 100m initial length was created on which the topside design elements were placed, and their configuration investigated. Placing the hanger and flight deck, 'fixed' the aft end of the

174 Using information in the UCL equipment data books.

design. Seakeeping and handling arrangements led to the bridge to be constrained by the L/3 length rule suggested by [*Brown, 1987*] as a position for good vision and seakeeping. The foremost item was located at L/6 from the bow to give sufficient clearance for line handling and green sea removal.

These lengths determined the forward arrangement. With machinery blocks in the position desired aft of amidships, positions for uptakes and downtakes were located and masts positions located. The remaining topside design problem was the selection of a minimum topside length based on two areas of the design. One problem was the longitudinal separation of the hanger block from the aft end of the machinery rooms. To satisfy structural continuity two options were available, firstly placing the auxiliary machinery two decks directly below the hanger or for the aft end bulkhead of the machinery block to coincide with the fore end bulkhead of the hanger block.

As the diesel generator inlets and outlets were to be at either ends of the auxiliary machinery rooms, and topside space was required for the ship's boats, the forward bulkhead of the hanger was longitudinally located with the aft bulkhead of the engine block. Uptakes and downtakes were positioned at this early stage by assuming spatial clearances typical of previous designs using similar prime mover arrangements. It was also assumed that one edge of the deck structure for the prime mover inlet and outlets was to be placed on the nearest bulkhead, maintaining structural continuity.

With the minimum length of the ship determined by space ahead of the bridge, the machinery block length and the space dedicated to aircraft, the remaining topside space was arranged with sensors and weapons. System clearances and electromagnetic interference exclusions zones used were those detailed in [*B.Eng., 1994a*]. Other design requirements, especially the separation between ESM equipment and non mast sharing electromagnetic emitters (such as the forward tracker) meant that a suitable functional arrangement could not be achieved in the upper deck length available. Topside length was increased to 112m, the smallest length at which the tracker office and bridge could both satisfy constraints. This and other constraints "fixed" the minimum superstructure volume.

Alongside the definition of minimum length, a minimum beam and depth were investigated. Minimum beam was given by an engine room width requirement of 12.6 m, although the form of the hull would ultimately control the ability to mount machinery. Depth was set by a minimum double bottom height, the engine room minimum height and the need to provide at least one passing deck in the main hull, requiring a minimum depth of 8.5m. The issues related to the numbers of passing decks were investigated at a later phase in the design, initially a minimum was chosen to avoid over-sizing the ship. Figure E.4 details the topside model with system elements and design rules for electromagnetic interference and spatial requirements given.

Design at the Super Building Block Stage

A hierarchy of Building Blocks was developed, taking into design configuration and style requirements, this is detailed in Figure E.5-E9. Using a hullform generated using standard values of hull coefficients and the minimum dimensions derived in the Major Feature Design phase, an initial hull was developed. The hull volume was used to scale Building Block requirements for those functions driven by gross ship size. The volume of superstructure was calculated from known [minimum] superstructure dimensions. The estimation of Super Building Block requirements from the summation of constituent sub functions was achieved, suitable margin and access policies were derived in line with Section 5.4.4. Allowances for void space were not made. It was assumed that void space would be the difference between the required and provided volumes. A margin policy was applied as in Section 5.4.4.

When all Super Building Blocks had been defined in function and requirements estimated, it was necessary to plan the layout of the Super Building Blocks. It was known that the actual volume required was much greater than the hull provided, but the undersize hull allowed assessment of specific areas of inadequacy, quantifying which design dimensions should be increased if possible.

A first stage in laying out the Super Building Block arrangement was to place the Propulsion Generation SBB in the only position in which it could fulfil all its requirements, occupying the central portion of decks 3 and 4, with longitudinal position defined by hull curvature and beam. The two separate blocks of the Electrical Generation SBB were also located immediately aft and forward of the Propulsion Generation SBB.

As in the Major Feature Design stage, the foremost position of the Aircraft Systems SBB, in the longitudinal plane was collocated with the longitudinal position of the aft machinery block bulkhead, on 1 and 01 decks. The Aircraft Systems SBB was compiled with the inclusion of all aircraft related functions as part of one block. The width of the block was determined by the hanger entrance, helicopter stowage requirements and the need for access past both sides. A linear constraint of flight deck length was also included, assuming a full width flight deck.

Previously a style/operational decision had been taken to collocate all communications and command spaces within the forward superstructure, with the aim of minimising damage by underwater explosions and minimising the cable\waveguide runs from sensors to associated processing equipment. Using the L/3 heuristic design rule, the forward location of the Bridge and Command and communication SBBs were defined. When allowance for access on either side of the superstructure was made, the length and breadth of the two deck high Command SBB were obtained. On the Type 23 frigate the SSM system is located forward of the bridge, this position was also decided upon for the SSM SBB. The space requirement for the SSM was specified in terms of exclusion zones rather than physical equipment size and consisted of a length and width (the entire beam of the ship at that longitudinal position). In this space other Building Blocks were prohibited.

Given that the forward superstructure was to contain only the Command & Communication SBB, Motion Control SBB and Sea Trace Forward Tracker SBB it made sense to locate the officers accommodation forward on the main passing deck. This was located with what was thought at the time to be an appropriate access allowance[175]. The components were then placed in the locations shown Table 7-12 with specific demands on maximum dimensions as given.

At this stage all ship functions were accounted for, and a semi-feasible layout produced. The available hull space was not sufficient to allow all requirements to be met. Several Super Building Blocks were undersized and an increase in hull size was required. The major dimensions of the ship at this stage are shown in Table 7-13.

One of the advantages of the functional approach to design is an ability to specifically increase the space available in the ship in regions where space is deficient without applying universal scaling factors to hull and superstructure dimensions. Analysis of the design at this stage indicated the following problems:-

175 This will be shown later to be insufficient.

SBB	Deck	Position	Dimension Limitations
Motion Actuation	3	Stern	Areas and length requirements for steering gear
Motion Command	2	Top of Command & Communication SBB	Clear vision requirement, Floor area, Superstructure width
Damage Management	2	Forward of Amidships, Starboard side	To be collocated with Propulsion Control
Propulsion Control	2	Above Prime Movers	
Buoyancy Support	2	Bow	Usable space and access
Electrical Distribution	2	Above Electrical Generation	Area requirement and access
Ratings Living Spaces	2	Aft to amidships, whole width	Gross area, bulkhead positions, Quarter-deck position requirements
Surface Systems	1	Forward of Hanger	Topside Length
Supply & Disposal	3	Forward of Machinery Block	Area and usability
Sea Trace System	1,3	Misc.	Local space availability and arcs of fire
Sonar	4	Forward of Machinery Block	Hydrodynamic positioning of dome.
Fuel	Tank Deck		Volume requirement
Hull			Weight allocated to Building Block Entry in spreadsheet CG estimated from Dimensions

Table 7-12 Specific Demands on SBBs

- There was a deficiency in the amount of fuel storage available and also some of the fuel storage that was available was not in the double bottom. The design intent was to minimise the amount of fuel on 4 deck, as undesirable for fire fighting as recommended by [*Brown, 1990*]. The initial double bottom of 1 m height was considered to be inadequate and was increased to 1.5m, a compromise between a greater depth design and a reasonable length and beam.
- There was felt to be inadequate space available on the passing deck, directly below the operational complex (Command and Communications) and so length was increased at this section by 13m.

The selective addition of space allows volume to be added where required rather than uniformly as would have occurred if the hullform volume had increased by scaling a geometric model used in traditional preliminary design methods.

For each change to the design there were small alterations in the layout and

	Final Design	Developed Design	Initial Design
Displacement Deep tonnes	4386	4388	3744
Volume Provided m^3	12098	11890	11147
Length BP m	126	126	112.8
Beam WL m	15	15	12.7
Draught Deep m	4.53	4.53	5.1
Depth m	9	9	8.5

Table 7-13 Monohull BB Design Parameters

position of Super Building Blocks. Minor alterations included the re-analysis of numerical and functional requirements due to the new larger volume of the hull, and updating of the estimated centre of gravity.

At this stage it was found that the stability requirement ($GM_{solid\ deep}$) could not be met, hence the design's beam was increased. Consequently both volume required and available grew, requiring an additional re-evaluation of Super Building Blocks size and location. Several consequential changes were made. Examples include updating bulkhead positions to ensure structural considerations were not neglected. Finally the dimensions of the Super Building Block Design were as in Table 7-13 prior to the decomposition to the next level of detail.

Design at the Building Block Stage

Figures E.5-E.9 shows a logical decomposition from each Super Building Block to constituent Building Blocks. During decomposition a compromise between functional and layout based hierarchies occurred. At this level of design detail the compromises inherent in a practical layout force a much greater emphasis on location than on function. A thorough re-evaluation of margins and access requirements for the individual Building Blocks was undertaken according to the function within each Building Block.

The exact sequence of configuring Building Blocks is not detailed here, however the problems encountered in the Building Block design phase are outlined. Within the Building Block design phase, the volume available in the ship was not altered although the volume requirement did vary numerically by a small fraction of the total with the void volume increasing or decreasing as necessary. The Building Block design phase provided a good estimation of final system and compartment locations. This was an achievement as the designer was able to use these results to influence overall dimensions and design features as problems arose.

Access requirements were re-estimated, taking into account the number and extent of major and minor access spaces within a given Building Block, and position in the design. This gave an access requirement closely linked to functionality and layout rather than based on a fixed fraction of overall gross volume. The benefits accrued by this change caused the largest problem in the design of the escort frigate using a Building Block based methodology. At the beginning of the Building Block design stage, the functions located on the main passing deck were known. Hence it became possible to change access allowances for these Blocks to reflect the larger access requirement of main passageway located functions. Once Building Blocks had been re-sized around the larger access requirement it became impossible to fulfil the spatial requirements of those Building Blocks decomposed from the Ratings and Officers accommodation Super Building Blocks, in the locations allocated. Other Building Blocks, on 3 and 4 decks, did not have access requirements as large as originally defined, as they were not located on a main passageway and space became available. This and an overall re-organisation of accommodation contributed to an unsatisfactory layout. The problems arose due to the chronology of the design which was prior to the research detailed in Section 5.4.4 on access requirements for naval ships.

Remaining layout iterations were performed with no significant changes. Following this stage of design the ship's major features were as Table 7-13. It should be noted that only at this stage was the design fully balanced in weight and space.

General Arrangement Preparation

Each Building Block was decomposed into compartments in order to develop a general arrangement. Access was allocated as necessary. Few problems were found in resolving the layout conflicts which occurred within some of the Building Blocks, due to the care taken previously to ensure that the constraints on any specific dimension could be met. The final arrangement and colour maps detailing the Block based nature of the design are presented in Figures E.12-13

Analysis of ship design performance has not been referred to in the preceding narration, but was a constant design issue. An advantage of the Building Block based design approach is an ability to perform specific analysis at the earliest design stages. Analysis of the design was undertaken in areas listed in Section 7.2.1. The important issue is the stage that analysis was performed and it's effect on the emerging design. The first performance analysis was undertaken at the end of the first Super Building Block design iteration. From that point onwards, performance analysis was undertaken every time all Building Blocks had been placed. At one point in the design, the results of analysis drove the design due to the beam being insufficient to give the required , the hullform was altered accordingly until the requirement was met whilst other desirable features were retained.

7.3.3 Discussion of Monohull Escort Building Block Design Methods

The two designs created using different design processes emerged with similar features, both lying in similar design regions, that of the 4000 - 4500 tonne escort as populated by the majority of escort designs [E.g. Type 23, *Thomas & Easton, 1993*]. In this respect both designs can be considered believable, with potential to fulfil the intended role, assuming normal design development. Neither design is of sufficient detail and development to allow comparison with current fleet designs. Nevertheless it is still pertinent to ask two questions:-

- "Why do the two designs differ in displacement and volume?"
- "Why are the main dimensions slightly different?"

These occur due to the heavier and larger Building Block design being more fit for purpose and having a better functional arrangement.

A specific aspect where the design using Building Blocks is considered more satisfactory than the traditional approach is the combination of hull and superstructure. Superstructure size and style should be selected on the basis of functional requirements, structural characteristics and the designer's own view on an appropriate 'style' of superstructure. Such issues are accommodated in a Building Block design process as the designer has control over the size and position of superstructure. In this case the style selected was the minimum size feasible arrangement, with only enough superstructure provided for the bridge [located on 02 Deck], the fitting of weapons, sensors, command systems and the helicopter. In particular the positioning of the command system, prime movers and the provision of hanger space led to a specific superstructure configuration.

The approach to superstructure design in the traditional design was based on the variation of superstructure proportion in the parametric survey, at a time when only numerical design information was available. This assumes that superstructure proportion is a continuous variable, an ill advised assumption unless a full analysis of superstructure layout is undertaken. This implies the Building Block based design produces a more practical and functional design of ship, reflecting a designer's thoughts and experience, rather than just meeting a somewhat arbitrary numerical requirement. Downstream, main hull volume can be chosen based on design elements remaining after the superstructure elements have already been defined.

Another advantage of the Building Block based ship design is that, from the earliest stages of the major feature design stage, inlet and outlet locations can be considered and a feasible solution, considering bulkhead locations, derived. By comparison the inlet and outlet requirements of the traditionally designed ship, could not be considered until much later in the design process, and the resulting interference of the Olympus inlets and the forward superstructure deck house caused severe problems with the Operations Room. To solve this problem the ship would have required extra length overall or the bridge moved further forward, both of which would have been less satisfactory.

A second example of the advantages of the Building Block methodology concerned fuel stowage. The majority of the large volume fuel requirement was stored in double bottom tanks. This reduces the ship's vulnerability and increases metacentric height in the deep condition. In the Building Block based design the height of the double bottom was regulated by a need to increase the double bottom fuel tank space to meet volume requirements. This in turn directly forced a greater depth of hull to achieve machinery and passing deck height requirements. Observing that the length and beam were directly controlled by other layout and performance considerations then the available volume of the ship was determined by local functional needs. Due to the large amount of fuel to be carried in this design, because of the demanding endurance requirement, stowing all the fuel in the double bottoms would lead to excessive hull depth. Thus the double bottom height chosen was a compromise informed by both local and overall requirements, both for arrangement and volume.

For the traditionally sized escort design the double bottom height was selected from the parametric survey before it was practical to properly consider such issues. Given fixed hull coefficients, only the effect of double bottom height and superstructure height on the major four hull dimensions could be considered. Powering and stability requirements led to a very small double bottom height. Length and depth were compromised with each other and it became impossible to simultaneously fully satisfy the aspects governed by these dimensions. When the traditional design was configured it became obvious that the double bottom height was less than desirable, with many fuel tanks being required on 4 Deck. By adding extra double bottom height at the parametric survey stage this could have been reduced but would have resulted either in insufficient superstructure to meet topside requirements or in a weather deck length which could not provide a suitable topside arrangement, given the fixed volume. Alternatively the whole design could have been revised to balance at a larger volume. Thus the traditional design was not as large as necessary to meet all it's functional requirements. Given a full re-iteration from initial sizing through to configuration this could been addressed but at the cost of possible problems in other features of the design.

It is suggested that the major dimensions of a ship design should be formed by reference to both local design issues as well as overall requirements for performance, weight and space. As a result of not doing this, the traditionally designed ship did not meet all requirements and would, in practice, have required further design iterations to meet all requirements. Focusing on individual changes to dimensions would have more difficult than in a Building Block design. Considering the double bottom and superstructure issues it is believed that in terms of choosing ship dimensions, the Building Block approach gives the designer a greater awareness of both whole ship and specific issues when defining the dimensions and arrangements of the design. Traditional methods can only define dimensions based on overall issues, until the design has been defined sufficiently to enable layout issues to be revealed, often requiring further design iterations to solve problems. Such re-iterations do not focus on resolving the issues and other problems may result.

A further advantage of Building Block based methods is the consideration of structural continuity and it's effect on usable space in specific hull locations. The amount of space "wasted" due to layout conflicts with bulkheads was considered, avoiding the misleading assumption that an acceptable layout can be achieved provided the overall scalar volume is balanced.

Both traditional and Building Block based ships designs are capable of meeting the speed requirement (30 knots). However, due to the lack of consideration of layout and hence the position of equipment in the parametric sizing of the hull, the uncorrected value for the traditional design was lower than estimated, resulting in a higher than intended. The designer had less "feel" for the design and downstream corrective action was required to meet design requirements. Contrast this with the final value of for the Building Block design, which was much closer to that intended. Obviously the results from a first traditional design iteration can be used to inform future design iterations, but the process is less controlled due to the constant separation of layout and numeric design synthesis in each design iteration.

The comparative designs demonstrate an advantage of proceeding to configuration stages quickly as initial estimates can be based on greater and more accurate information specific to that design, and less on general design rules and lanes.

The investigation above shows that the Building Block approach gives an ability to focus on both overall and specific design influences, provides a greater level of data, to inform important design decisions. The only significant problem with the Building Block design produced is that it is heavier for the same payload and internal equipment. This would imply that it would cost more to build. It is considered that if the traditional design was revisited to provide suitable double bottom and topside design arrangements, it would grow in size and displacement considerably. The information available at the decision making stages of a traditional design process would not guarantee that the designer was aware of the design's driving features, and make acceptable decisions. The higher level of uncertainty will increase risk.

This section has described the research into the definition of a monohull escort design using the Building Block Design methodology The design of two ship concepts to an identical statement of requirements has been undertaken. One concept was designed using a standard procedure, the other using the Building Block design methodology. The two ships had many features in common, due to the common equipment and narrow design space typical of frigate designs. However there were several important differences in the two designs, notably the longer dimensions of the Building Block based design, its ability to stow a larger amount of fuel in the double bottom, it's more feasible superstructure arrangement and an arrangement that was considered to better meet requirements.

7.4 OTHER MONOHULL DESIGNS

Escort designs, while the mainstay of a modern surface fleet are not the sole type of naval ship design. It is considered desirable to utilise similar design methods and methodologies in the development of all naval ship types. Within this section the development of much smaller and larger monohull designs are considered. Much of the supporting design information is presented in Appendix E.

7.4.1 Building Block Small Combatant Designs 1-5

The application of the Building Block methodology to smaller designs, in the size range associated with corvettes or offshore patrol craft, using a Building Block methodology is detailed in Appendix E.3. Of particular interest are the procedures used for developing families of designs in which one design is adapted to a modified operational requirement.

The main advantages of the Building Block approach when applied to small designs are those detailed previously in Section 7.3.3. Several changes in implementation details, such as the addition of the ability to vary fuel load with resistance have confirmed that a designer will be able to model a Building Block design without the simplifications previously applied.

The modelling of the topside in these designs was felt to be less acceptable in determining major dimensions than in the Building Block Escort design as the constraints on design generator were not solely length related and varied with assumed beam as well. This was noticeable with the placement of deck stores and operations complex. Both Building Blocks were area and volume dependant, and thus the minimum acceptable length was affected by the current beam. Until a minimum beam was identified for each design the topside length requirement could not be expressed.

Appendix E.3 discusses separately the effect of engine room height on the remainder of the CAD model. The small ship size required two completely different arrangements of decks at different longitudinal locations. This demanded either a vastly oversized design, or a compromise, structurally undesirable, design [see Appendix E.3]. As a result it detailed the need to consider prime mover and internal hull space requirements before development of final hull dimensions. This issue also highlighted the need for three dimensional models of the ship design, to assess all the configuration related design issues adequately.

7.4.2 Development of Small Combatant Design 5 Utilising Survivability Concepts and an Improved Parametric Survey

Small Combatant Design 5 introduces zoning and a limited parametric survey into the Building Block methodology. These are detailed conceptually in Section 5.4.5 and 5.4.8. This section describes the implementation of these concepts.

The starting point for Small Combatant 5 was Design 4's Super Building Block model after one design iteration. A first step in incorporating zoning into the design was to consider the number of zones which could be sensibly incorporated in the design, achieving reductions in the effect of damage without overly inconveniencing the ship under normal operations. Four zones were incorporated in the design.

Zone	Forward boundary
1	Bow
2	Fwd Bulkhead of Bridge
3	inter engine room bulkhead
4	Aft Bulkhead of Aft Engine room (to Stern)

Table 7-14 Proposed Location of Zone Boundaries

It is normal that zone boundaries should be based on prominent structural elements. This is so that the configuration of the design to allow operation when damaged uses the natural protection offered by the structural design of the ship. Bulkheads and other important features provide natural locations for zone boundaries, due to the ability to impede the movement of smoke, gas, fire and flood. To add four independent zones the following locations were suggested after examining the Small Combatant 4's Super Building Block model.

It was then necessary to consider which systems should be located in each zone and the degree of redundancy required, the arrangement in Table 7-17 was considered.

Displacement tonnes	1798
Volume m³	4677
Length m	80
Beam m	11.5
Draught m	3.8
Depth m	7.3
Block Coefficient	0.48
Prismatic Coefficient	0.6
Midships Coefficient	0.8
Circular M	6.9

Table 7-15 Small Combatant 5 Characteristics

Super Building Block representations were created of the specific zone equipment items, pre-existing Super Building blocks descriptions were altered, removing zone specific systems. Discussions as to the level of capability of each system were entered.

A new Super Building Block design phase was undertaken in which zone based systems were added to the ship design. Following the placement of all the Building Blocks in acceptable locations the design was found to contain too much volume, particularly centrally and forward on 2 deck. At this stage in the design the dimensions of Table 7-15 represented the design. In Section 5.4.5 it was suggested that extra design methods were required in order to model the implications of survivability and susceptibility. Several of these only required the addition of extra weight and space within existing Building Blocks (for passive susceptibility reduction, or the creation of new building blocks for active susceptibility reduction (e.g. chaff launchers).

Constraint	Range
Length / Depth	< 12
Beam / Draught	< 4
Displacement tonnes	minimum
Maximum Speed knots	> 21 , maximum
Cruise Effective Power Mw	minimum
Circular M	5< GM< 9
Prismatic Coefficient	0.55 < Cp < 0.65
Midships Coefficient	> 0.8

Table 7-16 Form and Performance Constraints Applied to Small Combatant 5

The application of survivability improvement measures such as citadels and zone based equipment, required that the Building Block design process should incorporate a zone plan in which features of the design, from the point of view of survivability, could be examined. The practical implication of this has been the use of a dedicated CAD layer in CAESAR. This has proven satisfactory in the Small Combatant design where few Building Blocks are required in each zone.

The inclusion of the zone based equipment as Building Blocks in the early stages of the design process allows a designer to consider carefully whether the arrangement, content and number of zones was satisfactory. As a result less re-design should be required as a design increases in detail.

Equipment	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**
Electrical Power Generation	Emergency	Main	Main	Emergency
Electric Power Distribution	√	√	√	√
Chilled Water	√	√	X	X
Salt Water Pump	√	√	√	√
Damage Control locker	√	√	√	√
Air Conditioning / Filtration Units	√	√	√	√

Table 7-17 Location of Survivable Systems

Application of the Building Block Parametric Survey

Following completion of the Super Building Block first iteration, the parametric survey procedure described in Section 5.4.8 was applied. Two Building Block scaling algorithms would vary with geometry by appreciable amounts. These were structural weight[176] and the fuel load[177]. As the ships structural weight and ships resistance changed with hull form, overall weight and space requirements would change.

The range of valid designs was limited to those in close proximity to the current Building Block solution, due to the number of constraints applied to the design by other design issues. A constant displacement survey was undertaken to produce a design space of new design variants. For each design point the change in structural weight and resistance from the original design was calculated. The control variables were the coefficients of block and water plane. Depth and Superstructure proportion, the normal parametric survey control variables were fixed by the previous design iterations.

Changes in performance with hullform were calculated alongside changes to hull size and dimensions. This information was added to a variable displacement parametric survey and a new design space was created. The changes between a design

176 Using the $L^{1.36}$ formula described in [*UCL, 1993*].

point in this design space and in the previous design space were subtle. Lengths changed typically by several metres, and the beam altered by centimetres, ensuring that each ship description fully represented the advantages and penalties of structural weight and fuel consumption for that hull form. A design point to be continued through to the next Super Building Block phase was chosen. The resulting design was a compromise between cruise speed performance, high speed performance, and a hullform which would not compromise the engine room arrangements. The new dimensions were as follows in Table 7-18.

Following this the Super Building Block design, using these dimensions, was investigated and the design decomposed to the Building Block level of detail. No major changes were required. The final design dimensions were as stated in Table 7-18. The Building Block Arrangement can be seen in Figure E.14.

Displacement tonnes	1815
Volume m	4689
Length m	81.07
Beam m	11.67
Draught m	3.90
Depth m	7.3
Cb	0.48
Cp	0.575
Cm	0.834
Cw	0.73

Table 7-18 Small Combatant Dimensions, Post Parametric Survey

The application of a variable displacement parametric survey allows small distortions from the parent Building Block model to be investigated. In a traditional design procedure variations between the results of constant and variable displacement parametric surveys are found [*Bayliss et. al., 1996*]. However when applied to the Building Block design methods, preliminary hullform studies have been undertaken by the designer in the Super Building Block design phases. When parametric variations are undertaken in such a stage, the range of investigations is smaller, given the additional constraints introduced by the extra configuration descriptions and so the effect of a change in displacement is less.

However the change in displacement and volume at each design point does have an effect on the geometry of the hullform at each design point as the individual designs are still generated by the need to meet stability requirements. This when combined with the small changes in design dimensions and features allows a designer to pick a more suitable hullform which will be closer to the completed design. Thus it is considered that, even for the relatively small range of the Building Block parametric survey, the extra effort involved in applying a variable displacement procedure is

177 This was determined by a fixed electrical load and the cruise power requirement of the ship.

justified.

The influence of zoning on a ship design is noted mainly in the distribution of systems and the location of bulkheads, these can influence the complete design and need consideration prior to dimension selection. The use of a parametric procedure to investigate the changes in design suitability with hullform is required due to the likelihood of the original, assumed hull form not being that providing the most suitable design.

7.4.3 A Building Block Landing Ship for Tanks

Having detailed the development of small and medium sized monohull ship designs using a Building Block methodology, it is necessary to develop the discussion of Chapter 6 with regard to large, vehicle carrying ship designs and design generators. In that chapter the design generators of large vehicle carrying naval designs was stated as being the issues surrounding the carriage of the vehicles. To demonstrate this proposition, the development of a Landing Ship for Tanks was undertaken, using the Building Block methodology. The requirements were detailed in Section 7.2.5. A fully three dimensional CAD model was used, due to the complexity of the configuration issues experienced. The following entities were modelled graphically in three dimensions:-

- Topside and Vehicle Deck equipment elements (in the Designer Generator Model and as Building Blocks)
- Building Blocks and Super Building Blocks
- Hullform
- Decks and Major Bulkheads
- Constraints on the Design

Typical Solid Model Building Block representation are shown in Figure E.23-30. A complete hull surface is also shown.

Bulkheads and Decks were initially created as planar rectangular surfaces. Bulkheads remained rectangular, for use as location aids, while deck surfaces were trimmed to form deck edges. Constraints on the design such as flight deck length or bridge visibility were created as planar surfaces.

Major Feature Design Stage

The majority of the design effort undertaken within this stage was the identification of the constraints on vehicle deck operations given an assumption as to a desired arrangement of vehicles, and ramps. The relationship between location of elements on the weather deck and the vehicle deck was also considered, requiring a topside model. The weather deck arrangement influenced the form of the vehicle deck, due to the requirements for engine exhausts.

Fifteen main battle tank models were added to the major feature model. Four instances of a reconnaissance vehicle were also added. Minimum clearances between tanks, and between tanks and longitudinal bulkheads were assigned[178]. Surfaces representing the deck and bulkheads were applied to the design space. Thus the minimum design space was created as shown in Figure E.27. This has the following constraints on the design:-

- Vehicle Deck Length (min.) 84.1 m
- Vehicle Deck Widths (min.) 7 m forward, 8 m aft, 9.14 m central section
- Vehicle Deck Height (min.) 2 Decks

A secondary payload of 20 Infantry Fighting Vehicles with 4 Reconnaissance Vehicles was assessed for suitability and impact on the minimum dimensions. No changes were necessary. In addition to the width requirements of the vehicle deck it was decided to locate troop compartments as wing compartments on each side of the vehicle deck. These compartments were to be composed of usable space with access, and a minimum of 3.5 m width each side was employed driving the minimum beam requirements.

The internal arrangements of the design were anticipated as being critical to the success of the design and at the earliest design stages relationships between individual compartments were assessed using the methods detailed in Section 5.6. These informed the debate as the suitability of the desired configuration.

Although Topside Integration was not the major design generator it was still essential that the various constraints topside arrangement places on the internal configuration were considered. These constraints were felt to be:-

- Exhaust Arrangement
- Aft Superstructure Bulkhead arrangement
- Bridge Visibility

The most demanding of these was the aft superstructure bulkhead arrangement. It was important that both of the forward and aft bulkheads of the superstructure block were continuous throughout the hull. It proved necessary to allow the vehicle deck to run through the forward bulkhead, with continuity being maintained by wing compartments, in order to reduce overall length. Thus it was important to ensure that the aft bulkhead was continuous at all widths and depths. This suggested co-locating the aft bulkhead of the superstructure with the aft bulkhead of the vehicle deck. The aft end of the vehicle deck was constrained to the forward edge of the helicopter flight

[178] In consultation with an ex officer of H.M.S. Fearless.

deck. Thus the flight deck length added to vehicle deck length formed the minimum permissible length of the design.

The exhaust arrangement was considered to allow the maximum forward longitudinal position of the Prime Mover arrangement to be calculated. Otherwise exhausts would impinge on Bridge spaces. The Bridge visibility requirement at this stage was implemented in terms of a plane surface above which the Bridge had to be raised to meet visibility requirements. The plane was continued forward over the Bow to a point at which the Bridge must be capable of seeing the water. The actual bridge position bridge was left open at this stage as the width of the superstructure and therefore its length and height were not known accurately.

The first topside design decision was that, as the major role of the helicopter was expected to be casualty evacuation, the helicopter and hospital components of the design should be collocated for ease of stretcher movement. This meant that the superstructure block, which was to contain both hospital facilities and engine exhausts, was to be located ahead of the flight deck. This dictated the longitudinal position of the engine room and hence the aft most position of the vehicle deck as the exhausts and the vehicle deck locations were to be mutually exclusive.

The major topside decision to be made was the relative location of the following components:-

- Helicopter Deck
- Superstructure Block
- LCVP and Crane spaces
- CIWS system

The LVCPs and cranes were to be located approximately amidships to minimise motions during loading operations. Thus with the flight deck required at the stern the location of the superstructure block was fixed. A requirement was detailed for a CIWS system to be located forward of the cranes and a raised bow deck arrangement was detailed. The aft CIWS was to be mounted on the aft superstructure.

This was all considered at a qualitative level of detail and then converted to a Topside model after solidification of minimum vehicle deck size. At this stage the minimum size of many dimensions were known and the Super Building Block Stage was used to solidify the requirements for weight and space in various location of the ship.

Super Building Block Title	Deck	Longitudinal Position
Army Vehicles (including vehicle Deck)	2,3	As far forward as possible given bow shape
Steering Gear	4	As far aft as possible given hullform
Helo Flight Deck	1	As far aft as possible
Propulsion Generation	4,5	Aft bulkhead continuous with flight deck (anticipated superstructure bulkhead position)
Hospital	1	Fwd of Helo Flight Deck
Boats (Cranes and LCVP's)	1	Fwd of Superstructure
CIWS1	1	Fwd of Boats
Command & Control	01	Above Hospital
Move Boats fwd for extra superstructure space		
Motion Command	02	Above Command & Control
Officers Accom (very undersized)	02	Aft of Motion Command
CIWS2	02	Aft of Motion Command
Elec. Generation	4,5	Fwd of Propulsion Generation
Ratings Accommodation (undersized)	4	Aft of Propulsion Generation
Army Equipment (inc. Army Fuel)	4,5,DB	In between fwd and aft crane for access
Army Accommodation (very undersized)	4	Fwd of Electrical Generation
Supply	5	Fwd of Electrical Generation
Ships Systems	5	Fwd of Electrical Generation
Prime Mover Fuel (very undersized)	DB and Deck 4	-
Buoyancy Support	1a,2	Deck 1a fwd, Deck 2 Aft

Table 7-19 LST Super Building Block Configuration Order

Subsequent to the Major Feature Design Stage the Super Building Block stage considered the design style more fully using the functional hierarchy of Building Blocks. A major consideration in the evolution of the functional hierarchy was the position of the embarked assault force within the hierarchy. It was considered that the primary function of the troops was to fight and therefore all services provided for the assault force were to be located within the fight functional group. The only exception to this was the army officer contingent, required to share functional spaces with their naval counterparts and collocated in the officers accommodation super building block.

A split hospital facility was included as required by NES 106[*NES 106, 1993*]. Two Building Blocks described this, the primary medical facility, containing all surgical/ward spaces, and a secondary medical position duplicating some of those functions. A Beaching Structure Building Block was included as part of the Hull Super Building Block. This was a purely numerical representation of extra structural weight, to be located at a location suggested by beaching requirements. The full functional hierarchy is detailed in Appendix E.

The initial depth decision was assumed noting that the propulsion machinery was required to be on separate decks from the vehicle decks if the needs of damaged stability and low shaft line angles were to be met. Following the definition of the CAD elements the initial configuration process was as Table 7-19. At this stage the design was deficient in internal volume. Those Super Building Blocks listed above, required an extra 2500m^3 of volume provision to meet spatial requirements. Alongside these deficiencies the design was not of sufficient size to place the following Super Building Blocks at all:-

- Damage Management
- Propulsion Control
- Army Catering
- Electrical Distribution
- Deck Stores

The dimensions of the design at this stage were as shown in Table 7-20. The totality of design problems were assessed including an insufficient Metacentric Height, and changes in dimension were assessed to provide a satisfactory overall design:-

- An increase in length between the stern and the aft end of the vehicle deck
- An increase in beam providing extra stability with a corresponding increase in the amount of usable space either side of the vehicle deck.
- An increase in the amount of superstructure volume to allow complete addition of the officers accommodation.
- An increase in double bottom height to allow complete storage of fuel and tank space.

Hull dimensions were reassessed and Super Building Block requirements re-modelled. The increase in superstructure proportion, increasing the superstructure length, affected ships length in conjunction with a requirement for space aft of the vehicle decks. The missing Super Building Blocks from iteration 1 were added. A Ballast capability, based on a controlled trim angle and draught adjustment capability was introduced for beaching[179]. After iteration 2 the dimensions of the design at this stage were as shown in Table 7-20.

Major design problems at this stage included the incompatibility of the vehicle deck space requirements and bow form and deficient stability. At this stage the design had not been assessed in terms of it's sensitivity to hull parameters and so a form of the variable displacement parametric variation techniques suggested in Section 5.4.8 was implemented. The requirements for the chosen geometry from this design space were as follows:-

Dimensions	**Post SBB1**	**Post SBB2**	**Post SBB3**
Displacement tonnes	4522	5880	6286
Volume m	11892	15983	18327
Length BP m	95	110	111.5
Beam WL m	13	16.5	17.32
Draught m	5	5.25	5.26
Depth m	11	11.5	11.5
C_B	0.715	0.60	0.60
C_P	0.76	0.7	0.71
Number of Main Hull Decks	4	4	4
DB Height m	1	1.5	1.5
GM deep solid m	0.64	1.65	2.15

Table 7-20 LST Ship Dimensions at the Super Building Block Stage

- Low draught[180]
- Meet minimum length requirement
- Meet minimum beam requirement
- Low resistance
- Low displacement
- Meet stability requirements

The beam requirement was affected both by a need to provide metacentric height and the requirement to provide useful space with associated access each side of the vehicle deck. The minimum displacement was chosen.

Iteration 3 finalised design dimensions to the extent that Super Building Blocks could be decomposed to Building Blocks. Greater consideration was placed on maintaining structural continuity and several Super Building Blocks were modified as a result. The major problems with the design at this stage were as follows:-

179 The beaching operation commences with the LST being trimmed by the bow so that after beaching the trim is removed and the ship is able to leave the beach.

180 The draught was required to allow efficient beaching operations. This considered in conjunction with other hullform characteristic.

- Insufficient Metacentric Height
- Excessive volume forward (in unusable locations)
- Excessive volume aft (in usable locations)

The most important of these was the stability requirement which drove the design to ever greater beams with a corresponding reduction in the suitability of the remaining features of the design. A decision was taken to allow a reduction in the design requirement to a figure in between 2-2.25 m.

Design of an LST at the Building Block Stage

The Building Block stage commenced with the remodelling of the Hull surface and construction of individual Building Blocks. Then the internal configuration was remodelled. The major changes to the overall configuration in this design phase were as follows:-

- Movement of the Secondary Hospital to the forward section of the Vehicle Deck.
- Modification of the superstructure to allow compatibility between the exhausts the aft CIWS system and the Helicopter flight. Control.
- Modification of the space athwart the vehicle decks to allow the Exhausts from the engines to pass through.
- A detailed assessment of the location of the components of the Army's Accommodation, giving the higher ranks more favourable locations and thus altering the disposition of the total army accommodation.
- Assessment of a logical relationship between the Building Blocks involved in the accommodation and commissariat requirements of the ships complement. This allowed the location of the associated Building Blocks to be investigated given configuration constraints and the volume available at the aft end of the ship.
- Distribution of the Ships Services and Supply components in a more logical manner than undertaken at the Super Building Block Stage.

At the end of the first Building Block iteration the design was assessed for its response to heeling moments , comparing the curve with NES 109 [*NES 109, 1990*] requirements. In all cases assessed, the design was acceptable. The power speed curve had been produced at all stages using the GODDESS program POWERING. The Fuel Building Block had been continually reassessed. The design contained an amount of unallocated space in unfavourable locations but it is anticipated that these would be filled as the design was increased to the compartment level of detail and the requirements for access in given locations refined. The final design can be seen in Figure E.28.

7.4.4 LST Design Discussion

The Amenability of Non Topside Major Design Generators

The LST design was the first Building Block design to be undertaken which did not utilise topside design as the design generator. The proposal of initial design

Displacement tonnes	6286
Volume m^3	18327
Length BP m	111.5
Beam WL m	17.32
Draught m	5.26
Depth m	11.5
C_B	0.6
C_P	0.71
Number of Main Hull Decks	4
Double Bottom Height m	1.5
GM m deep solid light solid	2 1.43

Table 7-21 LST Ship Dimensions (Post BB1)

iterations dimensions from vehicle deck requirements was considered successful but not without problems. The advantages noted in other Building Block design procedures were apparent, the designer controlled the dimensions of the ship, based on the ability to utilise the vehicle deck and inappropriate combinations of dimensions were avoided.

At the Major Feature Design stage minimum design length was governed by vehicle deck extreme length and also by the relative locations of vehicle deck and topside elements. The actual minimum length of the design with the configuration envisaged was reliant on an ability to maintain structural continuity between the aft end of the superstructure, the length of the vehicle deck and the length of the flight deck. As these three dimensions were not co-planar the identification of a minimum length was more complex than in Topside driven designs.

Although the minimum depth of the design was not located using the major feature design phase many of the critical issues of the design were simplified and assumptions made as a result of the modelling of the vehicle deck. The height of the armoured vehicles required that the vehicle deck was two decks high while the lowest of these two decks was be located at a suitable vertical location for damage stability purposes. These suggested a need for four main hull decks and a double bottom, greatly reducing the scope for variation of the ships depth. These features all combined to give the designer an idea of the suitability of the chosen design configuration without considering detailed weight and space balances. When the design was modelled fully at the Super Building Block level of detail many alternatives had been eliminated that might have remained within a purely numerical procedure.

The dependency of the main hull minimum length on the flight deck and vehicle deck illustrates that the weather deck is an important design feature even away from the Escort warship and should not be discarded from consideration for seemingly simple topside problems. For many ship designs compatibility between superstructure and engine exhausts is a demanding issue.

One problem raised by the LST major feature design phase was the assumption of a design style and the decisions that follow an assumption of style. It is considered that a designer cannot continue to design without a reasonable idea of the intended features in a qualitative, creative, sense. In this case the designer quickly assumed that the vehicle deck should be two vehicles wide and did not consider other arrangements at later stages. This leads to the danger of carrying a immature decision forward into latter iterations of the design. Design decisions taken as a result could be unwise. This relates to the problem of inadequate divergence in the design caused by the time taken to prepare one model. If the designer is careful and able to assess alternative design styles this should be avoided.

The reduction in design space caused by the modelling of the design generator immediately places a design in the region of the final design space. Even though in later stages the LST design increased in displacement, volume and dimensions these were caused by a need to provide beam for stability and configuration without a reduction in depth or length.

In more realistic design exercises it would appear advantageous to add Simulation based Design [*Jons et. al., 1994*] methods to the assessment of the original vehicle deck configuration. Realistic simulation of vehicle loading and unloading operations within an envelope would allow a designer to investigate effect of vehicle deck size on transportation efficiency and the ship design, allowing a trade off between local and global functionality to be undertaken.

The final arrangement of the LST retained the design character of the initial design. The only deviation from the original style was a realisation of the need to achieve vertical continuity with the aft edge of the superstructure. This forced the minimum design length to be that of the vehicle deck plus the length of the flight deck instead of the wholly vehicle deck driven design originally expected. This, while a function of the chosen architectural configuration, did show that the methods used can be adapted as the design increases in detail and the issues being investigated become much clearer.

The design of the superstructure was informed by the Building Block methodology in a positive manner. The designer wanted to locate certain functions within the single superstructure deckhouse and at different stages of the process these aims were met to greater or lesser extents dependant on the length of vessel and amount of unallocated internal space. However as the design progressed the desired compartments were located in the superstructure and the constraints between the bridge, accommodation, operations rooms, exhaust and CIWS defined the requirements for space and length in the superstructure.

In this section the design of a large landing ship using a solid model based computer aided design paradigm has been investigated. This design has focused on the satisficing of the vehicle deck arrangement followed by evolution of the design. The design studies have shown that the three dimensional modelling paradigm is a useful mechanism. The added perspective on the design given by accurate representation of the ship in the third dimension allows extra design insight to be formed. The evolution of the design from the design generator of the vehicle deck is believed to be a successful method of defining the minimum size of conceptual design ensuring that major design problems are considered as necessary.

7.5 SALIENT POINTS OF CHAPTER 7

Chapter 7 has detailed the design of monohull naval ships using a Building Block based methodology. Said methodology has proven successful at detailing design issues and requirements, allowing the designer to identify potential solutions that meet requirements, while allowing a designer the flexibility to change the designs global dimensions and features in a controlled manner in response to local deficiencies.

The application of the Building Block methodology to the escort design demonstrated advantages, particularly while selecting the sizes of superstructure and double bottom to provide a suitable arrangement of compartments and spaces, while heavily influencing the hull volume and design depth respectively. Traditional design methods do not allow the designer to identify these demands as easily.

The small combatant series of designs demonstrate an ability to re-design existing Building Block models to new design requirements and the ability to include zoning into the design. Hullform characteristics are recommended to be investigated by a parametric survey based on the characteristics of the Super Building Block design allowing the designer to identify the affect of changing the hullform, while not breaking constraints and issues raised by the Building Block model.

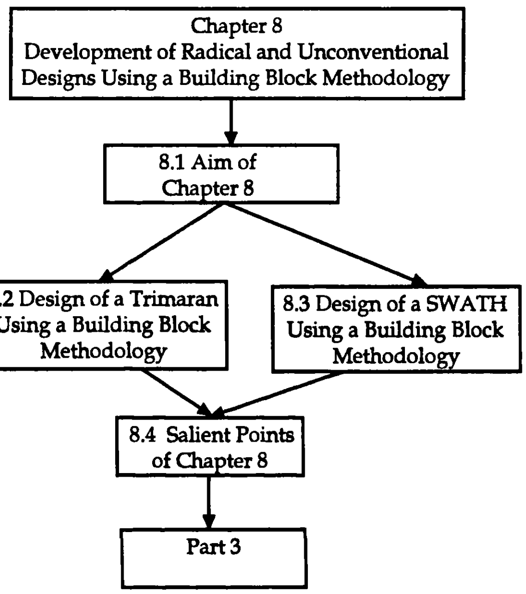
The Landing Ship Tank design detailed an ability to model the design using a non topside design generator, but showed how even in this case the topside influences the arrangement of the ship. The three dimensional nature of the design model allowed the designer to consider design issues more effectively.

Taken as a whole the monohull Building Block designs detail an ability to design ships with a methodology allowing the requirements of the design to emerge and dictate the form and features of the design. This provides an ability to illuminate fully the cost and risk implications that a modern preliminary design stage is intended to consider. While detailed design evolutions may change the design characteristics as designers and constructors attempt to manage funds, time, and technical issues, the programme should not discover that the design is too small for the intended use, provided the goals to be achieved are constant[181].

181 Preliminary ship designs will always be rendered as redundant, regardless of design methodology when programme ideals and goals change.

8. DEVELOPMENT OF UNCONVENTIONAL DESIGNS USING A BUILDING BLOCK METHODOLOGY

Figure 8-1 Chapter 8 Schematic

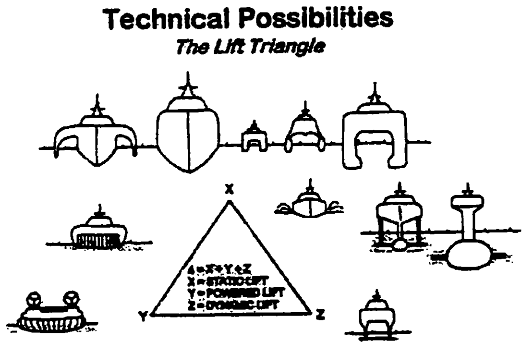


8.1 AIM OF CHAPTER 8

Chapter 8 extends the application of the Building Block design methodology to the requirements of unconventional vessel preliminary design stages. Trimaran and SWATH examples are demonstrated as these are currently the most commonly investigated naval ship requirements for unconventional craft. The discussion draws on the experiences of the author in [*Bayliss et. al., 1996, 1998a, 1998b*] in which the application of numerical initial sizing methodologies and techniques were adapted to meet the requirements of unconventional designs, notably the Trimaran Hullform.

Chapter 8 commences with a definition and overview of unconventional designs. It also suggests that unconventional vessel designers should consider other design techniques [Section 8.1.2]. Following this discussion of current preliminary design methods, the development of a Trimaran Escort using a Building Block approach is detailed in Section 8.2. Two SWATH designs are detailed in Section 8.3. Such varied design examples, in conjunction with the monohull designs of Chapter 7 and the submarine design detailed in Appendix B, detail the versatility of the Building Block design methodology. Chapter 8 closes with a summary of the above topics [Section 8.4].

Figure 8-2 Sustension Triangle [Levander, 1996]



8.1.1 What is an Unconventional Design?

Although the concept of the Trimaran and the SWATH have been detailed previously, exactly what constitutes an unconventional form of craft has not been defined. Many competing definitions exist, each suiting a specific purpose. An example is the use of a limiting Froude Number, for those designers concerned with the hydrodynamic implications of different design types, particularly those differing between "fast" and "slow" craft. Another example is the sustension triangle [*Levander, 1996*, Figure 8-2], with it's focus on the method of lift, whether static (buoyancy), hydrodynamic or aerodynamic based, or a hybrid.

Given that the focus of this thesis is ship design, a more general and less precise definition is used [from *NES 109, 1999*]. This definition [Table 8-1] differentiates between ships of commonly used technology and requirements, and those which provide more unusual and unconventional design features and thus should be designed using design specific information.

The monohulls previously detailed in Chapter 7, constitute conventional designs, while the unconventional craft comprise one Trimaran design and two SWATH designs. The unconventional design examples here focus on the types of buoyancy dependant unconventional design in service [i.e. SWATH] or likely to be in service in the near future [i.e. Trimaran] as naval designs. Small Hydrofoil or Air Cushion Craft are considered too specialised to consider here, requiring the advanced design methods detailed in Table 3-2.

A design is considered unconventional if any of the following criteria are met:-
Speed greater than $4 \times Length^{1/2}$
Number of hulls greater than one
Use of aerodynamic or hydrodynamic lift
Use of non rigid structural materials.

Table 8-1 Definition of An Unconventional Craft [NES 109, 1999]

8.1.2 Special Design Features and Requirements of Unconventional Designs

Chapter 8 details design issues affecting the design of unconventional designs.

Although many of the concepts detailed are applicable to several types of unconventional designs, they are described using the Trimaran as an example.

The Trimaran concept is such that to produce a coherent overall ship concept many individual or specific hull design constraints such as side hull beam, must be met as well as the overall requirements of the balanced ship in terms of volume, displacement, and gross ship characteristics. An example is the need to provide an air gap between the underside of the Trimaran cross structure and the waterline, as detailed below.

Both Trimarans and SWATHs provide large, wide, cross structures that provide large spaces on 2 deck and the weather deck, available for use in an advantageous manner. This benefit has been shown by many ship designers[182] and is one of the reasons that the Trimaran concept is being considered for naval roles. To maximise such advantages structural and configuration issues must be investigated as cross structure dimensions are detailed. This can be demonstrated by the reduction in the satisfaction of cross structure internal arrangements as more structural design elements, are introduced as a result of structural analysis such as [*Spragg, 1995b*]. The addition of such structural elements adds more constraints to the design and the freely definable cross structure becomes more subdivided.

A geometric model outlined in [*Bayliss et al, 1996*] proposes the approach adopted for the majority of Trimaran designs of a frigate size, namely a one deck high box structure with a double bottom providing space for structure with additionally the possibility of enhanced layout with services routing.

The restriction that this places on the possible solution is a requirement to ensure that the bottom of this cross structure is not subjected to excessive wave impact that could result in damage to the structure. As a result the underside of this cross structure has to be at an adequate height above the sea. Andrews and Zhang [*Andrews & Zhang, 1995b*] detailed that an air gap of 3.5 m was adequate for a 5000 tonne Trimaran form, whereas 3.0 m led to an excessive number of wave impacts. The number of internal main hull decks is fixed (i.e. 4 plus double bottom) for all sensible choices of deck and double bottom height once such an air gap requirement is detailed for an escort sized ship. An implication of this is that it is not desirable to consider a purely numerical synthesis of ship dimensions and displacement for Trimaran designs.

182 Notably [*Summers & Eddison, 1995, Alder, 1997, Smith, 1996, Mateus & Whatley, 1995, Betts et. al., 1997*].

This is due to the fact that the relationships between dimensions of side hull, main hull and cross structure will not scale linearly as assumed with gross characteristics, being driven by local design issues.

For a Trimaran form some of the designs numerically synthesised may be quite unrealistic. To base estimates of system requirements, volume and displacement on such forms is undesirable, as is the use of a Parametric Survey in which the displacement and volume remain constant while assessing alternative combinations of dimensions.

It is considered that the number of constraints on a Trimaran form due to pure naval architectural issues and systems location [such as the problems of Marine Engineering detailed by *Bucknell & Grieg*[183]*, 1998*] are so extensive that to develop the design in a numerical manner does not illustrate the design issues. In particular the design may balance at a point at which it is impractical to meet air gap requirements. The application of a Trimaran geometric model, with adequate wet deck clearance, to the initial sizing process often results in inconsistencies between volume available and provided. If a weight and displacement balance is attained then the volume required may be significantly less than the volume available. At the stage at which design dimensions are investigated it is necessary to investigate the amount of unused space in the more inaccessible parts of the Trimaran design. The shape and form of the main hull bow and the side hulls suggests a larger amount of void space than previously suggested for Monohulls.

Depending on the type and size of ship design, this void space may constitute all or most of the underwater side hullform. Therefore if the designer attempts to balance gross volume numerically without assessing the usability of the side hulls, without a historical database of Trimarans on which to base heuristic estimates, a suitable internal configuration is unlikely to result. What is required is a more detailed assessment of the space required in specific portions of the ship.

Trimaran access requirements are normally estimated from monohull design practice, dependant upon the net volume within the design, that is the enclosed volume minus machinery and tanks. For a Trimaran with a cross structure arrangement the spatial disposition is such that a double passageway, running either side of the main

183 Bucknell & Gregg detailed the potential problems of Marine Propulsion system selection and installation for a Trimaran in comparison with an equivalent monohull. While the author considers that the nature of the equivalence alluded to is not necessarily valid, the authors raise some valid points about the difficulty of marine propulsion systems design within the confines of a narrow Trimaran Main Hull.

hull, is likely to be the most advantageous for layout (Figure 8-3). If such a passageway system is employed, alongside transverse and longitudinal bulkheads the amount of usable space in cross structure is likely to require careful arrangement of those spaces in that area. This should inform other design issues.

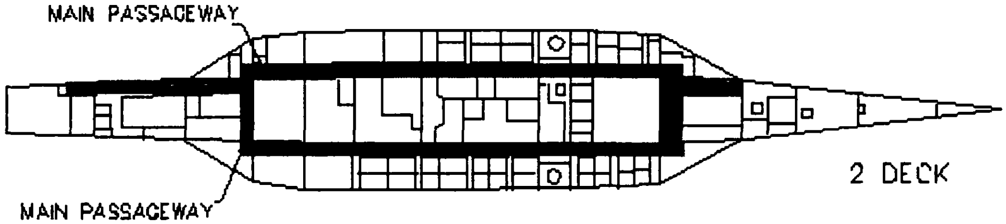


Figure 8-3 Example of Trimaran Access Requirements on 2 Deck

SWATHS and HYSWAS

The SWATH and HYSWAS concepts are considered as unlikely to achieve great penetration into the naval community due to the effect of geometry on the cost and complexity of construction. Often this appears to leave a more expensive solution for the same requirement[184]. However for those operational requirements in which such concepts are particularly applicable, it is essential that the full implications of those designs are investigated. This is partially recognised in almost all SWATH design methods [e.g. *Nethercote & Schmitke, 1981*] by the distinction between Hulls, Struts, Box and Superstructure, in which a balanced ship meets the spatial requirements by assigning space to a general portion of the design.

However such design processes assume, like Trimaran numerical methods, that the design space is continuous and scaleable. This is plainly untrue when considering Table 8-2's [non exhaustive] list of demands on individual elements of the design. Detailing a scaleable design model in which each design issue is continually satisfied would seem impractical due to the varying effect of change on each feature.

Similar, but more complex design issues emerge for the HYSWAS due to the need to balance the design in two completely different regimes, that of dynamic "flight" and the displacement condition.

Other unconventional designs can be seen to have specialised design procedures such as that detailed for civil "Fast Ships" by Graham [*Graham, 1996*]. Such design procedures may have an equivalent to the design generator concept embedded within a numerically driven design process. For example Warren [*Warren, 1997*] suggests that

184 [*Selfridge, 1996*] detailed a HYSWAS design to an approximation of the Statement of requirements for a Type 23 Frigate. For a similar (theoretical) budget a much faster but overall less capable design was achieved.

SWATH Element	Demands on Form and Size
Hull	Resistance Displacement Natural Frequencies Usable Space for Tanks Propulsion Stability
Strut	Access to Hulls Resistance Air Gap Waterplane Area Seakeeping Structural Continuity with both Hulls and Box
Box Structure	Separation of Hulls Damaged Angle of Heel Volume Requirements Combat Systems Propulsion Topside Design Access Routes Configuration Seamanship
Superstr-ucture	Seamanship Combat Systems Propulsion Issues

Table 8-2 Design Features Defining SWATH Characteristics

speed, particularly speed relative to other designer's conceptual designs is important in defining the success of a high performance design for tender. This explains the emphasis of hydrodynamic analysis in fast ship design methodologies [for example *Papanikolaou & Dafnias, 1997, Day & Doctors, 1997*]. Such design tasks are often treated as optimisation tasks and may be considered as best served by such a route, providing sufficient information is added to the optimisation model to detail the ability meet demanding requirements for passenger spaces and engine rooms. Such methods are not considered suitable for naval ship designs for the reasons expressed in Chapter 4.

Numerical design methods are considered less than desirable for successful unconventional naval designs and hence alternative methods are sought. Section 8.2 details the application of the Building Block methodology to Trimarans. This method is considered suitable to apply to the unconventional designs as it allows the designer to consider the space required in specific locations and the cost of space, in performance terms. The design that emerges is not artificially attractive as all demands have been considered prior to determination of the solution. This helps to remove a potential charge that conceptual unconventional designs are often impractical having been optimised for the feature that makes them attractive in a way that constructed ship designs are not.

8.2 DESIGN OF A TRIMARAN USING A BUILDING BLOCK METHODOLOGY

This section applies the Building Block methodology to the design of a Trimaran Escort design using the operational requirements specified in Section 7.2.3. The design procedure used is identical to that used in the Building Block escort design, detailed in

Section *7.3.2*, with the exception that the side hull underwater form is introduced initially as a purely numerical design description at the earliest stages and configured later in the design process. The cross structure and above water side hull form is introduced at the earliest major feature design stage. The resulting design is shown in Appendix F alongside colour maps detailing the arrangement of the functional groups.

8.2.1 Definition of the Initial Topside and Major Feature Trimaran Model

To gain an idea as to the minimum size of the Trimaran escort frigate it was necessary to investigate spatial relationships between major components of the design during the Major Feature Design stage. As with all Escort designs the Topside design was considered as the Major Feature design generator. The components that were considered to contribute to the topside design in this particular instance were:-

- SEATRACE system Trackers
- SEATRACE system Vertical Launch Silos
- Bridge Position
- Helicopter Hanger and Flight Deck Position
- Communications and Radar
- WR21 Inlet and Outlet and Combustion Unit
- Diesel Generators Inlet Outlet and Combustion Unit
- SSM missile launchers
- ESM Antenna

The amount of superstructure located systems was to be minimised for several reasons. Firstly to reduce the vertical centre of gravity decreasing the need for stability that would be provided by side hull separation. This aids a Trimaran design by reducing weight, displacement and cost along with other interaction effects. Adding volume to the main hull rather than the superstructure also allows an increase in length, decreasing resistance, potentially allowing fewer Prime Movers. A Trimaran escort design is likely to be more voluminous than an 'equivalent' monohull, to produce an adequate air gap. Should the design then require a large amount of superstructure in addition the resultant design would potentially have an excessive amount of void space or inappropriate compartment sizes.

Few Trimaran design research studies have taken the opportunity to move the flight deck onto the wide aft cross structure. There a helicopter would have more landing space and the longitudinal position would be such that the effects on operability due to the motion of the ship would be reduced [*Andrews & Bayliss, 1997, Barratt, 1984*]. This was considered important given the requirement to carry two helicopters. The need to locate two helicopters within the hangar meant that a wide and long superstructure deck house was required for the hangar and that main hull beam should, ideally, be consistent with hangar width to ensure structural continuity for such a large deckhouse.

For vulnerability and coverage considerations the surface to air system trackers were widely separated. Thus these components were to be placed at the extreme forward and aft topside positions of the ship at a height of 02 deck or higher. Vulnerability considerations also dictated that the SEATRACE vertical launch silos should be positioned to reduce the chances of more than one being damaged. The needs of the main surveillance radar governed the height and position of the main mast, and it was intended that the ESM system should also be located on this mast unless other considerations dictated otherwise [as was found to be the case]. The IFEP system was sited to allow the helicopter to land without interference from exhausts. The prime movers were separated longitudinally and transversely as much as possible to reduce vulnerability. These design requirements were the driving forces in the location of the major equipment on the topside of the Trimaran design.

It was necessary to assume initial dimensions for the Trimaran hullform on which to place the three dimensional Building Blocks. As in the monohull design, an arbitrary 100m long ship was defined. The cross structure was to be the same length as the side hulls, which were themselves assumed to be 37% of the length of the main hull, following general practice [*Zhang, 1997*]. The position of the side hulls at this stage was such that their centre point was at the amidships position of the main hull.

The ship study from which the propulsion concept was derived [*Rose, 1996, Smith, 1996*] mounted the single ICR Gas Turbine unit in the ship's superstructure to save internal volume otherwise used for inlets and exhausts. An ICR Gas Turbine has a large fluid flow rate and requires large ducts. In most ships such ducts traverse the main passing deck at such a position that they interfere with valuable amidships space. It was intended to investigate the impact of this design feature on the remainder of the design.

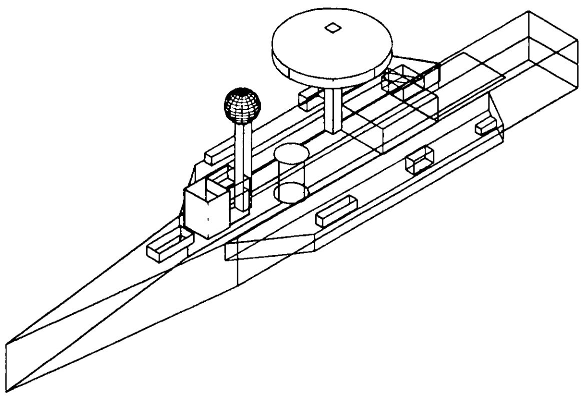


Figure 8-4 Trimaran Topside Arrangement

The first conceptual arrangement included superstructure mounting of the Gas Turbine. This arrangement while feasible was found to be a poor choice for this particular operational requirement.

It was essential for three specific functions to be placed on the third superstructure [02] deck to meet requirements. Two of these were the fore and aft Trackers [which required height in order to provide separated coverage] the final block required, on 02 Deck, was the Bridge, which was required to have height in order to maintain vision over the bow of the long main hull. The placement of these three blocks governed the location of many other superstructure elements, due to a need to provide structural support to these blocks on 1 and 01 decks. The hangar was used to provide support for the aft tracker, and the forward tracker and bridge was supported by accommodation and deck stores. If the hangar was to be placed in such a position that the helicopter could land aft on the box structure it was necessary to add the ICR Building Block to the forward end of the hangar block or the aft end of the Bridge deckhouse. Initial considerations showed the option of placing the ICR block adjacent to the hangar block was not feasible as the air inlet would be directly exposed to sea spray, the exhaust would also be too close to the flight deck, causing turbulence problems. The ICR block was therefore to be placed as part of the forward superstructure element, with an aft facing inlet shielded from direct sea spray, and a vertical exhaust. This arrangement causes major radar and ESM positioning problems. It was a design requirement that the ESM system should not be placed within 10m of any non mast sharing radar. This meant that, with the preferred positioning of the Trackers, the main radar and ESM mast would need to be at least 10m aft of the forward tracker and 10m forward of the aft tracker. The radar mast would also be uncomfortably close to the hot ICR exhaust. Using previous designs as a guide, in lieu of unclassified information, a minimum vertical and horizontal separation was provided for the mast and ICR exhaust. This could only be met by placing the mast as part of the forward part of the hangar.

The major problem with the entire topside concept was that to achieve the topside design envisaged, the enclosed hull volume provided was in excess of that required. The topside mounted ICR arrangement also reduces the utility of the amidships weather deck space. It was unsatisfactory to provide such superstructure volume while excess hull volume was available. The proposed benefits of a topside mounted ICR system was not fully achieved.

An alternative topside arrangement was considered featuring a feasible mast arrangement and an internally mounted prime mover. The alternative topside design arrangement provided two deck houses, a helicopter hangar and the Bridge / Forward tracker space. The positions of these deckhouses were governed by a need to maintain structural continuity with the ICR engine block located centrally inside the main hull. The ICR inlet was incorporated into the forward superstructure block while the exhaust was separate from and in between both deck houses. The WR21 exhausted further from the helicopter flight deck avoiding turbulence problems. Exhaust effects on the main radar were also avoided. This arrangement utilised more effectively both external deck area and the internal volume. The only exception was the imposition of trunking on the operational spaces on 2 deck. The problems of ESM/Tracker/Radar interference dominated the topside arrangement process requiring placement of equipment on two widely separated masts. The following features of the topside were then configured:-

- Diesel Generators
- Forward VL Silo
- Remaining VL Silos
- SSM Systems
- Torpedo Tubes

The vertical launch silos were separated for vulnerability reduction. Options for two 16 missile silos, one 16 and two 8 missile silos or four 8 missile silos were investigated. The most acceptable solution resulted in a 16 missile silo being placed forward of the bridge. Two 8 missile silos were mounted above the side hulls just forward of amidships. The SSM system was placed in an amidships position in between the ICR inlet and exhaust. The topside configuration selected is detailed in Figure F.1. The overall dimensional constraints that were derived as a result of this configuration were:-

$L_{MH} \geq 127m$
$B_{MH} \geq 10m$

8.2.2 Design Using Super Building Blocks

Following the successful topside and major feature design step the location of the various Move and Fight topside elements was used to judge the most sensible decomposition of functions and spaces into a small number of Super Building Blocks. The resulting functional breakdown is shown in Figure F.3-F.7.

A major difference between the functional decomposition used in the monohull and Trimaran Building Block Escort designs arises from the different propulsion systems that were involved in the two designs. For the monohull design the propulsion system was separate in all respects from the electrical power generation system. Hence electrical generation and distribution Building Blocks were grouped under the INFRASTRUCTURE function as the major role of the electrical system was to provide a support function for the fighting and living functions of the ship.

As described in Section 7.2.3, the Trimaran escort design has a full electric propulsion system and the vast majority of the electrical power generated is required for the propulsion of the ship, consequently the electrical generation functions of the Trimaran featured as part of the MOVE functional group.

Following the initial topside design phase, the Trimaran design consisted of a description of the topside dimensions without describing the three underwater hull forms. It was considered important to estimate the minimum design depth required, when considering the minimum air gap requirement. For the monohull design, the minimum depth was given by the need for a two deck engine room, a double bottom and one passing deck. However for Trimaran the requirements were an adequate draught, an air gap, a cross structure double bottom, and a cross structure deck height.

With minimum dimensions specified for the first iteration by topside or other functional requirements, the enclosed volume of the ship was obtained and ship's size dependent Super Building Blocks defined. At this stage the side hulls were not modelled accurately underwater due to the small amount of information that was available and the limited side hull spatial demands. Since the side hulls provide stability, buoyancy and experience resistance, approximate dimensions and form characteristics were employed. The above water side hull, cross structure and main hull whose form and shape are important with respect to obtaining the configuration were fully modelled, along with the both structure main deck. The box structure double bottom was not fully modelled as it was not considered appropriate to utilise that volume for any other function.

It is not appropriate to report the entire range of design choices made in the first Super Building Block iteration, although the major choices in the sequence are shown Table 8-3. The first blocks to be placed were those whose locations had been defined in the topside design phase.

Following the initial placement of the Super Building Blocks, several were

Order	SBB Name	Vertical Position, deck	Longitudinal Position (-ve aft)
1	Hangar	1, 01	-10m
2	Motion Command	02	21 ≈ (L/3)
3	Fwd Tracker Sys.	02	15.5 (aft of Motion Command)
4	Command & Communication	2	5 (below bridge in side main hull)
5	Aft Tracker Sys.	02	Above Hangar
6	Buoyancy Support	2	57 Traditional location
7	Officers Accom.	2	Port Cross Structure
8	Fuel (2 blocks)	DB, 5	Various
9	Catering /Offices	2	Aft end of Cross Structure
10	Fwd VLS	1,2	Fwd of Superstructure
11	Ratings Accom.	3	Aft
12	Motor & Main DG's	4,5	Aft
13	WR21	4,5	fwd of motor
14	Damage Management	2	Starboard Box Structure
15	Motion Actuation	3	Aft
	Engine Room Bulkheads Positioned		
16	Supply & Disposal	3,4	Fwd of Engine Block
17	Propulsion Control	2	Starboard cross Structure
18	Sonar	DB, 5	Fwd of Fuel
19	Port & Starboard DG + Motors	1,2,3	Aft of amidships above side hulls
20	Port & Starboard VLS	1,2	Fwd of DG's above side hulls
21	SSM Systems	1,2	Amidships

Table 8-3 Trimaran Escort SBB Layout Order

moved, others were split into more than one block to meet overall volume and space requirements. A major decision was made in that it emerged as impractical, without vastly increasing the main hull beam, to design a helicopter hangar capable of stowing two helicopters with a maintenance envelope within a width of 11m,that of the main hull. As a result full structural continuity of the hangar had to be reconsidered. The hangar was relocated so that the forward and aft bulkheads of the hangar were supported and the side bulkheads of the hangar were located on longitudinal structure marking the external edges of the fore-aft passages in the cross structure. At this stage the following features required attention:-

- The design displacement was insufficient.
- The design volume was too large.
- The metacentric height was too large.
- The resistance performance was not good enough to achieve the desired maximum speed.
- A lack of volume forward above 1 deck made the provision of support for the Bridge superstructure block difficult to achieve without adding large amounts of unallocated space into the main hull.

The design required extra displacement, however the need to change dimensions to provide this extra displacement was a function of the remaining four problems. Additional beam (overall or main hull) was inappropriate due to the excess stability indicated by the initially high value of GM. Structural weight could have been reduced along with gross volume by a reduction in the overall beam. A new value of 25 m was investigated with no other changes being made to the design. This meant that a complete revaluation of the use of the cross structure on 2 Deck was required. However it was felt that, as the draught was fixed by the need to provide the extra displacement without increased hull depth, the resultant increases in displacement to meet the new weight target would need to be achieved by increased length and a modified hullform.

Dimension	Value
Length $_{MH}$ m	145
Beam $_{OV}$ m	25
Beam $_{MH(WL)}$ m	10
Draught $_{MH}$ m	5.4
Depth $_{MH}$ m	12.1
Coefficients $_{(Main\ Hull)}$	
Block	0.49
Prismatic	0.65
Midships	0.75
Length $_{SH}$ m	55.1
Beam $_{SH}$ m	2
Draught $_{SH}$ m	2.9

Table 8-4 Initial Trimaran BB Design Parameters

From [*Rose, 1996*] minimum combinations of beam and C_M for an acceptable engine room layout were assessed and a limited study of the variation of main hull resistance with length and C_P undertaken using the Series 64 approach [*Yeh, 1965*]. The remaining ship's dimensions and hull parameters were assessed in terms of the effect on the displacement and amount of unassigned space and ability to achieve the maximum speed. The study showed that the minimum length at which both speed and configuration issues could be satisfied was 145 m with 55 m long side hulls. The dimensions of the ship at this stage are given in Table 8-4.

The first decision taken in the second Building

Block iteration was remove the constant deck head spacing of 2.7m. From the original iteration and the amount of excess space within the main hull it was found that there was no need to constrain the engine room decks to this deck head height. The height of both 4 and 5 decks was increased to 2.8m each while the main passing deck (2 deck) was retained at 2.7m. 3 deck had its deck head height reduced to 2.5m to compensate. 2.8 m allows a more acceptable engine room height given the ICR turbine requirements. The double bottom was maintained at 1.3m. This value was not sufficient to allow the carriage of all the fuel in the double bottom, but further increases in the double bottom were limited by external factors controlling the ship depth, such as structural weight and air gap. The volume requirement was altered for those SBBs located on decks whose heights had changed. The overall effect was a reduction in unassigned volume. The Super Building Block arrangement was altered to reflect the change in ship dimensions and changes in functional requirements. A trim system was required forward of amidships to restore an acceptable LCG.

The routing of the large ICR intakes and exhausts interfered with the Command and Control arrangement and extra space was required for this function, above that originally anticipated. The decrease in the cross structure beam meant that the accommodation and offices placed in these sections were reduced in space and alternative locations were found. The two longitudinal cross structure bulkheads meant that careful location of the forward VLS silo was necessary. The position of the side hulls was also carefully considered. To gain structural continuity with bulkheads and to minimise volume enclosed, the outboard cross structure was aligned with that of the side hulls and was 90% of the side hull length.

8.2.3 Design Using Building Blocks

Major Features of the Building Block Design Iterations

The initial number of Building Blocks created was 53, although many were subsequently divided to meet localised or overall requirements for space. By the end of the final general arrangement stage the number of blocks was 165.

The first major design decision within the Building Block phase was to move the Technical Space Block from 2 deck to 3 deck to increase the space available to the undersized Operations Room block. Other changes made it necessary to place the CPO's and PO's accommodation in the starboard cross structure. Structural continuity was maintained by moving the cross structure forward edge and main hull bulkhead to

Prime Movers	Max Speed using Prime Movers
1 DG	12 knots
2 DG	15 knots
3 DG	17.5 knots
4 DG	19 knots
1 WR21	26.2 knots
1 WR21 + 1 DG	27 knots
1 WR21 + 2 DG	28 knots

Table 8-5 Trimaran Prime Mover Combinations

coincide with the VLS Silo aft bulkhead. These changes in bulkhead positions were reflected on lower decks. At this stage the discrepancy between weight and displacement was too great and it was necessary to compromise one of the following design requirements:-

- Air gap
- Equipment carried
- Weight margins
- Top speed

The decision was made to increase the draught [by 50mm] and accept a reduction in air gap [to 3.45m] without increasing ship volume. Following this the effect on powering performance was noted[185]. Table 8-5 gives the combinations of prime movers available.

Dimension	Ship	Main Hull	Side Hull
Displacement Deep (tonne)	4246		
Volume Gross Enclosed (m^3)	15180		
Side Hull Displacement %	3.5		
Length OA(m) Length BP (m)	147	145	55.1
Beam (m)	25	10	2
Draught (m)	5.45	5.45	2.92
Depth (m)		12.1	
Block Coefficient		0.49	0.45
Prismatic Coefficient		0.65	0.60
Midships Coefficient		0.75	0.75

Table 8-6 Final Trimaran BB Design Characteristics

At this stage specific access routes were introduced in the layout. It was found that the space available in the cross structure once the 'ring' access route [see Figure 8-3] had been placed, was less than originally anticipated. The P.O.'s accommodation spaces were moved to the central hull which required many of the stores spaces to be moved from their previous locations.

Stability in both deep and light cases was given by solid metacentric height and the values were 3.01m deep, 2.44m light, considered satisfactory at this stage. Final design investigations assessed compartment vertical and horizontal access, modifying the ship layout to ensure this was sensible.

Table 8-6 lists the parameters describing the Trimaran Building Block design,

185 The actual speed in an electrically propelled ship also depends on the amount of generated power utilised for hotel loads. The propulsion system was sized so that the Electric Propulsion Motors could accept the full power output of 1 WR21 and any 2 of the 4 Diesel Generators. The output from the other 2 generators would feed the hotel load.

following the decomposition of the Building Block Design into compartments.

The Trimaran Building Block design study shows that for a warship capable of carrying two helicopters with good landing position, a highly survivable prime mover and surface to air missile silo arrangement, the Trimaran ship is reasonably small in terms of displacement, with a resultant cost impact.

8.2.4 Critique of the Building Block Design Process When Applied to Trimarans

The application of the Building Block design processes to a Trimaran concept was not, in general, as straight forward as applying the methodology to monohull ships. Much of this was due to problems in assessing the growth of the ship as a result of excessive volume. However the ability to develop the concept with regard to the layout and physical performance indicators meant that many design decisions were investigated for their impact on the ship and then discounted or accepted. In a more traditional synthesis the numerical route might have lead to what subsequently was revealed to be a 'blind alley' which would have either delayed the concept design process, or lead to a constrained (over tight) design or even a belated redesign in deep feasibility.

The benefits of applying the Building Block design methodology to the Trimaran Building Block design were the same as those revealed for the Monohull Building Block designs. The control of the ship's dimensions and overall characteristics was driven by specific requirements, as well as overall ship requirements. Unfeasible combinations of deck heights and other dimensions, which would have survived in a traditional design procedure past the parametric stage, were not even considered as specific issues dictated the ship's minimum depth. This, in some cases, meant that divergence of the design was not achieved prior to convergence. Whilst such a design methodology is not a search process for the 'optimum' combination of values to meet a set of performance criteria, it is conceivable that the design procedure adopted did not consider enough alternative solutions.

The question as to whether enough alternatives have been considered is likely to apply to any configuration based preliminary design tool. This is due to the need to assess the design configuration at each iteration, suggesting that a lot of time is spent performing basic layout tasks. In contrast a quick and broad study typical of a numerically based approach is likely to allow a convergent design exploration. However this can only be done within the limits of specific algorithms and accepting that the concepts that arise from such a sizing process will not reveal configuration based disadvantages clearly visible in a configuration based approach.

This section has described the preliminary design of a Trimaran Escort using a Building Block procedure. The preliminary concept design evolved in several phases by incremental decomposition from the topside design and design of the major ship features through to a General Arrangement. The following major conclusions were noted in the course of this Trimaran Building Block development exercise.

- While it is not essential to balance the design at the Super Building Block stage to the same degree as is required for a numerically sized design, it is essential that the discrepancies are no more than is readily removable at the Building Block and General Arrangement stages.
- More emphasis should have been placed on assessing the direction in which the ship would 'grow' as the design progressed. Thus as the design progresses into the Building Block stage, reasonable increases in weight or space should not cause the design to no longer be on a design plateau.

The Trimaran design produced is not considered completely successful as it appears that with the constraints applied in this case, a ship to meet the speed and displacement requirements would enclose too much volume to allow the spaces to be positioned as budgeted. This however was a flaw in the initial requirement which asked for a large air gap.

8.3 DESIGN OF A SWATH USING A BUILDING BLOCK DESIGN METHODOLOGY

8.3.1 Introduction to SWATH Building Block Design

The SWATH Escort Designs detailed within this section are designed to the same operational requirements as the Trimaran Escort detailed in Section 8.2 and the Monohull Escorts detailed in Chapter 7. The operational requirements were presented in Section 7.2.6. The design investigation presents a modified Building Block methodology, defined to allow the important design issues of the SWATH design type to emerge. The modified Building Block methodology utilises all the core components of the Building Block methodology detailed in Chapters 5 but differs in the order in which design evolution was attempted.

When applying the Building Block Methodology at the earliest stages to the Trimaran, the model did not include the underwater portion of the side hulls as configurable design elements. As little equipment was to be located in the hulls, the design underwater hull model solely used numerical information at the earliest stages. When using the Building Block design methodology to design a SWATH it is considered necessary to modify the methods used in order to reflect the difficulties of meeting the requirements of the SWATH geometry. The major change proposed was that four preliminary design steps should be undertaken before and during the first full

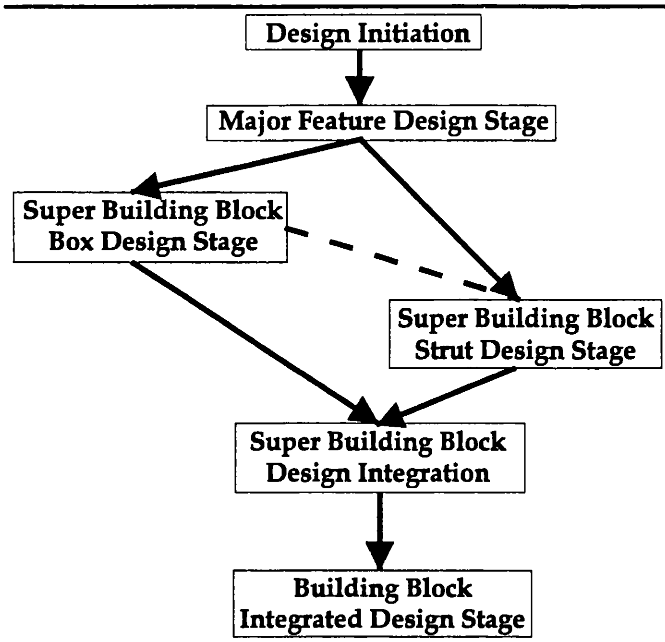


Figure 8-5 SWATH Building Block Procedure

Super Building Block Stage:-

- A Major Feature Stage, based on Topside Design (to estimate minimum Box dimensions)
- A preliminary consideration of box structure configuration
- A preliminary assessment of hull and strut dimensions
- A synthesis stage in which the initial hull and box designs would be combined.

This would allow an initial set of dimensions to be generated in the Major Feature stage but instead of defining minimum hull dimensions, this stage would define minimum box dimensions. The box structure design stage allows minimum box structure dimensions to be estimated in isolation from the underwater form of the design. Using information gained in these two design steps, the underwater hull and strut forms required to maintain the cross structure at the correct height, with due stability and speed were capable of identification. This reduces the design space quickly to the one in which architectural and hydrodynamic considerations are met. This process is considered in Figure 8-5.

Following separate consideration of design components, the parts were integrated together. A balancing stage assured that the sum of the parts was a valid design, with changes being made to all design elements. Following this the design was decomposed to greater levels of detail until the design was complete.

Another change in design methods was the consideration of weight and space balances and their influence on subsequent design steps. In the monohull and Trimaran design procedures, designs have not balanced exactly at every iteration. Instead the aim has been to converge towards a balanced solution gradually. This is acceptable for designs that are not weight critical. A SWATH is very sensitive to changes in weight. Therefore the design must be balanced for weight and subsequent changes in dimensions or form should result in re-balancing.

Due to the large amounts of void space likely to occur in the struts and hull and the consequent difficulty of balancing required and available space in each areas of the design, it was considered unhelpful to balance the volume numerically. Therefore the assessment of the "tightness" of the design was performed visually by the designer. The box space was to be fully used, while spare space within the struts and hull would be assessed as necessary, in conjunction with the changes in performance that would result from changing hull and strut dimensions to remove the space.

8.3.2 Development of SWATH Escort Design 1

Length m	100.00
Beam m	32.50
Box height m	3.50

Table 8-7 Initial Box Dimensions

Major Feature Design Stage

The major feature design stage was heavily influenced by a need to maintain a small box length to minimise the overall size of the SWATH design. This was necessary due to the "naturally" wide form of most SWATHs The length was defined by a need to meet the same topside constraints at the Major Feature stage that the Trimaran and monohull escort designs had met. However due to the inherent seakeeping advantages and the height of the cross structure of the SWATH, the location of the bridge and the foremost equipment were not subject to the heuristic rules detailed in Table 6-4. This, and the permissible width of the box structure allowed a shorter minimum length.

The topside design was defined by the relationship between the large helicopter hangar and flight deck, the ICR gas turbine housing, which was by necessity mounted in the box structure, and the forward superstructure complex supporting the Bridge. Length reductions were achieved by mounting the VLS silos away from the centreline, allowing several topside elements to share the same longitudinal location.

The functional hierarchy developed by the designer for the SWATH escort design is similar to that developed for the Trimaran design due to the similarities between the equipment items carried by both designs. The changes that were made mainly concerned the location of the specific MOVE elements in the MOVE functional group due to the change from one main propulsion train to two propulsion trains, one located in each hull.

Box Design Stage

The Box design stage commenced with the development of the main Box deck and the relationships implied by the locations detailed in the Major Feature Design stage. The initial Box dimensions were as shown in Table 8-7.

Hull and Strut Design Stage

Using initial dimensions, as detailed in Table 8-7, it was necessary to investigate the style and dimensions of Hull and Strut combinations that met the following criteria:-

- Provide sufficient buoyancy to balance weight of design.
- Provide sufficient space (including access) for Propulsion Train, Tanks and other Hull and Strut mounted elements.
- Provide suitable Stability at large and small angles.
- Provide suitable natural frequencies for heave, pitch and roll.
- Provide wet deck clearance.

These criteria were investigated by postulating struts of the same length of the Box and separated by the width of the Box. Complete strut and hulls were postulated based on standard, circular hull forms for such items derived from [*UCL, 1993*]. Surface representations of the hull and struts were created and located below the Box structure. The Building Blocks representing those elements within the hull and struts were located. These informed the need for changes to be made to hull and strut forms in order to allow the systems to be located. Once dimensions had been evolved in order to allow the Building Blocks to be satisfied, the displacement, natural frequencies, stability and resistance were considered. The following design features were re-assessed to provide the desired performance:-

- Strut Separation — To reduce intact stability to the desired level, while improving seakeeping, also reducing Box width.
- Strut Length — To improve (reduce) natural frequencies.

The Integrated Design Stage

At this stage the hull, strut form and box arrangements were no longer compatible and consequently the whole design was re-assembled and re-evaluated. The major change in the complete design arrangement was the change of hull form to allow the design to meet seakeeping (natural frequency) requirements with a lower draught.

In subsequent design evolutions the internal configuration of the hull, box and struts altered, providing a more integrated and acceptable arrangement meeting all requirements. In the course of one more Super Building Block level and one Building Block Design iteration the design's dimensions changed as shown in Table 8-8.

Design Stage	Final	Post SBB2	Initial
Displacement Deep (t)	4453	4458	3800
Volume (m^3)	18728	18749	19181
Above Water Strut Volume (m^3)	2010	2025	1920
Underwater Volume (m^3)	4344	4349	3707
Displaced Volume of Struts (m^3)	1005	1127	960
Volume of Hulls (m^3)	3339	3222	2747
Volume Box (m^3)	12374	12374	13554
Hull and Strut Dimensions			
Length Hull (m)	110	110	100
Length Strut (m)	87	90	80
Vertical Hull diameter (m)	4.45	4.65	5.00
Horizontal Hull diameter (m)	5.5	5.35	5.00
Hull Separation (m)	25.25	25.50	30.00
Draught Deep (m)	7.45	7.99	8.00
Depth (m)	16.95	17.49	17.50
Displacement Distribution	0.77	0.74	0.74
Immersed Strut Draught (m)	3.00	3.34	3.00
Strut Width (m)	2.75	2.50	2.50
Box dimensions			
Length (m)	100	100	100
Beam (m)	28	28	32.50
Box Height (m)	3.5	3.5	3.5
Box Clearance (m)	6.00	6.00	6.00
Superstructure Volume (m^3)	2574	2574	2179

Table 8-8 SWATH Escort Design 1 Characteristics (Final Design and Post SBB2)

Development of SWATH Escort Design 2

SWATH Escort Design 2 was developed to meet the speed requirement not met by Design 1. The propulsion system assigned to Design 1 was incapable of propelling the design at the required speed [28 knots]. Design 2 used a second ICR Gas Turbine and up-rated propulsion trains to achieve this speed. This required the following changes to be made:-

- Change of hullform to house larger propulsion motors and to meet new stability requirements caused by changes to design weights.
- Increase in Strut Width.
- Rearranged Box Configuration to allow 2 Gas Turbines to be located.

- Increased Design Volume and Displacement.

	Design 2	Design 1
Displacement Deep (t)	4825	4453
Volume (m^3)	19764	18728
Above Water Strut Volume (m^3)	2192	2010
Underwater Volume (m^3)	4707	4344
Displaced Volume of Struts (m^3)	1096	1005
Volume of Hulls (m^3)	3610	3339
Volume Box (m^3)	12864	12374
Hull and Strut Dimensions		
Length Hull (m)	112	110
Length Strut (m)	87	87
Vertical Hull diameter (m)	4.60	4.45
Horizontal Hull diameter (m)	5.65	5.5
Hull Separation (m)	25.00	25.25
Draught Deep (m)	7.60	7.45
Depth (m)	17.10	16.95
Displacement Distribution	0.77	0.77
Immersed Strut Draught (m)	3.00	3.00
Strut Width (m)	3.00	2.75
Box dimensions		
Length (m)	105	100
Beam (m)	28	28
Box Height (m)	3.5	3.5
Box Clearance (m)	6.00	6.00
Superstructure Volume (m^3)	2574	2574

Table 8-9 SWATH Escort Design 2 Final Characteristics

These changes resulted in a larger design resulting which was much heavier than the initial design. The final design is detailed in Table 8-9.

Discussion of SWATH Development Methods

The separation of the Building Block SWATH design methodology into Hull and Box based portions at the earliest stages provides an ability to investigate in separation the requirements of each portion of the hull, provided the designer is clear as to the desired location of the Building Blocks. This notably allows the designer to postulate a suitable box configuration which is independent of demands placed on the box by the hulls and struts. As the box is the location of operational spaces and systems the provision of a box arrangement which meets functional requirements is important. The identification of constraints on the hull and strut form proved invaluable in determining an acceptable hull geometry for this design. In more realistic exercises, in which more varied hullforms are proposed the identification of internal hull and strut configuration constraints on hullform [and vice versa] should prove useful, given the sensitivity of the SWATH form to changes in dimensions at the earliest stages.

The hull / box synthesis stage allowed the important issues of both above and below water portions of the design to remain intact while less important issues were compromised to provide a valid complete design.

Problems encountered during the SWATH design procedure include the time taken to investigate the full effect of changes to the underwater hullform and the limiting effect this has on the exploration of a wide design space. This problem was mitigated by the increasing number of constraints introduced by the nature of the SWATH design which specifies many minimum design characteristics to meet criteria for Seakeeping, Stability and configuration issues.

8.4 Salient Points Of Chapter 8

Chapter 8 has detailed the ability to define three unconventional hullform vessels using Building Block based methodologies. The Trimaran design has detailed the need to consider thoroughly the internal and external architecture of major systems to allow a suitable combination of hull geometry and superstructure to be developed. The resulting design was larger but more capable than the preceding Monohull Building Block Escort design. The requirement to investigate areas of potential advantage for the Trimaran concept, namely Topside configuration and hydrodynamic performance suggest that a methodology such as the Building Block methodology is necessary. This is to ensure that both advantages are allowed to enter the design process at a stage in which they can both influence the emerging design. Similarly the box structure of the SWATH design and the link between this and the two struts and hulls were informed by the configuration requirements of each and also hydromechanic properties. The concept of separate design stages each focusing on the desired properties of each design segment followed by integration, lead to the cross structure informing the hull and strut forms, as desired.

Conclusions of Part 2

Part two has detailed the definition and application of a ship design methodology to meet the requirements detailed in Part one. The solution, the Building Block methodology has used the concepts of design configuration and dimensions emerging simultaneously to allow the designer to control the evolution of the design to meet the design requirements.

A major feature of the Surface Ship Building Block design methodology is the use of several levels of Building Block to represent the design at different stages of the process without losing the link between design configuration and size. A functional hierarchy based on the concept of four functional groups, FLOAT, MOVE, FIGHT and INFRASTRUCTURE allows the different levels of the ship design to be related. Another major feature of the methodology is the use of the concept of the design generator to detail a starting point for the definition of the Building Block design. This allows the major operational requirements to be linked to the technical issues which define the size and cost of the design.

Examples have demonstrated, that when applied to monohulls, Trimarans or SWATHs, to varying design requirements, the introduction of configuration issues alongside those normally considered at the initial sizing stages is suitable for use for naval designs with their multitude of design requirements and un optimised nature.

Part 3 Conclusions

Part three concludes the discussion of the Building Block methodology. Part three consists of a single chapter, references and leads to the detailed design appendices. Chapter 9 details the thesis conclusions, stating the justification for the new design methodology that has been the focus of discussion in Part two. Chapter 9 summarises the methodology while noting the perceived advantages and dis-advantages.

Section 9.4 proposes areas of future research for the Building Block methodology. Reference sources are detailed and appendices follow. The appendices contain more detailed information regarding the ship designs detailed in Chapter 7 and 8 and a summary of an example submarine design created using the Submarine Building Block methodology. Appendices also detail a proposal for the "SURFCON" Computer Aided Preliminary Design Suite.

9. THESIS SUMMARY

9.1 SUMMARY OF REQUIREMENT FOR A NEW METHODOLOGY

Previous discussions have defined in detail the requirement for a new ship design methodology. In this summary the most important issues are re-visited, and further work proposed.

Chapter 2 noted that the design of most engineering artefacts is not solely a mechanistic process, in which logic and mathematics can automate the design processes employed. This suggests that an important element of the design process is the designer, employing human traits such as creativity. The development of a new design methodology for naval ships as presented in this thesis is necessary to provide the designer with a broad approach, assisting in the production of a good design solution, that represents a preliminary ship design that is likely to be technically feasible and meet the prevailing requirements. The key elements of design were considered and detailed in Chapter 2 and the following can be considered as the most important.

Creativity is necessary within a design process [Section 2.3], as often the translation between a stated requirement and a suitable solution does not simply require a derivative of a previous design. This is particularly important in areas for which no suitable previous designs exist from which new designs can be evolved. Where a design requirement changes with time, due to changing priorities and technology, for example, in ship design, it is considered essential that an ability to develop radical solutions is available.

Decision making is another element of the design process that contributes heavily to the efficacy of design solution development. Two approaches are currently advanced, one in which the designer is the decision maker, and computer based decision making, methods [as advanced by *Mistree et. al., 1990, Sen & Yang, 1994,* Section 4.3.3]. It is considered that computer based representations of decision making are often reliant upon modelling the design problem using a continuous design space in which mathematics and subjective prioritisation provide a valid route to a final solution. This approach is not considered applicable to the naval ship preliminary design task due to a need to assess all design characteristics and requirements as mathematical equations or to assign "weights" to all design properties subjectively.

Synthesis is a major feature of a design process [Section 2.3], a process of *"fitting* *together of parts ... to produce an integrated whole"* [*Asimow, 1962*]. This process can be performed in many ways. Many methods, however, follow similar principles, notably the development of small subsets of the design requirement, the postulation of design sub elements satisfying those sub requirements, and the development of an integrated design product from the constituent sub elements. The information available to the designer at this critical stage of design significantly affects the final design artefact. In particular it is considered that the complexity of the design requirements of large made to order engineering systems is such that a truly optimal design cannot be achieved. [*Simon, 1981*] suggested that many, equally valid "satisficing" designs may result and that the path undertaken in finding the final solution is important [Section 2.3].Hence the design method is a design solution determinant. This provides a reason for the study of design methods and methodologies for complex systems.

An ideal design synthesis method would present the designer with all possible design information in a structured manner. This is generally impractical or unmanageable and a more common approach is to split the design process in to preliminary and embodiment design stages [*Pahl & Beitz, 1984,* Sections 2.4-2.5]. The embodiment [for mass produced objects or detailed design, for large made to order objects] stages provide a final solution, analysed and assessed in great technical detail. In order to perform the very complex design development task, an initial representation of the design solution is required, the task of the preliminary design stages.

Preliminary design methods are thus required to allow the definition of a design description in which great changes in design direction are unlikely to occur, to act as the starting point for detailed design. Preliminary design operates with a lower level of design information, assessing broad trends and relationships between design requirements and technical features, often developing the requirement as well as an indication of the solution. Several authors [e.g. *Andrews, 1994a, Erikstad, 1996,* Section 2.5] have suggested that this design stage is the most critical due to its implications on cost, project planning and the emergent design features. Thus if this is considered true, along with the thoughts of Simon, it appears that the methods by which preliminary design is performed are very significant.

The modern emphasis on concurrent engineering [Section 3.5] with a focus on the performance of detailed design tasks at the preliminary stages in order to reduce development time and costs is important and enhances the importance of preliminary design.

The use of computers is an essential part of the modern design process for complex engineering artefacts [Section 2.6]. Currently computers are most prevalent in the analysis of a pre-defined design for suitability or as advanced, flexible, replacements for manual draughting techniques. However the use of computer aided design is entering the traditional roles of the designer[186]. Two forms of computer based design system are postulated in this thesis, the artificially intelligent design computer and the design support tool. It is suggested [Section 2.6] that the design support tool is currently of more use to the creative designer as such systems remove the more mundane design tasks from the designer. This allows a designer to focus on elements of design such as creativity and complex thought, at which a human designer is more capable when compared with a computer. The artificially intelligent design tools currently available do not allow sufficient levels of creativity to enter the design process, reliant as they are on pre-programmed rules [for expert systems] or pattern recognition [for neural networks].

The Major Issues of Preliminary Ship Design

A modern navy requires complex naval ships capable of performing a range of tasks in the demanding environment of the ocean. The designs that emerge from the naval ship acquisition process do so after many years of design and development, with multiple approval phases, changes to requirements and budget and other complexities introduced by a need to demonstrate that funds are being spent wisely on a large, made to order design for which there is not an economic or operational justification to develop a prototype and then apply lessons to the first of class. As stated in Section 3.2 this has led to conservative design processes and evolutionary design.

As the design is not generally assessed in prototype form, much of the design development at the preliminary stages is focused on "de-risking" the design, Andrews' "*search for assurance*" [*Andrews, 1993*], reducing the probability of the final design not performing as demanded. An important part of this is the understanding of technical risk and the feasibility of the requirement. For complex "wicked" problems the requirement and a possible design solution evolve together [*Rittel & Weber, 1973*, Section 2.5]. It has been argued that the role of a naval preliminary design methodology is not necessarily to develop a specific design solution to be developed further, but to

186 [*Andrews, 1998*] considered that the impact of computers on the design process has changed design such, that the work of [*Mandel & Chrissostomidis, 1972*] required revisiting in the context of the modern computer.

define sufficiently, a technical design to enable procurement decisions to be made. If poor programme decision making is to be avoided the design must be representative of a suitable design solution to the requirement.

As the preliminary design description is considered important, the methods by which naval preliminary design is undertaken are also considered important. Currently "numerical synthesis" methods [Section 3.4] are commonly used in naval ship design. Such methods rely on the development of the ship design initially by definition of weight, space and systems, iterating the design until a numerical balance between requirements and provision is achieved. This is followed by a method of assessing the merits of similar designs systematically derived from a baseline design, using a parametric survey [such as *van Greithuysen, 1994*]. Such methods attempt to locate the most favourable portion of an assumed continuous design solution space. Following such identification, the chosen design form is developed further, introducing detailed internal arrangements and performance analysis.

Such approaches emerge from historical ship design in which evolutionary design was the normal approach. However modern naval ship design methods must also allow for the reduction in the number of new designs being developed, with a consequential increase in the extent of change between subsequent ships of the same broad type. This suggests that to merely adapt a previous design to the new requirements may not be appropriate. This is particularly true when the requirements of the design requirement lead to the design inhabiting a completely different portion of the naval ship design solution space. In particular the concept of the design generator [Chapter 6], that feature so demanding that it defines ship size, is difficult to introduce at the earliest design stages using mathematical methods, in order to inform the decision making processes.

Other issues such as the introduction of radical or unconventional designs such as Trimarans, and changes to the types of ship system carried, suggest that current evolutionary design methods are also less appropriate and that a design methodology is required that allows the important design issues of such ships to be introduced during initial design when they are most important in design development. Design issues relevant to unconventional designs often revolve around the architectural aspects of the design, notably interactions between gross size, hullform parameters, space, functionality and system configuration.

Alternative design approaches, focused on introducing new design research technology exploiting computer based methods, into the naval ship design process are examined in Chapter 4. That discussion concluded that only one of these possible approaches fully meets the demands placed by modern naval ship design on the designer, the Building Block methodology. The reasoning behind this statement suggested [Section 4.3.6] that many alternative design methodologies shared several characteristics, which while admirable for some design tasks, are considered inappropriate for initial design of naval ships. In particular a tendency to treat the design process as the programming of a "Black Box" computer system to automatically produce a preliminary design is considered unappealing for naval design, given that one aim of preliminary design tasks is the evolution of the requirement, as well as the provision of an initially costed solution. As such the designer learns much from the act of synthesis as well as the result. The use of techniques to optimise hullform characteristics in preliminary design [such as *Keane et. al., 1990,* see Section 4.3.2]was also considered inappropriate as modern ship design is much more complex than a simple search for the most hydro-dynamically efficient hullform. Rather the process must capture the interaction between size, form, architecture, requirements, capabilities and systems. The imagery of [*Simpson et. al., 1997* see Figure 4-2] is particularly valid for naval ships with the variation between the detailed design and the constructed design being notable in terms of weight and cost.

Decision making design systems which base design decisions on subjective judgements of priority are considered impractical for a complex naval design due to the disparate nature of the issues, requiring judgmental decisions between the importance of issues as diverse as range and accommodation location. Neural Networks are not considered useful, as a requirement of successful training is the provision of an extensive library of designs to teach the network. This precludes the use of design methodologies based on such systems in the development of radical or un conventional naval designs.

The most important consideration however is a need to consider all issues affecting the preliminary ship design at the same time, so that design decisions are made on the basis of holistic issues, local design issues, system requirements and performance requirements. This was detailed [Chapter 4] as requiring the introduction of architectural content to the preliminary design description, leading to the Building Block design methodology.

The Building Block approach was modified from an initial submarine design methodology developed by [*Andrews et. al., 1996*] and used by the author in [*Dicks & Spragg, 1995,* see Appendix B]. The resulting Building Block methodology for surface ships is summarised in Section 9.2.

9.2 SUMMARY OF THE BUILDING BLOCK METHODOLOGY

The summary detailed in Section 9.1 has provided a requirement for a new naval surface ship design methodology. The proposed method of meeting this requirement is the application of the Building Block methodology. Taken at a summary level, the Building Block methodology is described by the following sequence:-

- A need for a new conceptual design is conceived and an idea of the likely design style to meet that requirement suggested. An initial, minimum sized design is located in overall naval ship design space by the use of the design generator concept. A design generator is that feature or system of the design, usually linked to operational requirements that is expected to exert the most influence on design form and size.
- Drawing on novel ideas or historical data a series of building blocks are defined in a computer system. Each Building Block contains geometric and technical attributes regarding the functions of that block.
- A design space is generated and the Building Blocks are configured operationally and technically as required or desired.
- Overall balance and performance of the design are investigated using simple and flexible algorithms and, if necessary, using analysis programs external to the main system.
- The configuration is then manipulated until the designer is satisfied a sufficient description has been produced for the current stage of design.
- Decomposition of the building blocks to greater levels of detail is undertaken, as necessary to increase confidence in the design solution.

Using the Building Blocks to produce the configuration is regarded as the main synthesis act of the design, ensuring that design constraints and requirements, whether physical or otherwise, are investigated. This process can be visualised as Figure 5-7.

9.3 SUMMATION OF EXPERIENCES

As a result of experience gained by developing the ship designs detailed in Chapters 7 and 8, it has been possible to identify the major advantages and issues related to the practical design of ships using a Building Block based approach. These are detailed in this section.

The Advantages of Introducing Design Generators at the Earliest Design Stages

The introduction of the design generator concept to produce the initial definition of necessary design characteristics ensures that the designer, providing the correct design generator is assumed, placing the design in an appropriate design space to meet the requirement. As modern naval ships are frequently driven by the design generator to their final form [as detailed in Chapter 6] the use of design generators to quickly identify demanding and impractical topside or internal conceptual arrangements is considered useful. For an architecturally dominated synthesis such as assumed by the adoption of the Building Block methodology, the design generator also allows a designer to reduce the number of initial design iterations to design convergence.

Advantages of Building Block Methods

An advantage of using the Building Block Methodology is an ability to consider elements and requirements of the design, at a point at which design features can be modified. In particular the ability to inform the choice of overall ship dimensions and the distribution of hull and superstructure volumes is considered essential for modern naval ship designs in which cost, capability and risk are the dominant issues. The above three issues are considered to be the key for radical and unconventional designs, such as Trimaran, for which evolutionary design is considered inappropriate and the development of a coherent architectural arrangement is fundamental to a successful design. The methodology is also able to recognise and deal with design discontinuities [*Brown, 1995a*] as they arise.

The Building Block design methodology allows a designer to apply design theory to a practical design task, presenting an open "Glass Box" toolbox, able to be manipulated to the needs of the current synthesis, with rapid changes to design definitions and a level of control over the design computer. During the design synthesis a designer must make decisions and not the computer.

The Use of Functional Hierarchies

The use of a functional hierarchy approach to the Building Block description within the design methodology provides the benefits of different levels of definition into the design process without losing links between global design issues, specific system requirements and design style. Of particular utility is an ability to develop a representative design using a high level definition, while maintaining visibility of architectural and functional issues. At later Building Block design iterations the confirmation of the design's properties is undertaken at a greater level of detail, allowing more specific design issues to affect the overall form of the design.

A functional hierarchy of Building Blocks also allows a designer to consider the overall impact of the removal of specific system capabilities and functions in a comprehensive manner, something that a numerical synthesis may not achieve, due to the treatment of systems as elements of numerically defined space and weight.

Disadvantages of the Building Block Methodology

All design methods and design methodologies have issues which can be considered to be unsuitable or less than satisfactory. The disadvantages of the Building Block methodology that need to be addressed are as follows:-

- Mental agility requirements
- Pre-determination of design form
- Speed of design evolution
- Difficulties of education
- Reliance on architectural issues

The mental agility and experience required is considerable due to the many different levels of detail at which a designer operates during a Building Block design procedure. It is important that the designer is able to focus on the important design issues and is not swamped by design data. In many ways this problem is usually mitigated by the initial synthesis description of the design as a reduced number of Super Building Blocks.

There is a risk in adopting the Building Block design methodology in pre-selecting the form of the resulting design as a result of design intuition, without subsequently assessing the validity of the selected configuration. A skilled designer will avoid this.

The speed of design development is, as a result of the focus on architectural design representations, slower than could be achieved by a purely numerical synthesis followed by a parametric survey and a general arrangement stage. However, the timescale of modern preliminary design stages suggest that time spent performing design synthesis is less relevant to programme completion than political decision making, requirement development and commercial / corporate issues. A criticism that has been made of the Building Block methodology is that it is not a "push button" solution, when compared with automated systems such as "CONDES" [*Hyde & Andrews, 1992*], or designer produced spreadsheets. In this respect the criticism is true as developing a functional breakdown of Building Blocks and performing design iterations does take a reasonable amount of time. However the resulting design synthesis is much more informative, and also informed by the designer. A key design methodology aim was to avoid the black box design methods common in naval preliminary design tools.

The inclusion of architectural issues has also been considered by some[187] as a

187 An informal viewpoint expressed by a colleague of the author.

negative feature as one viewpoint suggests that the requirement to locate all Building Blocks in each iteration allows more flexible, less demanding compartments such as tanks and stores spaces to "drive" the form of the hull and superstructure design, in a manner that does not help the designer. In particular it may be argued that the location of spaces such as stores and tanks should be driven by the hull and not vice-versa. This may be a valid viewpoint but the impact on the design can be minimised by modelling such spaces at a lower level of definition. For all spatial assignments it is reasonable to demand proof that the proposed solution is practical. The skill lies in identifying which spaces to detail at which level.

A Recommended Design Methodology for Naval Ships

The above summary has detailed those important issues associated with the preliminary design of modern naval ships considered to be most completely and successfully performed using a methodology [illustrated in Figure 5-7, Table 5-5] integrating all design requirements into one, holistic synthesis [as *Andrews, 1984* recommended, see Figure 4-9]. Such a methodology allows important design issues to emerge, placing the ship design in a position in the design space likely to provide a successful solution. It is considered that the Building Block design methodology for conventional and unconventional surface ships is the only current methodology to do so and as such is recommended for future use in the ship design community and for further development.

9.4 Future Research Into The Building Block Methodology

The current Building Block design methodology is considered to be a complete design methodology capable of supporting of preliminary ship design programmes. To improve on the definition and methods of the methodology it is beneficial to perform further research. This section suggests areas of future research.

Research can be separated into three areas, practical applications, improved methods and expanded design type coverage.

The first of these is considered most important, as while the Building Block Methodology has been applied to simulated design exercises [Chapters 7, 8], it has not been employed for a design within the midst of a full surface ship development programme and the compatibility between wider programme issues and design methodology is not proven.

It is considered necessary to develop computer based design tools to be used within a Building Block design programme, so that a designer is able to concentrate on design. These developments should be undertaken within a commercial/governmental environment[188] rather than an academic environment. Such proposals are outlined in Section 9.4.1.

The provision of expanded coverage can be undertaken in an academic environment, along with developing more effective approaches to performing specific design tasks. The design methodology should be modified where necessary to allow development of more unusual or more commercial design types. These topics are discussed in Sections 9.4.2-9.4.3.

9.4.1 Practical Applications

Development of Computer Tools

The Building Block design methodology is independent of specific computer aided design tools, and could conceivably be employed in a less efficient form without computer support. However, for the practical application of the Building Block design methodology to succeed within the confines of modern naval procurement programmes it is considered necessary that the mundane tasks associated with the preparation of architectural representations of naval ship design using Building Blocks are managed by a computer aided design tool. Reduction in the amount of time spent managing information allows corresponding increases in a designer's ability to concentrate on the design.

Such a computer based design tool exists in the form of SUBCON for the Submarine Building Block design methodology and has proven successful [*Andrews et. al., 1996, Dicks & Spragg, 1995*] in aiding the designer in developing detailed preliminary designs in a short space of time[189]. Therefore the most important step in gaining acceptance of the Surface Ship Building Block Methodology is the introduction of a SUBCON like system dedicated to the application of the surface ship methodology. This requirement forms the basis of Appendix A, detailing the desired functionality of a proposed "SURFCON" system [*Dicks, 1998*].

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188 The author's submarine design co-author, Adrian Spragg, has developed several submarine design models for a future attack submarine requirement, to a level of detail and accuracy commensurate with a full conceptual design programme.

189 The author's submarine design [Appendix B] was developed in an identical amount of time to several other designs developed using [*Burcher & Rydill, 1994*] based design methods. The design can be considered to be of the same degree of completeness as those designs.

Application within Naval Procurement Programmes

The final step in achieving recognition of the advantages of the Building Block methodology detailed in Part two, is to repeat the comparative design exercises undertaken in Section 7.3 within a real ship design programme. The introduction of project pressures in the form of politics, financial and resource restrictions, enforced deadlines, technical practicalities and other influences that cannot be replicated in an academic environment should identify whether the differences between numerical synthesis and the integrated architectural based synthesis proposed in Part two are significant. Ideally the comparative design would be undertaken by two naval architects producing rival designs using the same basic information, contributing to the design project equally. From this the compatibility of Building Block design procedures with a design programme should become known. Project pressures are likely to prevent this from occurring.

9.4.2 Design Research Methods

Development of Alternative Design Types

While the Building Block Design methodology has been demonstrated for the most common forms of the Monohull and Unconventional ship designs, the examples described in Chapters 7 and 8 have not been exhaustive in both ship role and vessel type. It would be sensible for future research to expand the knowledge of the suitability of the Building Block design methodology in the following areas:-

- Aircraft Carrier Designs.
- Merchant designs.
- Air Cushion Vehicles.
- Dynamic Lift Vehicles.
- Hybrids of Air Cushion, Dynamic Lift and Buoyancy supported Vehicles.

It is anticipated that, with modifications, the Building Block methodology should be able to deal with the different requirements of these design types. In particular the profit based commercial design requirements should allow a thorough analysis of the effect of different design forms on design economics. Notable merchant designs that would benefit from Building Block methods include the configuration driven ferries and cruise liners. For these ships the conflicting needs of ship operability and passenger facilities define the form of the vessel [*Levander, 1991*]. Following the author's direct involvement in Building Block methodology research, research has been undertaken at UCL and NTNU Trondheim, by Thor Einar Kolstadlokken, demonstrating the application of the Building Block methodology to Cruise Liners of both conventional and radical [SWATH] form. The author acted as a consultant. A summary is presented in Appendix G with the author's permission.

Air Cushion Vehicles, Dynamic Lift Vehicles and Hybrids pose a different design problem. These design types share some features with more conventional ship designs, due to a need to balance weight, space, system requirements and performance within a constrained design space. However the forms of lift provided in this case are heavily dependent on the introduction of accurate analysis data at the earliest stages of the design process and as a result it is considered that the Building Block methodology may alter in form. This should be investigated.

Warship Architecture, Configuration And Topside Design Methods

The satisfactory development of detailed Topside designs within a Building Block design exercise relies on the provision of design methods currently in preparation by Bayliss [*Andrews & Bayliss, 1998*]. As a result few other developments in this areas can be demanded at this stage. However it is likely to be necessary to continually revise and assess the Building Block design methodology as the nature of warship design changes with time and technology. This is most likely to affect the type of systems represented as Building Blocks and their demands on architectural configuration and operational requirements. This may alter the form of the design generator for vessel types. An approach which may be of interest is to introduce more architectural design practices, such as the spatial analysis techniques of Hillier [*Hillier & Penn, 1994*] within the Building Block methodology.

9.4.3 Other Future Research Topics

The Building Block Design methodology may be considered for future adaptation for other large made to order design artefacts [as recommended by *Andrews, 1998*] in which many conflicting design issues are manifest, and a design generator that can be considered to be configuration driven. Examples of areas in which Building Block design techniques may prove useful and should be investigated include offshore production systems, architectural development of offices, town planning, facilities planning and factory design.

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APPENDICES

Appendix Tables

Appendix Figures

Appendix A. SURFCON Technical Overview

Appendix A presents extracts from a proposal [*Dicks, 1998*], by the author to the Ministry of Defence, for a Computer Aided Preliminary Ship Design system with the Building Block design methodology for surface ships at its core. Contained within are specifications for the components of a computer aided design system provisionally known as SURFCON. Intellectual property rights are claimed by the Ministry of Defence Procurement Executive and the permission to publish is acknowledged. The discussion presented here is edited to avoid repetition from the main text.

Appendix A.1 User Requirements

This section details user requirements for the proposed "SURFCON" system, applying the proposed Building Block methodology to computer aided preliminary ship design. The user requirements have been subdivided into technical requirements[a], computational requirements[b] and other requirements, centring mainly on procedural issues.

Technical Requirements

The scope proposed for SURFCON includes ships varying in both type [monohull, SWATH, Trimaran etc.] and role [minesweeper, frigate, aircraft carrier etc.]. This wide range of ship types requires the development of new analysis tools, or modification of existing tools. It may be appropriate for some of these not to be provided initially but to follow the commissioning of a more limited system.

Fundamental to SURFCON is the use of a graphically based CAD system. Using this, Building Blocks are both placed and moved as the design develops. The CAD system must also support the representation of a 3D hull form. Numerical synthesis issues need to be addressed by the provision of balancing routines

SURFCON must provide an interactive design environment in which the designer can make decisions and quickly view results. Naval architectural analysis tools [for stability, powering etc.] should be configured to allow rapid feedback of design performance. Furthermore, these analysis tools should reflect the detail included in the design. For example, if little design definition is available then a design's stability may be sufficiently assessed by a simple calculation of Metacentric height. As the level of definition

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[a] Those relating to Naval Architecture and ship design.

[b] Those relating to the computer based implementation of a Building Block methodology.

increases intact GZ curves and wind heeling analysis may become possible and more appropriate with progression to a full damaged stability analysis when the design is well defined. Analysis tools should use relevant aspects of the ship geometry and design description to perform calculations with minimal designer interaction, allowing standard calculations to be undertaken quickly.

Consideration should be given to the relationship between SURFCON and the GODDESS design system [*Yuille, 1978, Pattison et. al., 1982, Barratt et. al., 1994*]. Analytical tools provided by GODDESS may find use within the SURFCON suite. The portability of the SURFCON design description to GODDESS analytical routines should be explored.

Some of the design data included in a Building Block will be ship system specific, however much will be based on estimates drawn from previous designs, either as fixed or parametric data. This will require information to be codified within SURFCON in a form similar to that currently supplied by CONDES [*Hyde & Andrews, 1992*], with selective regression from similar designs. This data needs to be presented in a form allowing Building Block data to be defined, given the freeform nature of the functional hierarchy detailed in Chapter 5[c]. As the SURFCON system enters regular use, it is likely that previous Building Block designs will be used for information or modification. Facilities are required to allow design information from previous Building Block designs to be added to new designs. It is also desirable to automatically document design history to allow the complex evolutionary path of design descriptions to be retained for future reference. This could be undertaken in a similar manner to features provided in SUBCON [*Andrews et al., 1996*].

A method is required to rapidly convert hull design intentions into a CAD model of a faired hullform. Modification of existing hulls should also be possible.

The major design stage of SURFCON should be a combined synthesis and analysis phase reliant on analytical and graphical representations of design features. The naval architect requires a range of flexible design tools allowing the configuration of design features and resulting design performance to be assessed. Whilst a layout tool will be required initially, eventually performance assessment may be highly diverse, including aspects such as signature modelling or ship motion simulation. Furthermore, such analyses should present results rapidly to allow subsequent design manipulation to respond to performance deficiencies.

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[c] Often in UCL research several NES weight group regressions algorithms describing related functions are combined to form the requirements for a Building Block.

The designer will require access to the design definition and design independent data to set up and modify data, this should be provided visually using standard interface conventions. An analytical tool command language will be required, similar to that provided by the PRESTB/STABIL/STCRIT components of GODDESS [*Yuille, 1978, Pattison et. al., 1982, Barratt et. al., 1994*]. The ability to perform single analytical calculations interactively is also required. Finally the system must be capable of being operated by naval architects and must adhere to naval architectural conventions for drawings, units of measurement, use of descriptive terms and visual representation.

Computational Requirements

The major computational requirement is to remove all repetitive housekeeping tasks from the designer. This allows design time to be spent investigating problems, producing tentative solutions instead of housekeeping. The system should not perform design without recourse to the designer, thus optimisation and other automated design methods are not appropriate.

The nature of the methodology is to integrate configuration issues at the earliest opportunities, using graphical computer aided design techniques to facilitate the placement and movement of Building Blocks within a ship hull description. A suitable method for achieving a clear representation is by use of 'solid' Building Block and 'surface' based hullform models. These should be displayed and manipulated in three dimensions. The system should allow CAD system editing functions to be performed, to introduce, modify and delete design elements. Particularly important is an ability to manipulate, both mathematically and visually, a surface description representing the fair hullform. All graphical design functions should occur through the CAD system with automated updating of other affected systems as necessary.

The underlying design data, that is represented visually by the CAD system, is to be stored in a separate data storage system[d]. This should be capable of being inspected, and the data maintained, by a computer literate naval architect. Data transfer between this system and the graphical CAD system should occur automatically and seamlessly. It is impractical to use the Building Block design methodology unless the design processes are sufficiently interactive to allow a designer to react to changes in design suitability. Computer hardware should be fast enough to allow changes and analytical assessments to be carried out in real time. This requires both fast graphical and computational capabilities.

[d] This is likely to be based on a commercial database management system.

Display systems should be capable of viewing three dimensional design models in many colours with rapid changes of design view.

It is likely that the SURFCON system will require frequent updates. It is essential that the system is developed with this in mind. Analysis routines should be written to communicate with a central analysis system component providing links to all separately developed analysis code. The task of the SURFCON central analysis system is to convert the design description to the data required by each analysis code. This will allow simple integration of new analysis tools. Similarly the provision of a well-documented 'macro' programming language should allow small modifications to system operations to be developed by a ship designer.

Commercial software code is often more widely tested and more reliable than bespoke code. Hence, where practical, commercially available code should be used or minimum change modifications made. This code will generally be readily applicable to the development of the CAD engine and the data management system. Similarly underlying operating systems, system devices and hardware should be of a mass market nature. Specific hardware development is to be avoided.

It is essential that the final design description is communicable to other interested parties in clear and flexible ways. Therefore system devices such as monitors and printer/plotters should produce visual and 'hard' copies of design data. Such output should conform to traditional naval architecture customs where practical.

Other Requirements

The remaining requirements placed on the SURFCON system are related to its use within a Ministry of Defence ship procurement project. The nature of concept ship design is such that several alternate design studies will be undertaken to various levels of detail for each design requirement. This requires separation of elements of the design, the design database, and the design system and analysis results. GODDESS achieves this by using a specific 'Project' database for each study. A similar system is recommended.

Much of the data involved will have a security classification and normal classified data management techniques need to be implemented. It may be necessary to use the system outside secure environments and facilities should be provided to modify internal design databases, analysis tools and other potentially classified computer based elements to remove the classified aspects.

The procurement of the SURFCON system is to be implemented in a phased manner allowing an initial operational 'core' capability to be achieved quickly. Additional functionality is to be introduced once the core is stable and reliable.

Appendix A.2 Scope of Application

Application of the System in the Procurement Process

This section places the proposed SURFCON system within the wider procurement process of the Ministry of Defence's ship design programmes. The SURFCON system is intended for application in design stages in which the features, implications and risk of a proposed ship design are under investigation. The system is considered to be useful at all design stages in which the major features and characteristics of the design are under discussion and liable to change. It will be useful for Concept Studies, Concept Design and early Feasibility studies [as defined in Chapter 3]. The typical tasks of the system will be as follows:-

- Prepare several different conceptual level designs to meet a broad outline operational requirement.
- Perform divergent and convergent design studies into alternative ship styles to meet a requirement.
- Analyse and compare alternate design concepts for suitability [including tender evaluation].
- Explore the ability of a ship design to mount a specified combat or propulsion system.
- Examine the ability to modify an existing design to a new requirement.
- Examine minimum cost designs to meet a requirement.
- Detail risk inherent in a specific ship requirement.

The system is considered to be less useful during detailed design, after gross characteristics and features have been defined. Thus the system is not intended for use during design definition, design for production, through life support or disposal. The provision of design support for batch re-designs is considered part of preliminary design.

Applicability to Different Ship Types

The SURFCON system is to be solely concerned with the development of surface ships. Submarines are sufficiently well defined using the existing SUBCON tool [*Andrews, et. al., 1996*] and there is not a requirement to provide one multi purpose design system, given the distinctly different nature of surface ship and submarine design. However SURFCON may develop from SUBCON given the similar underlying methodology.

Modern concept design studies require comparative design between monohull and unconventional hullforms. Furthermore, these must be developed sufficiently to reveal any possible advantages or disadvantages of implementing a radical design concept. As a result a minimum requirement of SURFCON is to model monohull, Trimaran and SWATH design methods to an appropriate level of definition and assessment. Trimaran capability is required for the Future Surface Combatant programme. SWATH capability is required given that British SWATH design experience is growing[e]. Knowledge and understanding of each of these design types is sufficiently mature to allow inclusion as a permanent feature of the system. Catamarans, Hydrofoils and SES, while developed for commercial applications, are less likely to be valid solutions for naval requirements. Design data and methods for such craft should be capable of later addition to the system. Future procurement programs may require the investigation of more unusual design types. The system should therefore be open and flexible allowing for dynamic lift as well as buoyancy support [e.g. HYSWAS and other hybrids].

For monohulls, SURFCON should eventually replace CONDES. For other ship types, it should remove the need for ad hoc synthesis tools produced on an individual basis, where possible.

Ship Roles

Given both the paucity and diversity of new naval ship requirements, it is unacceptable to procure a ship design system that is capable of meeting the requirements of only one specific ship role. SURFCON must be sufficiently open and flexible to allow the design of all naval ships, from the smallest mine countermeasure and offshore patrol vessels through escorts, to aircraft carriers and amphibious warfare vessels providing acceptable design data is provided by the designer. Such a diversity of operational requirements imposes many different design issues on the designer. These must be managed in a seamless design environment. Different roles will have different design generators [see Chapter 6], which will require appropriate approaches to be developed. The design requirement to be developed most frequently is the escort which should have significant influence on the facilities provided.

Appendix A.3 System Overview

This section introduces the capabilities proposed for SURFCON. It details major system components, scope, methods of operation and interactions.

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[e] RMAS Cawsand and Bovisand are two SWATH vessels used as passenger transport craft by the Ministry of Defence in Devonport, Plymouth.

Major System Components

The SURFCON system is required to provide the following major capabilities [the following list of components makes reference to these capabilities by number]:-

1. Create and manipulate graphical representations of a ship design at the concept design stage.
2. Provision and modification of hullform descriptions.
3. Integrated design and analysis of major features.
4. Short and long term storage of design specific and design independent data.
5. Analysis of overall design performance and design balance.
6. Overall project data management.
7. Data output.

The following separate software components are required. Development names have been assigned to avoid confusion.

- **MODELLER** :- An integrated two and three dimensional surface and solid modelling system [1,3,7].
- **TOPINT**:- Integrated Topside Design and Analysis Tool[f] [3].
- **SURFHULL**:- A Rapid Hullform Generation Method [2].
- **SURFDATA**:- A Relational Database Management System [or other method of data storage] [4] with modular data storage.
- **SURFBAL**:- An Automated Design Balance Assessment Tool [5].
- **MODELANALYSIS**:- A Model to Analysis conversion management and interface program and a suite of analysis tools **[SURFANALYSIS]** [5].
- **SURFPROJ**:- An integrated master control program and project data management system [6].
- **SURFOFFICE**:- Standard desktop publishing and office support software suite [7] including **SURFWORKBOOK.**
- **SURFINT**:- Interface programs to Simulation Based Design tools [4,5,3].
- **SURFOS**:- Operating System and system management tool.
- **SURFPLOT**:- Naval Architecture Output Program [7][g].

The following hardware components would also be required:-

- System Processing unit.
- Large [20 inch or greater] colour monitor.
- High speed, high resolution, 16 bit [or higher] colour graphics controller.
- Three dimension control system [trackball, dials or software control].
- A3 [or greater] colour and A0 general arrangement plotting capability.
- Monochrome line printer.
- Rapid system backup capabilities.

A detailed hardware specification is not proposed, to allow hardware improvements occurring during the SURFCON procurement process to be exploited. The nature of the SURFOS operating system will depend upon corporate policy at the time of system specification.

A degree of flexibility between functions contained within the components is necessary, at this stage, to allow a sensible range of options to be considered during

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[f] TOPINT may utilise MODELLER for graphical capabilities.

[g] SURFPLOT may become redundant, dependant on the capabilities of MODELLER.

Group Name	System Components
Design Synthesis Tools and Graphical Systems	MODELLER, SURFINT, SURFHULL, TOPINT [see footnote f]
Data Storage Facilities	SURFDATA, SURFPROJ
Balance & Analysis Tools	SURFBAL, MODELANALYSIS, ANALYSISSUITE
Reporting Facilities	SURFPLOT [see footnote g], SURFOFFICE [SURFWORKBOOK]

Table A-1 SURFCON System Areas

SURFCON development. Thus the need for a separate plotting program [SURFPLOT] will depend on the particular capabilities of the solid modelling tool chosen.

Methods of Operation

The designer will enter the SURFCON system through SURFPROJ. This will assess access privileges and either open an existing design or create a new one and its associated data storage structures. Following this selection SURFPROJ will open MODELLER. The majority of design development is to be undertaken within MODELLER. Other components will be opened, operated and closed from within MODELLER. Standard housekeeping operations will occur automatically once preferences have been set, for example automatically archiving the design database at regular intervals.

All design and analysis activities are undertaken from MODELLER. For example generating a new hull with SURFHULL would be initiated from a command within MODELLER. When the external process is complete, the external program would be closed and data transferred back into MODELLER. Thus the graphical representation of the design is the focus of all activity.

SURFPROJ needs to provide the ability to call other system components to support design operations, these include:-

- Design Independent Data modification.
- Analysis Macro Program specification.
- Design Output preparation.

Such tasks will be performed by calling the relevant procedure from within SURFPROJ by the selection of a menu item or icon. The majority of design tasks will be object orientated and undertaken from within MODELLER. The first stage in each design task will be the selection of a Building Block to modify, followed by a view of that building block's current attributes, the modification will follow. Thus a single operating style will be provided for many different operations.

For design elements such as the Master Building Block, special representations are required to allow this 'invisible' element to be selected. To assess overall performance, the designer would select the Master Building Block and would be presented with the current

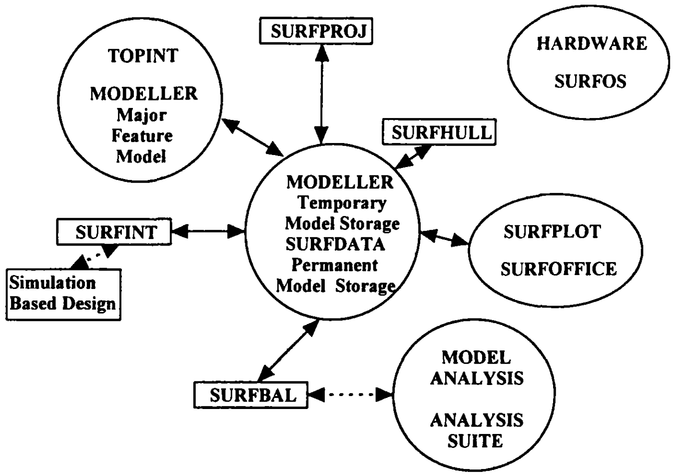

Figure A-1 SURFCON System Interactions

attributes and a menu system detailing possible operations. The majority of design tasks will be undertaken with a mouse using standard procedures such as point, select entity, view data graphically or numerically on the display, enter modifications and accept operation.

Interaction Between Components

SURFCON by its nature is defined by the relationships between system components. The overall relationship between system components is shown in Figure A-1.

From this the central relationship between SURFDATA and MODELLER with which all subsidiary systems interact can be seen.

This section contains a series of flow charts illustrating the components of SURFCON used for various design tasks and the interaction between these components. The following tasks are considered:-

(i)	Creating a project	[Figure A-2]
(ii)	Saving a project	[Figure A-3]
(iii)	Opening a project	[Figure A-4]
(iv)	Creating a Building Block hierarchy	[Figure A-5]
(v)	Preparing functional data	[Figure A-6]
(vi)	Preparation of major feature design definition	[Figure A-7]
(vii)	Generation of a new hull	[Figure A-8]
(viii)	Placing a Building Block	[Figure A-9]
(ix)	Balancing a design	[Figure A-10]

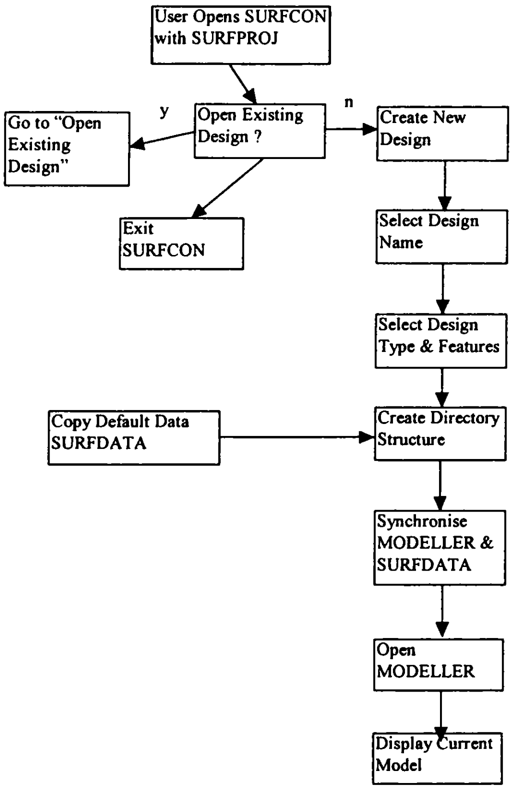

Figure A-2 Creating a Project

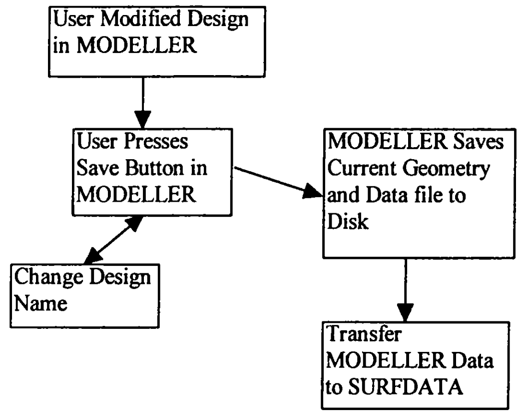

Figure A-3 Saving a Project

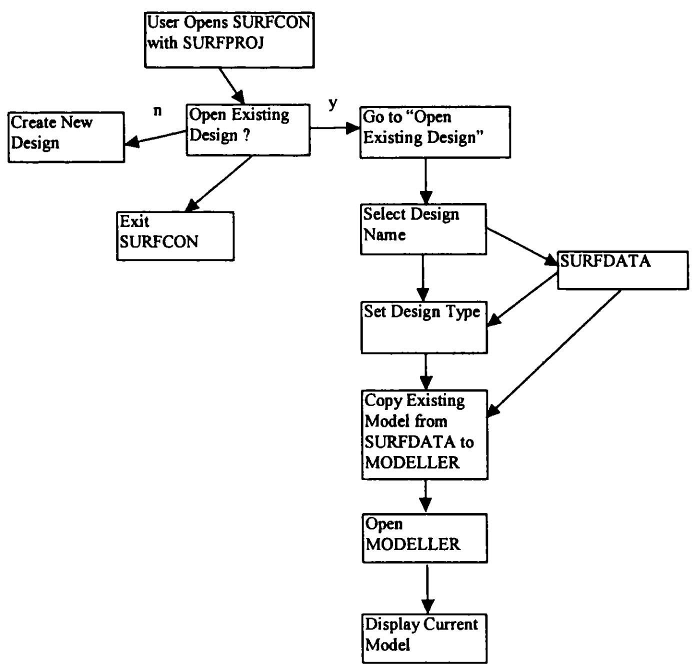

Figure A-4 Opening a Project

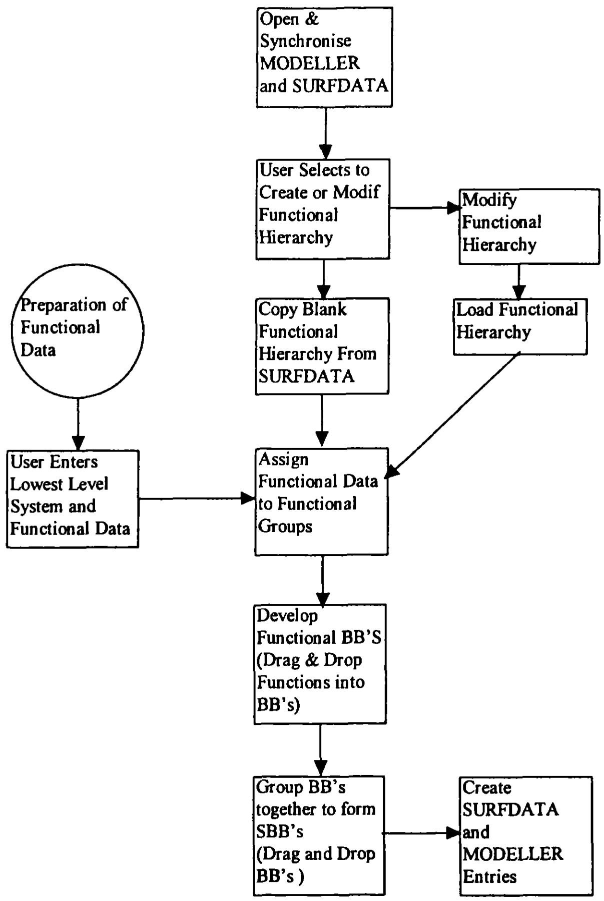

Figure A-5 Creating a Building Block Hierarchy

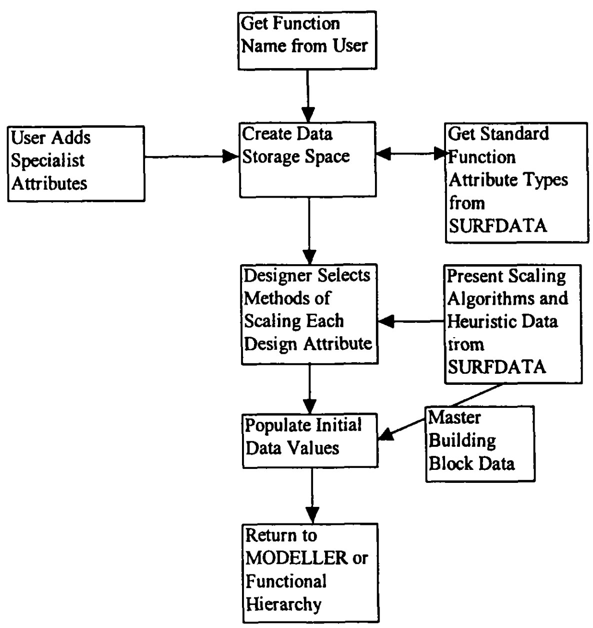

Figure A-6 Preparing Functional Data

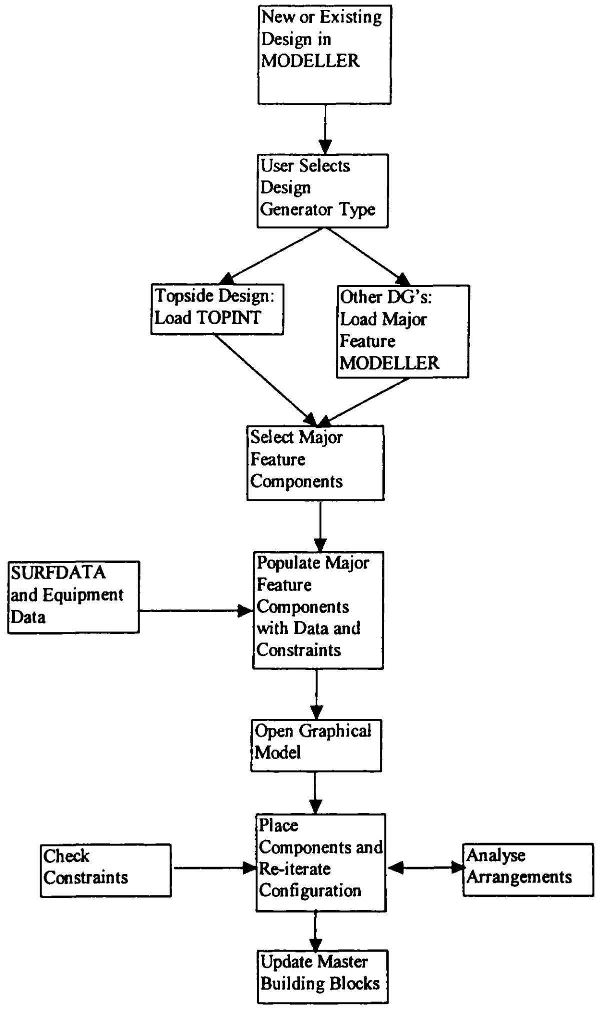

Figure A-7 Preparation of Major Feature Design Definition

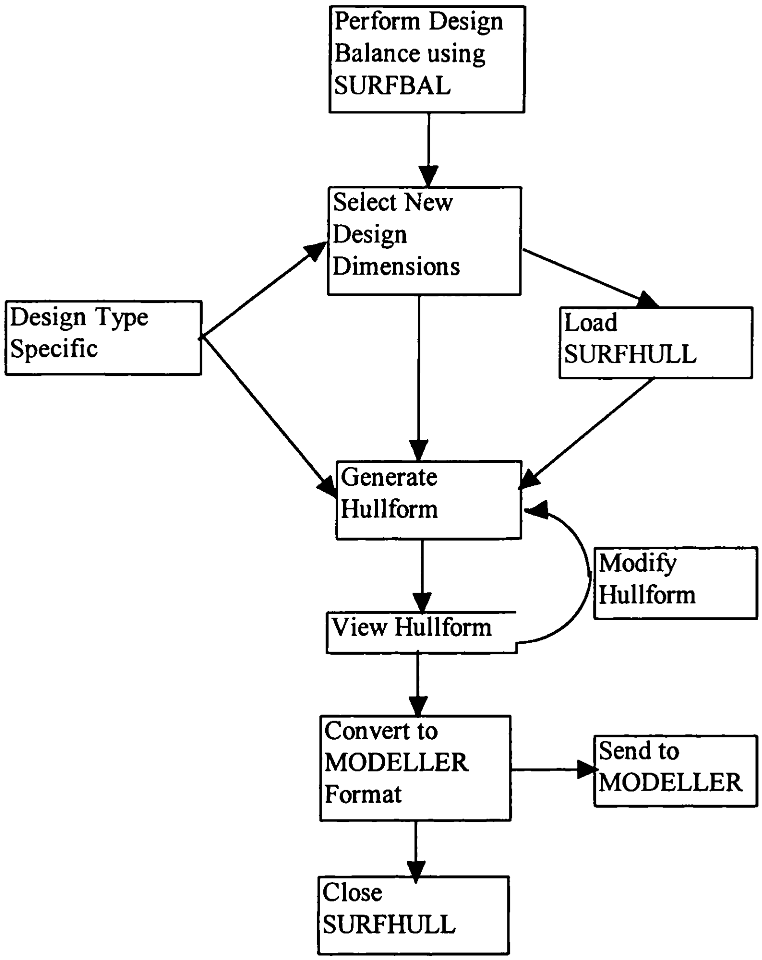

Figure A-8 Generation of a New Hull

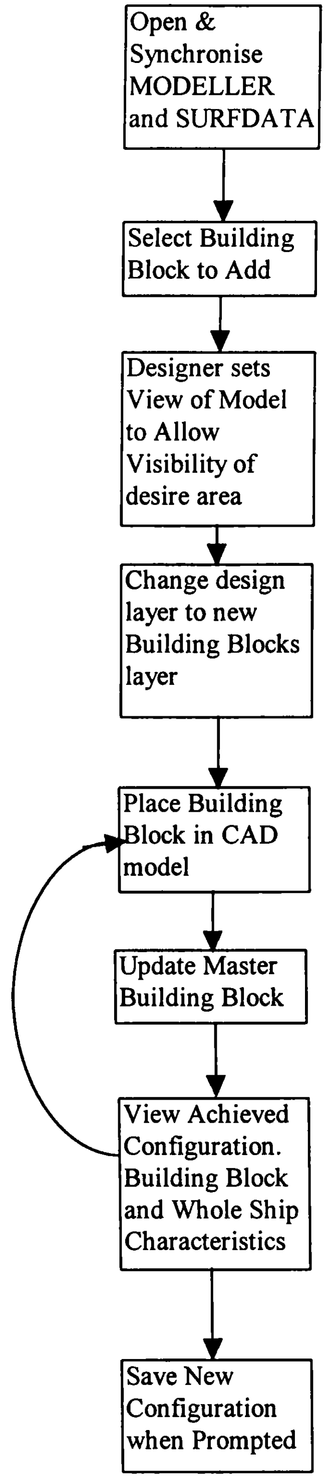

Figure A-9 Placing a Building Block

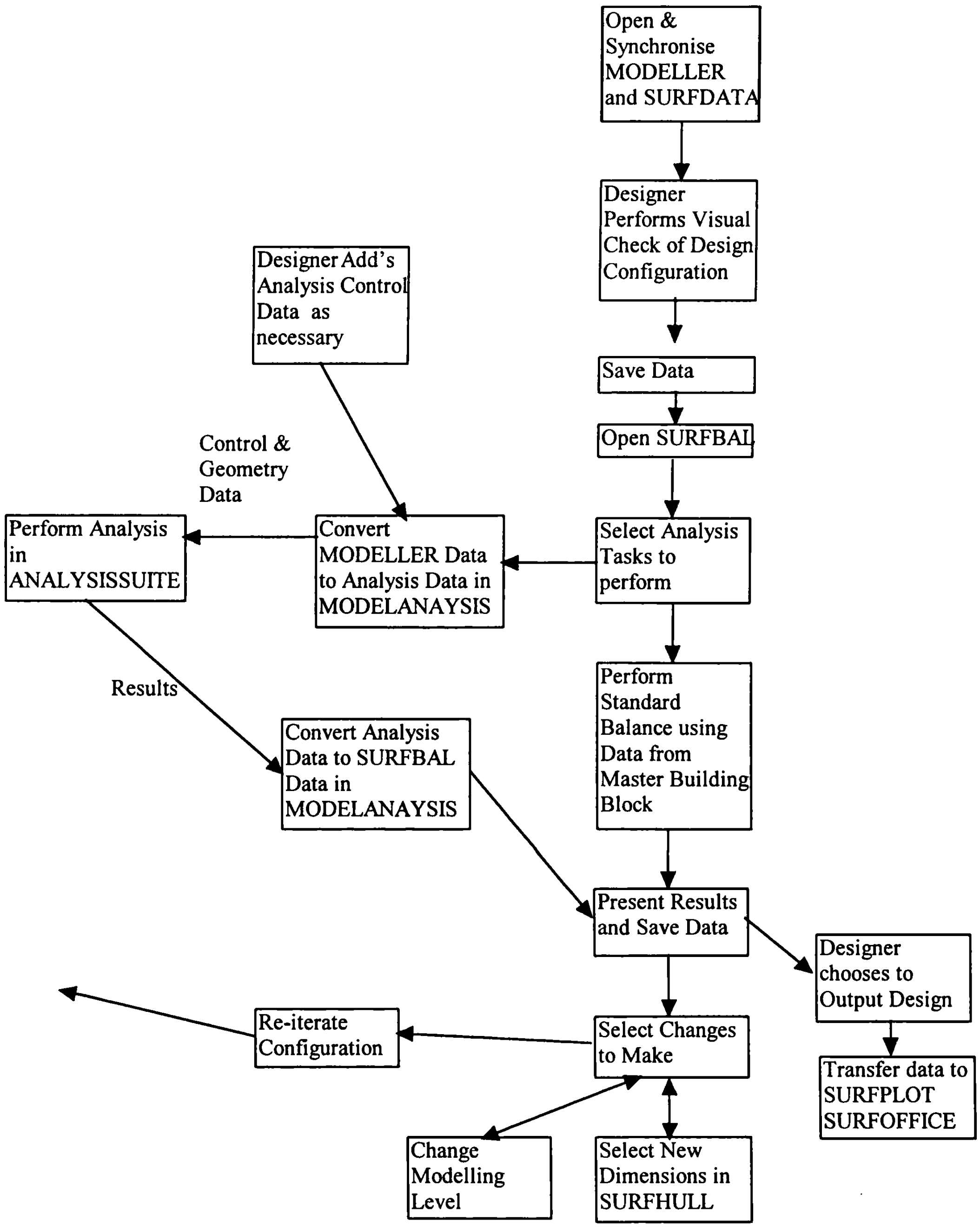

Figure A-10 Balancing a Design

Appendix A.3.1 Application to Different Ship Types

SURFCON is to include the capability to develop SWATH and Trimaran designs. Consequently it is necessary to provide design and analysis facilities for each. Three types of procedure are anticipated:-

- Procedures that apply equally to all three ship types.

- Procedures that apply to monohulls, that can also be applied with extensions to SWATH and / or Trimaran designs.
- Capabilities that need to be duplicated separately for each ship type with major differences in content, providing similar output.

SURFCON must change the range of design and analysis tools to fit the design. For example three powering analysis tools will be required. Each would be called automatically depending on ship type and would provide results in appropriate formats. Examples of each type of procedure can be considered as follows:-

Category	Example Procedure
Type Independent Procedures	Building Block Manipulation Tools [MODELLER] Building Block Scaling Algorithms [majority of] Combat System & Marine Engineering Data Major Feature Design and Analysis Project Initiation [SURFPLOT] Interfaces to Simulation Based Design [SURFINT]
Procedures that can be applied with extensions	Hullform Definition [SURFHULL] Data Presentation [SURFPLOT] Master Building Block [in SURFDATA] Stability Assessment Costing Forecasts Balance Assessment
Type Dependant Procedures	Powering Analysis [including manoeuvring if required] Structural Weight Algorithms Seakeeping Analysis

Table A-2 Examples of Procedures and their Application to Different Ship Types

Appendix A.4 Design Synthesis Tools and Graphical Systems

Ship and Building Block Modelling Tools

MODELLER is the major CAD component of the SURFCON system and is also the main interface between the designer and the underlying data. MODELLER requires links to, and methods of calling, many other system components. It is proposed that MODELLER is based on a modification of an existing commercially available CAD system. The modelling features required are:-

- Three dimensional parametric solid modelling using constructive solid geometry.
- Three dimensional surface modelling using NURBS or other surface generation techniques.
- Two dimensional drawing techniques [or a separate SURFPLOT tool].

Parametric solid modelling is used to develop the geometry of the Building Blocks. Parametric solid modelling provides a method of adapting and modifying the geometry of the solid Building Block representations using dimensions, algorithms and editing techniques. The ability to assess the physical characteristics of the geometry is important for weight distribution estimation. Surface modelling is required to take the hullform definition developed in SURFHULL and convert it to an entity that can be used to trim Building Blocks to size.

MODELLER should be capable of displaying a number of windows, each should be re-sizeable and able to view any portion of the design from any viewpoint in three dimensions. A choice between viewing the design as a wire frame image or as a solid rendered image, in real time, should be available.

MODELLER should interface with SURFDATA to allow the introduction of a complete functional hierarchy from SURFDATA. This will contain all design elements and Building Block representations at the start of each design session. The updated data should be returned to SURFDATA at the end of each design session. Each Building Block representation should be stored as both geometric and alphanumeric data. All Building Blocks and Super Building Blocks will be subject to the following operations:-

Data Management Procedures

- Open and transfer SURFDATA model into MODELLER.
- Edit functional data in individual Building Blocks.
- Change space and system scaling method.
- Modify functional hierarchy.
- Change Super Building Block and Building Block components.
- Edit Master Building Block contents.
- Update SURFDATA model with data from MODELLER.

Geometric Modelling Procedures

- Introduce and place a Building Block in the Graphical model at a specified location.
- Introduce a Hullform to the model from SURFHULL and assign to a functional Building Block.
- Introduce design aids [including decks, bulkheads] as surfaces.
- Copy a Building Block element [with a new name].
- Move a Building Block element.
- Resize a Building Block element.
- Trim or Extend a Building Block to a design aid, hull surface or other Building Block.
- Constrain two Building Block elements together.
- Trim design aids to hull.
- Delete Building Block graphical representation temporarily.
- Remove a Building Block element.
- Rotate a Building Block element.
- Divide a Building Block element into two or more components [sharing the same overall requirements].
- Update temporary design specific data storage whenever above tasks take place.

External Program Requests

It is necessary to call many different SURFCON components from within MODELLER. The following represents the calls required and the data exchanged.

External Component	Data sent to External Component	Data Received on completion
SURFHULL	New hull dimensions	Receive hullform
SURFBAL	Master Building Block data Analysis Requirements	Balance Indication Analysis Results New Design Dimensions
SURFPLOT	Geometric model	None
TOPINT or Major Feature MODELLER	Major feature system data	Minimum design dimensions
SURFINT	Major feature system data Building Block data	Minimum Building Block dimensions
SURFOFFICE	Geometric and Alphanumeric Data	None

Table A-3 MODELLER's External Links

These external components should be accessed through MODELLER using dialogue boxes. Exceptions are the SURFHULL and TOPINT components. These, due to their graphical demands, should be called from within MODELLER, but will temporarily take control of the display as necessary.

It is necessary to provide a clear method of distinguishing between different graphical Building Block elements visible on the display. Furthermore, the geometric model will quickly become complex and the facility to only display a limited proportion of the data is desirable. Thus a display clarification technique is required, layering. Layering is the specification of separate layers in the CAD model for each Building Block. Each layer can be assigned an individual colour, texture, line type, properties and can be hidden or frozen from view at any stage independently of other layers. It is recommended that a colour convention is implemented with specific ranges of colours representing specific functional groups. It is necessary to implement sufficient different colours to distinguish between adjacent blocks of the same functional group. Between 16 and 32 colours appears suitable based on SUBCON experiences [from the author's experiences in *Dicks & Spragg, 1996*].

Major Feature Design Tools

For major feature design stages that are driven by physical configuration rather than functional issues, it is acceptable to use MODELLER to provide the CAD capabilities. As detailed in Chapters 5 and 6, the designs major features are modelled before the definition of the Building Blocks and the functional hierarchy, consequently it is proposed that the major feature design file should physically be different from the main Building Block data file. Major features are to be modelled as three dimensional solid models or surfaces. It is likely several elements will require two parameters to adequately define the size of the element and the separation required by functional issues, e.g., helicopter size and helicopter landing spot spacing. It is desirable that while both should be constrained together, they should appear on different drawing layers so that the physical or functional view [or both] can be selected for display. The following features are required to perform the Major Feature Design stage:-

- Collection of Major Feature systems, space and constraint data from MODELLER.
- Assignment of space and constraint diagrams to geometric models and assignment of constraints and layers as above.
- Placement of a representative parametric surface[s] representing the bounds under consideration, e.g. vehicle deck boundary, flight deck.
- Placement of design guides and aids on the surface on a separate layer.
- Placement of major feature geometric models on surfaces.
- Identification [visual or automatic] of violated design constraints.
- Modification of all design elements in the following forms.
    - Copy, Move, Mirror, Rotate, Resize.
- Export chosen dimensions back to Master Building Block in MODELLER Building Block model.
- Export Design Geometry as a locked layer back to MODELLER for design guidance.

SURFINT is a capability that depends on the maturity of simulation based design methods. Assuming that a simulation capability is considered desirable, SURFINT would form the interface between a separate simulation based design engine and the SURFCON model [stored in SURFDATA] and MODELLER.

Topside Integration Tool

The topside integration tool is intended to follow the recommendations presented in [*Bayliss, 1997, Andrews & Bayliss, 1998*]. The tool is required to allow the designer to investigate topside arrangement considering configuration, arcs of fire, EMI, signature reduction, seamanship, access, efflux and exhaust. It will require the placement of design elements, and assessment of the suitability of the proposed arrangement. The system should be capable of application to any ship type provided the weather deck geometry is provided. The tool can be decomposed as follows:-

- Receive Building Block and Systems data from SURFDATA.
- Receive or Prepare weather deck geometry.
- Add topside integration specific data to Building Block and Systems Data elements.
- Place elements on weather deck as required.
- Select analysis methods required.
- Perform and present analysis.
- Allow design changes to be made.
- Send final design arrangement back to SURFDATA.

The development of the topside integration tool is seen as a separate task to the development of SURFCON. The eventual outcome of the development work will be a system capable of incorporation into the SURFCON system. As such it is to be developed along similar lines and will utilise a similar methodology of blocks with associated data, a graphical interface, and integrated analysis programs. It is important to recognise that there will, eventually, be a eventual requirement to integrate the topside tool and associated methodologies. Although operating in similar manners, there will be different requirements for database information and analysis programs. The development of SURFCON should allow for this later integration by having an open architecture that will allow modification and integration without altering the SURFCON methodology already developed.

Hullform Generation Tools

A hull generation tool is required, both to show the space available in different locations and to provide data to support performance analysis. These tasks do not require exact representation of hull features as both the analysis tools and layout development are crude at the earliest design stages. Therefore hullforms developed within SURFCON must be representative of the correct dimensions but not necessarily fully faired forms.

Hullforms are introduced at the start of each new design stage, following a change in ship characteristics. The introduction must be completed quickly and semi-automatically in response to a request. The types of hullform to be modelled include monohulls, with and without hard chines, Trimarans, SWATH's, and wave-piercing forms. SURFHULL is to generate the hullform description, its tasks are:-

- Accept demand input information from MODELLER.
- Initiate the SURFHULL modelling features.
- Interrogate the SURFDATA component for current ship type.
- Present a Dialogue Box requesting the new hullform dimensions and style.
    - Typical Dimensions include:-
        - Deep Design Displacement.
        - Total Hull enclosed Volume.
        - Hull displacement proportions.
        - Length, Beam, Depth, Draught in deep condition for each hull.
        - Major hullform shape coefficients [C_P, C_M, C_W, C_B] for each hull.
        - Other form parameters as required, including aft cut up location Transom form, Rise of Floors, Flare etc.
        - Cross structure dimensions [for multi hulls].

From the new hullform dimensions SURFHULL generates a surface based representation of the hullform, meeting requirements and the designers stylistic intentions. Once the hullform exists, the following operations should be possible:-

- View the hullform graphically in three dimensions.
- Allow modification of the hullform parameters to alter design style indicating changes to displacement, volume and form.
- Plot and print hullform data in numerical and lines plan format following naval architectural conventions.
- Save hullform data separately from the main Building Block model storage.

- Transfer the SURFHULL description to MODELLER in a format suitable for modification in MODELLER. Assignment of the hullform description to a Building Block description is required to allow hullform characteristics to inform the HULL STRUCTURE Building Block and the Master Building block as required.
- Provide the hullform descriptions required by the analytical tools.

A second form of hull generation in the SURFCON system is to be the rapid development of outline hull dimensions at the end of a balance and analysis stage. This is a form of parametric survey in which alternate routes for the subsequent design iteration are compared and one chosen to form the dimensions of the next iteration. This is to be implemented within the SURFBAL system component. The following features are required of this component.

- Receive the results of the design balance and analysis from within SURFBAL.
- Allow designer to select a new form based on discrepancies from design balance and analysis.
- Select hull dimensions and form characteristics that are constrained by other design issues.
- Prepare alternate geometries of the same displacement, volume and stability, sharing constrained characteristics, by altering unconstrained form coefficients.
- Re-assesses displacement and volume requirements caused by the change in form [for example structural weight].
- Using simple rules predict changes in resistance and seakeeping performance for each design geometry. For example triplet based powering or natural frequency based seakeeping.
- Display a design space of alternate geometries, presented as graphs of dimensions with trends illuminated. The graphs should be prepared from any combination of the four main hull dimensions and four main hull coefficients. Each design point should have simple representations of performance displayed allowing the change of performance with hullform to be addressed.
- The designer should then select a point to investigate further as a full Building Block design iteration.
- The chosen dimensions should be returned to MODELLER and a new design iteration started.

The parametric part of SURFBAL requires geometric models to be provided for each ship type. For a monohull this may comprise the four main hull dimensions and four main hull coefficients. The Trimaran and SWATH variants should operate on the basis of the form of individual hulls rather than the whole design[h].

It is important to distinguish this procedure from traditional parametric surveys. This survey is limited to evaluating the effect of changing unconstrained hull design features, it does not consider the effect of superstructure as this is detailed in the Building Block procedures, neither does it provide a free form design space. Instead those unconstrained design features are investigated to determine suitable values.

Appendix A.5 Data Storage Facilities

Three forms of design data are permanently stored within the SURFCON system [as opposed to short term storage within MODELLER]. These relate to the overall management of individual projects, design data for specific ships, and data regarding naval ships in general. Two system components are required to manage this data, SURFPROJ and SURFDATA.

Appendix A.5.1 Project Storage Requirements

SURFPROJ is responsible for the creation of design data, managing relationships between parts of the design description and between different designs. SURFPROJ is the design system's overall top level control system, acting in a similar manner to the top level systems in GODDESS and SUBCON. It is envisaged that SURFPROJ will be initiated by an icon or command line in SURFOS. The opening functions would be:-

- Assess user identity and password.
- Assign access rights to the user based on previous definitions.
  - User access :- Solely capable of performing design tasks.
  - Database Maintainer access:- Capable of modifying design independent database entries.
  - System Maintainer :- Capable of modifying system configuration and components as required.

SURFPROJ would then allow the user level designer to:-

- Select an existing project to open.
- Create a new project.
- Choose a ship type to be developed.
- Create a new design within the current project.
- Open an exiting design in the current project.

The ship project is a container for several designs related to the same operational requirement for a new ship design. Thus several different designs can exist within one project. The ship type to be selected can be monohull, Trimaran or SWATH. Once selected for a specific design this should not be changed.

When opening an existing design, the SURFPROJ component is responsible for setting all environment variables necessary to allow the correct system components for the current ship type to be enabled. When creating new designs, SURFPROJ is responsible for creating the directory structure and standard files required for the design specific data, assigning environment variables and default settings. SURFPROJ is also responsible for the introduction and storage of overall design requirements, with targets for performance and descriptions of required design features. Besides these functions SURFPROJ should provide the "Database Maintainer" with the facilities required to enter the SURFDATA database's maintenance mode and change data entries as required. When used by the "System Maintainer", additional features are required to allow the updating of system components,

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[h] The designer will have fixed the design space available for the cross structure by the configuration of that feature.

default settings, security issues and user definitions. The final task of SURFPROJ is to provide the means to open the MODELLER system with design specific data available. This will require the initiation of a dialogue between SURFDATA and MODELLER, ensuring that long and short term data storage areas are synchronised.

Design Specific Storage Requirements

SURFDATA is the storage component for both design specific and design independent data. It is likely [but not certain] that the underlying technology of the SURFDATA component is a relational database management system. Design specific storage space is required to maintain the permanent record of the current status of the design. The permanent storage is to be linked to the temporary storage within MODELLER components. Design operations are not performed on the design specific storage but on the temporary representation.

At the start of a session SURFPROJ will initiate MODELLER and copy design specific data from SURFDATA into MODELLER. Design modifications will then be made. At the end of modelling sessions or at pre-defined intervals the revised data in temporary storage will be copied to the permanent storage area, replacing outdated data.

At the start of a new design SURFDATA should enable the preparation and storage of various levels of functional hierarchy. This requires creation of Building Block and Super Building Block data storage locations, and their population with data. The tasks can be specified as follows:-

- Specify operational requirements.
- Create Master Building Block and populate with operational requirements.
- List functions and spaces required to be developed.
- Associate each function or space with a Building Block.
- Assess methods of scaling or providing design data and apply to individual Building Blocks.
- Develop graphically a hierarchy of functional Building Blocks and Super Building Blocks, related to Functional Groups and the Master Building Block.
- Populate Super Building Blocks with Building Block derived data.

Operational requirements are used to specify performance targets for the complete design. These are added to the Master Building Block description to allow comparison with achieved performance later in the design process.

To populate Building Blocks, it is necessary to suggest which functions are required and which spaces and systems are required to fulfil that function. Each space or system places demands on the ship for space, weight and system requirements, these are specified by type [e.g. scaling algorithm, fixed data etc.]. Building Blocks will be created containing all the spaces and system requirements associated with a particular function. Super

Building Blocks should be populated using the requirements of all the associated Building Blocks.

As it is essential that the design tools use the latest design data, it is not proposed that system components will interrogate SURFDATA directly for design specific data. Instead the tools will use the updated data maintained in MODELLER.

Design Independent Storage Requirements

Design independent data must be provided and stored separately from the design specific data. Design independent data is applicable to many designs. An example would be the requirements and features of a particular weapons system, or the provision of scaling algorithms. The data consists both a numerical representation of features and a graphical representation of form.

Systems data is to be included in the database to allow commonly utilised equipment items to be added to many different designs. Such items must be capable of introduction to MODELLER and major feature modelling components of SURFCON as individual systems or as part of Building Blocks and Super Building Blocks. Typical examples include the representation of weapons, sensors and prime movers.

Design independent data must be provided to enable those Building Block's that change with ship size or other ship features, for example structure and accommodation, to be defined. In CONDES [*Hyde & Andrews, 1992*] such data resides in a database and is accessed using flexible methods of defining scaling algorithms based on selected ship designs. This data should be converted from the current weight group system to a free form Building Block definition. Sufficient scaling algorithms should be provided to allow the complete definition of a ship design in Building Block form from CONDES scaling algorithms. The current CONDES database applies to Monohulls only and Trimaran and SWATH designs often require different scaling algorithms. Algorithms for Trimarans have been postulated by the author in [*Bayliss et. al., 1996*]. If the system is to be used to develop merchant ship style naval designs then the development of appropriate algorithms will be required.

Design independent data is not to be directly referenced once used within a design. Instead the data used should be copied into the design specific data storage area and referenced by other programs from there. The design independent data storage is for reference and not for direct use. The modification of such data should only be attempted by "Database Maintainer" level operators from within SURFPROJ.

Appendix A.5.2 Macro Language Capabilities

A macro language capability is required to allow the designer to add simple functions and analytical features to the MODELLER components without resorting to external, hard coded, components. The functions of the macro language should include full arithmetic and function based programming with access to the Building Block data maintained in SURFDATA. The macro language capability may be provided inherently by the CAD system selected to fulfil the role of MODELLER or the Data management system [SURFDATA]. A typical use of the macro language could be as follows:-

MACRO:-"Calculate centre of gravity of Fuel Tanks" **Required information** [for each Fuel Building Block]:- Fuel Building Block volumes Fuel Building Block centres of gravity
Calculation:-sum[Volume * Centre of gravity] /sum [volume]
Result:- Overall Centre of Gravity of Fuel Building Blocks in three dimensions

Table A-4 A Typical Macro Language Example

The macro language should be fully documented and available for use from within the MODELLER environment.

Appendix A.6 Balance & Analysis Tools

Balance Tools

SURFBAL, the proposed design balance tool within SURFCON, should perform an assessment of the required and provided features of the design allowing the designer to progress towards a balanced design. SURFBAL should use Building Block data supplied by SURFDATA and MODELLER. The tasks of SURFBAL are as follows:-

- Interrogate the Design Specific Data Stores for relevant data and requirements.
- Interrogate Analysis Tools for performance data.
- Compare the provision of functionality with the requirements.
- Produce reports relating over and under provided functionality to guide the designer.
- Detail the next iteration's design dimensions and characteristics.

The balance is to be examined for all functional requirements that can be specified numerically. Other non numerical balance issues will be solved by the designer graphically before the involvement of the SURFBAL component. The numerical design balances will include the following in several specified ship conditions.

- Weight / Buoyancy.
- Overall Volume.
- Local volume [tank deck, superstructure etc.].
- Specific Dimensions [topside length etc.].
- Services [AC/ CW/ Electrical].

- Complement / Accommodation.
- Stability.
- Propulsion Power/ Fuel Consumption/ Endurance.
- Seakeeping.

For performance based balances the condition of the ship will be passed through the MODELANALYSIS component. This will allow an analytical estimate of the performance of the model to be compared with the operational requirements specified in SURFPROJ.

SURFBAL will require the balancing routines to consider the differences in displacement distribution, volume distribution, dimensions and analytical assessment of performance for SWATH and Trimaran designs.

Use of Analysis Tools within SURFCON

To minimise software development, existing, validated code should be used where possible. To facilitate this SURFCON will require a linking program [MODELANALYSIS]. This should contain sufficient information regarding pre-written analysis code to allow input files for such code to be written automatically using data from SURFDATA and user analytical requirements [specified in SURFPROJ or interactively]. It is thus likely that MODELANALYSIS will be updated regularly. Analysis should be conducted in the following manner:-

- SURFBAL would attempt a design balance in which the analysis requirement would be stated and request MODELANALYSIS to perform data conversion and control file generation.
- MODELANALYSIS recognises the need for a piece of analysis to be performed and translates relevant SURFDATA descriptions into an input format suitable for the standalone analysis code. MODELANALYSIS requests/prompts the designer to provide additional data as required.
- A control file suitable for controlling the analytical routines employed will be generated as necessary. Where analytical tools require combined control and geometry files such a combined input will be provided.
- The analysis code would be applied to the data and results passed back to MODELANALYSIS which prepares graphical or numerical data in a format suitable for SURFBAL.
- The designer would examine the resulting data in SURFBAL and decide upon the direction of a new design iteration, or halt development.

From this it can be seen that MODELANALYSIS must be capable of translating SURFDATA data into all formats required by the analytical tools.

Naval Architecture Analysis Tools

In this section the desired analytical capabilities of the SURFCON system are detailed. Unless otherwise stated identical capabilities are required for all three ship design types within the initial scope of the system.

GODDESS [*Yuille, 1978, Pattison et. al., 1982, Barratt et. al., 1994*], contains much of the functionality described in this section and the practicality of exporting GODDESS programs or portions of GODDESS code within, or in association with SURFCON should be investigated.

Stability

One of the most utilised analytical tools is likely to be the stability and hydrostatic analysis tool. Experience with GODDESS suggests that it should be feasible to introduce one tool with the requisite capabilities for all three initial ship types.

In non configuration based conceptual design systems only a solid metacentric height assessment is undertaken. With the increase in ship design definition inherent in the SURFCON system it is possible to model both intact and damaged stability [curves at an early stage, if required. This should allow a more comprehensive assessment of stability for unconventional and multi hull designs. The stability program should allow investigation of NES 109 criteria [*NES 109, 1990*] and associated extensions for novel ship types in intact and damaged conditions.

Seakeeping

Seakeeping is introduced for two specific design cases, firstly an approximate analysis to assure that there is unlikely to be a problem with seakeeping, for non seakeeping driven designs. For designs with specific operability requirements, for example for loading operations at sea, or for helicopter operations, it is desirable to provide detailed analysis before final design dimensions are selected.

The assumptions inherent in seakeeping require separate programs to be introduced for the three ship types. Each program should utilise state of the art prediction techniques for the generation of Response Amplitude Operators and operability data. This should be compared with predefined criteria as defined by the designer. Again input files should be accepted by the system directly from the MODELANALYSIS component.

For monohulls it is anticipated that a strip theory program will be used. For Trimarans a suitably modified monohull seakeeping prediction program will be required. In all cases output should be returned to the SURFBAL component, to allow the comparison of operability criteria. It is likely that the complexity of full seakeeping analysis will not be necessary for many designs. Instead simple assessments of natural frequencies should be provided by the macro language.

Powering & Resistance

Unlike seakeeping, powering and resistance analysis does not require complex theoretical models. The difficulty is the provision of a broad range of alternate methods of predicting resistance, given the range of ship types that can be developed. Powering and resistance programs should operate as follows:-

- Receive design data and control files from MODELANALYSIS.
- Select analytical routines specified in control file.
- Check analytical routine and design data are compatible.
- Perform powering & resistance estimate at specified speeds.
- Estimate limited propeller characteristics.
- Estimate fuel consumption at specified speeds.
- Estimate endurance at specified speeds.

At least the following resistance prediction methods should be provided:-

- Taylor Gertler [monohull escorts].
- Triplet [all monohull ship types].
- SWATH Methods.
- DRA Trimaran Prediction Tools.
- Holtrop & Menon [monohull].

Powering estimates should be backed by estimates of the diameter, weight and open water efficiency of propellers. The resulting weight should be added to the correct Building Block replacing previous estimates. From the relevant Prime Mover Building Block, the specific fuel consumption of the prime movers at all speed ranges should be available. This can be used, in conjunction with powering data, to predict endurance at different speeds. Many of the required routines currently exist within GODDESS.

Structural Analysis

The assessment of structural weight requirements should be provided by several methods. The most commonly used will be a regression analysis of data contained within SURFDATA. For certain designs it may prove necessary to reassess weight following a first attempt at structural design. In this case for monohulls and Trimarans, it may be appropriate to either use and approximate expression for bending moment or balance the ship on a wave as detailed in [*Chambers, 1993*]. From the estimate of required section modulus and the known geometry methods similar to those employed by Chambers can be applied to develop estimates of equivalent thickness' etc. For SWATH's a method based on transverse loading should be provided. The functions of the structural design program would be as follows:-

- Receive design geometry and control file from MODELANALYSIS.
- Perform wave balance and estimate maximum bending moments and shear forces.
- Request designer to select critical sections
- Estimate section modulus required for critical sections.
- Allow interactive selection of equivalent thickness for plates.

Other Tools

It is possible that a demand for manoeuvring tools may be evident for specific ship design requirements and these would have to be incorporated into the suite of tools.

Functional costing procedures [see *Dicks, 1997*] should be considered for implementation, dependant on the current policy for cost evaluation by design teams. If included, such a requirement requires in depth investigation of methods, and provision of a suitable cost estimation database.

Appendix A.7 Reporting Facilities

Data Documentation Facilities

Within, or external to SURFDATA a method of reporting the contents of the various design databases is required. The method should be capable of being called from within the MODELLER and SURFDATA components and should list the different data storage areas available for documentation. The designer should select one of these and be offered a list of individual design data elements to document. Once selected the data should be output either to the display or to a printer.

Report Generation Facilities

SURFOFFICE is the name given to the introduction of a standard commercial word processor and spreadsheet onto the SURFCON platform, this is to allow the system to develop reports on demand. Both elements should be capable of being opened from within the SURFCON system, from an icon located in MODELLER or SURFPROJ. The capabilities of the word processor and spreadsheet elements should be as follows:-

- Full word processor capabilities.
- Full spreadsheet capabilities.
- Cut and paste of graphical data into word processor or spreadsheet.

SURFWORKBOOK is an element of SURFOFFICE in which the procedures utilised by the designer are automatically documented. At design commencement the workbook report would be generated and all subsequent design changes would be automatically entered into the system. Space would be provided for designer comments. SURFWORKBOOK could be provided in a hypertext format in which different design changes would be linked to separate pages automatically and a "browser" used to view the design history.

Drawing Output Facilities

SURFPLOT will either be an external component or an inherent feature of MODELLER. In either case the task of SURFPLOT is to convert the Building Block models open in MODELLER into a form suitable for plotting as a general arrangement diagram. This requires the provision of plotting routines to physically output the data, but also methods of converting three dimensional Building Block models into a two dimensional plan view. It is likely that two dimensional CAD tools will be required to allow the converted data to be modified.

MODELLER RENDER is anticipated as being an internal component of MODELLER with the task of outputting standard rendered views displayed on the monitor to a colour printer. Also required is the ability to save the file in standard bitmap based graphics formats for inclusion in electronic documents.

Appendix A.8 Summary

The proposed SURFCON system is to enable the junior naval architect to develop new preliminary naval surface ship designs of Monohull, SWATH and Trimaran form on a desktop computer using the Building Block design methodology. The design types to be modelled include all naval combatant types from minesweepers to aircraft carriers. In many ways the system is to be analogous to the existing SUBCON system for submarines.

The proposed SURFCON surface ship preliminary design system is to consist of a three dimensional CAD system, "MODELLER", capable of modelling ship definitions by the use of solid and surface modelling techniques and a method of storing design data on a permanent basis, "SURFDATA". MODELLER allows the designer to perform the synthesis of the preliminary design while considering configuration issues in conjunction with numerical design issues. These major systems are backed by system components providing methods of generating hullform descriptions for all major design types, analysing the design's performance and balance and noting the needs of the ship's design generator. Further system components allow the designer to manage the design, prepare engineering drawings and to document the design and design process.

Appendix B. Multi Mission Submarine Appendices

Appendix B.1 Introduction

The author's Multi Mission Submarine Design [*Andrews et. al., 1996, Dicks & Spragg, 1995*] was an important point in the evolution of the Building Block methodology for submarines prior to the development of the Building Block methodology for surface ships. Appendix B presents details of the resulting submarine design, including information regarding the three dimensional solid model used in the development of the design, using an actual concept design system. As such, this system points to the future capabilities of "SURFCON" like systems.

A submarine design requires many different design features to balance before the design is considered satisfactory. An important issue is the assessment of internal pressure hull space compared with space requirements, the comparison of buoyancy and weight, the capacity of ballast tanks and the assessment of hydrodynamic performance. Other issues include the reserve of buoyancy, trim and compensation capabilities, signatures, combat system effectiveness and the nature of the internal and external configurations. At the end of each design iteration the designer assesses the design balance and design intentions in such areas. The design is altered as necessary in a new design iteration. If the balance is suitable the design is complete or is decomposed to a greater level of detail to confirm suitability.

Design Aim

The Multi Mission Submarine design was prepared using information from the UCL submarine design course data book [*UCL, 1995*]. The aim was to investigate the use of the SUBCON system [*Andrews et. al., 1996*] with a view to informing the surface ship Building Block methodology. As a result of this designs other intention, of educating the designers in the art of submarine design, this design was prepared to a higher level of detail than the surface ship design and is considered comparable with the other designs of the UCL submarine design course that are prepared using the outline design methodology of [*Burcher & Rydill, 1994*] in the same time. The design methodology utilised was that described in Chapter 5. In the context of this thesis another aim is apparent, that of applying Building Block methodology features to a fully developed computer system as opposed to a prototype CAPSD systems 1 and 2. Although presented subsequently to the surface ship designs of this thesis, in chronology the submarine design was undertaken

Primary Role Weapons	Torpedoes Anti Ship Missiles
Primary Role Sensors	Passive / Active Bow Mounted Sonar Reelable Towed Array Sonar Flank Array Communications Equipment Data Handling / Action Information Equipment Electronic Warfare Equipment Navigation Radar
Secondary Role Weapons	Mines Tactical Anti Surface Cruise Missiles
Secondary Role Sensors	Remotely Operated Vehicles
Secondary Role Transportation	Covert Action Swimmer Delivery Vehicle

Table B-5 Submarine Payload

before all surface ship designs, focusing and modifying the surface ship design methodology.

Operational Requirement

It is necessary to justify the capability of the Building Block design methodology to design radical conceptual designs. The submarine design transforms the radical suggestions of [*Houley, 1993*] into a feasible submarine design capable of meeting the challenges of the post cold war era [*Emery, 1995*]. Houley envisaged modular submarines, capable of changing payload equipment between missions. This was achieved using a system of "Adaptable Mission Modules". Each module, as envisaged by the module designers [*Dicks & Spragg, 1996*], mounts a multi purpose weapon discharge system. The 2 m diameter tube allows a multitude of weapons and equipment items to be operated, from cruise missiles to swimmer delivery vehicles and remotely operated vehicles. Another radical feature is the assumption of the requirement to provide a form of non nuclear propulsion. In this case a Methanol Liquid Oxygen Fuel Cell system [*Adams, 1995*] is fitted for patrol operations with Diesel Electric operation during transit. The submarine is capable of transiting from home waters to the Persian Gulf and loitering for a patrol time of 30 days at 6 knots on the near silent fuel cell system.

Payload and Platform Studies

As the operational requirements show, a very capable submarine was required and initial studies were undertaken to detail the level of equipment required. It was decided that the equipment groups shown in Table B-5 were required for the operational role.

Cost and operational effectiveness studies were undertaken on the available primary sensor equipment and it was found that a very capable sensor fit was achievable.

Final Design Characteristics and Major Design Features

The final design is in many respects similar to the arrangement of nuclear attack submarines, with a single pressure hull structure. The major differences are amidships, where the adaptable mission module systems are located. Also located near amidships are the liquid oxygen and reforming elements of the fuel cell system. Methanol is located between the pressure hull and casing, utilising flexible storage bags.

Principle Dimensions

• Displacement [Submerged]	6543 t
• Displacement [Surfaced]	5800 t
• Length [Overall]	96.5 m
• Maximum Beam	11.8 m
• Deep Diving Depth	300 m

Propulsion

- 1x 12 Mw PMM Transverse Flux electric Motor, 2 x 2.36 Mw Diesel Generators, 700 Cell LAIS Battery
- 1.2 Mw Liquid Oxygen/Methanol fuelled Fuel Cell

Operational and Transit Speeds

• Maximum Submerged Speed	25 kts	[2.7 hrs]
• Maximum Submerged Speed [Air independent]	10 kts	[14 days]
• Maximum Surfaced Speed	13.5 kts	
• Transit Speed Submerged	11 kts	
• Transit Speed Snorting	7 kts	
• Transit Indiscretion Ratio	0.29	
• Endurance Speed [Air Independent]	5.5 kts	[29 days]
• Total Design Mission Time	70 days	

Payload [Changes from Table B-5]

- 4 Torpedo Tubes / 20 Rounds from Torpedoes, Anti Surface Missiles, Mines.
- 4 Adaptable Mission Modules. Each Module capable of providing :-
    - 3 Land Attack Missiles or 9 Mines or
    - 1 Swimmer Delivery Vehicle / 1 Remotely Operated Vehicle.

The final submarine design's internal configuration is demonstrated in Figure B-2.

Appendix B.2 Design of a Submarine Using a Building Block Design Methodology

The development of the Surface Ship Building Block methodology was preceded by the development of a submarine equivalent methodology. The definition of a submarine design using this methodology is detailed in this section in order to provide clues as to the overall applicability of the Building Block concept in the general field of naval design. Further definition of the design process are presented by [*Dicks & Spragg, 1995*].

For the first novel Building Block design as detailed in this section the Building Block stages were preceded by a numerical initial sizing stage in which the design style was evolved by comparison of the cost and size implications of combat and propulsion equipment and design style. This was achieved using the SUBBY program [*Schild, 1992*], based on the purely numerical initial sizing method [*Burcher & Rydill, 1994*] as described in

Chapter 3. SUBBY provides numerical definition of Submarine features in terms of dimensions, weights and volumes. However the resulting numerical balanced design was quickly deemed unsatisfactory for the specific demands of this submarine, notably with respect to the influence of the Adaptable Mission Modules on the pressure hull and thus were not utilised.

Several different locations and orientations for the Adaptive Mission Modules were investigated and these are summarised by [*Dicks & Spragg, 1995*]. The number of modules and payload items that could be fitted into the submarine were dependant upon the position of the modules within the submarine. The initial sketch of the final solution was detailed by [*Dicks & Spragg, 1995*].

Length m	7.5
Diameter m	2.1
Weight Estimate tonnes	50

Table B-6 Adaptable Mission Module Features

Weight, volume and facilities of the modules were estimated such that both operational and engineering aspects were satisfied. At this stage the modules had the dimensions shown in Table B-6.

Form Displacement tonnes	4861
Submerged Displacement tonnes	4658.6
Surfaced Displacement tonnes	3663.1
Length OA m	75.18
Length PH m	64.42
Diameter m	9.4
Cost £ million	260
Complement men	75
Reserve of Buoyancy %	0.15

Table B-7 SUBBY Baseline Design Characteristics

Once the range of design parameters regarding module and propulsion systems had been derived and the remaining payload features investigated, it was possible to create a baseline design using SUBBY from which cost and performance trade-offs could be performed. The baseline design was fitted with enhanced diesel electric propulsion. The major features of the design at this stage were as shown in Table B-7.

Options and COEIA Studies

A series of single variable trade-off designs were produced using SUBBY [*Schild, 1992*]. These allowed changes of displacement and cost with capability to be analysed. The attributes of the baseline design that were altered were :-

- Deep Diving Depth 150m - 400m
- No. of Torpedo Rounds 16- 28
- No. of Torpedo Tubes 4 - 6
- Diesel Electric Submerged Speed 4-13 knots
- AIP Submerged Speed 4-13 knots
- Diesel Electric Submerged endurance 2- 15 days
- AIP Submerged Endurance 10 - 30 days

- No. of Modules 2 - 6
- % of Module External to Pressure Hull 0 - 100%

From such trade-off studies it was found that in the design region being considered, the majority of increases in cost and displacement were proportional to increases in capability. Several evolutions of the baseline were developed varying in capability and cost. The style of design was maintained in each case, the only major change being the formulation of 5 enhanced Diesel Electric Concepts and 7 related Hybrid propulsion concepts.

Design	BASE 04	AIPBA 04	BASE 05	AIPBA 5	AIPBA 6	AIPBA 7
Deep Diving Depth [m]	300	300	300	300	300	300
No of Torps	20	20	20	20	20	20
No of Modules	4	4	6	6	4 internal	4 external
Propulsion Method	Diesel Electric	AIP / Diesel Electric	Diesel Electric	AIP / Diesel Electric	AIP / Diesel Electric	AIP / Diesel Electric
Submerged Endurance [days]	10	30	10	30	30	30
Submerged Speed [knots]	6	6	4	4	6*	6*
Cost £M	288	312	270	287	260	258

[* Reduced Battery Capacity compared with other designs.]

Table B-8 Alternative Submarine Designs [Selected]

Form Displacement tonnes	6260.9
Submerged Displacement tonnes	6000.2
Surface Displacement tonnes	4744.6
Pressure Hull Volume m³	4731.7
Length OA m	81.80
Length PH m	66.72
Diameter PH m	9.8
Diesel Electric Motor Capacity Mw	5.2
Number of Battery Cells	900
AIP Fuel Cell Size Mw	1.1
LOX & Methanol Capacity	30 days 6 knots
Length / Beam	8
Complement men	75

Table B-9 AIPBA6 Design Characteristics

Design AIPBA6 was regarded as the preferred option, due to its combination of good submerged and transit performance, high operational capability and relatively low cost. Detailed development began based upon this design specification. The details of design AIPBA6 at this stage were as shown in Table B-9.

Appendix B.2.1 Design Using SUBCON

The Submarine Building Block methodology was employed once initial numerical sizing was complete to portray the submarine as a three dimensional model. The stages of the design model were as described below. The procedures adopted using SUBCON were to take the existing AIPBA6 concept design features to form a minimal set of multi function Building Blocks, and to gradually increase the definition of the SUBCON model until all major components of the design were represented individually.

The first stage synthesised a ten block layout. These ten blocks were of the major internal SUBBY groups such as propulsion, accommodation, adaptive mission modules. The pressure hull was a rectangular block, with flat ends. Using this a first general layout scheme was achieved and many design features such as aft arrangement became more tangible. This level of detail was insufficient however to form a complete model and a twenty block model was then produced. A second stage of modelling followed this with an enhanced number of internal blocks and a domed cylindrical pressure hull.

External systems were considered part of the pressure hull structure, simplifying the model at this early stage. All Building Blocks had their volumes and weight reassessed. From this a variation in the fore end layout was proposed. Several external components such as propeller and shaft were modelled. At this stage the design consisted of 109 blocks.

The third stage of modelling was addition of external features. This included the modelling of external main ballast tanks, methanol tanks and other external design issues such as the ability to place the reelable towed array aft of the aft dome. At this stage the design consisted of 140 blocks.

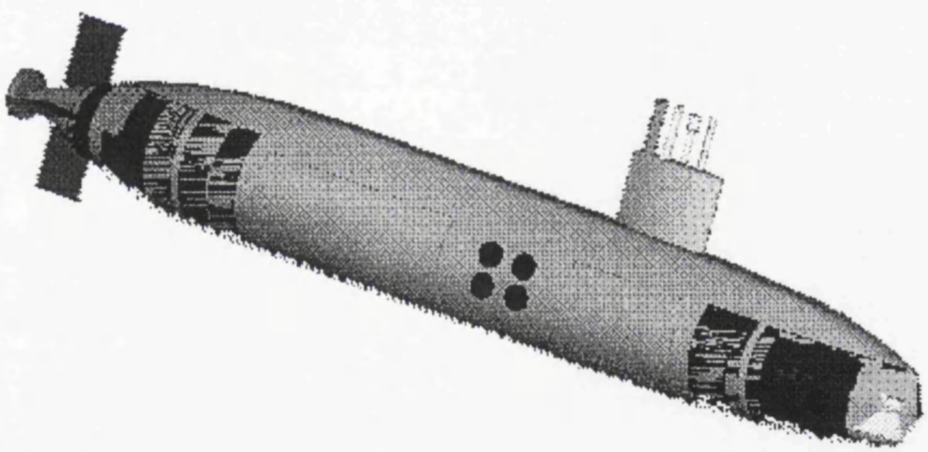


Figure B-1 Multi Mission Submarine SUBCON Model

A reference of the final parameters and features of the design is presented below. The final submarine model and the general arrangement is shown in Figure B-2. The submarine design prepared using a commercial design tool SUBCON demonstrated the applicability of the Building Block methodology to submarine design.

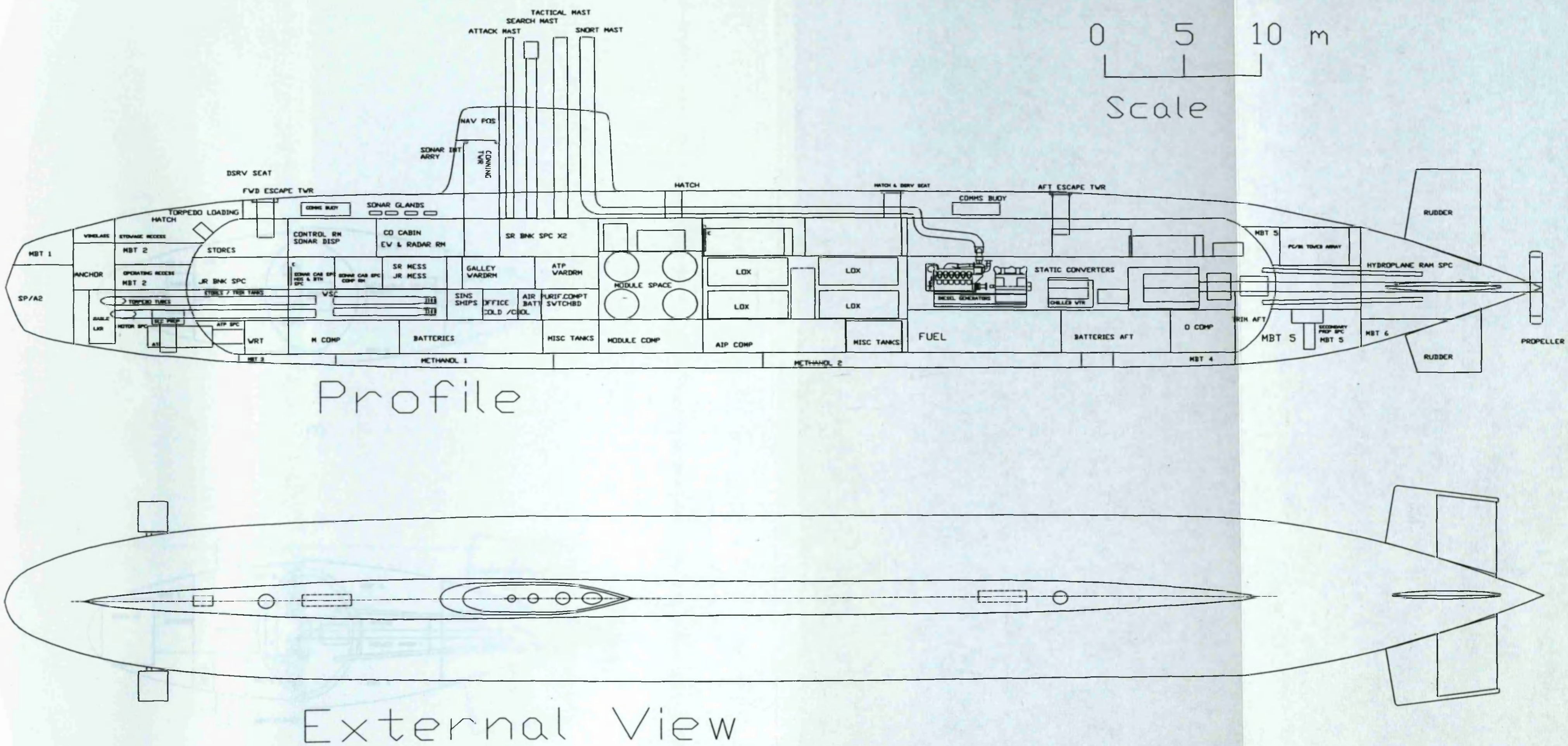


Figure B-2a Multi Mission Submarine
(Profile & External Views)

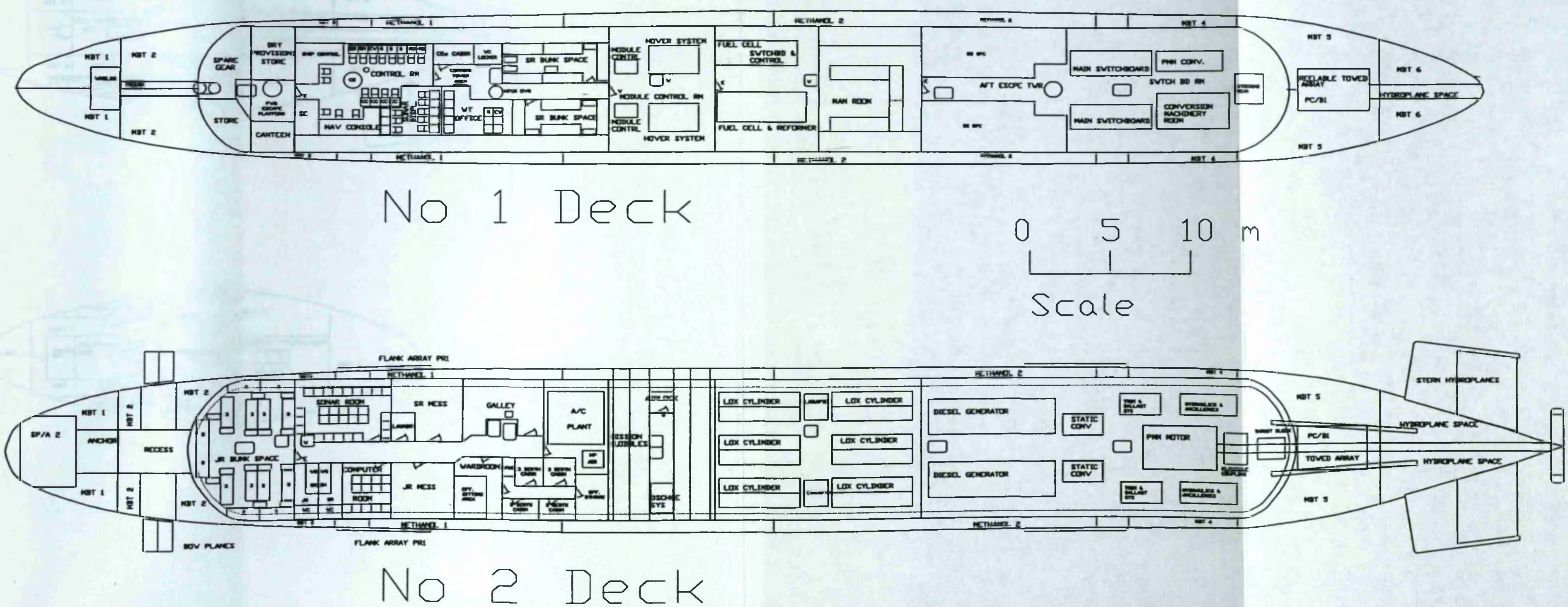


Figure B-2b Multi Mission Submarine (1 & 2 Deck)

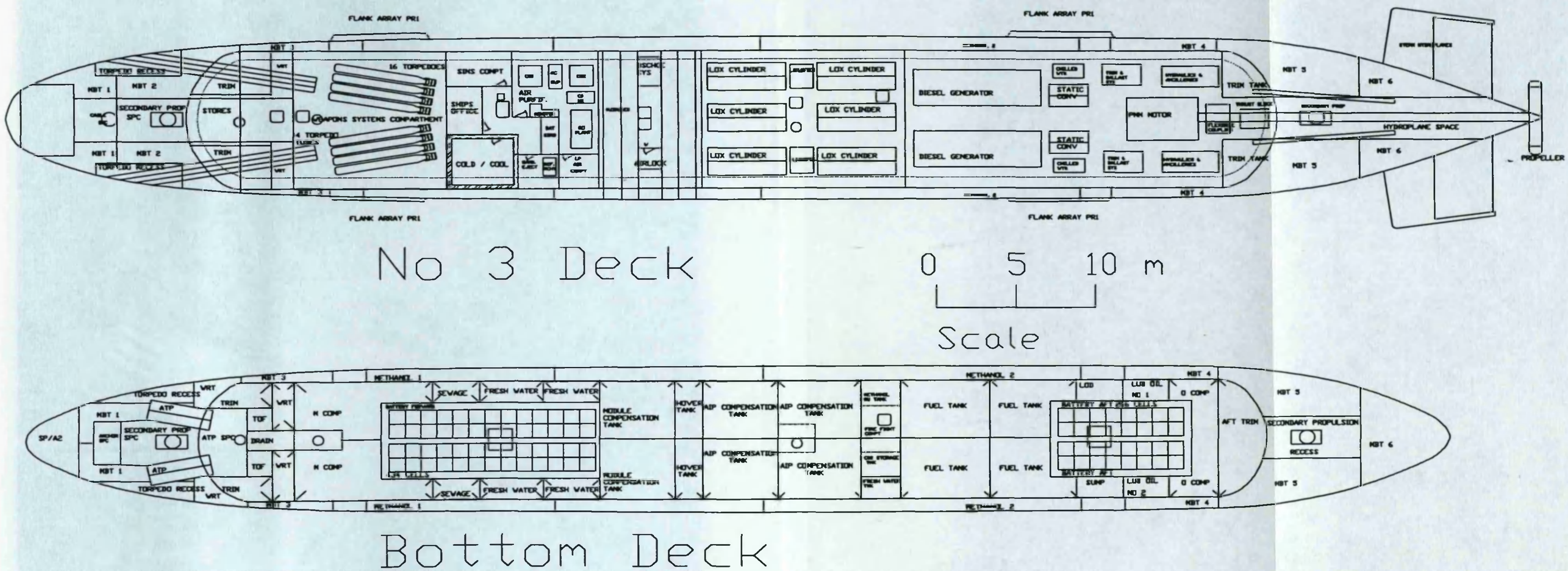


Figure B-2c Multi Mission Submarine
(3 & Bottom Deck)

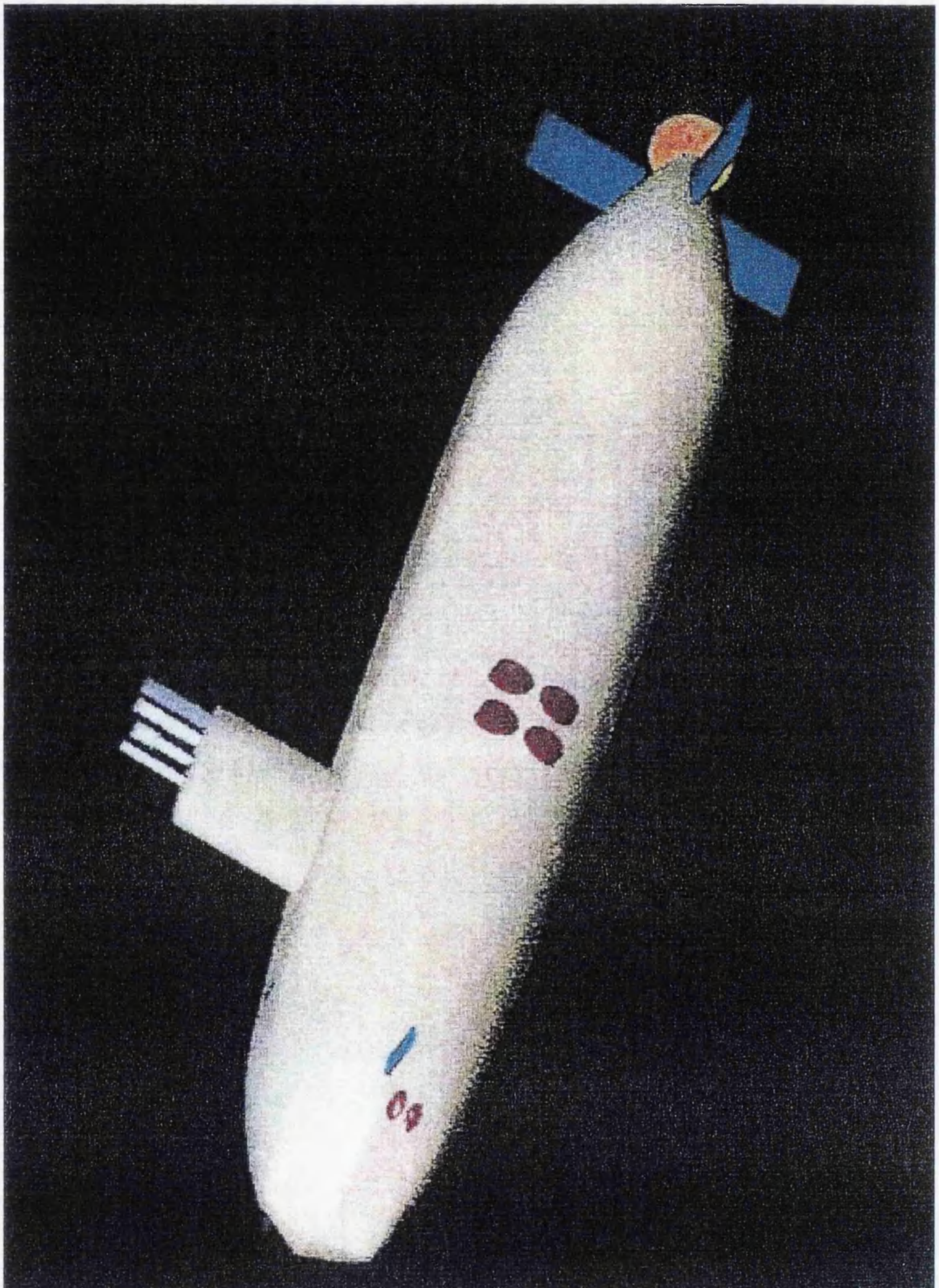


Figure B-3 SUBCON Multi Mission Submarine

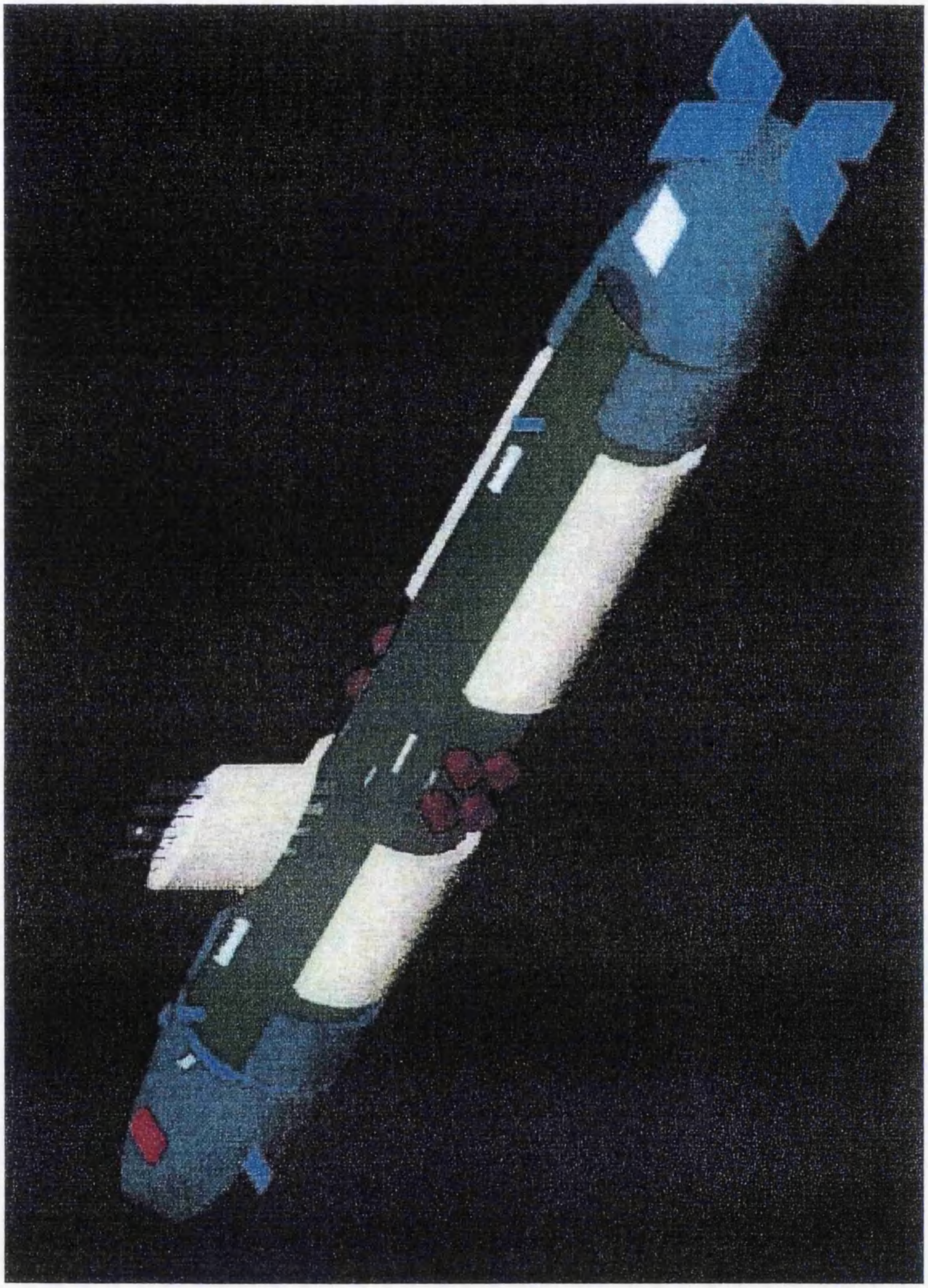


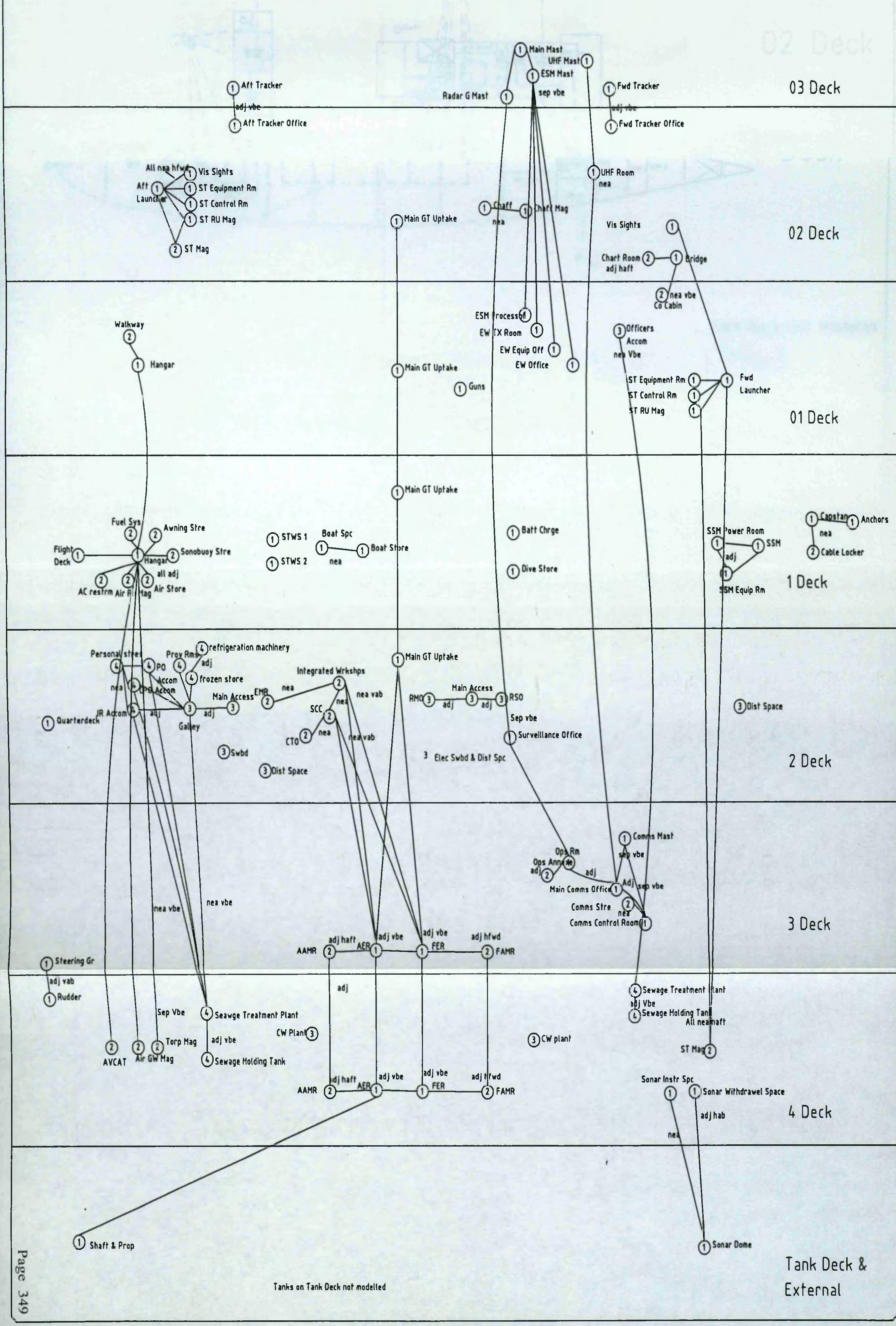
Figure B-4 SUBCON Multi Mission Submarine [with hull removed]

Appendix C. Building Block Design Methodology Appendices

Appendix C.1 Architectural Design Method Appendices

Figure C-1 Non Dimensional Arrangement of [Alder, 1996]

Numbers Indicate Compartment Type (see Section 5.6 for explanation)



of the design "Alder 96". Using a non dimensional method of assessing compartment locations a new model has been derived.

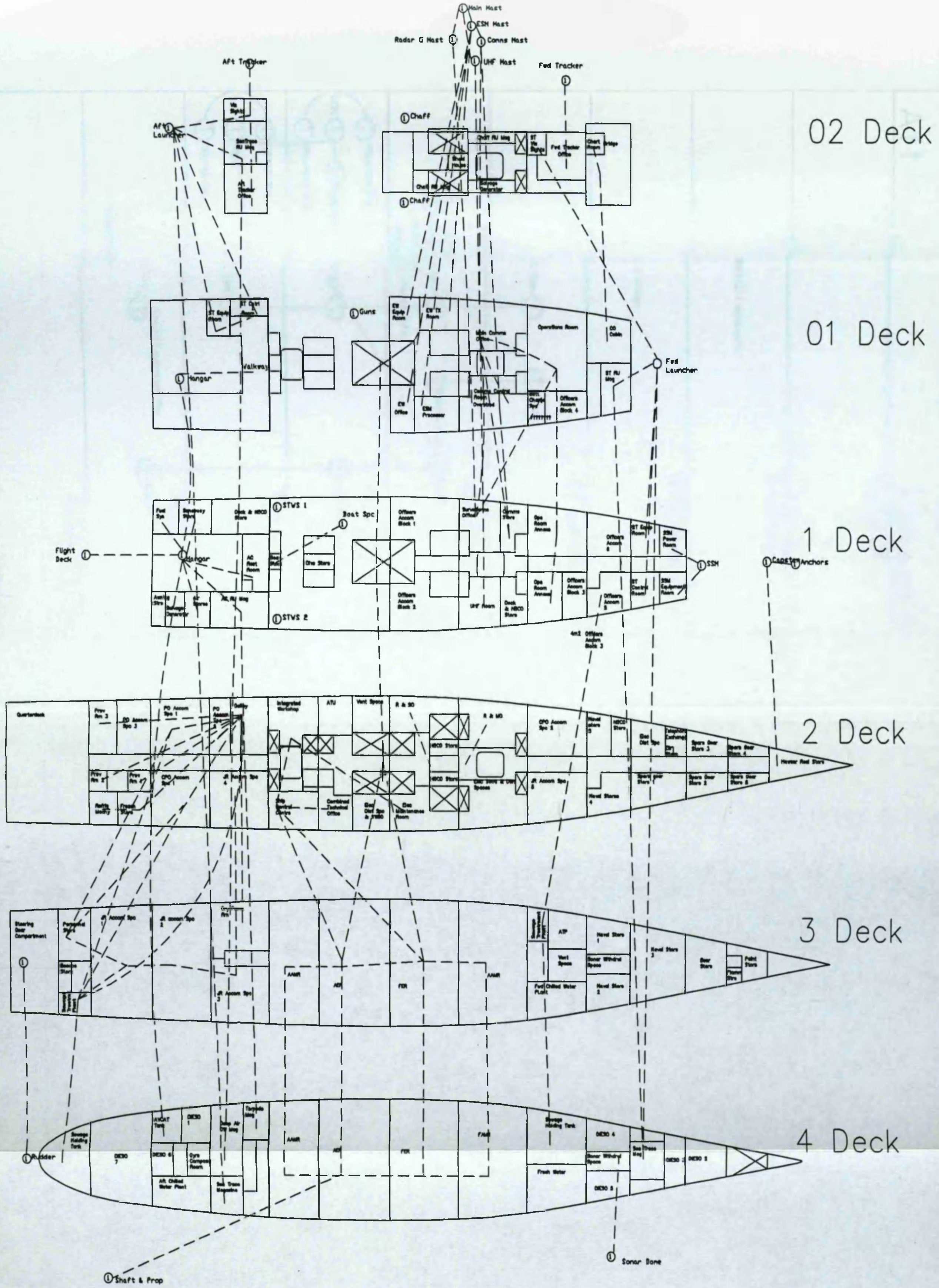


Figure C-2 Revision of [Alder, 1996]
Revision of Alder 96 B.Eng. Design
using Non Dimensional Methods

Figure C-3 Stylised FF-21 Arrangement (levels 1 & 2)

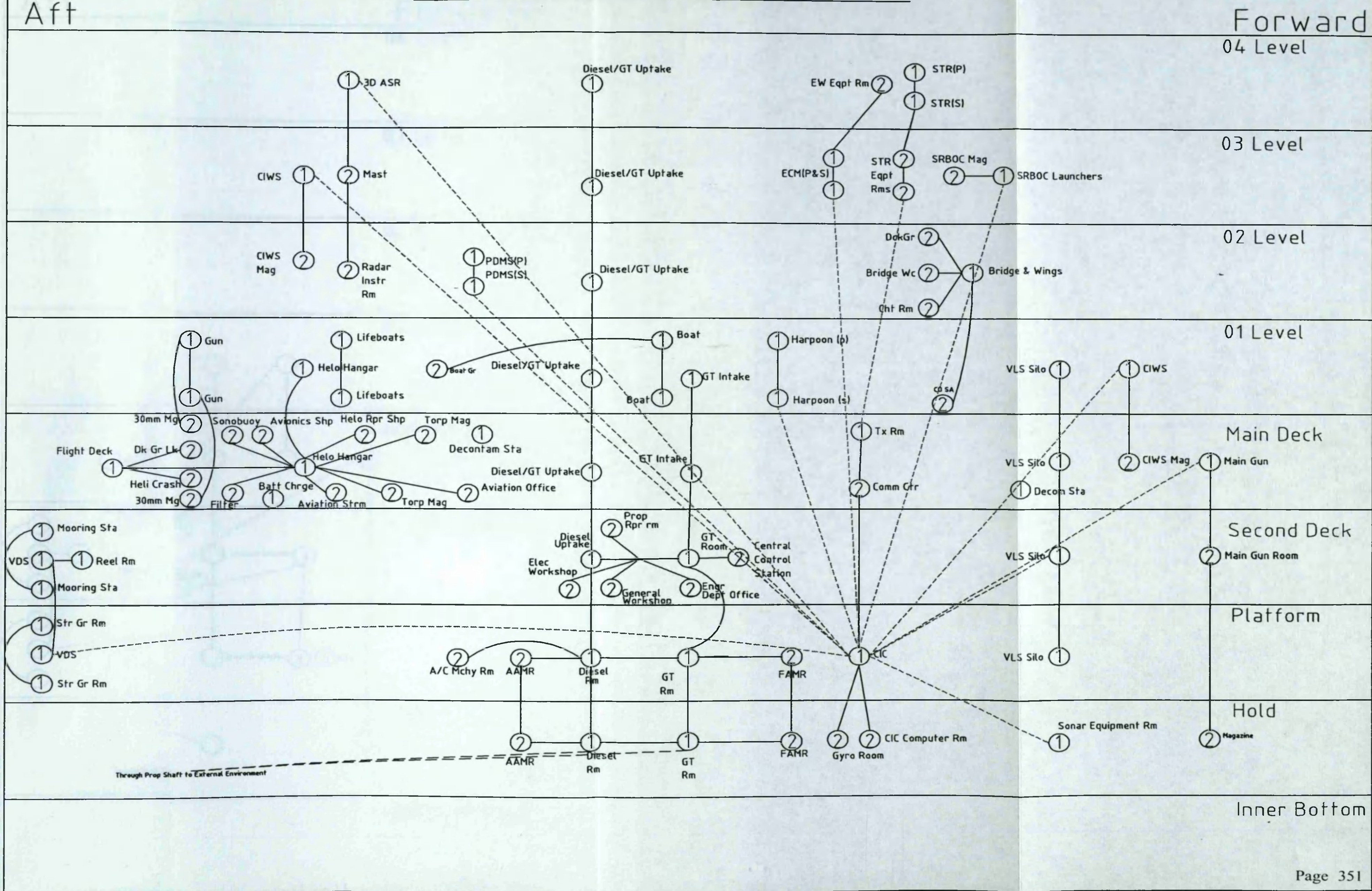
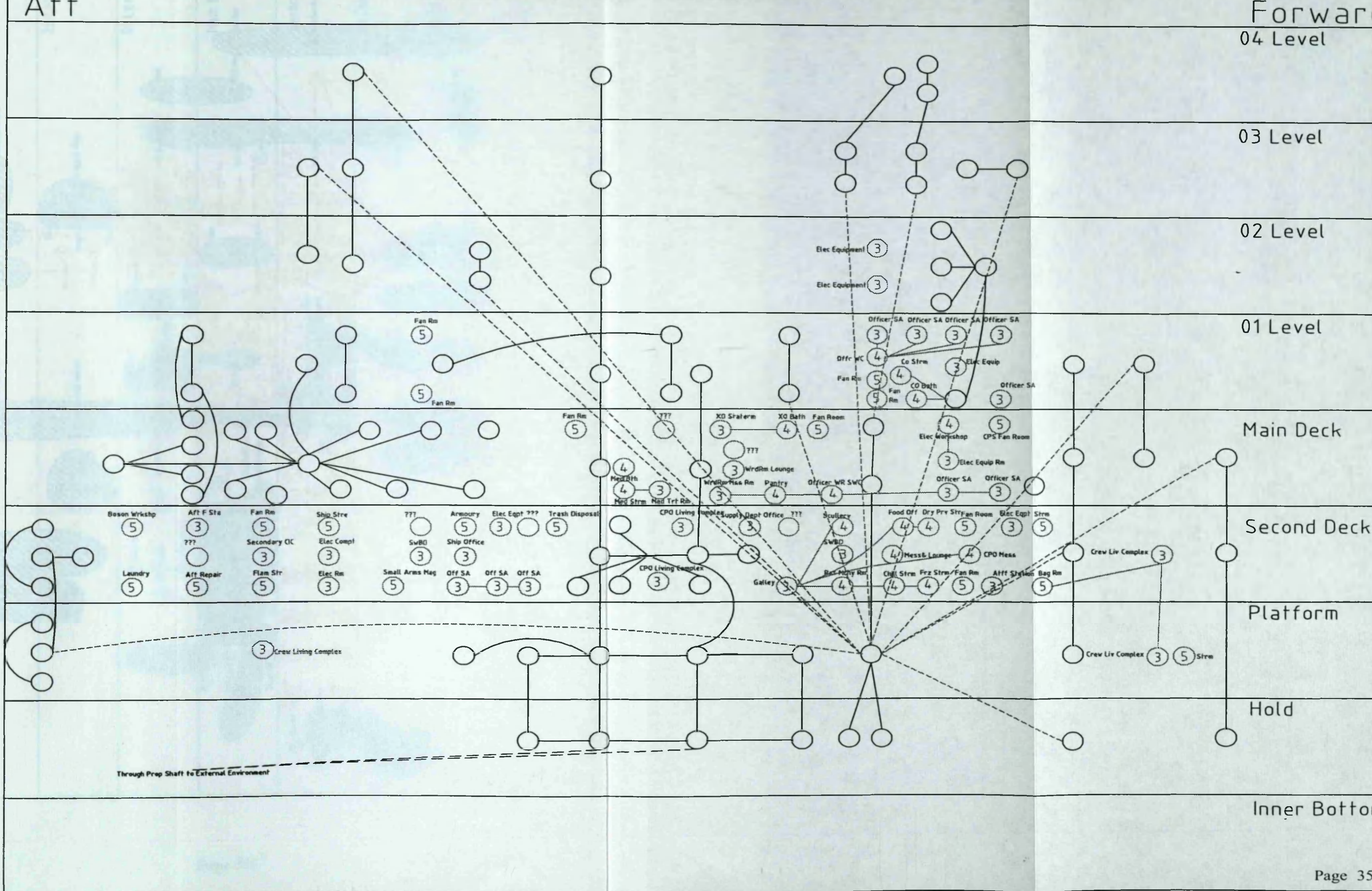
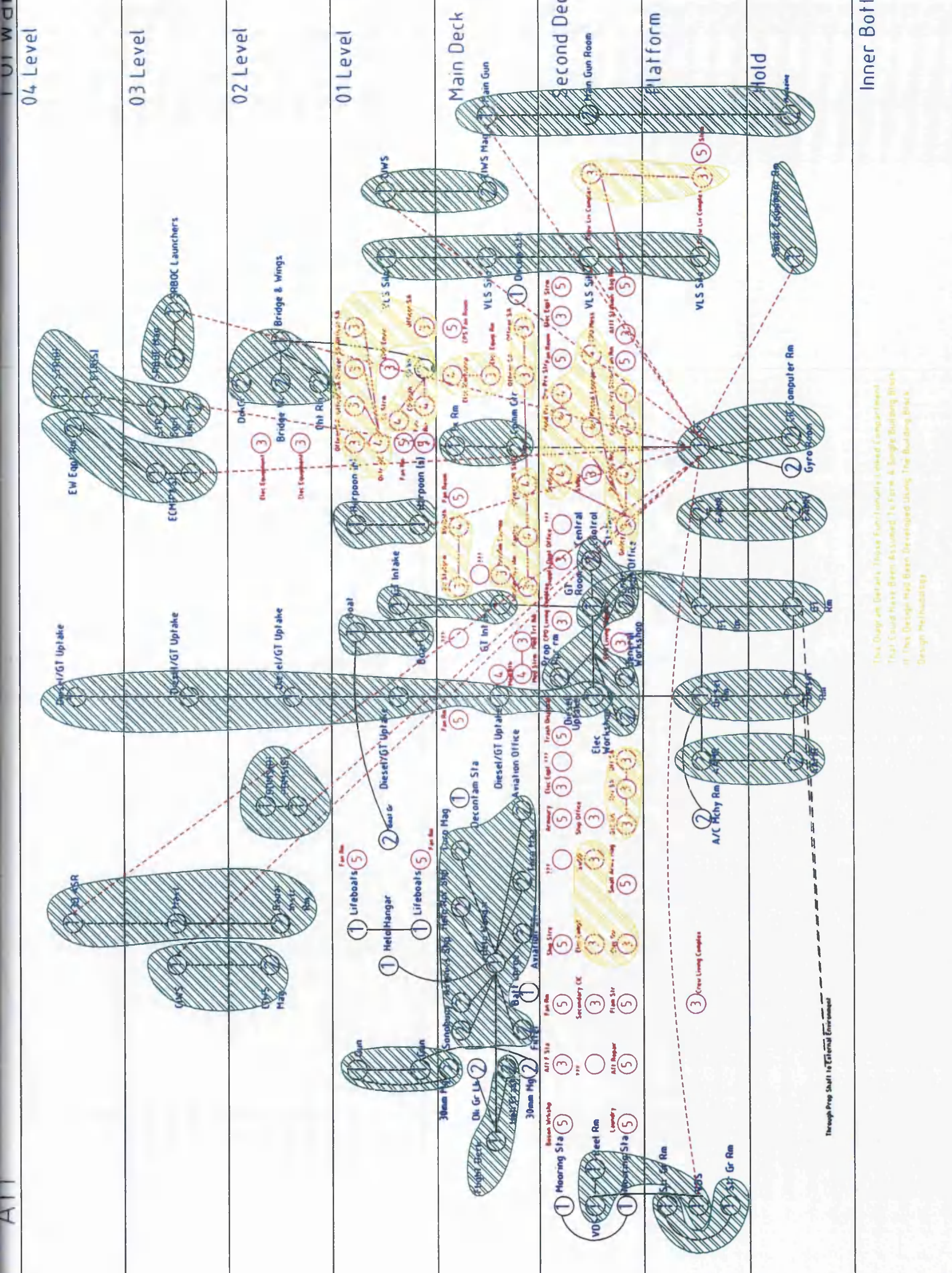


Figure C-4 Stylised FF-21 Arrangement (Levels 3-5)





04 Level
03 Level
02 Level
01 Level
Main Deck
Second Deck
Platform
Hold
Inner Bottom
Aft
Diesel/GT Uptake
Bridge & Wings
SRBOC Launchers
EW Eqpt Rm
ECM
Lifeboats
Helo Hangar
Main Gun
Main Gun Room
VLS Silo
CIWS
CIWS Mag
Harpoon
Computer Rm
Gyro Room
Central Control Station
General Workshop
Elec Workshop
Aviation Office
Decontam Sta
Mooring Sta
Reel Rm
Sonar Computer Rm
A/C Mchy Rm
Crew Living Complex
Through Prop Shaft to External Environment

Figure C-6 HMY Britannia Stylised Internal Arrangement (Levels 1 & 2)

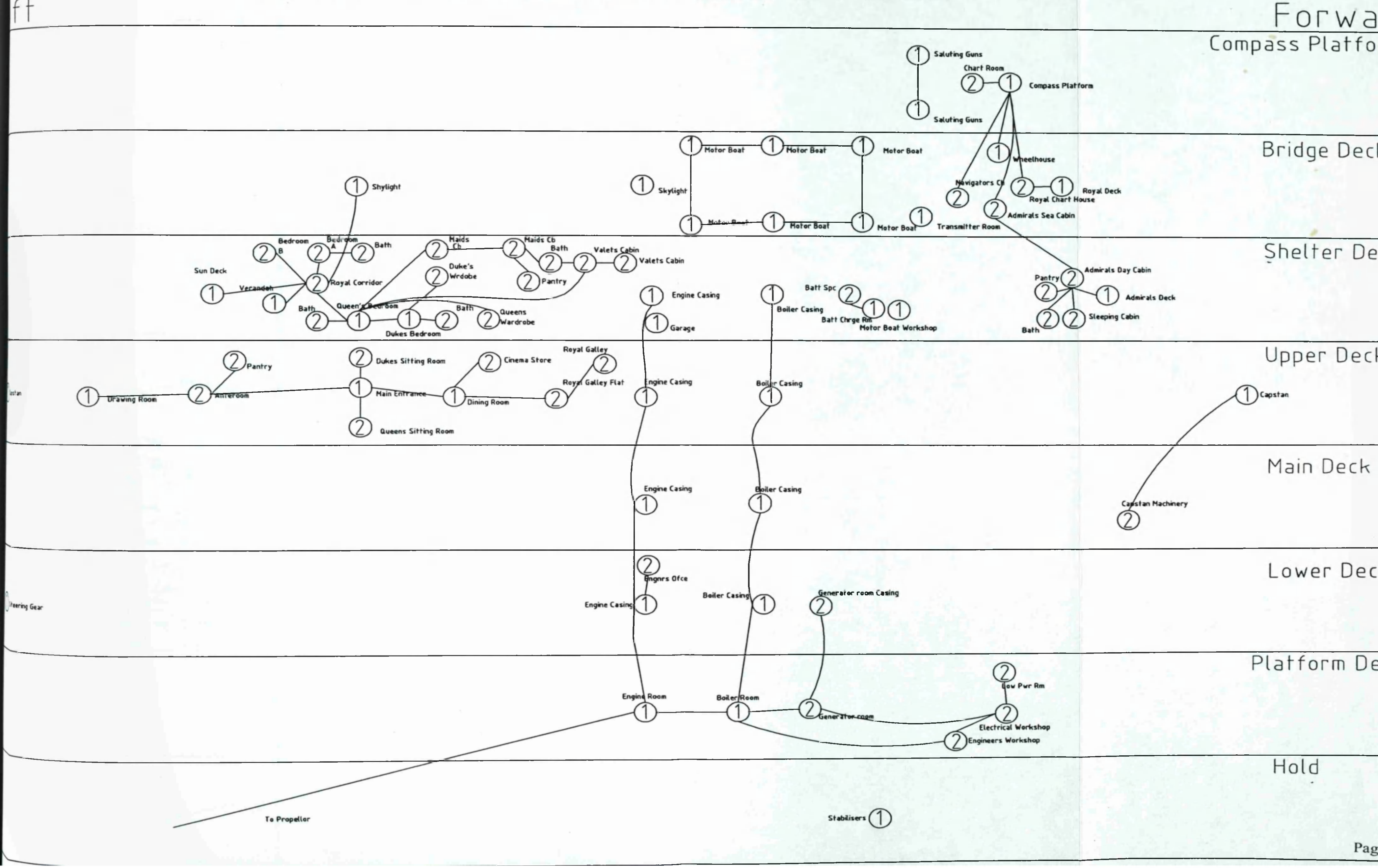
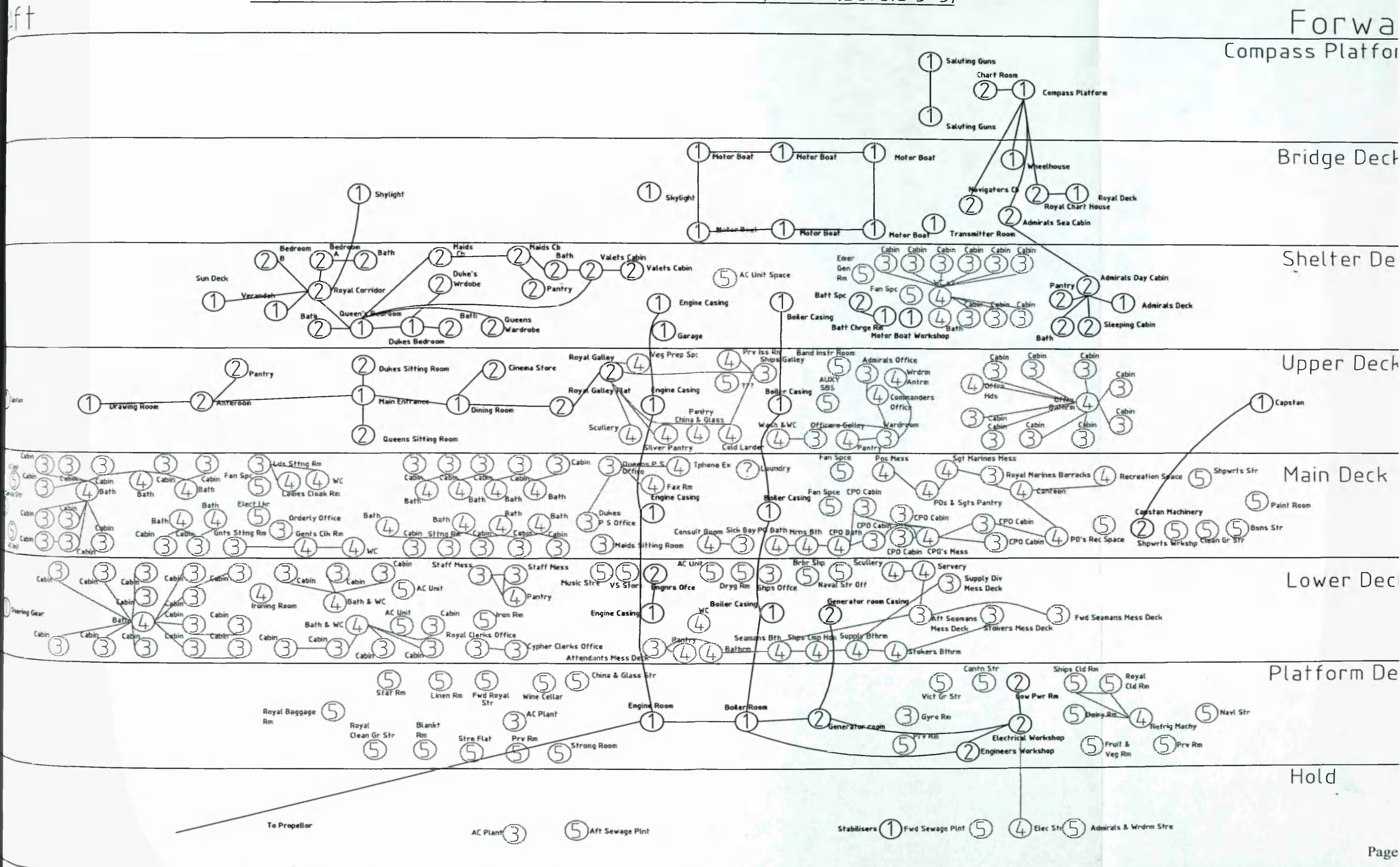


Figure C-7 HMY Britannia Stylised Internal Arrangement (Levels 3-5)



Appendix D. CAESAR Appendices

Appendix D.1 Introduction

Appendix D contains representative diagrams and text files used in the development of a ship design using the CAESAR computer aided design system [*Zhang, 1994*]. Appendix D.2 provides graphical illustrations of the visual workspace presented by CAESAR, namely a three dimensional wireframe representation of the different decks included within the hull and superstructure of the current design. Appendix D-3 details the input text file format necessary to inform CAESAR of the minimum requirements of each compartment or Building Block. Appendix D-4 details a typical audit output from CAESAR, detailing those spaces whose actual compartment sizes are less than the required spaces.

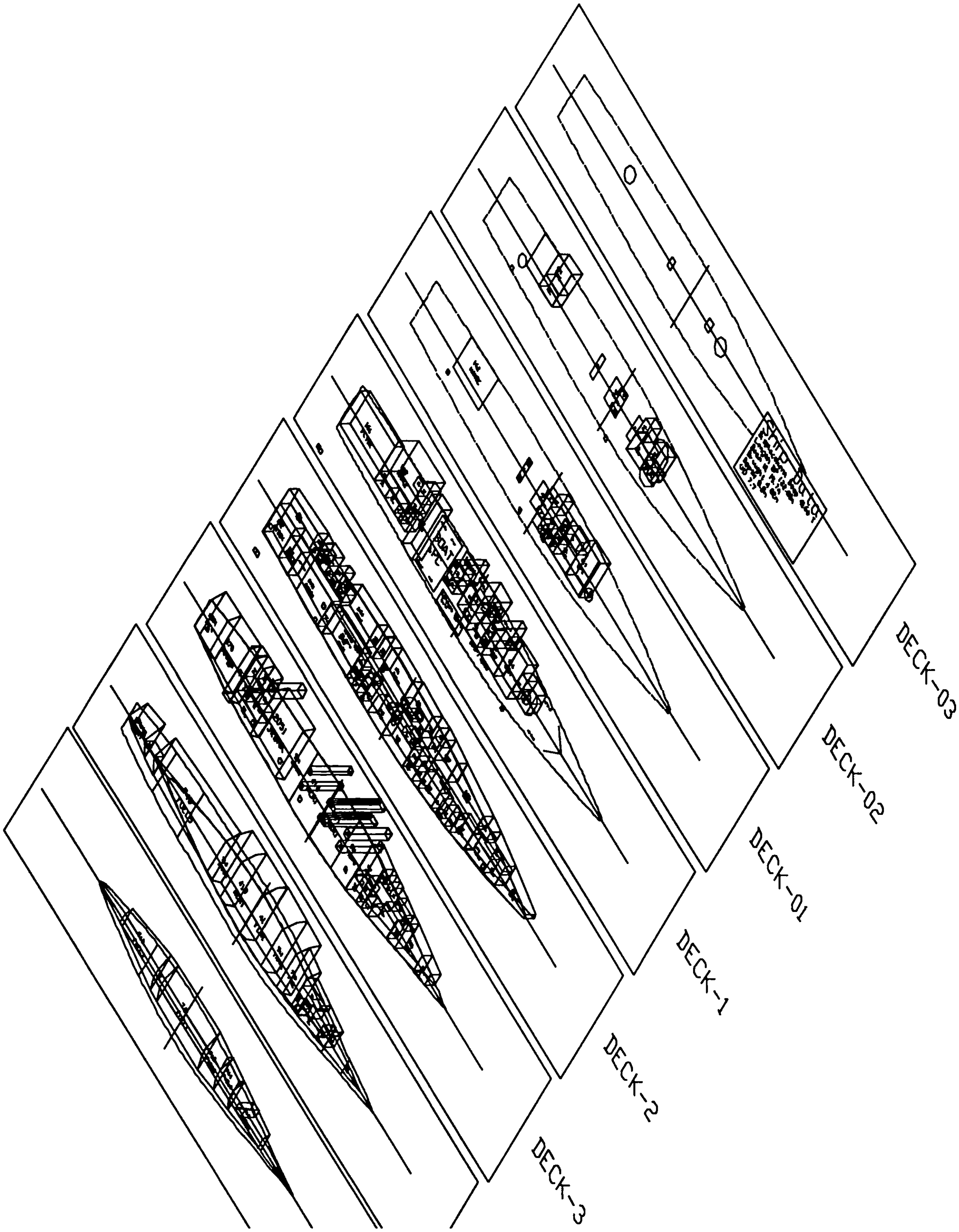


Figure D-1 An Example CAESAR Workspace

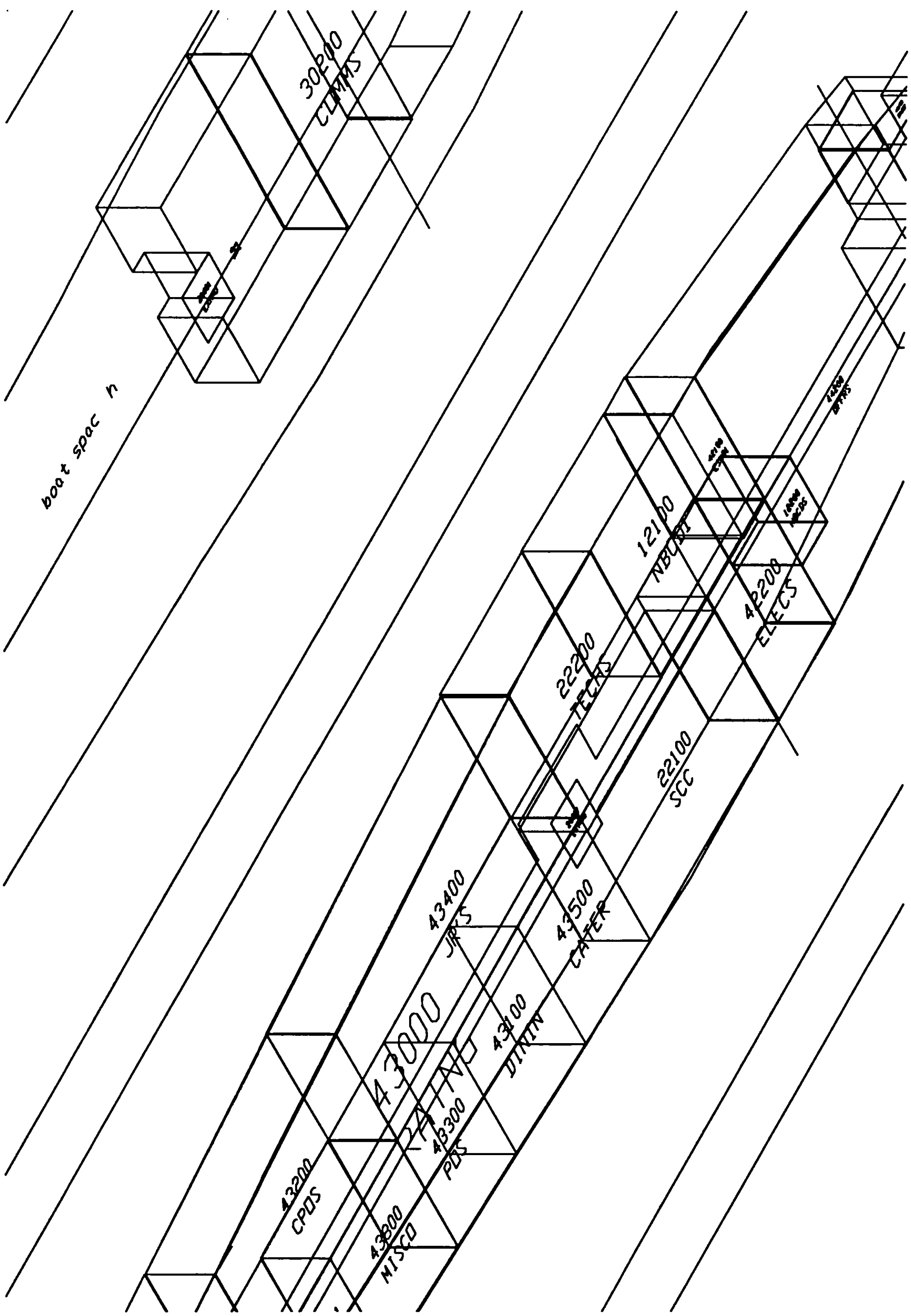


Figure D-2 Typical CAESAR Compartment / Building Block Representations

Appendix D.3 An Example CAESAR Compartment Input File

Space	ShrtNme	LongName	Min Area	Min Vol.	No. of Decks	
10101	ANCHR	ANCHORS&CABLES	0	0	0	Float Blocks
10102	CAPST	CAPSTAN	2.08	5.616	1	
10103	CABLE	CABLELOCKER	26.2	70.72	1	
10211	NBCD1	NBCD1	14.89	40.21	1	
10221	NBCDS	NBCDSTORE	10.41	28.11	1	
20001	ICRGC	ICRGCOMPARTMENT	92.4	517.44	2	Move Blocks
20031	FWDPS	FWDPROPSWBD	11	30.767	1	
20032	ICRGG	ICRGGEARSPACE	24.75	69.3	1	
20033	FWDES	FWDELECSWBD	13.86	4.95	1	
20034	FDMGC	FWDMGSPACE	10.56	29.568	1	
20021	GTINL	ICRGINLET	10	0	7	
20022	GTEXH	ICRGEXHAUST	10	0	7	
20111	DGSPC	MAINDGSPACE	104	582.4	2	
20112	DGINL	DGINLET	13.74	76.856	7	
20121	AFTMT	AFTMOTOR	85.67	479.804	2	
20122	FWDMT	FWDMOTOR	116.44	652.06	2	
20123	TRANS	TRANSMISSION	0	17.624	1	
20131	EDC6	EDC6	9.36	26.208	1	
20132	AFTSB	AFTSWITCHBOARD	4.6	12.636	1	
20133	EDC5	EDC5	9.36	26.208	1	
20134	EDC4	EDC4	9.36	26.208	1	
20134	AFTMG	AFTMGCMPRTMENT	9.984	15.6	1	
20201	PRTDG	PORTDGCOMP	34.32	92.664	2	
20301	STBDG	STBDDGCOMP	34.32	92.664	2	
20221	PRTSB	PORTSWBD	26.43	71.35	1	
20231	STBSB	STBDSWBD	26.43	71.35	1	
20222	PRTIN	PORTINVERTER	0	2.08	1	
20322	STBIN	STBINVERTER	0	2.08	1	
20411	FUEL	FUEL	0	646.60	1	
20421	COMPW	COMPTANKS	0	273.1	1	
20511	SSC	SSC	44.72	120.744	1	
20521	INTWK	INTEGRTDWRKSHPS	55.41	149.6144	1	
20522	CTO	CTO	26.3	71.10	1	
20523	EMR	EMR	10.42	28.132	1	
20611	CMPPT	COMPASSPLATFORM	26.208	70.72	1	
20612	CHTRM	CHARTROOM	5.304	14.248	1	
20613	WHLHS	WHEELHOUSE	5.304	14.248	1	
20711	STRGR	STEERINGGEAR	36.12	96.59	1	
20721	GYRO	GYROCOMPASS	11.76	31.45	1	
30011	OPSRM	OPERATIONS ROOM	78.65	196.6	1	Fight Blocks
30012	OPSAN	OPS ANNEX	78.65	196.6	1	
30021	SURVG	SURVEILLNCE OFFG	48.279	130.35	1	
30031	COMST	COMMS STORE	4.07	10.175	1	
30032	EWTXO	EX TX OFFICE	9.24	23.1	1	
30033	EWOFF	EW OFFICE	13.31	33.275	1	
30034	EWEQR	EW EQUIP ROOM	10.23	25.575	1	
30035	UHFRM	UHF ROOM	28.05	70.125	1	
30036	MCO	MAIN COMMS OFFICE	41.91	104.78	1	
30037	CCR	COMBCOMMSRM	49.06	122.65	1	
30111	GWMAG	GW MAGAZINE	25.3	64.9	1	
30112	AIRMG	AIR MAGAZINE	66	165	1	
30113	SONOB	SONOBUOYS	16.5	40.7	1	
30121	HANGR	HANGAR	165.88	845.988	1	

30122	TRPMG	TORPEDO MAG	22.55	55	1	
30123	AIRST	AIR STORES	30.8	77	1	
30211	SSMER	SSMEQUIPMNT RM	10.296	25.74	1	
30212	SSMOR	SSM POWER ROOM	11.616	29.04	1	
30311	16VLS	16CELL VLS	30.8	138.6	2	
30312	LCR1	STLAUNCHER CNTRL	11.88	29.7	1	
30313	STER	SEATRACE EQUIP RM	14.3	35.75	1	
30321	AFTTR	AFTTRACKER	35.2	88.11	1	
30341	8VLSS	STBD VLS SILO	15.4	69.3	2	
30351	8VLSP	PORT VLS SILO	15.4	69.3	2	
30361	FWDTR	FWD TRACKER	35.2	88.11	1	
30811	HOA	HULL OUTFIT A	12.65	58.19	2	
30812	WTHDL	SONAR WTHDRWL SP	5.5	13.75	1	
30813	SONIS	SONAR INSTRU SPAC	14.85	36.96	1	
40111	CPOCB	CPOCABIN	54.096	146.055	1	Infra. Blocks
40112	CPOBT	CPOBATHROOMS	5.55	14.99	1	
40113	CPOTT	CPOTOILETS	1.575	4.242	1	
40114	CPOMS	CPOMESS	18.354	49.56	1	
40121	POCAB	POS CABINS	76.692	207.07	1	
40122	POTLT	POS TOILETS	3.0	8.11	1	
40123	POMSS	POS MESS	35.57	96.05	1	
40131	JRBNK	JR BUNK SPACE	202.5	546.74	2	
40132	JRMSS	JRMESS	82.4	222.5	1	
40133	JRBTH	JRBATHROOM	16.76	45.24	1	
40134	JRTLT	JR TOILETS	9.08	24.51	1	
40011	CPODH	CPODINING	10.143	27.4	1	
40012	PODH	PODINING	17.094	46.16	1	
40013	JRDH	JRDINING	46.08	124.04	1	
40021	CANTN	CANTEEN	8.62	23.27	1	
40022	GALLY	GALLEY	44.688	119.51	1	
40023	BEERS	BEERSTORE	2.31	6.24	1	
40024	CNTNS	CANTEEN STORE	1.45	3.85	1	
40025	COLDC	COLD & COOL	5.95	16.233	1	
40026	PRVRM	PROVISION ROOMS	5.7	15.37	1	
40027	REFRG	REFRIGERTION MCHY	2.6	6.988	1	
40031	JRBAG	JR BAGGAGE	2.46	6.65	1	
40032	OFFBG	OFFS BAGGAGE	.04	12	1	
40041	CHAPL	CHAPEL	8.62	23.28	1	
40042	MEDST	MEDICAL STORE	0	3.848	1	
40043	SCKBY	SICKBAY	17.47	47.17	1	
40051	TX	TX	4.2	10.5	1	
40052	TV	TV	8.216	20.74	1	
40053	SRE	SRE	3.744	9.36	1	
40054	R&SO	R&SO	7.88	9.71	1	
40055	R&MO	R&MO	4.7	12.32	1	
40211	COCB	COS CABIN	8.19	22.11	1	
40212	COSLP	COS SLEEPING CABIN	7.875	21.26	1	
40213	CODIN	COS DINING CABIN	21	56.7	1	
40221	2ACAB	CLASS 2 CABINS	26.77	72.1	1	
40222	CL3CB	CLASS 3 CABINS	132.83	358.63	1	
40223	OFFBH	OFFICERS BATH	9.1	24.5	1	
40224	OFFTT	OFFICERS TOILETS	5.04	13.61	1	
40225	WRDRM	WARDROOM	25.2	68.04	1	
40226	WRDPN	WARDRM PANTRY	6.825	18.43	1	
40227	WRDAN	WARDRM ANTERM	15.12	40.82	1	
40321	AWNST	AWNING STORE	9.71	26.2	1	
40322	BOSON	BOSONS STORE	5.55	14.97	1	

40323	BOOKS	CONFIDENTIAL BKS	3.4	8.57	1
40324	HAWSR	HAWSER REEL	7.02	17.52	1
40325	DIVES	DIVESTORE	5.82	15.75	1
40331	LIQDS	LIQUIDS	0	112	1
40311	INFLM	INFLAMMABLE STRES	6.73	18.18	1
40312	NAVST	NAVALSTORE	78.09	214.95	1
40313	PAINT	PAINT STORE	8.127	21.93	1
40314	SPRGR	SPARE GEAR ST	52.6	142	1
40315	DRYRM	DRYING ROOM	5.46	14.7	1
40316	LAUND	LAUNDRY	23.52	63.51	1
40317	VICTG	VICTUALLING GEAR	7.29	19.69	1
40341	CW	CHILLED WATER	20.9	56.42	1
40342	SWGE	SEWAGE TREATMNT	10.5	28.35	1
40351	AIRC	AIRCONDITIONING	33.77	87.8	1
40352	CVENT	VENTILATION	33.77	87.8	1
40353	SEAWT	SEAWATER PUMP	7.32	19.77	1

Appendix D.4 An Example CAESAR Output File

A CAESAR Volume Audit [Undersized Spaces]

VOLUME UNDER-ASSIGNED COMPARTMENTS

Under-Assigned Compartments : 21

Spgp	Title	A_req	V_req	Vdk	A_ass	V_ass	FlrDk	U/S
20010	ICRGC	108.00	756.00	2	78.13	632.14	DECK-5	S
20020	INLET	10.00	387.50	7	11.22	201.91	DECK-4	S
20110	DGSPC	113.21	754.44	2	54.00	445.05	DECK-5	S
20120	MOTOR	194.34	1314.86	2	51.54	748.49	DECK-5	S
20410	FUEL	0.00	582.90	1	154.42	296.22	BASE_LINE	S
20411	FUEL2	0.00	556.68	1	79.42	265.32	DECK-5	S
20420	COMP	0.00	273.10	2	42.23	173.13	BASE_LINE	S
20520	TECHS	88.76	311.47	1	46.50	116.25	DECK-3	S
40010	DINNG	69.83	226.25	1	69.83	188.54	DECK-2	S
40020	GALLY	68.13	218.90	1	68.13	183.95	DECK-2	S
40040	MEDCL	25.09	85.01	1	25.09	67.74	DECK-2	S
40310	STRES	174.79	566.32	1	196.01	490.02	DECK-3	S
40320	DECK	39.89	112.01	1	43.62	109.05	DECK-1	S
30360	FWDTR	32.00	92.12	1	32.15	80.37	DECK-02	S
30320	AFTTR	32.00	92.12	1	32.04	80.10	DECK-02	S
30340	STBLR	14.00	72.45	2	13.72	71.36	DECK-2	S
20320	STBEL	25.41	84.00	1	31.10	83.96	DECK-2	S
40050	MISCO	27.60	82.11	1	32.60	81.51	DECK-3	S
20610	BRDGE	35.42	109.03	1	35.42	88.55	DECK-02	S
30110	HELOS	98.00	387.50	1	127.13	317.83	DECK-3	S
30120	HANGR	199.30	1016.76	2	200.73	1003.67	DECK-1	S

Appendix E. Monohull Design Examples

Appendix E present appendices to be viewed in conjunction with the contents of Chapter 7. Included are illustrations of all aspects of the monohull design examples.

Appendix E.1 Traditional Monohull Escort Appendices

Appendix E.1 details the arrangement of the traditionally designed Escort Monohull design post the design general arrangement stage [Figure E-1].

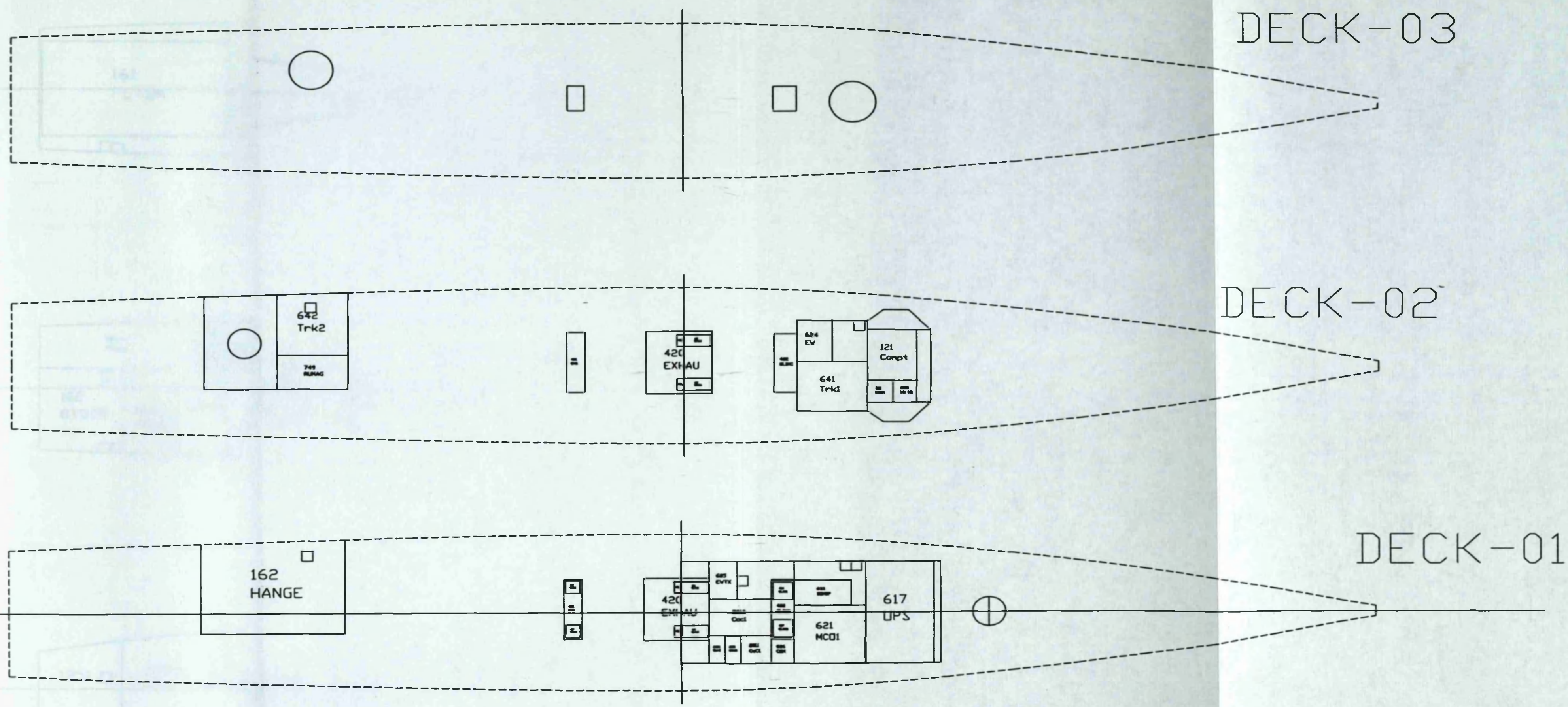


Figure E-1a Traditional Escort Monohull Design (Decks 01-03)

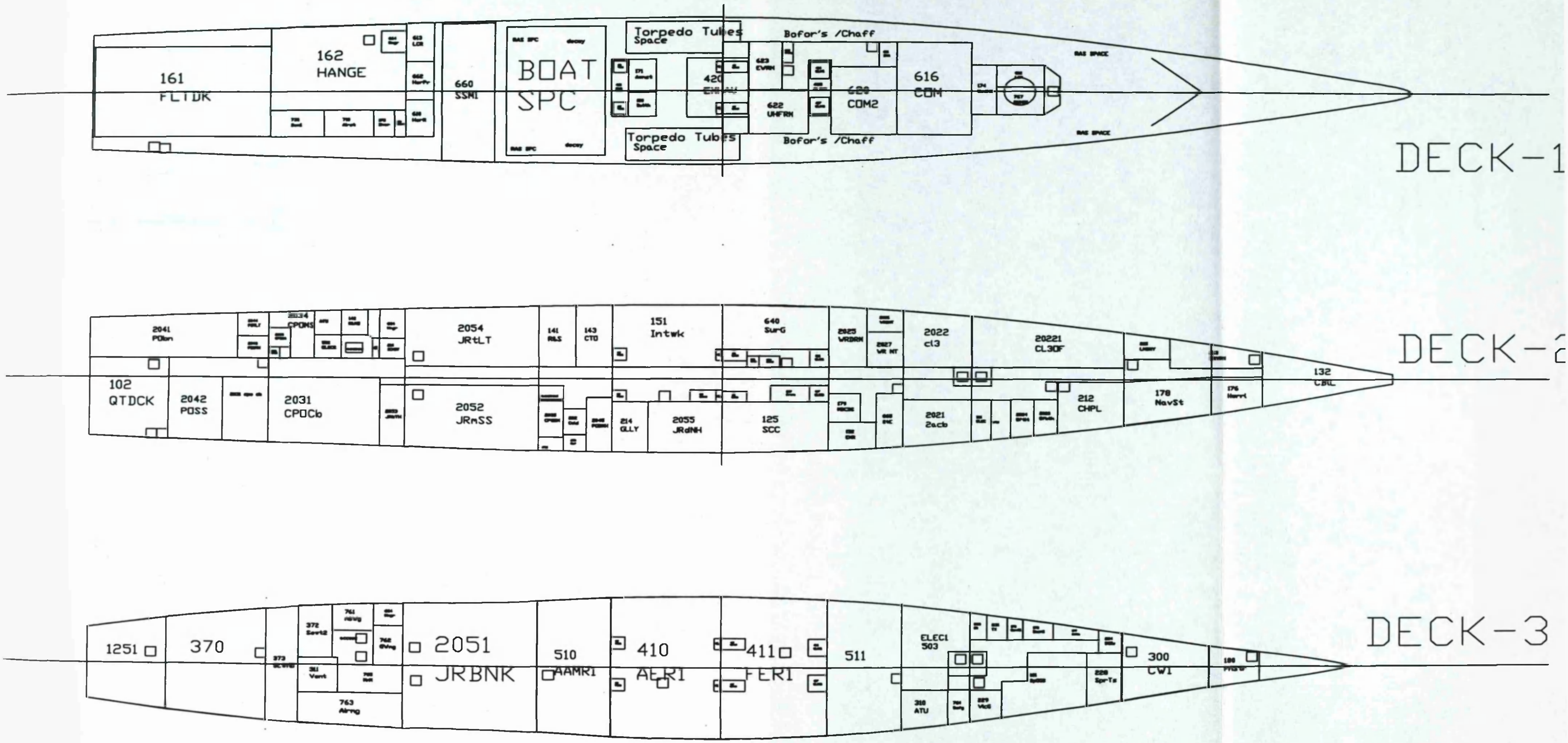


Figure E-1b Traditional Escort Monohull Design
(Decks 1-3)

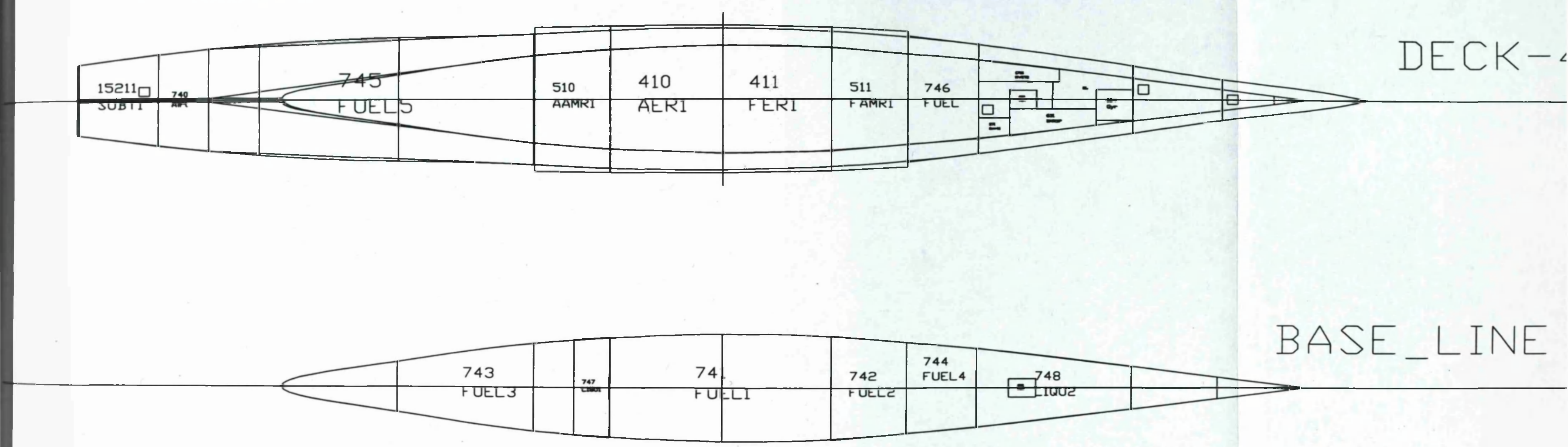


Figure E-1c Traditional Escort Monohull Design
(Decks 4 & Base_line)

Appendix E.2 Building Block Monohull Escort Appendices

Appendix E.2.1 Building Block Monohull Escort Topside Design Appendices

Figure E-2 details the two dimensional models used to develop the minimum sized topside arrangement for the Monohull Escort Building Block design, as detailed in Chapter 7.

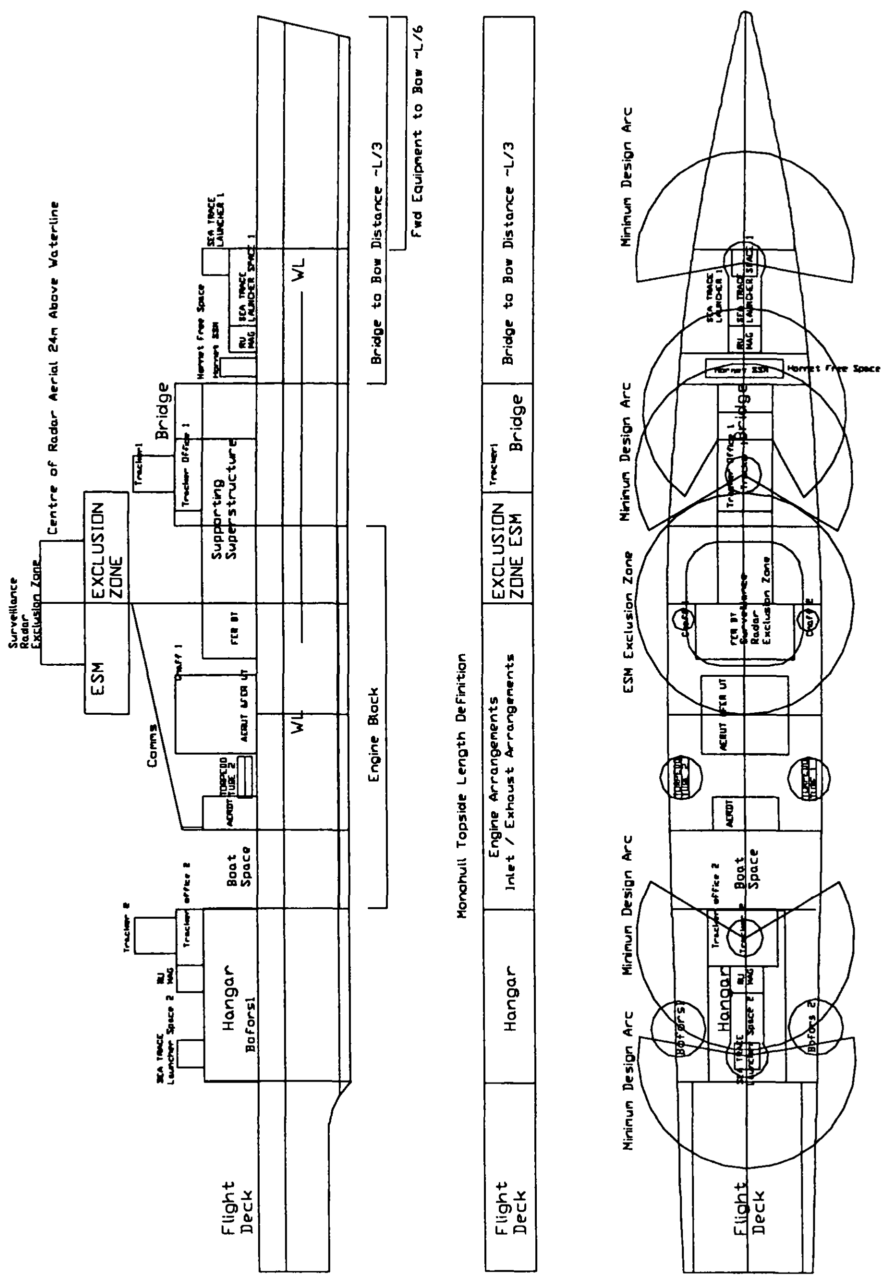


Figure E-2 Monohull Escort Building Block Design Topside Model

Appendix E.2.2 Building Block Monohull Escort Functional Hierarchy

This appendix details the functional hierarchy of Functional Groups, Super Building Blocks and Building Blocks used to develop the Monohull Escort Building Block design, as detailed in Chapter 7.

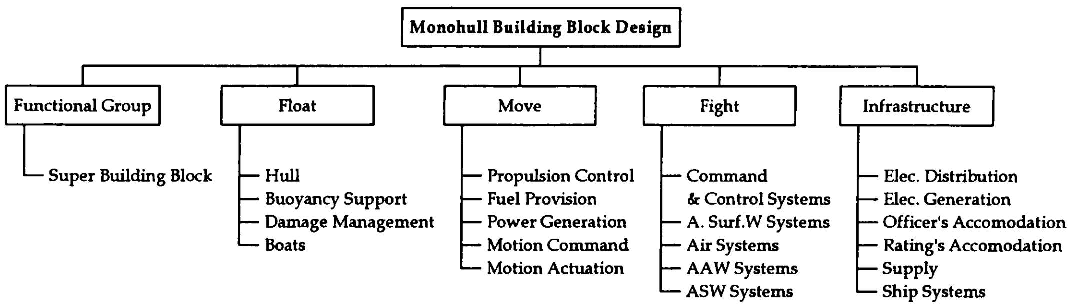


Figure E-3 Relationship Between Overall Design, Functional Groups and Super Building Blocks

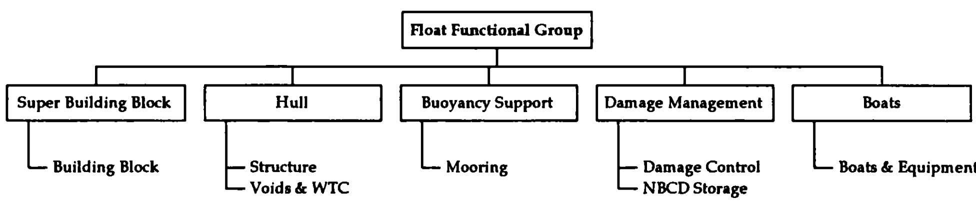


Figure E-4 Super Building Blocks and Building Blocks of the Float Functional Group

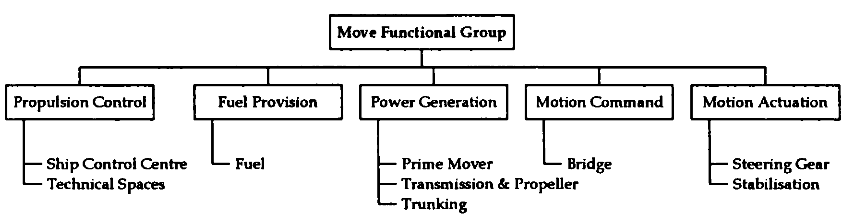


Figure E-5 The Move Functional Group

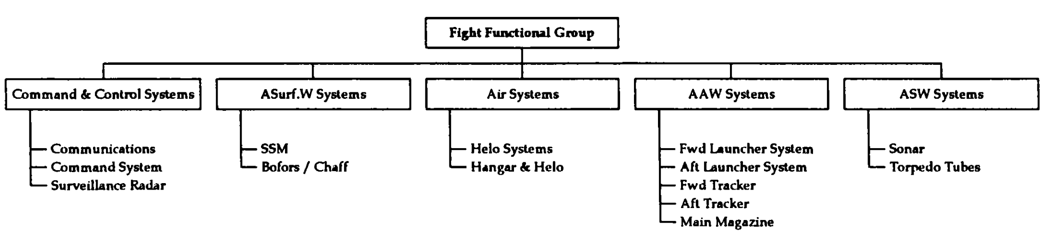


Figure E-6 The Fight Functional Group

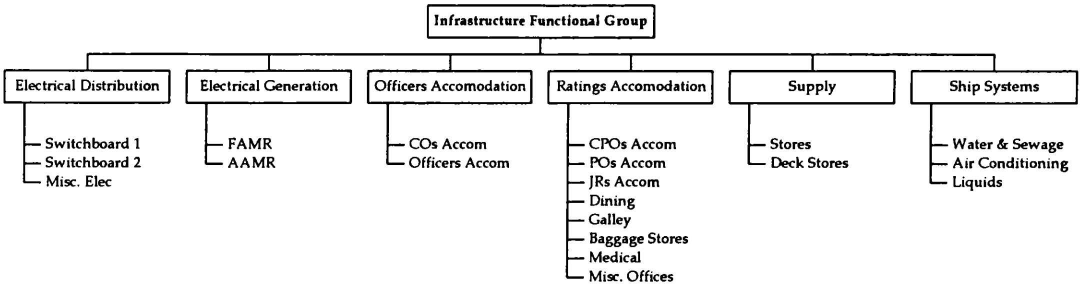


Figure E-7 The Infrastructure Functional Group

Appendix E.2.3 Building Block Monohull Escort General Arrangements

The following pages detail the arrangement of the Monohull Escort Building Block design at three points during development. The first arrangement details the design post the Super Building Block design stage [Figure E-8]. The second arrangement details the design post the Building Block design stage [Figure E-9], while the third arrangement details the completed design [Figure E-10]. Colour maps of the Monohull Escort present the location of the Building Blocks of each of the four functional groups [Figure E-11]. Figure E-11 details the distribution of the four functional groups throughout the Building Block monohull design, adding credence to the concept of the Building Block concept.

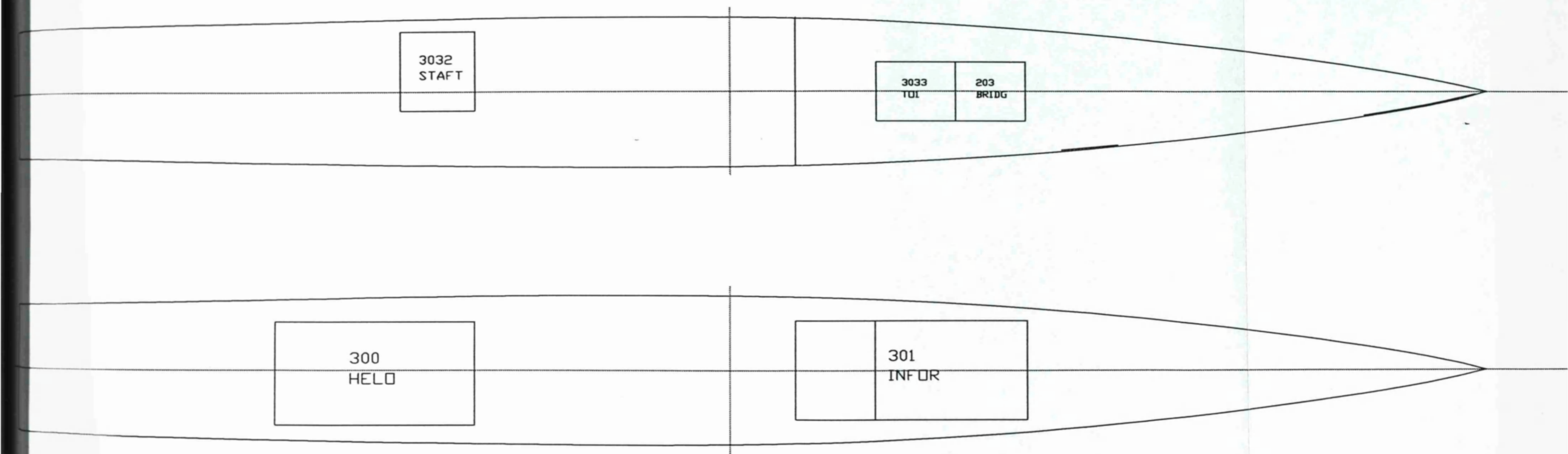


Figure E-8a Monohull Escort Building Block Design (Super Building Block Stage)

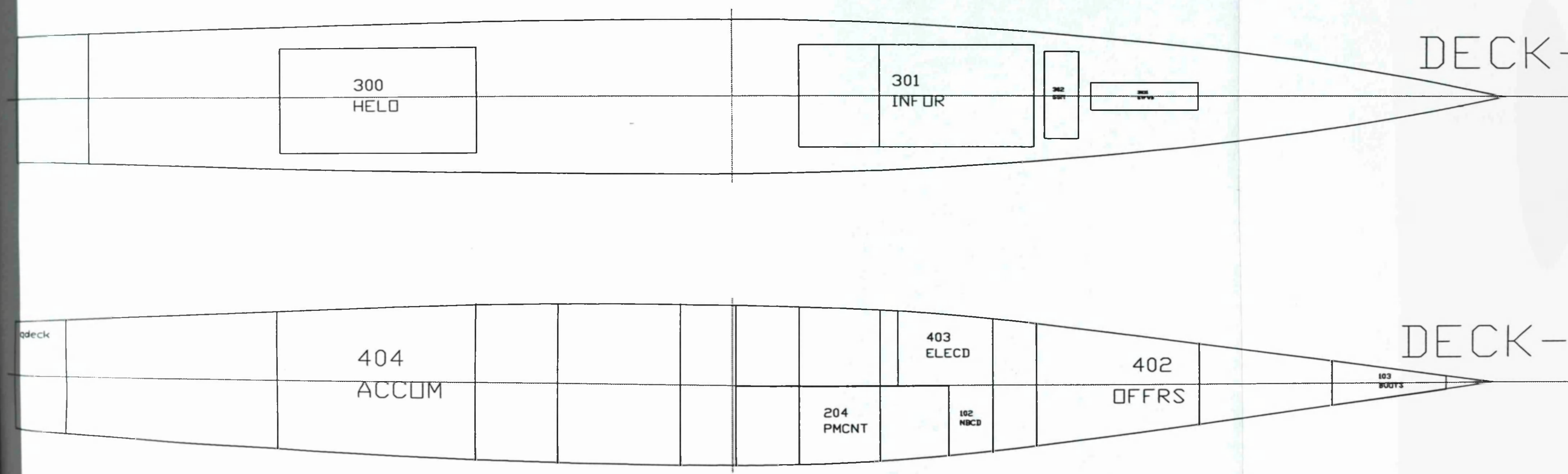


Figure E-8b Monohull Escort Building Block Design (Super Building Block Stage)

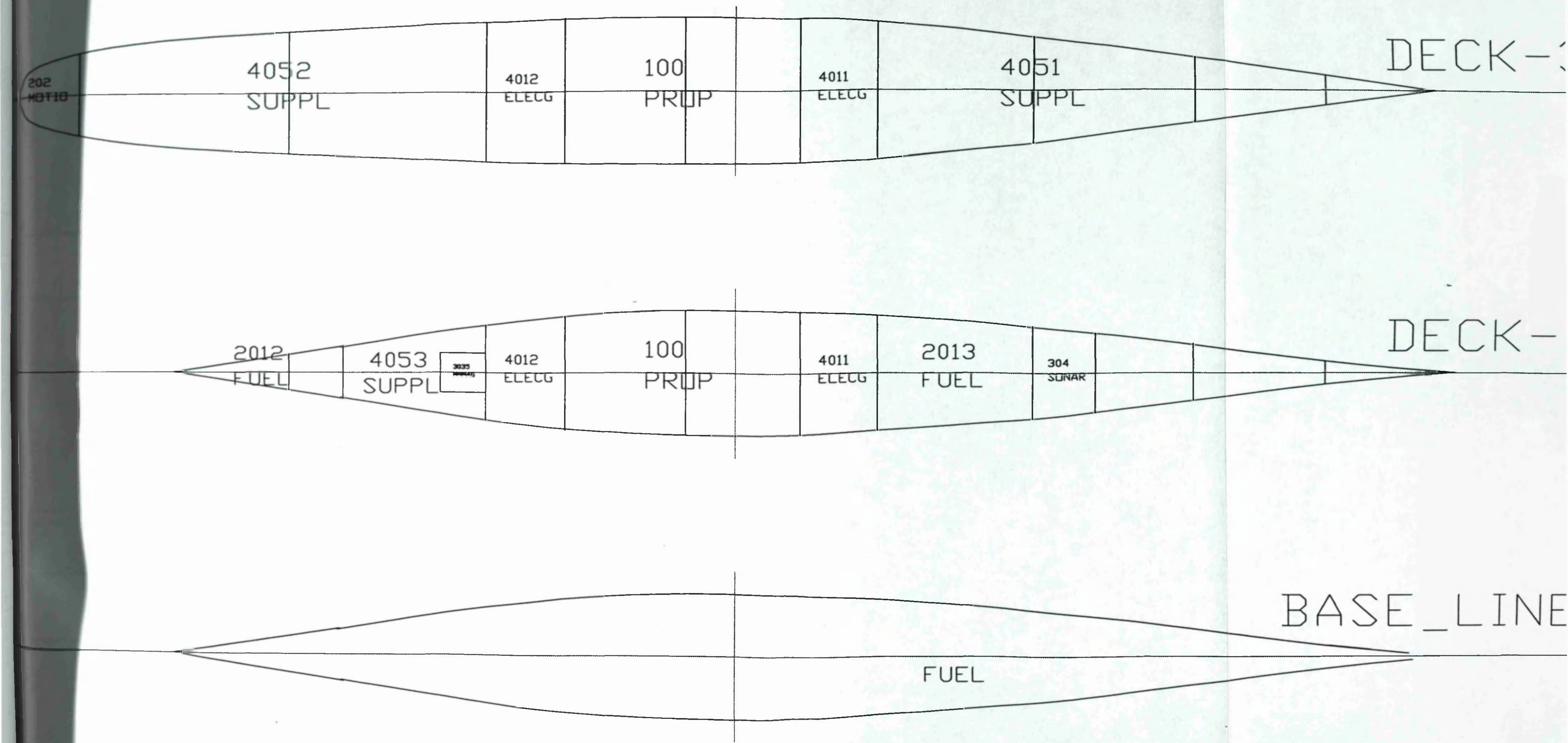


Figure E-8c Monohull Escort Building Block Design (Super Building Block Stage)

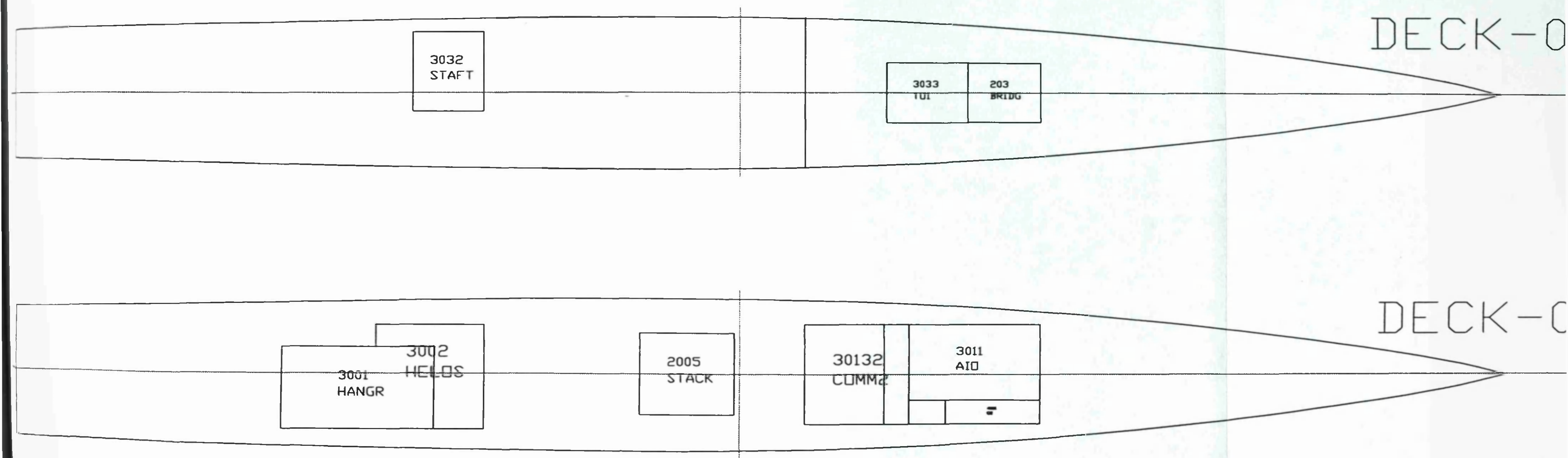


Figure E-9a Monohull Building Block Escort (Building Block Stage)

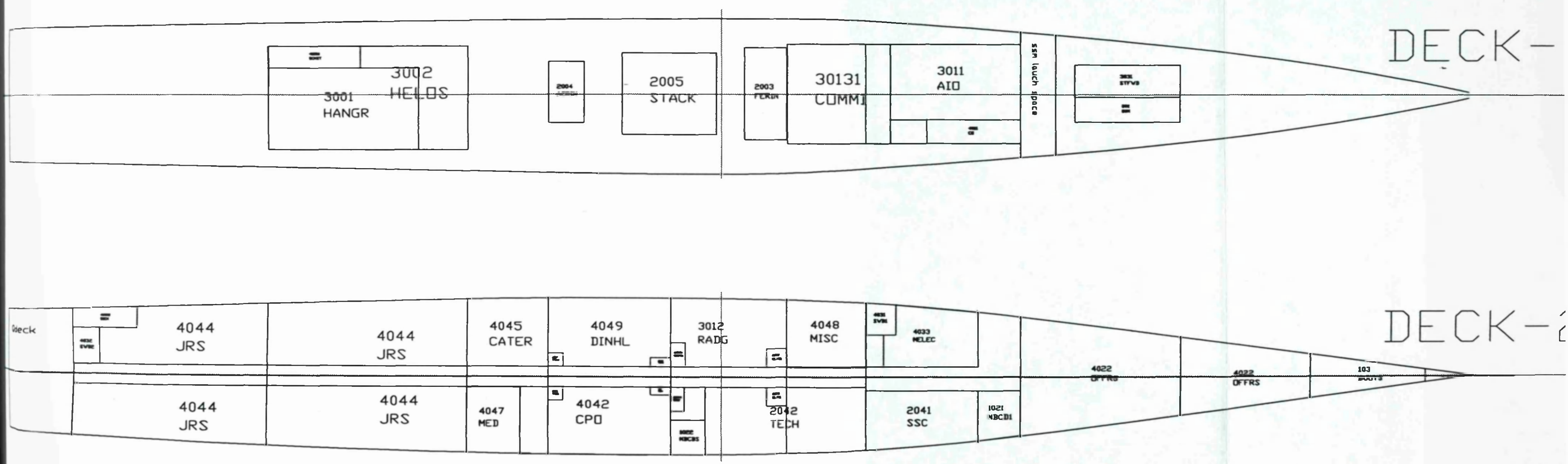


Figure E-9b Monohull Building Block Escort
(Building Block Stage)

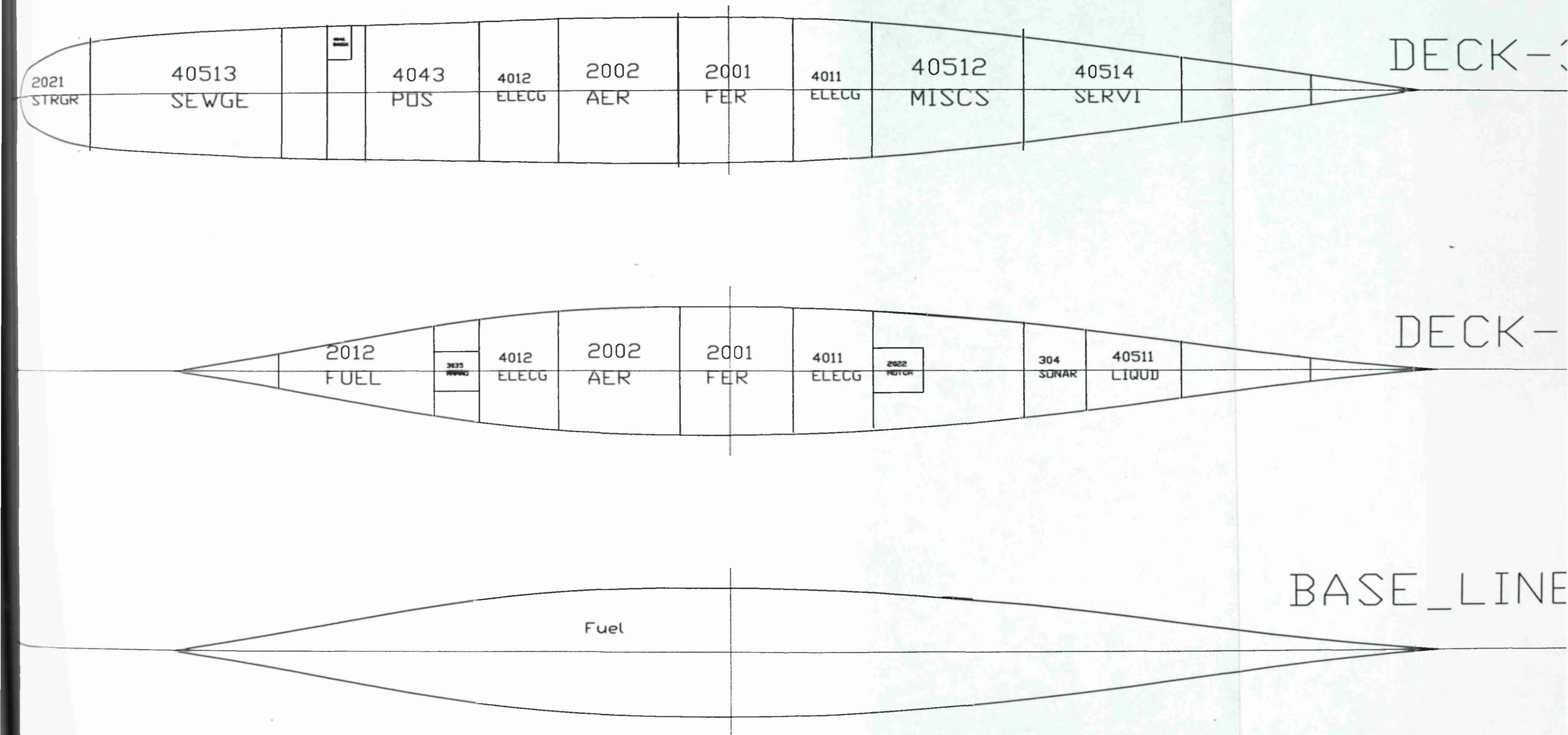


Figure E-9c Monohull Building Block Escort (Building Block Stage)

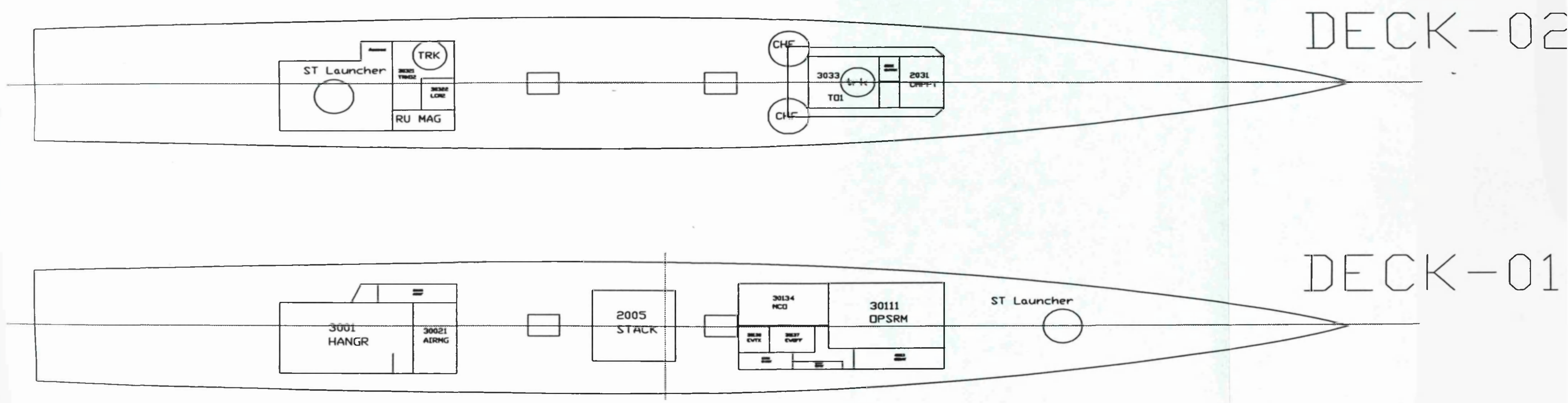


Figure E-10a Monohull Building Block
Escort Design General Arrangement (Decks 01 & 02)

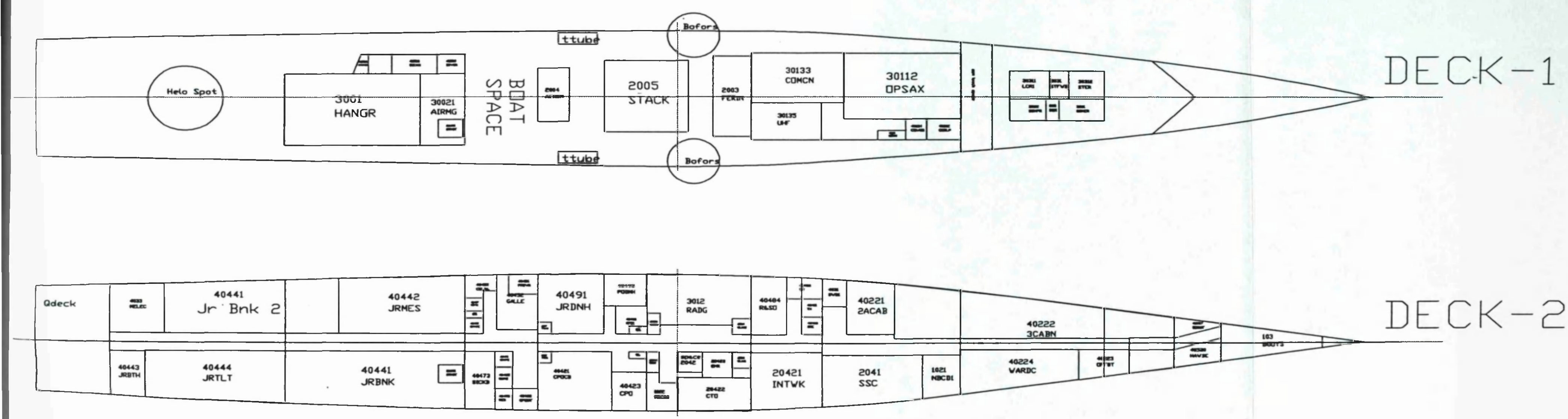


Figure E-10b Monohull Building Block
Escort Design General Arrangement (Decks 1 & 2)

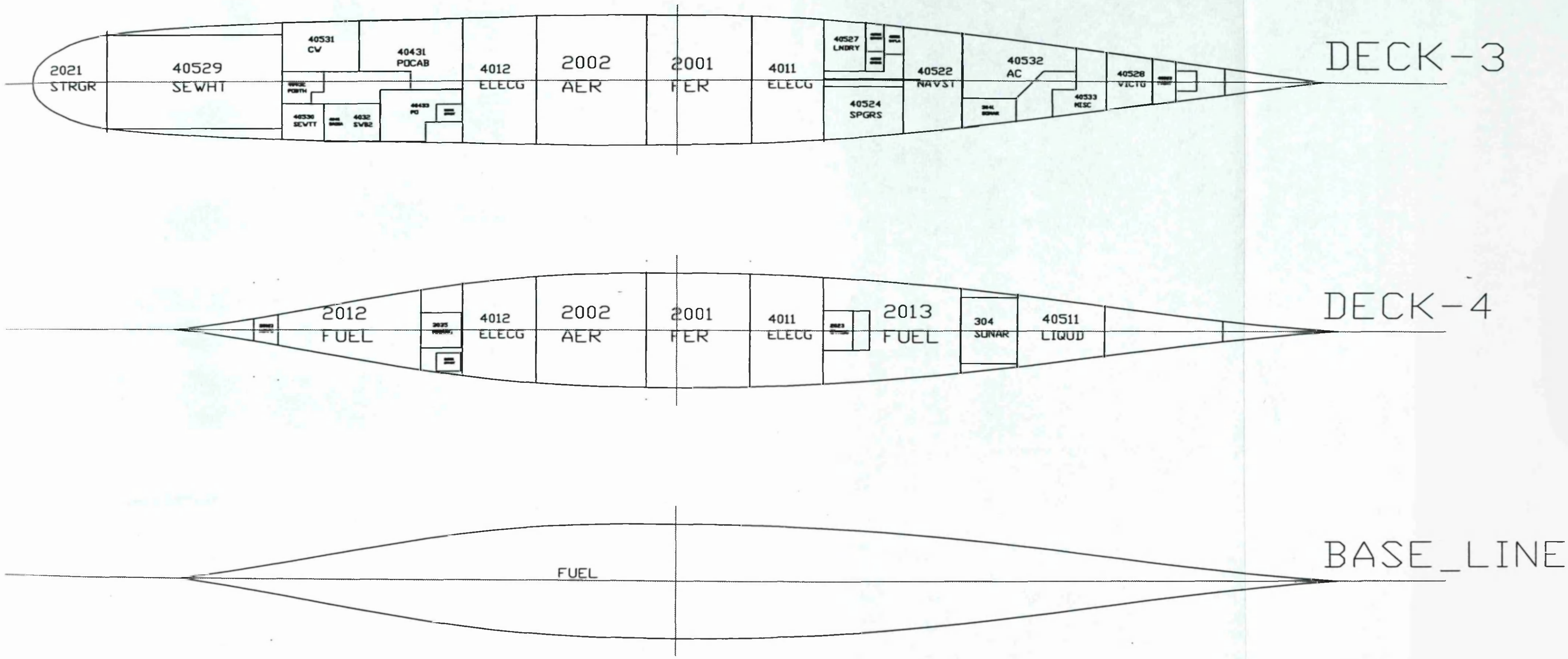


Figure E-10c Monohull Building Block
Escort Design General Arrangement (Lower Decks)

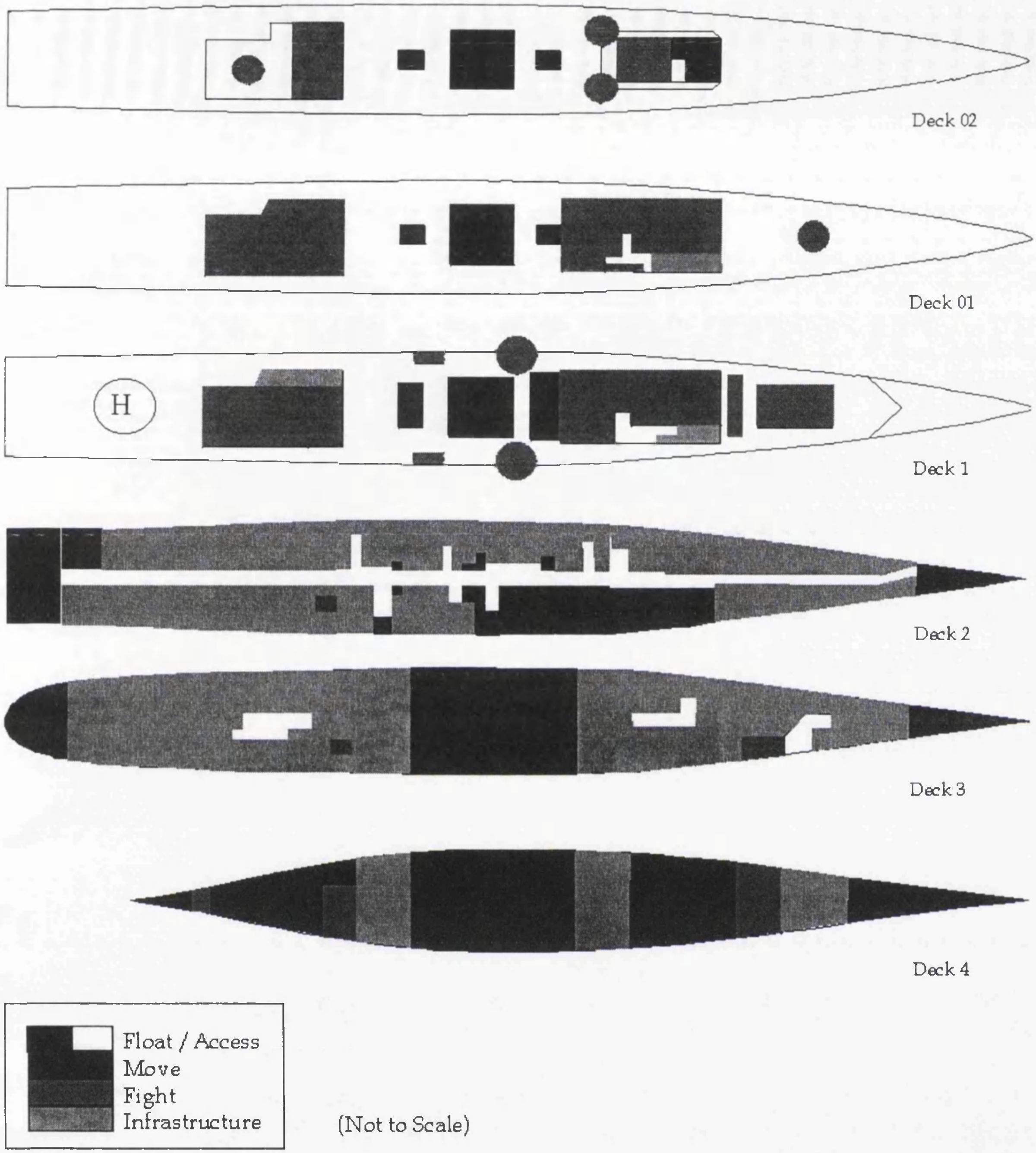


Figure E-11 Monohull Escort Building Block Design Colour Maps

Appendix E.3 Small Combatant Designs Appendices

Appendix E-3 details the application of the Building Block methodology to small naval designs. The modification of an existing design, modelling the impact of a new weapon system on gross ship characteristics is also detailed. This is performed by the investigation of several alternative designs, with similar equipment, meeting common performance and cost criteria. Section 7.2 detailed a requirement for a small patrol vessel suitable for military activity within a reasonable distance of an operating port. Four

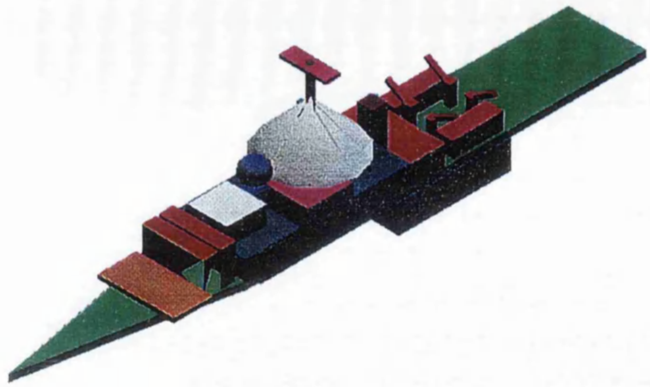


Figure E-13 SMC Model 3 Topside Design Model

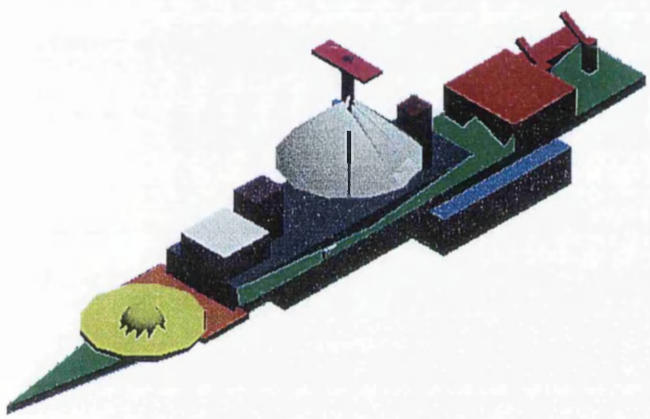


Figure E-12 SMC Model 4 Topside Design Model

alternative combat systems were postulated, sharing similar characteristics.

Topside Modelling of Small Combatant designs

As with the Monohull Building Block Escort design, the small combatant was assumed to have a topside design based design generator. Due to size only one superstructure deckhouse was added to each design. Two major constraints on topside arrangements were postulated, the separation of the Radar E / ESM mast from the CIWS radar in designs 2, and 4, and for all four designs the separation of all equipment from the main mast for communications aerial runs.

Many design issues influenced the arrangement, notably longitudinal space forward of the bridge and the volume required for operational spaces in the superstructure. Rendered images of Small Combatants 3 and 4's topside design models are shown as Figure E-13 and Figure E-12.

Design of four Small Combatant Designs at the Super Building Block Phase

Small Combatant Design 1 was developed prior to the remaining Small Combatant designs. The first hullform was defined, as were the Super Building Blocks, on the basis of the ship having the minimum dimensions determined by the Major Feature Stage. The majority of Super Building Blocks were located in the same location and approximately in the same order for each of the four designs. The first iteration of Small Combatant Design 1 was as Table E-1, and Row 17 details that the first iteration of Design 1 was not acceptable. The following problems were encountered:-

- The design weight was 750 t greater than its displacement.
- The design volume was 1650 m^3 than required.

- The design GM was less than the desired 1.5 m.
- Required engine room height was incompatible with the deck height requirements.

Order	Name of SBB	Location
1	Motion Command	Deck 01 at L/3 from Bow
2	SeaSwan / Radar E	Aft of 23000
3	Slope Superstructure	-
4	Fwd Bofors mount	Fwd of 23000 on Deck 1
5	RAS Space	Fwd of Bofors on Deck 1
6	76 mm Gun	Fwd of RAS Space on Deck 1 , 2
7	Mooring	Fwd of Gun on Deck 2
8	Motion Actuation	Aft most position on Deck 2 /3
9	Ops Complex	Underneath 23000 on Deck 1
10	Deck Stores	Aft of Ops Complex on Deck 1
11	Boat Space / Surf Sys	Aft of Deck Stores
12	Frog SSM	Aft of Surface systems
13	Fuel	Double Bottom
14	Prime Mover / Electrical Generation	Deck 3
15	Officers Accom	Fwd on Deck 2
16	Ratings Accom	Aft on Deck 2
17	Damage Management Propulsion Control Electrical Distribution Supply / Disposal	Un-placed due to lack of space

Table E-1 Order of Super Building Block location in Small Combatant Design 1

Resistance was assessed as satisfactory using several methods[i]. Using this information the fuel requirement of the design was varied with resistance characteristics, for the first time in a Building Block design. The changing fuel requirements did not affect the designer's ability to produce a design once a first accurate assessment was undertaken. Following a parametric investigation, assessing the effect of changing dimensions on the deficiencies stated above, two alternative options suggested themselves:-

- A Two Deck solution
- A Three Deck solution

A three hull deck solution drove the design to a larger and more expensive displacement. An important design constraint was a need to provide 3.6 m of deck height to the engine spaces, compared with the 2.7 m of deck head height provided elsewhere. Two separate two deck solutions were postulated. The first two deck solution required a 3.6 m high 3 deck to allow machinery spaces to fit on one deck, with a constant height double bottom. This design concept forced all compartments located on 3 deck to have a 3.6 m deck height, which was unacceptable.

[i] Series 64 [*Yuh, 1965*], the GODDESS POWSPD program [*Barratt et. al., 1994*]and a UCL resistance estimation graph [*M.Sc., 1993*].

	Design 1	Design 2	Design 3
Displacement [t]	1884	1884	1877
Volume [m³]	4983	4983	5004
Length [m]	82	82	87
Beam [m]	11.8	11.8	11.4
Draught [m]	3.8	3.8	3.85
Depth [m]	7.3	7.3	7.3
Block Coeff.	0.5	0.5	0.48
Midships Coeff.	0.833	0.833	0.8
Prismatic Coeff.	0.6	0.6	0.6

Table E-2 Small Combatant Design 1,2 and 3 Gross Ship Characteristics

A second potential solution was to alter the double bottom height under the engine blocks to height of 1 m. At other locations a double bottom of 1.9 m would be employed, allowing 3.6 m high machinery decks and 2.7 m deck heights. This was structurally less desirable. Investigations suggested that overall the second design option was more favourable leading to the dimensions shown in Table E-2 for Small Combatant 1. This design was developed through a second and third iteration in which design changes were caused by variation in the fuel requirements. Finally the design dimensions were as shown in Table E-2.

Definition of Small Combatant Designs 2-4

Small Combatant Designs 2-4 considered the definition of alternate, similar designs to the Small Combatant design requirement. To model the ability to design similar but different small combatant designs two different approaches were used. The first approach modified the existing Small Combatant Design 1 definition [to produce Design 2]. Another approach [Design 3] began with a new Major Feature stage. Using two different mechanisms to develop variations on Design 1 allowed the assessment of whether the adaptation of an existing design to new system arrangements would meet the following requirements:-

- A new design should not inherit irrelevant design issues from the parent design, distorting the process.
- A new design's dimensions and configuration should be fully justifiable.
- Is time and effort saved by re-using relevant design information and decisions?

The major changes were, the location of the Close In Weapons System in Design 2, and the addition of the SSM missile system and Flight deck in Design 3. Almost all other Super Building Blocks changed in numerical size but did not change location in the ship design. The dimensions of Designs 2 and 3 at the end of the Super Building Block phase were as shown in Table E-2.

Adapting Design 1 to the prevailing requirements of Design 2 was a rapid process compared with re-developing Design 3 from initial design stages. This suggests that more studies could be undertaken in a fixed period. Once Design 2 was complete there were no reasons to deviate from Design 1's original dimensions. The small design changes made did not affect overall requirements sufficiently to require a change of dimensions. Therefore decisions made in Design 1 did affect Design 2's dimensions. This was acceptable in this case, as those decisions were applicable to this design. The development of Design 3 showed that many of the Design 1 decisions were unconsciously repeated for Design 3, although the addition of the Flight Deck required a longer design to meet the design generators requirements with consequent changes to gross ship characteristics. In Designs 2 and 3, assumptions as to internal configuration, deck heights, engine room arrangements and general style of Design 1 remained. As a result the following issues could be raised:-

- The Building Block methodology can be used on designs starting from separate design generator models and will produce designs that are independent where requirements dictate, or follow the same trends where requirements are similar, provided the designer is careful.
- When one design is created from another by removal or addition of small Super Building Blocks, changes may not have a large effect on the overall dimensions and potentially irrelevant design decisions may result.
- The "rapidity" of converting a design from an existing one is much greater than starting a new design from the earliest design stages, as the Major Feature design in which minimum dimensions are used to assess which size range the ship lies in is avoided.

This is important for preliminary design stages as these often require several similar designs to be prepared, based on a common baseline, to assess changes in design resulting from addition or removal of systems, capabilities and requirements.

Displacement [t]	1735.9
Volume Available [m³]	4536
Length [m]	80
Beam [m]	11.5
Draught [m]	3.8
Depth [m]	7.3
Block Coeff.	0.48
Midships Coeff.	0.8
Prismatic Coeff.	0.6

Table E-3 Small Combatant Design 4 Gross Ship Characteristics

Small Combatant Design 4 details a greater degree of change from a parent design. Design 4's requirements were reduced to require the basis design [Design 2] to be notably reduced in size to meet the new requirements. The final gross ship characteristics are detailed in Table E-3. The reduction in size was smaller than initially expected, as fuel requirements increased, due to a reduction in length adversely affecting resistance in cruise speed. The design investigation suggested that the design, whilst derived from previous designs, did have its features dictated by the new requirements. Hence it is considered acceptable to derive a second design study by starting the second design from the earliest design stages or by modifying a parent design as necessary. Figure E-19 illustrates the discussion of Appendix E.3 by provision of the general arrangement of Small Combatant 4 at the end of the Super Building Block Design Stage. The three remaining Small Combatant designs shared similar arrangements and are not detailed here. Further detail is provided in [*Dicks, 1996*].

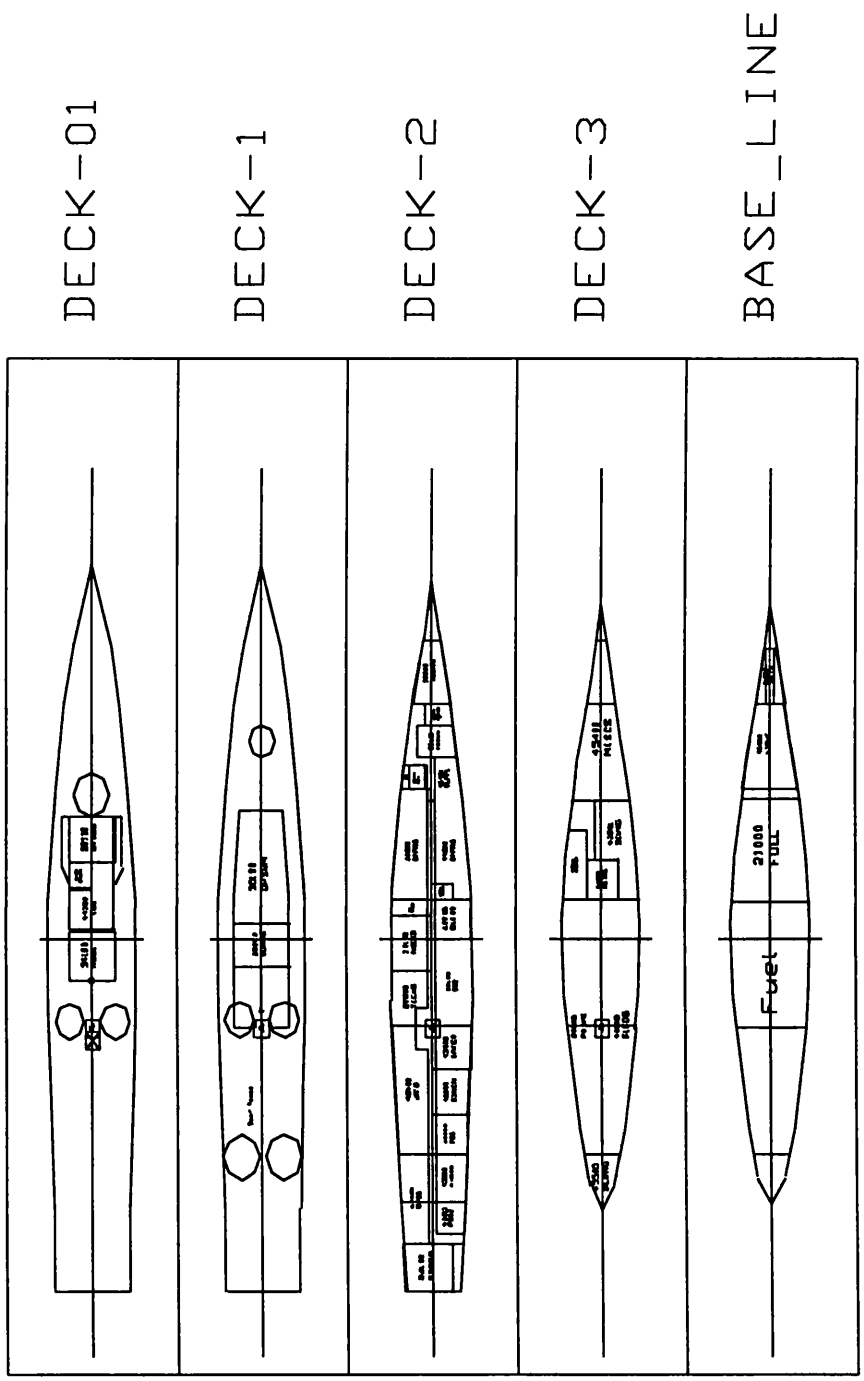


Figure E-14 Small Combatant 4 General Arrangement [Post Building Block Stage]

Appendix E.4 Landing Ship Tank Appendices

Appendix E-4 details the development and final solid model of the Landing Ship Tank. The functional hierarchy used to develop the design and the three dimensional solid models used to represent the design as Building Blocks, are presented.

Landing Ship Tank Functional Hierarchy

Figure E-15-Figure E-20 detail relationships between the Overall LST Design and the constituent Building Blocks.

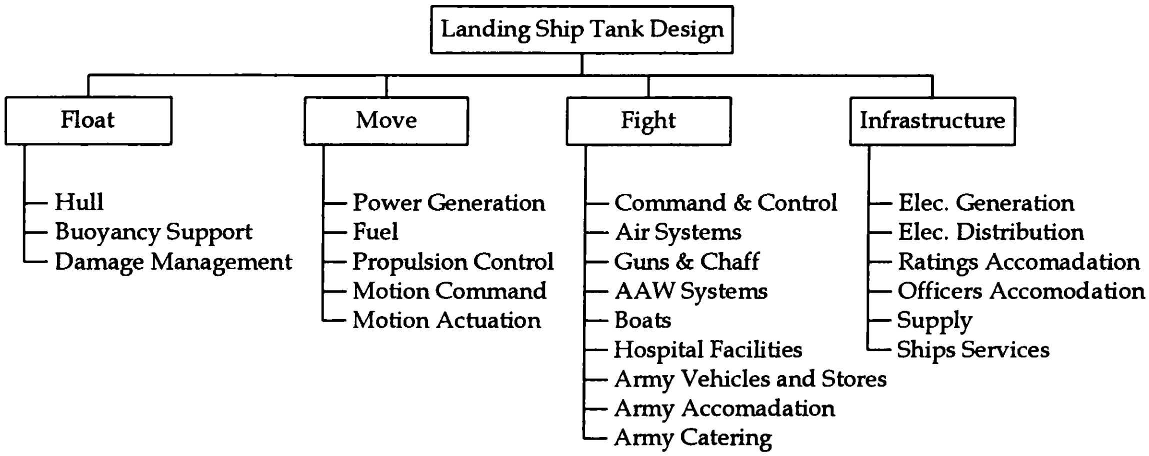


Figure E-15 LST Overall Functional Hierarchy

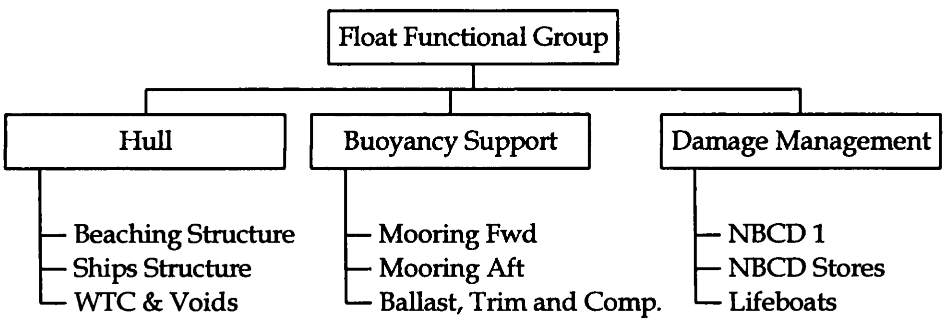


Figure E-16 Float Functional Group Component Super Building Blocks and Building Blocks

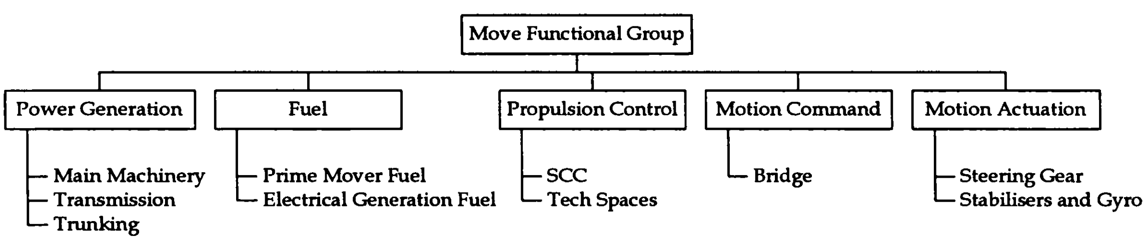


Figure E-17 Move Functional Group Components

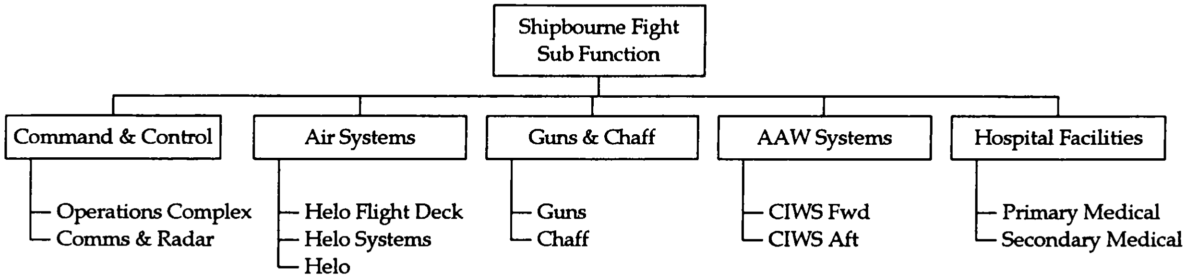


Figure E-18 Fight Functional Group Components [Shipborne Fight Element]

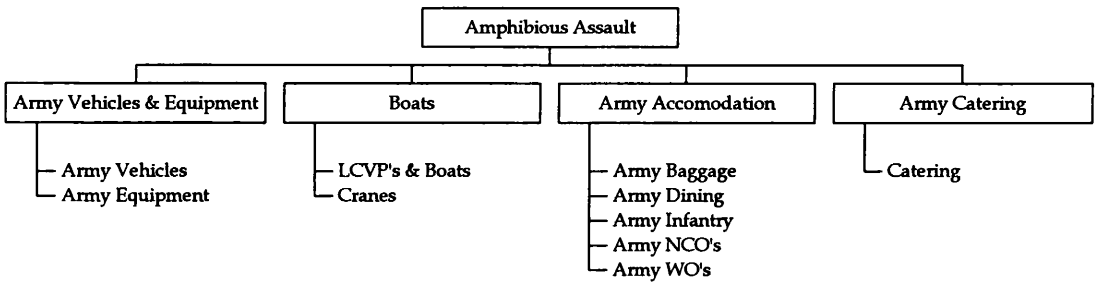


Figure E-19 Fight Functional Group Components [Amphibious Assault]

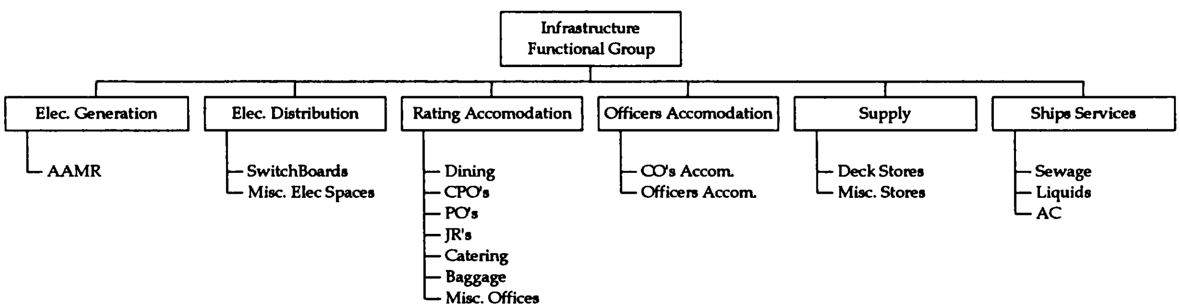


Figure E-20 Infrastructure Functional Group Components

Landing Ship Tank Solid Model Illustrations

The solid models detailed in Figure E-21-Figure E-28 were developed using Autodesk Mechanical Desktop as "parts" representing Building Blocks and Design Generator design elements.

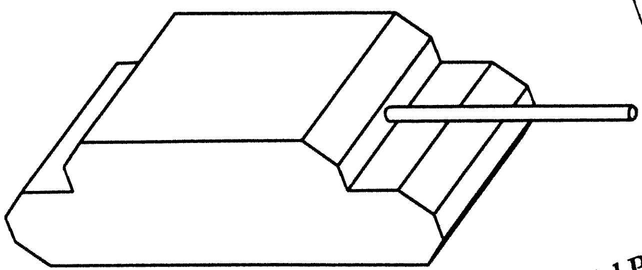


Figure E-21 Challenger 2 MBT Solid Model Part

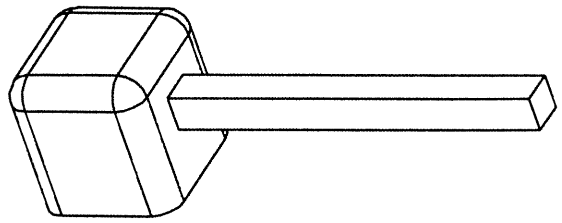


Figure E-22 25 Tonne Crane Part

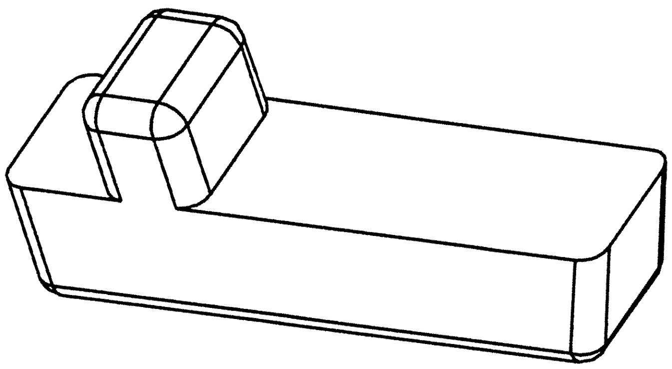


Figure E-23 Landing Craft Part

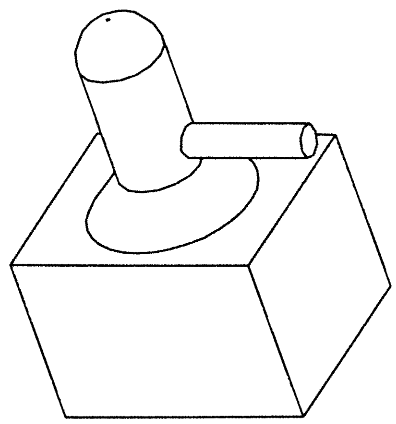


Figure E-24 CIWS1 Part

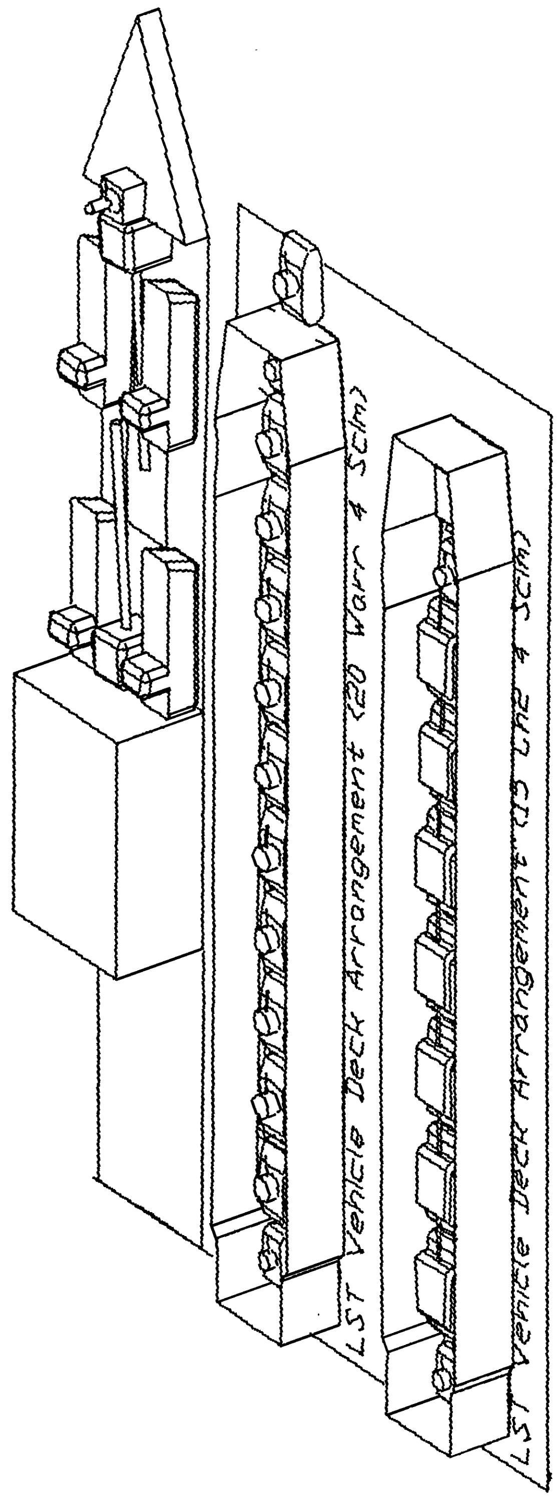


Figure E-25 LST Design Generator Arrangements

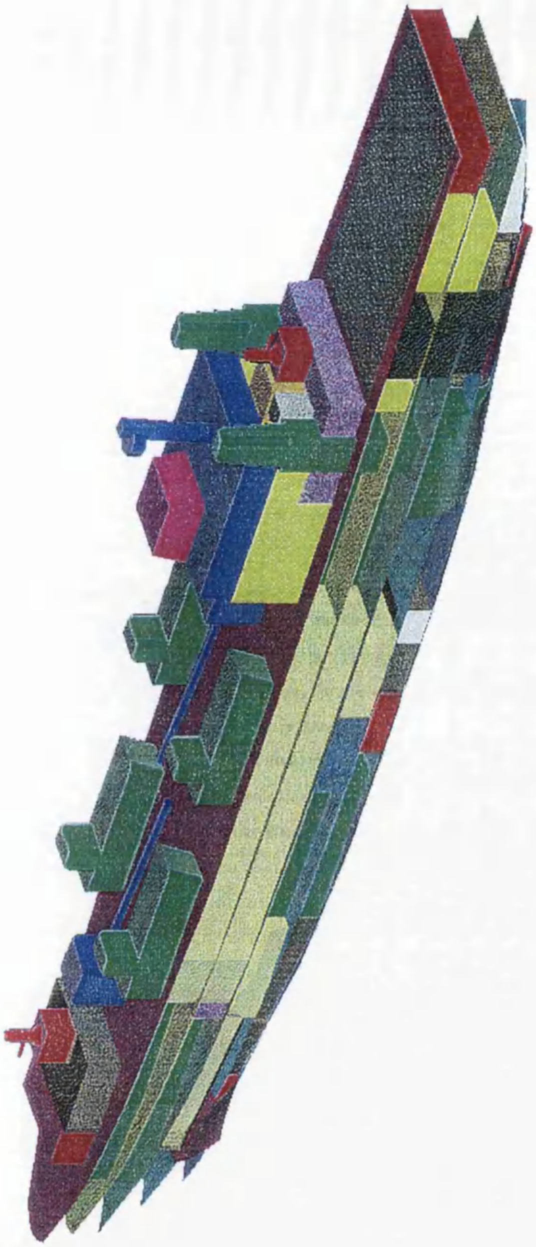


Figure E-26 LST Design Internal Arrangement

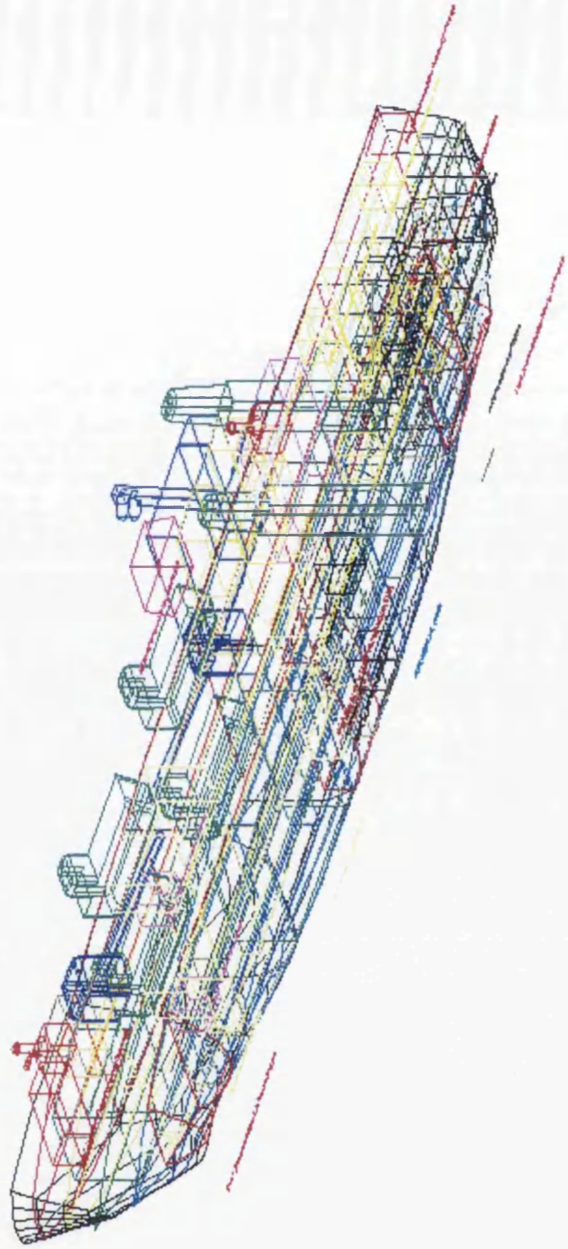


Figure E-27 Wireframe Representation of Complete LST Model

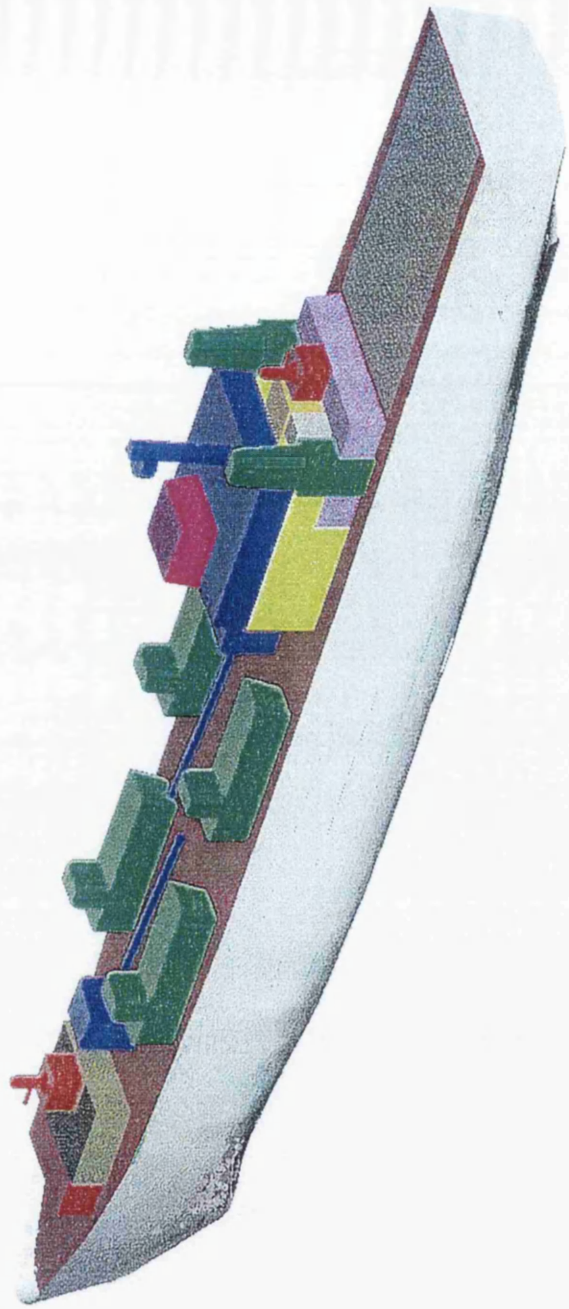


Figure E-28 Complete LST Model

Appendix F. Unconventional Design Appendices

Appendix F.1 Trimaran Appendices

Appendix F provides additional design information regarding the Trimaran and SWATH designs detailed in Chapter 8. Appendix F-1 details the Trimaran Building Block design while Appendix F-2 details both SWATH designs.

Trimaran Topside Models

A major design issue with the Trimaran Escort design was the development of minimum topside dimensions. The selection of Prime Mover location heavily influenced this investigation. Figure F-1 illustrates the design model used to develop the minimum sized topside arrangements with an internal Gas Turbine System. Figure F-2 details the topside arrangement of a design with a superstructure mounted Gas Turbine system.

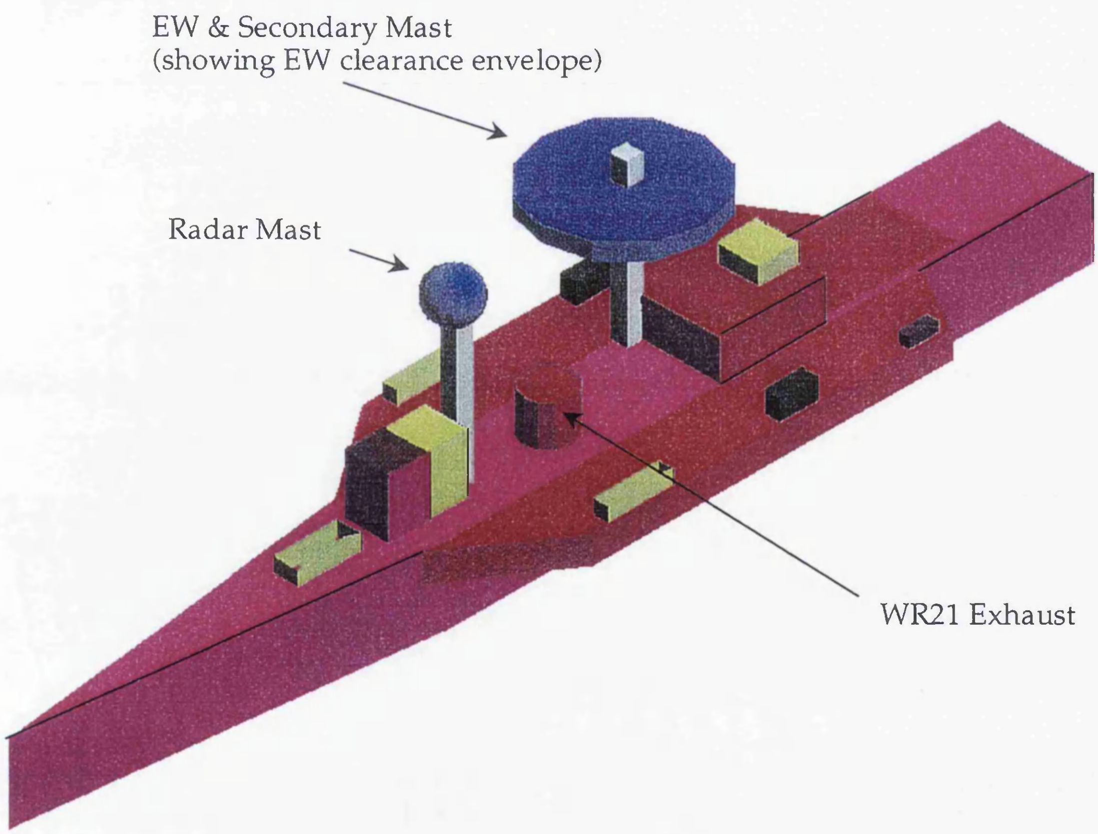


Figure F-1 Internal Gas Turbine Trimaran Topside Model

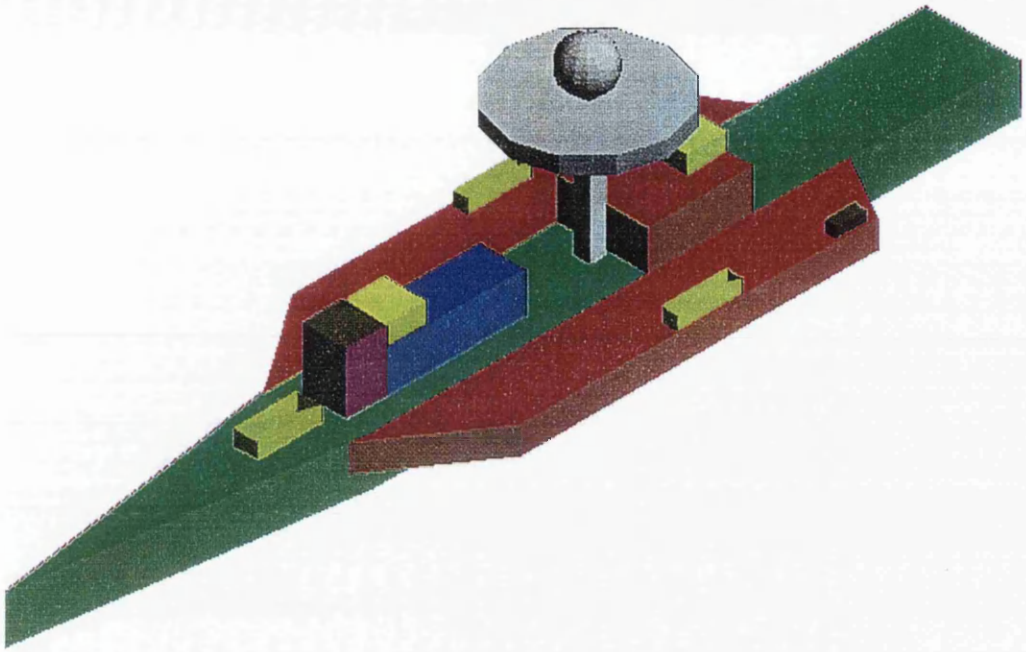


Figure F-2 Superstructure Mounted Gas Turbine Trimaran Topside Model

Trimaran Functional Hierarchy

This appendix details the functional hierarchies used in the development of the Trimaran Escort Building Block Design.

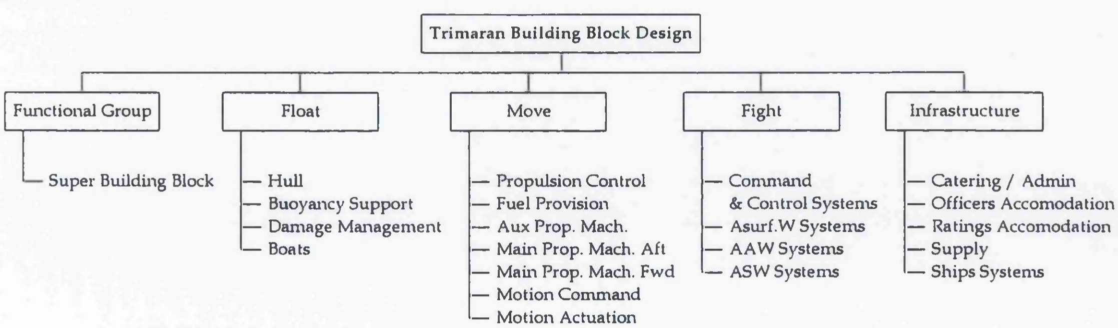


Figure F-3 Trimaran Building Block Model Overall Functional Hierarchy

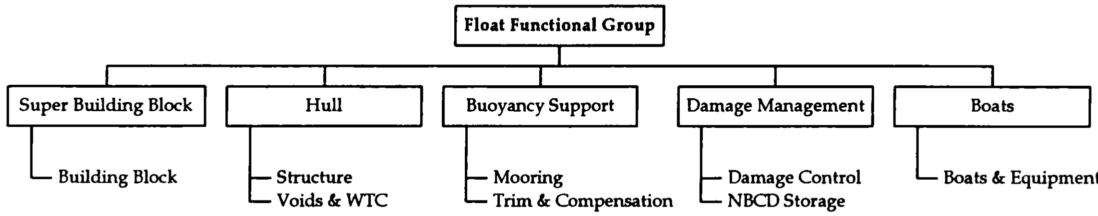


Figure F-4 Trimaran Building Block Model Float Functional Group

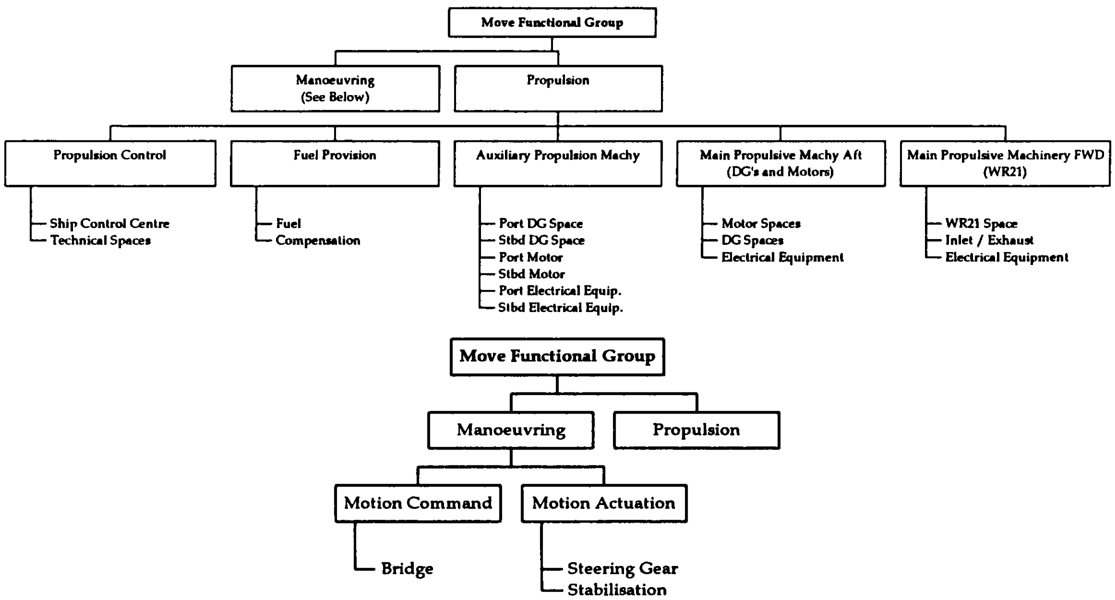


Figure F-5 Trimaran Building Block Model Move Functional Group

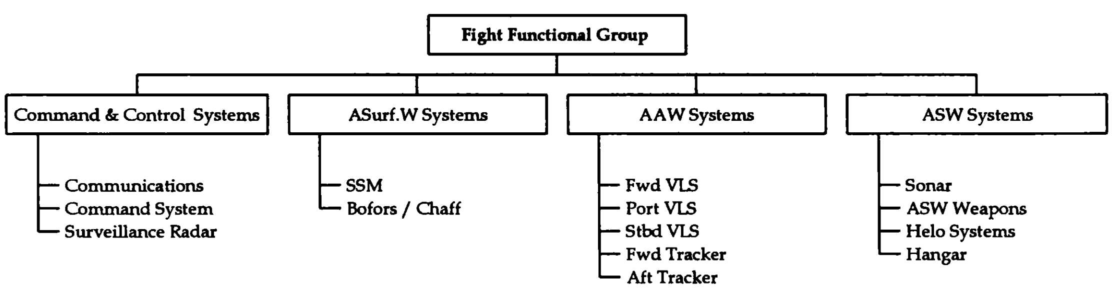


Figure F-6 Trimaran Building Block Model Fight Functional Hierarchy

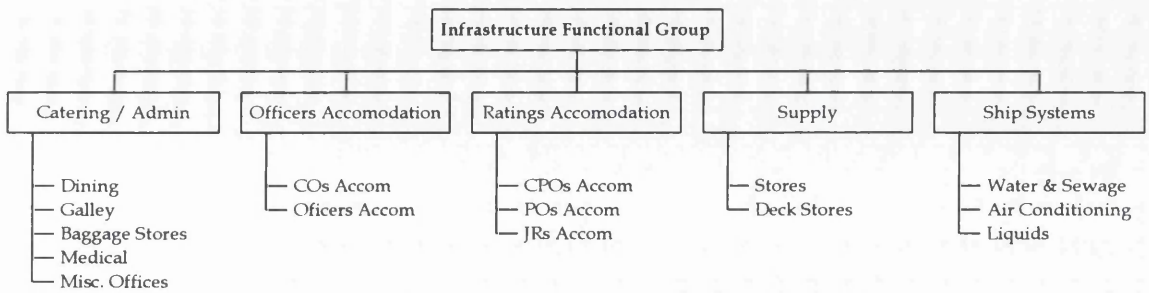


Figure F-7 Trimaran Building Block Model Infrastructure Functional Group

Trimaran Functional Maps

The following functional maps of the Trimaran Escort Building Block design illustrate the locations populated by elements of each of the four functional groups. The colour maps are not to scale but are representative.

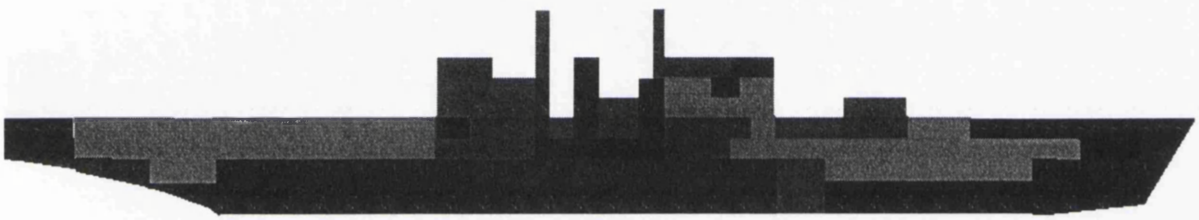


Figure F-8 Trimaran Functional Colour Profile Map

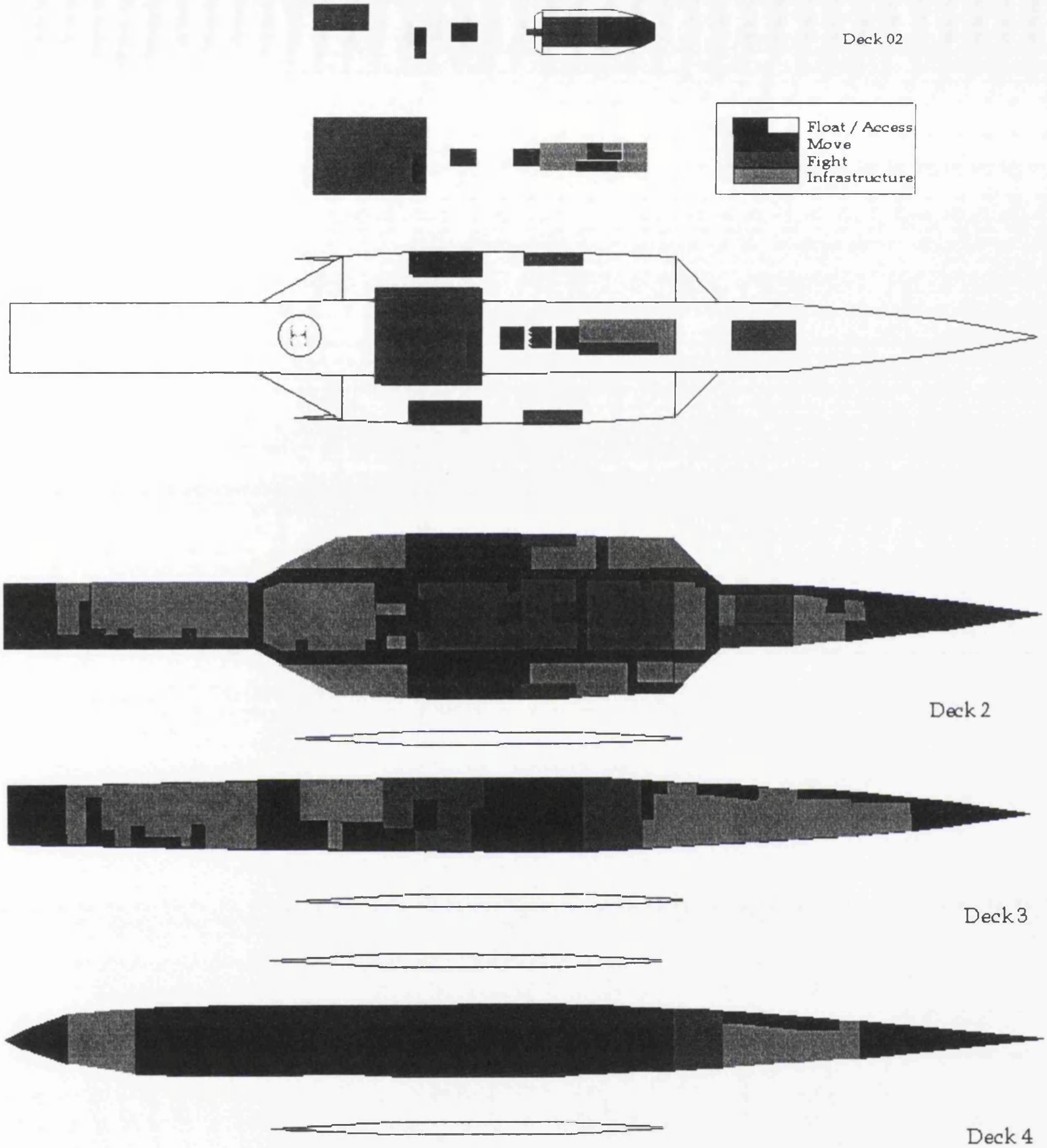


Figure F-9 Trimaran Functional Colour Deck Maps

Trimaran Escort General Arrangement

Figure F-10 details the internal arrangement of the completed Trimaran Escort Building Block design.

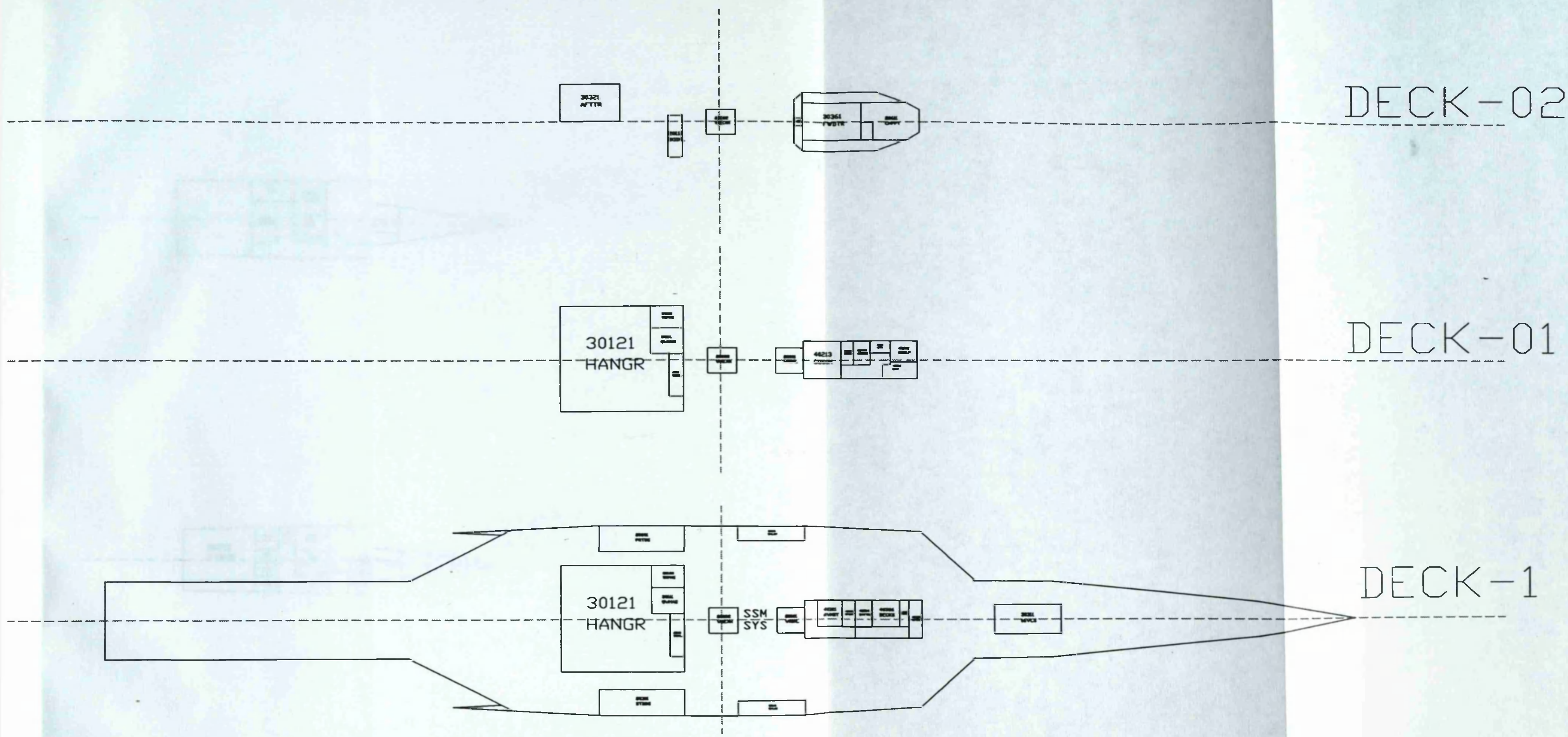


Figure F-10a Trimaran Building Block Design (Decks 02-1)

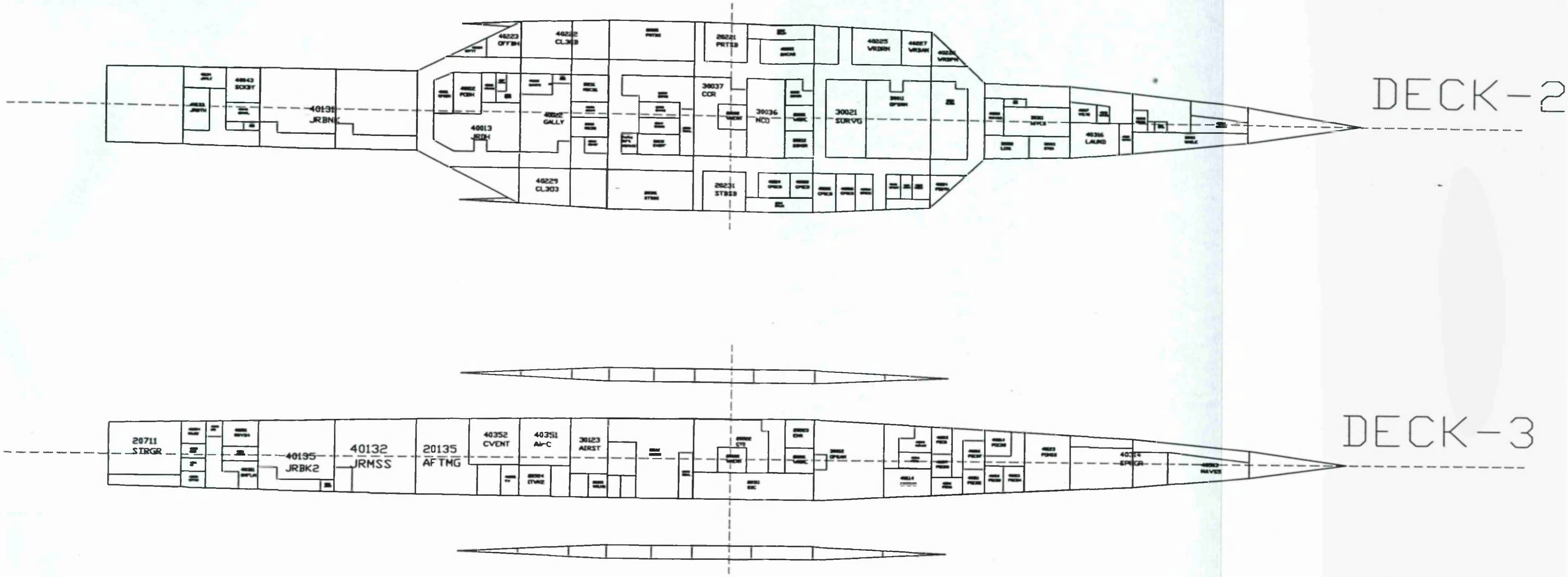


Figure F-10b Trimaran Building Block Design (Decks 2 and 3)

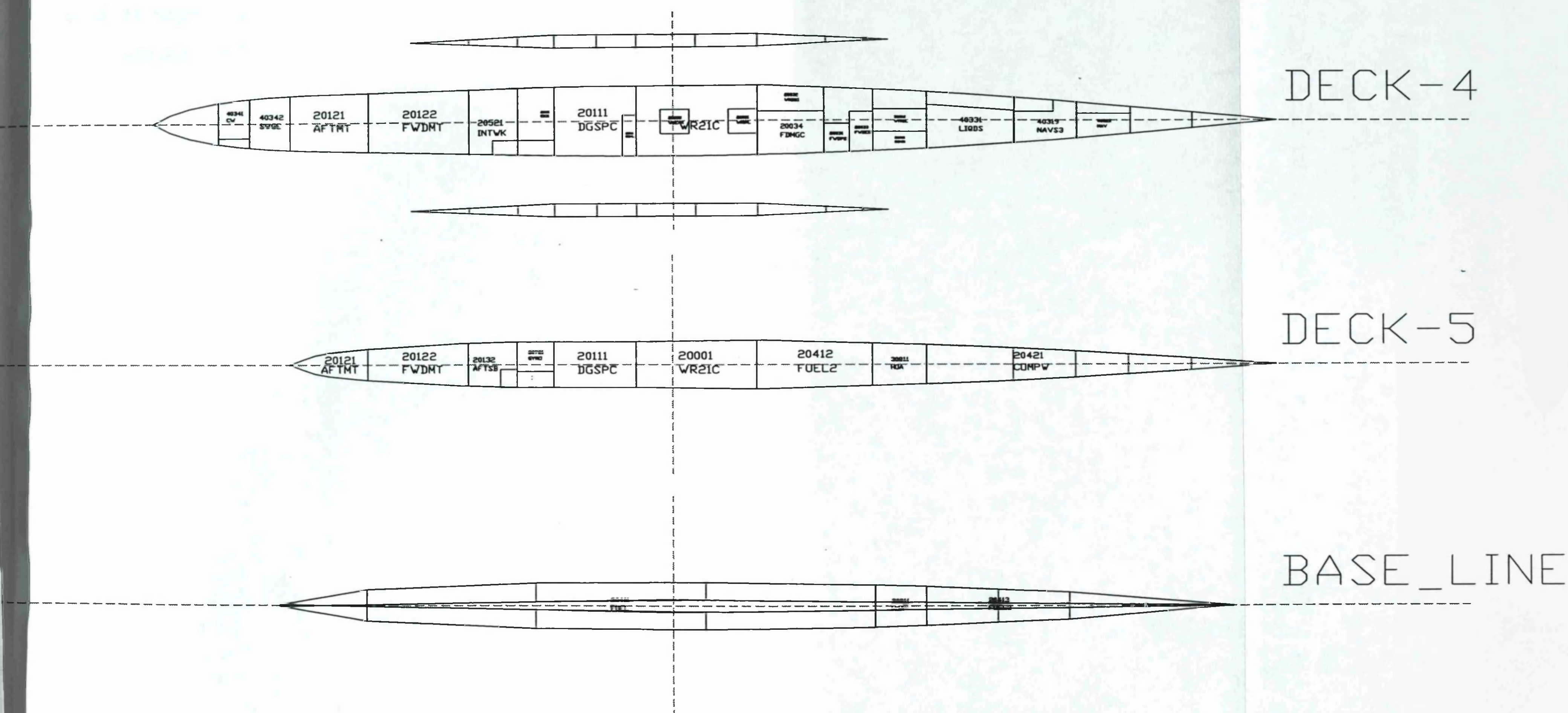


Figure F-10c Trimaran Building Block Design (Decks 4,5 and Baseline)

SWATH Solid Model Illustrations

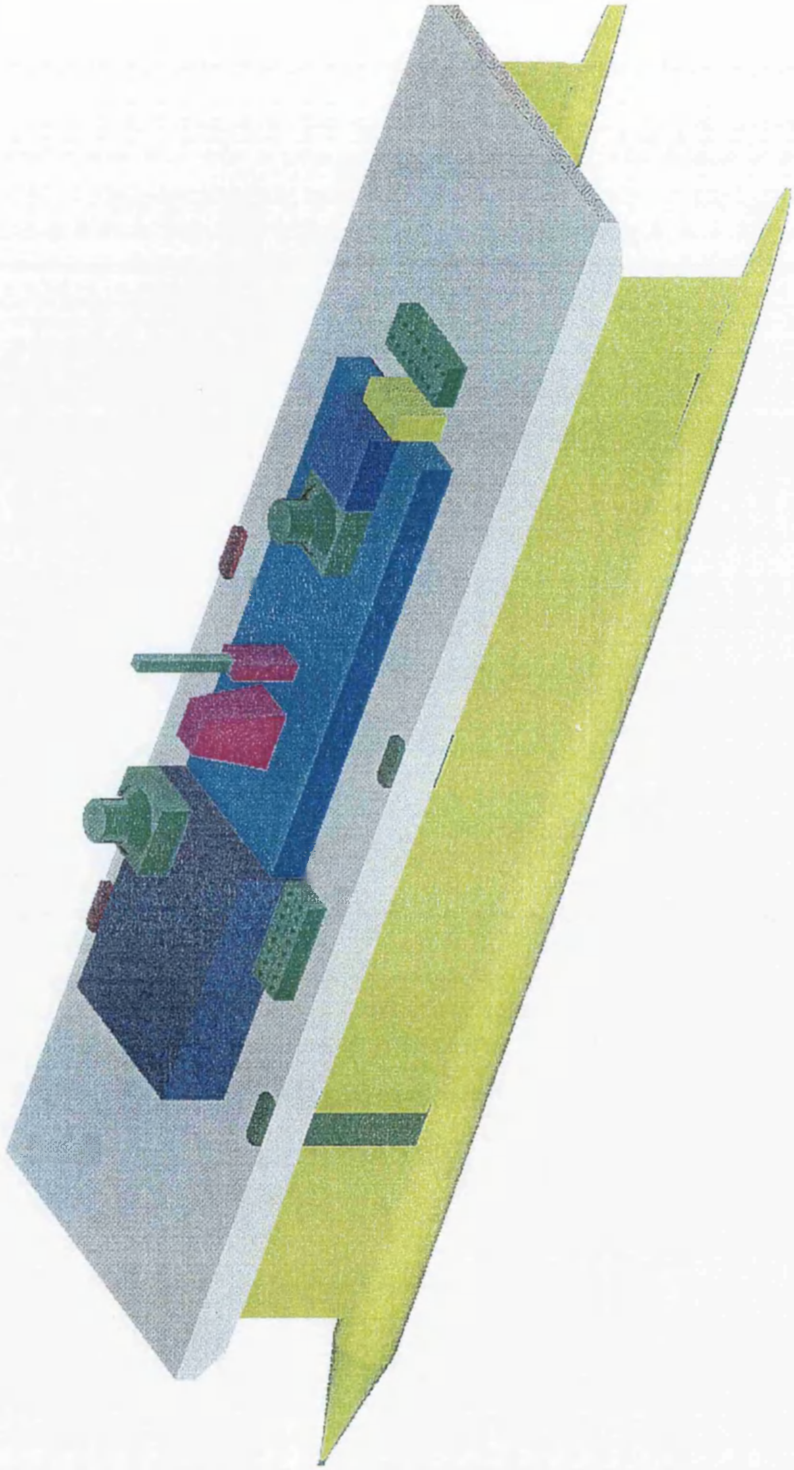


Figure F-11 SWATH 1 Design at the Super Building Block Stage

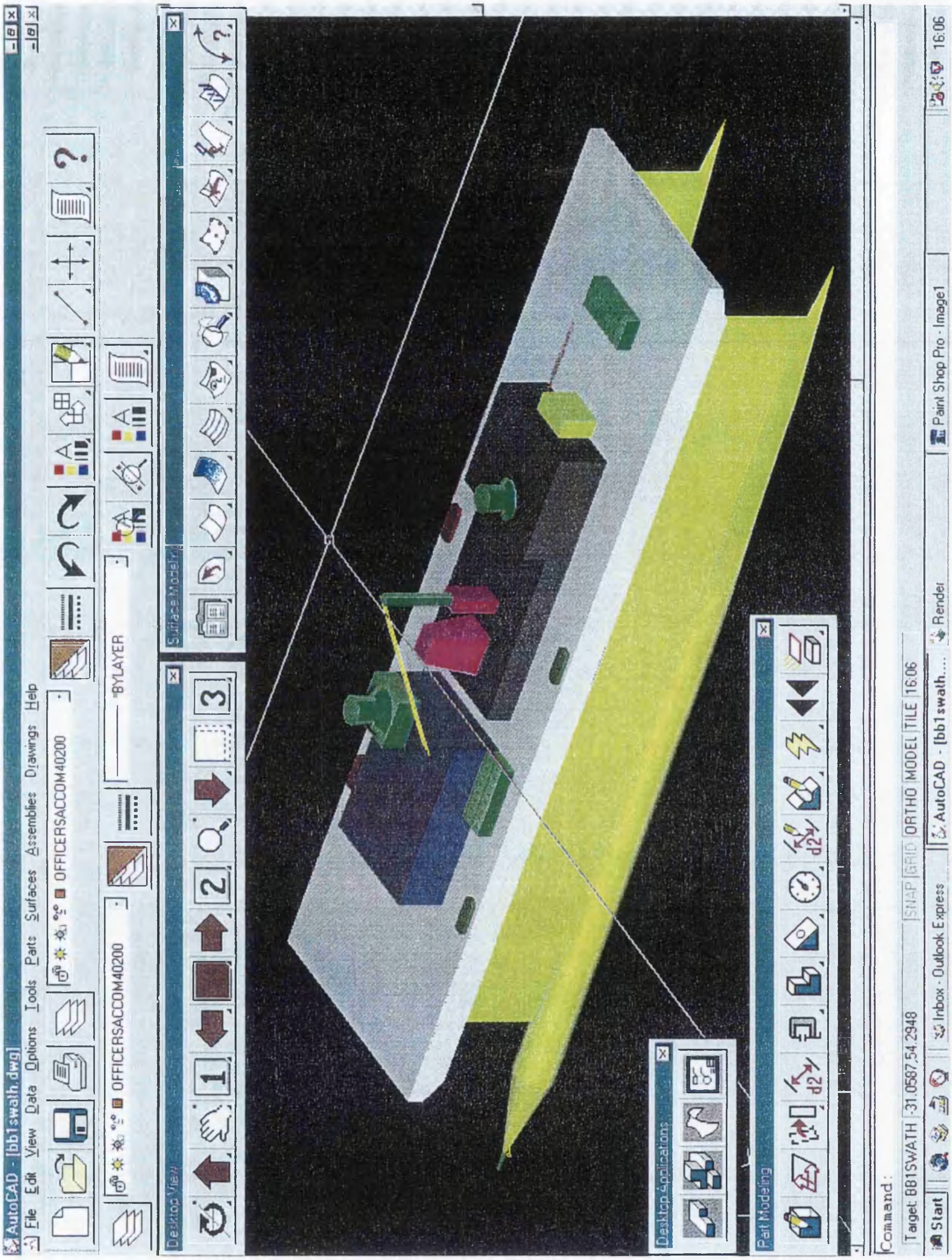


Figure F-12 SWATH 1 Design Solid Model at the Building Block Stage

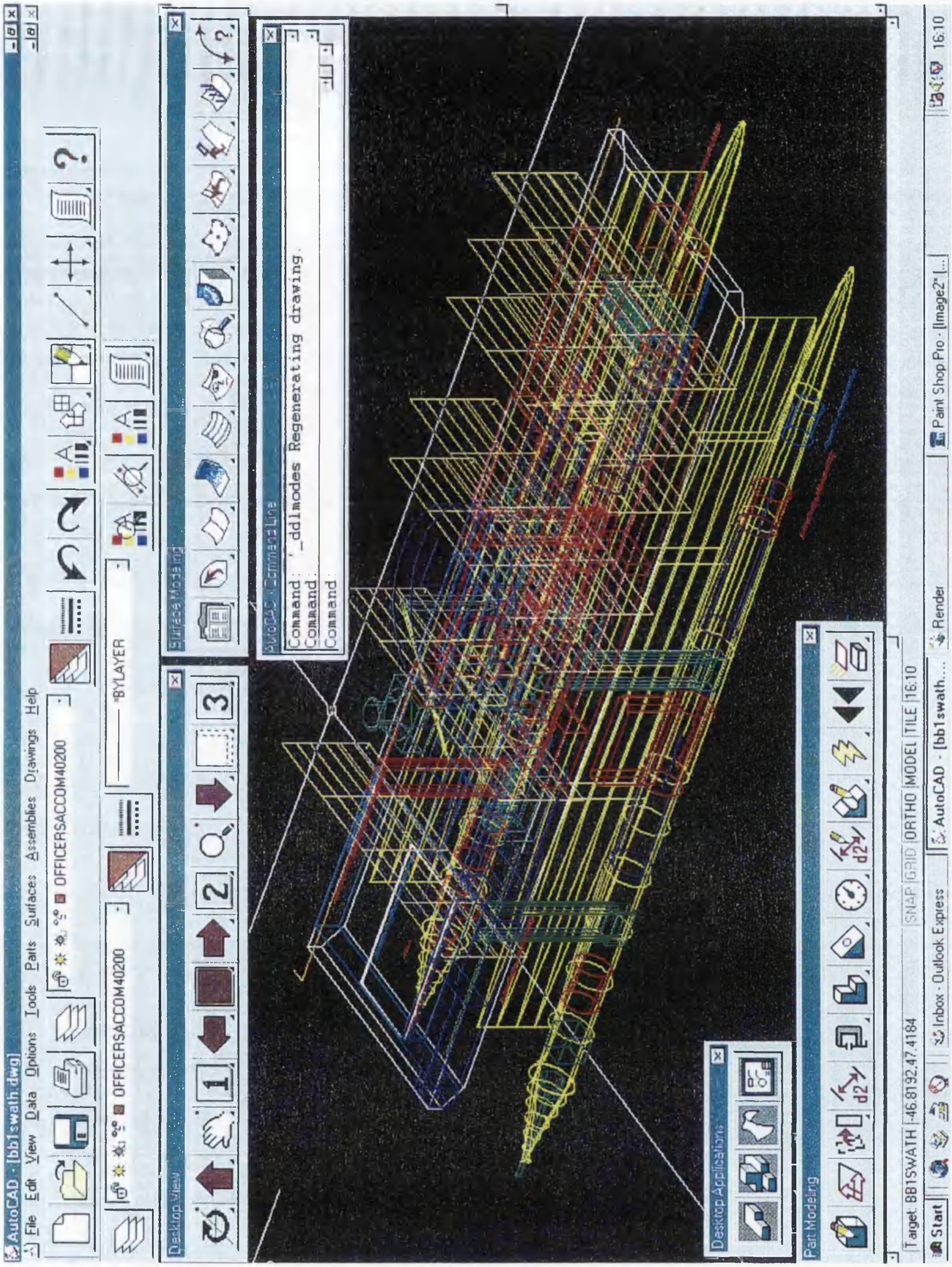


Figure F-13 SWATH 1 Design Wireframe Model at the Building Block Stage

Appendix G. Application of the Building Block Methodology to Cruise Liners

Appendix G.1 Introduction

Appendix G details briefly the research undertaken by Thor Einar Kolstadlokken at University College London in the Autumn of 1998. This research was undertaken with a view to developing the Building Block Design methodology as published in [*Andrews & Dicks, 1997*] for non military applications. In particular the research explored the applicability of the Building Block approach for commercial applications in the field of Cruise Ship design. Two figures detail the Monohull and SWATH Cruise Liner designs developed by Kolstadlokken using the Building Block Design Methodology.

The research presented was developed exclusively by Thor Einar Kolstadlokken for a Masters thesis. The author acted as a consultant, providing guidance and assistance where required.

Appendix G.2 Summary of Kolstadlokken's Research

Thor Einar Kolstadlokken has given permission for a summary of his research to be provided in this Appendix. The extract used is from the introduction and conclusion of a draft version of the Masters dissertation [*Kolstadlokken, 1998*].

"Introduction

This report is split in two parts.

Part I contains the presentations of the methodologies and theory which I have based my work on. The system-based ship design method and SeaKey system is presented first, describing the methods five phases and the computer based program that comprise the framework for a design task.

Next is a presentation of the Building Block methodology, including the background for developing it for naval use, and a more detailed presentation of definitions and procedures.

The principles of axiomatic design developed by N. P. Suh are also presented, with emphasis on the Independence Axiom, functional requirements' hierarchies and the connection between functional requirements and design parameters. The System-based ship design method and the principles of axiomatic design are presented quite briefly, while the Building Block methodology has been *given more attention. This is primarily because the Building Block approach is the basis for the thesis, secondly because the referenced material is not publicly available, as the sources are yet to be published.*

Part II opens with two design case studies, one conventional cruise vessel and one unconventional vessel. These designs form the "research specimens", and the problems specified in the task description are investigated and discussed. In the following chapters, based on these discussions, I present my proposals for a functional split up, the use of an axiomatic design equation and an adapted design procedure for Building Block synthesis of a cruise vessel. Finally, the conclusions from the work are summed up.

Conclusions

The presented background and theory together with the case studies show the many similarities between the systems based ship design process and the Building Block methodology. They also show that the Building Block method is applicable in design of cruise vessels.

The proposed functional split up for a cruise vessel follows the same pattern as the split up used in design of naval vessels, though it is intended to comply with the Independence Axiom. This is achieved partially by assigning some support functions to the payload functions, thus obtaining a high degree of main function independence. The split up consists of 6 levels from whole ship down to compartments. and analysis of the reference vessel shows that all compartments could be assigned one group without significant conflicts or inconsistencies. Based on the functional split up an attempt has been made to incorporate the use of design matrices in the Building Block approach. Although the principles of functional requirements' independence is useful in ship design, it is not obvious that the using the design matrices is worth while.

The current Building Block design procedure has been adapted in an effort present a procedure suitable for cruise vessel design. This new procedure is influenced both by the current system based design procedure and the principles of the Independence axiom.

The ability to estimate volume, weight and cost appears to be equal for the current design method and the Building Block approach, as their starting point is equal. The Building Block approach offers a better basis to monitor the influence of design decisions on cost and weight. The effect on function or system level can be *equally handled by both, but with the Building Block method the designer can assess the influence on configuration and ship gross characteristics with more confidence.*

The estimates of centre of gravity and radii of gyration will be made with less uncertainty when the design is produced with building blocks. This improves the reliability of stability and seakeeping analysis. The Building Block approach also enables the designer to carry out a damaged stability assessment at an early stage with a feasible subdivision and layout.

The Building Block method also lets the designer investigate the suitability of proposed access layouts as escape routes, lifeboat space requirements and influence of the layout. as well as fire zone influence on configuration, all at early stages.

As the ship synthesis is layout centred in the Building Block methodology, it is a good tool to assess space requirements and issues regarding passenger traffic lanes in general. It is an equally good tool when the basis of the investigation is the level of luxury, although it seems unlikely that this is a parameter that will change in the course of the design process.

To utilise the Building Block methodology, it is necessary to take advantage of computer aided design tools and database systems. Preferably these software systems should be integrated into one Computer Aided Ship Design program suite. Without such a tool, the advantages of the design methodology are negated by the time consumed by modelling in a non-purpose CAD tool and manually transfer data to the database. Thus the Building Block methodology is not suitable for practical design work until a working program suite is produced."

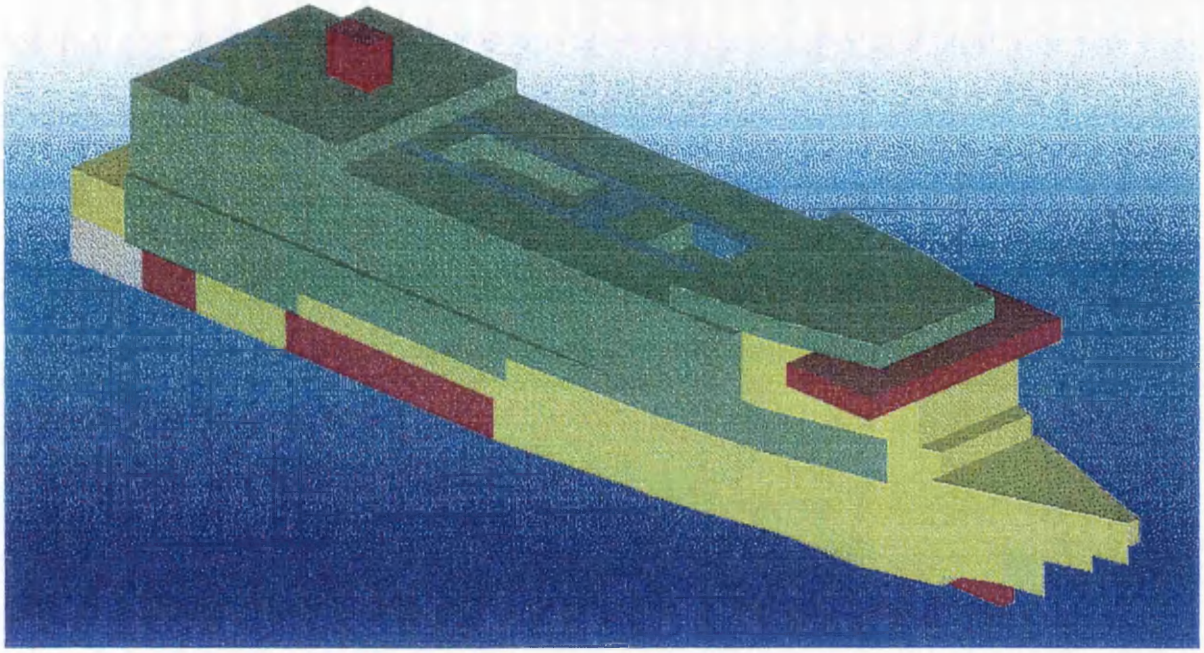


Figure G-1 Kolstodlokken's Building Block Monohull Cruise Liner

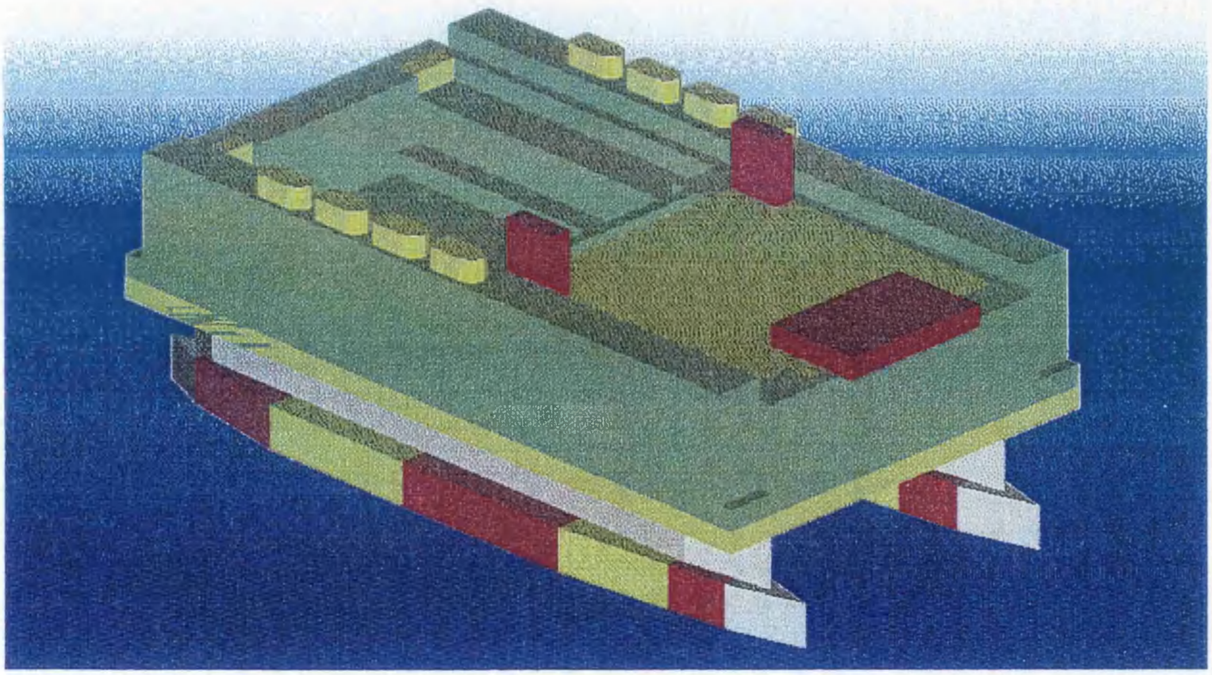


Figure G-2 Kolstadlokken's SWATH Building Block Cruise Liner