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FACULTY OF ENGINEERING, SCIENCE AND MATHEMATICS

School of Engineering Sciences

Engineering Management of Early Stage Warship Design

by

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ABSTRACT

FACULTY OF ENGINEERING, SCIENCE AND MATHEMATICS
SCHOOL OF ENGINEERING SCIENCES

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ENGINEERING MANAGEMENT OF EARLY STAGE WARSHIP DESIGN

By Johannes Philipp Stratmann

Warship Feasibility Studies are highly complex projects. The thesis attempts to highlight the relevant factors inherent within industry and academia and then derives a methodology for managing early stage warship design.

The initial data were gathered at the VT shipyard by interviewing key personnel. The collected data are then analysed using the MS Visio flowchart package to create input/output diagrams for all existing areas of work. Identifying explicit and implicit links allows the existing areas of work to be linked and inherent areas to be identified. The resulting connection diagrams are then analysed and compared with existing literature. The analysis results in the creation of several loops depicting the data flow during the assessment phase.

Two case studies are carried out to further refine the developed interface model. This model is further improved by carrying out in-depth investigations into previously neglected design factors. A series of algorithms are developed that can be used to determine balanced designs for corvettes and fast attack craft. These algorithms are used to identify factors and events that need extra attention during the design process.

Different tools for managing the dataflow across the identified interfaces are researched and a set of control mechanisms is described in more detail. One mechanism, Margins, is further investigated using the developed algorithms in combination with knowledge obtained at VT to determine suitable margin ranges and applications.

The results from the interface analysis and interface management studies are combined to derive a management methodology, consisting of a project schedule, a set of functional flowcharts and an accompanying guidance manual.

This methodology is tested and validated on a design study. The results from the validation are used to determine any required changes to the methodology.

The developed methodology is found to provide an effective tool for managers and designers during the early stages of warship design in a defence environment.

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IV. DECLARATION OF AUTHORSHIP

I, Johannes Philipp Stratmann…………………………...………………., [please print name]

declare that the thesis entitled [enter title]

Engineering Management of Early Stage Warship Design…….………………………………

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VI. Nomenclature

Aircon	Air-conditioning	
A_m	Midship Area	
ARM	Availability, Reliability and Maintainability	
Aux	Auxiliary	
A_w	Waterplane Area	
B	Beam	
BW	Black Water	
CADMID	Concept-Assessment-Demonstration-Manufacture-In-service-Disposal	
Cb	Block Coefficient	$\frac{\nabla}{LBP \times B \times T}$
Cm	Midship Area Coefficient	$\frac{A_m}{B \times T}$
CO	Commanding Officer	
CODAG	Combined Diesel and Gas	
COEIA	Cost and Operational Effectiveness and Investment Appraisal	
COGAG	Combined Gas and Gas	
COTS	Commercial off the Shelf	
Cp	Prismatic Coefficient	$\frac{\nabla}{A_m \times LBP}$
Ct	Total Resistance Coefficient	$\frac{R_t}{0.5 \rho S V^2}$
Cw	Waterplane Area Coefficient	$\frac{A_w}{Lwl * B}$
D	Depth	
D&C	Design and Construction	
DB	Double Bottom	
DefStan	Defence Standard	
DK	Deck	
Domain	Area of Work	
DPA	Defence Procurement Agency	
DSEi	Defence Systems & Equipment International	
ER	Engine Room	
F	Freeboard	
FAC	Fast Attack Craft	
FATS	Factory Acceptance Tests	
FMECA	Failure Modes Effect and Criticality Analysis	
Fn	Froude Number	
FO	Fuel Oil	
FPC	Fast Patrol Craft	
FRP	Fibre Reinforced Plastics	
FSC	Future Surface Combatant	
FW	Fresh Water	
GA	General Arrangement Drawing	
Gc	Generator Cruise Load	
Genset	Generator Set	
GM	Distance from VCG to Transverse Metacentric Height	
GPMG	General Purpose Machine Gun	
GUSEM	General Unified Systems Engineering Model	

GW	Grey Water
HATS	Harbour Acceptance Trials
HF	Human Factors
HOSTAC	Helicopter Operations from Ships other than Aircraft Carriers
HSC	High Speed Craft
HVAC	Heating, Ventilation and Air Conditioning
ILS	Integrated Logistics Support
ILSP	Integrated Logistic Support Plan
IMO	International Maritime Organisation
INCOSE	International Council of Systems Engineering
IPPD	Integrated Product and Process Development
IPT	Integrated Project Team
ISP	Integrated Support Plan
ITT	Invitation to Tender
JR	Junior Ratings
KaMeWa	Waterjet Manufacturer
KMt	Distance from Keel to Transverse Metacentric Height
Kts	knots 1kts = 0.514m/s
L	Length
$L/\nabla^{1/3}$	Length-Displacement Ratio
LBP	Length between Perpendiculars
LCF	Longitudinal Centre of Flotation
LCG	Longitudinal Centre of Gravity
LO	Lube Oil
LOA	Length Over All
LORA	Level of Repair Analysis
LSA	Logistic Support Analysis
LSAP	Logistic Support Analysis Plan
LSAR	Logistic Support Analysis Record
Lwl	Length Waterline
MoD	Ministry of Defence
MOE	Measures of Effectiveness
MOP	Measures of Performance
MTU	Engine Manufacturer
Nav Arch	Naval Architecture
NBCD	Nuclear, Biological, Chemical and Damage
NES	Naval Engineering Standard
Nm	nautical miles 1nm = 1852m
NME	Crane Manufacturer
Off	Officers
OPC	Overall Propulsive Coefficient
OPNAV	Office of the Chief of Naval Operations
OPS	Operations Room
OPV	Offshore Patrol Vessel
Pc	Cruise Power
Pe	Effective Power
RAS	Replenishment at Sea
RCM	Reliability Centred Maintenance
RIB	Rigid Inflatable Boat
RRB	Rapid Response Boat
R_t	Total resistance
RV	Research Vessel
S	Surface Area
SATS	Sea Acceptance Trials

SE	Systems Engineering
SF	Special Forces
SFC	Specific Fuel Consumption
SG	Sub Group
SHP	Shaft Horsepower
SOLAS	Safety of Life at Sea
SOW	Statement of Work
SR	Senior Ratings
SRD	Systems Requirement Document
SSmf	Superstructure material factor
T	Draught
TF	Gas Turbine Manufacturer
TLC	Through Life Costing
UAV	Unmanned Air Vehicle
UK	United Kingdom
UPC	Unit Production Cost
URD	User Requirement Document
USA	United States of America
Vc	Cruise Speed
VCG	Vertical Centre of Gravity
Vm	Maximum Speed
VT	VT Shipbuilding, formerly Vosper Thornycroft
VTMPC	VT Multi Purpose Corvette
w	Passagewidth
WEMG	Warship Engineering Management Guide
WLC	Whole Life Costs
WLCC	Whole Ship Life Cycle Costing
Δ	Displacement (tonnes)
∇	Underwater Volume (m^3)
ρ	Density (kg/m^3)

1 INTRODUCTION

1.1 OVERVIEW

Warship Design is acknowledged to be a highly complex process [1], including conflicting demands, changing requirements and cost-benefit trade-offs. Much of the knowledge contained within the industry is implicit, as companies tend to safeguard their intellectual property to maintain their competitiveness.

One such shipyard is VT Shipbuilding in Portsmouth, formerly known as Vosper Thornycroft Ltd. and now part of the VT Group of companies.

VT is a major contractor for Ministry of Defence (MoD) warships, thus it has to adapt to the constantly changing procurement requirements of the government. The latest of these procedures is known as SMART Acquisition. The main aim of SMART is to speed up the procurement process whilst minimising costs. This is achieved by combining principles from commercial industries with defence related requirements.

SMART redefines several different aspects of the overall design process, including the area of feasibility studies. This is an area of the design process that is carried out at an early stage and requires much attention by shipyards and designers. Under the new guidelines, feasibility studies are known as the ‘assessment phase’, which now covers broader aspects than under previous procurement processes, as SMART introduces many factors, which have previously not been paid sufficient attention, such as Integrated Logistics Support and Through Life Costing. These need to be integrated into the design process.

To reaffirm VT’s position as a major warship contractor in the UK it is necessary for the company to fully understand all implications of the new procurement cycle. This is also likely to benefit the MoD and the general population, by potentially reducing the cost of equipment to the government.

In order to assess ways of improving the understanding of feasibility studies, it is necessary to make explicit some of the knowledge contained within the company and to investigate how feasibility studies are carried out within the company at the present time. It is also necessary to identify the current MoD requirements and existing published views.

1.2 AIMS AND OBJECTIVES

This research sets out to develop a generic methodology for managing early stage warship design in a SMART procurement environment and thus aid shipyards and designers in understanding the factors involved.

The final result is to provide a description of the early stage design process, how it functions and to propose a management methodology for said process. This methodology should provide a step-by-step guide to enable it to be easily deployed within VT and other design offices, if required.

The methodology is based on systems engineering principles to match the principles applied in the procurement process.

1.3 PROCESS

To derive the generic methodology several steps are carried out.

First the established views published in the public domain are reviewed in the literature review. This leads to a clearer definition of the research area. One aim of the literature review is identify the area of the procurement process relating to feasibility studies.

A study is then carried out to determine the factors inherent within the process at VT. The results are used to determine a first interface model.

Carrying out two case studies, on different types of vessels, further refines the developed interface model. This model is further improved by carrying out in-depth investigations into previously neglected design factors. Also, a series of algorithms is developed that can be used to determine balanced designs for corvettes and fast attack craft. These algorithms are used to identify factors and events that need extra attention during the design process. The results are fed back into the model to ensure all potential problems are accounted for.

The next step of the research investigates different tools for managing the dataflow across the identified interfaces. A set of control mechanisms including margins and review meetings is described in more detail. Margins are further investigated using the previously developed algorithms in combination with knowledge obtained at VT to determine suitable margin ranges and applications.

The results from the interface analysis and interface management studies are then combined to derive a management methodology, consisting of a project schedule, a set of functional flowcharts and an accompanying guidance manual.

This methodology is tested and validated on a design study. The study is based on a trimaran hullform to investigate the adaptability of the methodology for novel hull concepts. The results from the validation are used to determine the required changes to the methodology.

Finally a summary is provided showing that the developed methodology appears to allow for all required factors and is likely to optimise the early stage design process for warships.

1.4 RESULTS

The developed methodology can be applied to warships ranging from small fast attack craft to frigate type vessels, but has also shown potential to cope with more radical designs, such as the trimaran OPV used during the validation stage. As such it can not be considered generic but has shown the potential to be applicable to a broader range of vessels if slight modifications to the base dataset are carried out. Also, the methodology enables designers to develop a workable solution first time round without limiting innovation, as shown by the trimaran validation study, and thus differs from existing methodologies.

2 LITERATURE REVIEW

2.1 INTRODUCTION

This part of the research aims to establish the current state of knowledge with regards to the project's objectives. An attempt is made to identify the current academic and industrial knowledge to avoid replicating previous work and to identify likely areas on which to concentrate the research.

2.2 WHAT IS SMART?

The ways weapons for the armed forces are procured have changed considerably over the years.

Bryson [2] notes that the ship design process is highly iterative and involves industry as well as government. All individuals involved work towards creating a design capable of achieving the required operational capability whilst working to the given constraints, such as manning and money.

The process outlined by Bryson is based on achieving defined capabilities. These capabilities are defined by Naval Staff Targets, which are translated into Naval Staff Requirements. Major outline concept design studies are carried out to determine possible ways of achieving the naval staff's view of the future fleet capabilities.

During Feasibility the lead shipbuilder carries out more in-depth investigations into cost versus capability trade-offs. This implies that the lead shipbuilder has already been chosen and hence limits the scope for competition. Also, due to the nature of the final decision resting with the Naval Staff, there is little encouragement to use Commercial off the Shelf (COTS) products.

Little to no consideration is given to Human Factors (HF), Integrated Logistics Support (ILS) and Through Life Costing (TLC). The main concern regarding capability – cost trade-offs is with Unit Production Cost (UPC). This is due to a decision having to be made to satisfy budget constraints.

Andrews [3] bases his description of the design process on the so-called Downey cycle [4]. He also states that this approach to designing the total warship is outmoded. The process described by Andrews is similar to the one described by Bryson, so it can be presumed that Bryson based his report on the same Ministry of Defence document.

However, there are some discrepancies worth noting. Contrary to Bryson, Andrews states that during Feasibility several, not just one, contracts are placed with industry. The aim of the feasibility study stage is to explore the viability of the requirements.

It is stated that more consideration needs to be given to factors such as Availability, Reliability and Maintainability (ARM) and ILS. Also, Human Factors (HF) is becoming increasingly important although it is not included in the design process as yet. Whole Ship Life Cycle Costing (WLCC) is mentioned along with a caution that it has severe implications for the design process. WLCC is essentially the same as TLC and therefore throughout this thesis the term TLC is used whenever total life cycle costs are referred to.

Andrews is not the first to mention TLC in the context of warship design. Palmer [5] states that initial procurement accounts for only 25% of the through life cost, whilst Brown and Tupper [6] state that UPC is about 20% of TLC for a warship.

However, TLC is not officially treated as a factor in warship design until the advent of SMART procurement in the Strategic Defence Review of 1998 [7].

SMART aims to enable the MoD to acquire defence capabilities faster, cheaper, better and more effectively integrated [8]. SMART encompasses the whole life approach, which is typified by the use of TLC. By using SMART the MoD is aiming to improve the relationship with industry and create a more open process.

With the increasing realisation of the importance of TLC some efforts were made to account for these costs. Brown [1] describes the process of Cost and Operational Effectiveness and Investment Appraisal (COEIA). This process is described in more detail in ANEP 52 [9]. The underlying assumption of COEIA is that Systems Engineering (SE) is applied. The use of COEIA also indicates a shift from requirements based design to capability-based design.

Capabilities, defined by Measures of Effectiveness (MOE), are transformed into Measures of Performance (MOP). This allows assessing whether functions fulfil the required capabilities [9]. However, this functional assessment approach also leads to several difficulties for the naval architects involved in the design cycle. The difficulty for designers stems from not having a predefined system solution until a first design has been developed and the design's MOPs have been compared to the original MOEs. For example a designer might struggle to establish whether a fast attack craft or destroyer is the desired solution for a particular capability Thus there is the need for continuous customer feedback to ensure the developed solutions fit the customer's criteria.

SMART Procurement includes the whole life cycle management of a product [8]. To understand SMART and factors associated with a whole life cycle approach it is necessary to describe Systems Engineering in more detail.

2.3 WHAT IS SYSTEMS ENGINEERING?

"Systems Engineering is the set of activities which control the overall design, implementation, and integration of a complex set of interacting components or systems in order to meet the needs of all users and other stakeholders." [8]

The traditional depiction of the design process as a spiral implies that only one aspect is considered at a time [1]. This leads to the need for a revised design methodology as the design spiral misrepresents the design process [1]. In reality designers tend to "manipulate at least three parameters simultaneously" whilst assessing their impact on "some half dozen more" [1]. This is further backed up by Tibbitts who states that Ship Designers need to be System Engineers [10]. SE, by its very nature, involves the integration of complex interacting factors [8]. Also, design and development of ship systems in real time and in parallel is possible and again implies that the depiction of the design process as a spiral is no longer accurate [10].

In SE all components of a design are considered, such as ILS and ARM. It is important to note that one of the main concerns with SE under MoD guidelines is the transformation of user requirements (also known as capabilities) into system requirements. This requires Functional Analysis [9]. Functional Analysis is the process of systematically identifying the functions carried out by a system and its subsequent sub-systems [9]. It follows on from requirements capture and the purpose of the Functional Analysis phase is to identify the functions involved in satisfying the requirements, as well as to ensure that no requirements have been forgotten and that no duplication has occurred [9]. However, this is only possible in an idealised top-down approach. In reality it is not always possible to determine the actual achieved MOE for the system in question as the sub-system MOP targets may still be under development.

The Japanese Lean Supply Systems were one of the inspirations for Systems Engineering [11]. To create an optimum design it is necessary to optimise the system as a whole and not just a small part of it. This is known as a pareto optimum [12]. Care has to be taken to avoid local optimisation.

The explicit need for SE in the design of a warship is mentioned by Gates and Rusling [13].

The International Council of Systems Engineering (INCOSE) has proposed the General Unified Systems Engineering Model (GUSEM)[14, 15] as a baseline for most SE applications. The model is centred on what is essentially a giant database to capture and trace requirements associated with the design throughout all stages of the process.

The MoD has also presented its own high-level model in the Warship Engineering Management Guide (WEMG) [16]. The model is based on the V-diagram, see Figure 1, which describes the Procurement Process as a series of activities that increase in detail and are then verified once a system solution has been identified.

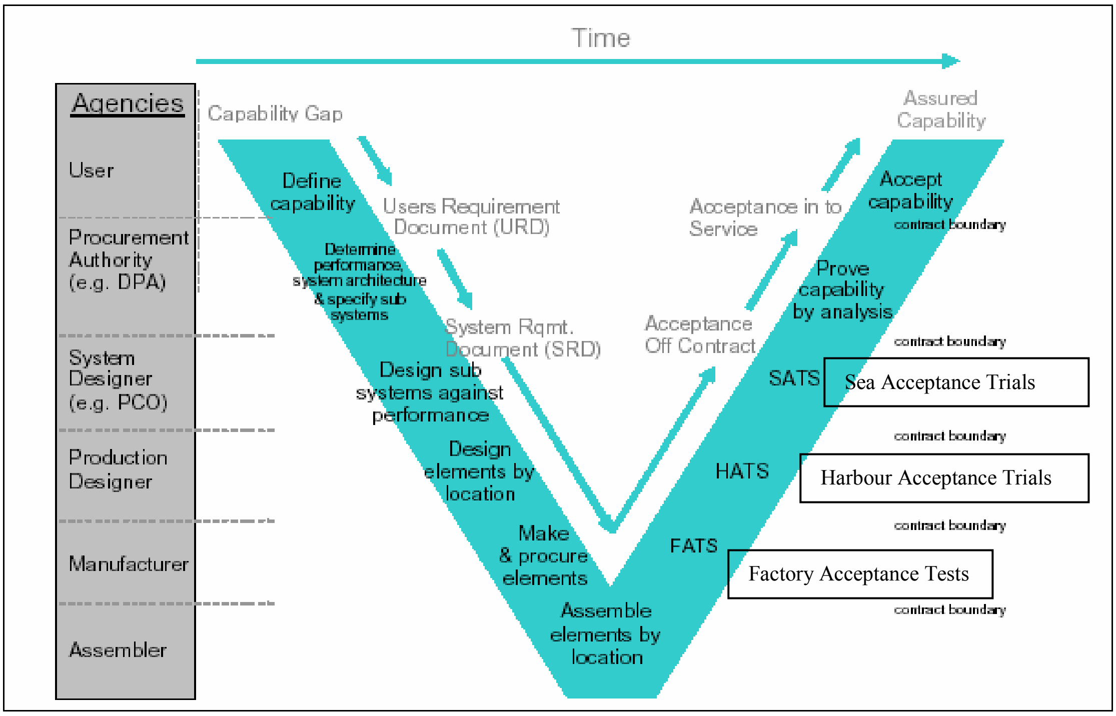

Figure 1 [16] – SMART V Diagram

The guide also describes that it is more realistic to model the process as a “distorted V”, to allow for the fact that at an early stage of the design several solutions might be investigated in parallel, or that several solutions are investigated in sequence but not into great levels of detail, see Figure 2.

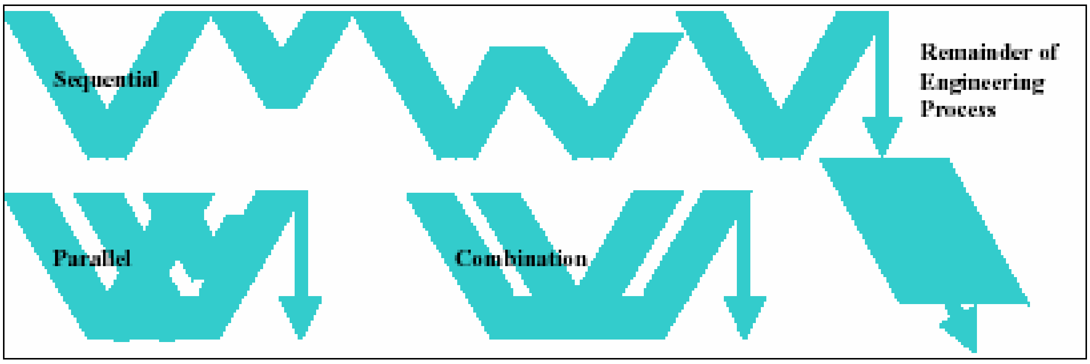

Figure 2 – Distorted V Diagrams

2.3.1 SE Methodologies

A distinction needs to be made whether warship design is treated as a soft or a hard system. It is important to establish the type of system thinking applied to allow for an efficient management methodology to be derived.

First it is necessary to establish what a system is. According to the MoD [17] a system is a "human-made entity with distinguishing and defined purpose that draws on integrated, constituent parts, each of which does not individually possess the required overall characteristics or purpose". This complex statement clearly illustrates the difficulties facing designers when trying to understand SE methodologies.

The following is an example of systems in warship design. The weapons domain is not capable of propelling the vessel and hence is a system. Systems Engineering is required to integrate the systems in such a way that the required capabilities are achieved. The development of systems engineering and its meaning is further described in section 3.2.

A hard system is one where objectives are given up front and where systems boundaries are clearly defined [18]. In a hard system approach the system is designed to meet the required objectives. This infers that the objectives are well known and established as givens, see above.

However, due to the nature of SMART procurement it is necessary to include areas of work, termed domains throughout this thesis, such as HF. This domain does not have a clearly defined boundary due to its human interaction nature.

Soft system methodology is applicable to designs where the goal is becoming more defined as the project progresses. This is true under SMART procurement where the User Requirement Document (URD) is gradually being converted into the Systems Requirement Document (SRD) using input from the designs derived from the initial high-level SRD.

It can therefore be derived that a soft system methodology is more appropriate to warship design than a hard system methodology [18].

This indicates one of the major problems in connection with SMART procurement. Whilst in theory SMART procurement allows for solution-oriented [19] design in practice this does not always work. Solution-oriented design is based on developing the solution whilst simultaneously refining the problem. The MoD tends to restrict solutions in an attempt at reducing UPC. This is contrary to the ideas behind SMART procurement but is to satisfy the budget constraints imposed by the yearly Defence Budget.

2.3.2 SE within VT

Based on several documents [20-23] there is strong evidence that SE is used within VT. This conclusion is drawn from the fact that SE and factors such as supportability are mentioned in all these references. However it seems that most applications of SE are implicit and not formalised. One of the major factors contributing to problems during the design process is the lack of requirements analysis, allocation and consequent traceability [20]. Yet these three are vital under the SE principles applied in SMART procurement. The lack of these tools can partly be attributed to the conservative nature of the shipbuilding industry, which has not had the rapid innovations observed in, for example, the software industry.

2.4 WHAT ARE FEASIBILITY STUDIES?

Traditionally [1-3, 24] Feasibility Studies were concerned with proving the viability of engineering design factors. By this is meant that a design, having been proven in the concept stage, is assessed in more detail and all engineering factors are proven to work. During feasibility studies a detailed estimate of performances is derived and an improved cost estimate is established. The outcome of the feasibility stage is a design refined into a “valid basis for the full design at an acceptable level of risk” [25]. However, as mentioned throughout the literature review and several other sources [3, 5, 6, 24, 26] it is necessary to include several others factors such as TLC in the studies. This is due to the increasing emphasis on through life support and design for supportability under the SMART Procurement Initiative.

However, SMART does not have a “feasibility study” stage but looking at the procurement process shown in Figure 3 and applying the information supplied by the MoD [8] the area under investigation for the purpose of this project is the assessment phase. The assessment phase encompasses part of the traditional concept stage as well as the feasibility stage. During assessment the solution is defined to satisfy the capabilities as set out by the user in the URD [8]. This implies that the shipyard should explore different options at the start of the assessment phase, similar to the traditional concept phase, in order to determine the most cost-effective and practical system to satisfy the required capabilities. The assessment phase is started off by initial gate and concludes with main gate approval. Initial gate is the first approval point in the acquisition cycle and no solution is evaluated at this stage whereas main gate is the major decision point during the acquisition cycle and at main gate the solution and its associated boundary conditions are agreed [8]. This implies that the solution needs to be sufficiently detailed and de-risked in order to pass main gate. It should be noted that the requirements tend not to be fixed but rather to evolve during the assessment phase. The final outcome at main gate, in terms of the requirements, is the systems requirement document.[8]

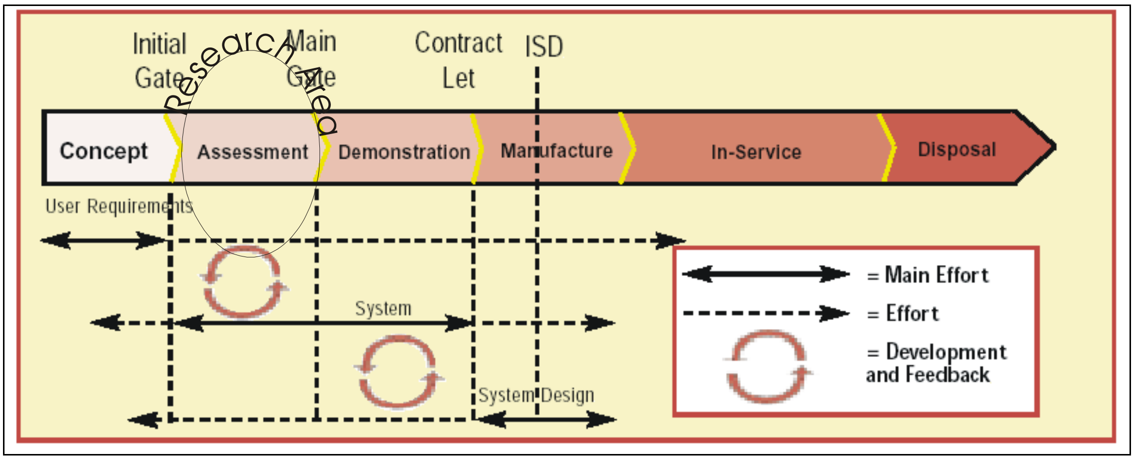

Figure 3[8] – Illustration of SMART Procurement Process

2.5 UNITED STATES OF AMERICA (USA) ACQUISITION PRACTICES

The following section attempts to investigate which practices exist in the USA and whether any information can be used to further the research in this thesis.

There are several articles published on US acquisition practices and their implications on ship design [10, 27-30]. However, most of these are concerned with the description of high-level events.

The use of Integrated Project Teams (IPT) is described by Keane [27]. He argues that they are essential for the acquisition of “effective, balanced and affordable warships”. The merit of IPTs is that at an early stage of the design process all of the life-cycle process owners are involved. This is a good indication that TLC is important in both the UK and the USA.

Tibbitts [28] provides an interesting insight into the history of the acquisition processes in the USA. Many of his findings, such as the need for a closer industry-government dialogue, are mirrored in the UK literature. However, it seems that the paper is aimed more at the overall high-level integration of the acquisition process into the corporate world. It does provide further confirmation of the importance of the early-stage design process though, as it argues that no matter what shape the acquisition process takes it ultimately always starts with the design cycle of the desired system.

Whitcomb [29] describes four different computational tools that can be used to support the ship design process during the product development cycle. All the tools described aid the implementation of design philosophies. They could provide useful tools when comparing design solutions but are not deemed applicable for the day-to-day methodology solution sought in this thesis.

Laverghetta [30] describes how the current USA process requires “maximum use of Integrated Product and Process Development (IPPD)”, which means that all aspects of design including ILS, HF and technology alternatives need to be considered at the earliest possible stage in the design process. This closely matches the requirements set out under SMART Acquisition and described in earlier sections of chapter 2. Furthermore Laverghetta acknowledges that these increased up-front efforts will require an increase in early stage design funding over traditional approaches. This justifies the need for research into early stage design in order to minimise the required funding increases.

Whilst all of the papers based on the USA acquisition process provide an interesting insight, their emphasis is more on high-level integration than low-level management. However, they do justify the emphasis of this thesis on early-stage ship design research. They also highlight some similarities between the USA and UK approach to acquisition, such as the emphasis on SE and through life costing and.

2.6 SUMMARY

The literature review has shown that the acquisition process in both the UK and USA has changed significantly and that several new processes need to be considered at an early stage for shipbuilders to deliver a successful solution. The shift from requirements based procurement to capability based procurement requires designers to include more through-life aspects of design during the early-stage design cycle. Also, the move from feasibility studies to the assessment phase requires designers to consider concept issues that previously would have been completed before the onset of the feasibility stage.

Whilst the literature provides a good overview of high-level and low-level issues it does not provide a day-to-day management methodology that can be used by designers to easily comply with all the requirements of SMART. Thus the work carried out in this thesis is deemed necessary as it is aimed at providing such a methodology. This means that the methodology will be analysed, regularised and written down for probably the first time.

3 RESEARCH STRATEGY

3.1 INTRODUCTION

The literature review shows that the subject is very complex and that there are several, at times conflicting, viewpoints. Therefore the decision was made to spend some time investigating on which areas to concentrate the research.

3.2 INITIAL MODEL

Based on the findings from the literature search and applying the ideas of SE and SMART to the assessment phase an initial model was created using a system's engineering viewpoint, see Figure 4.

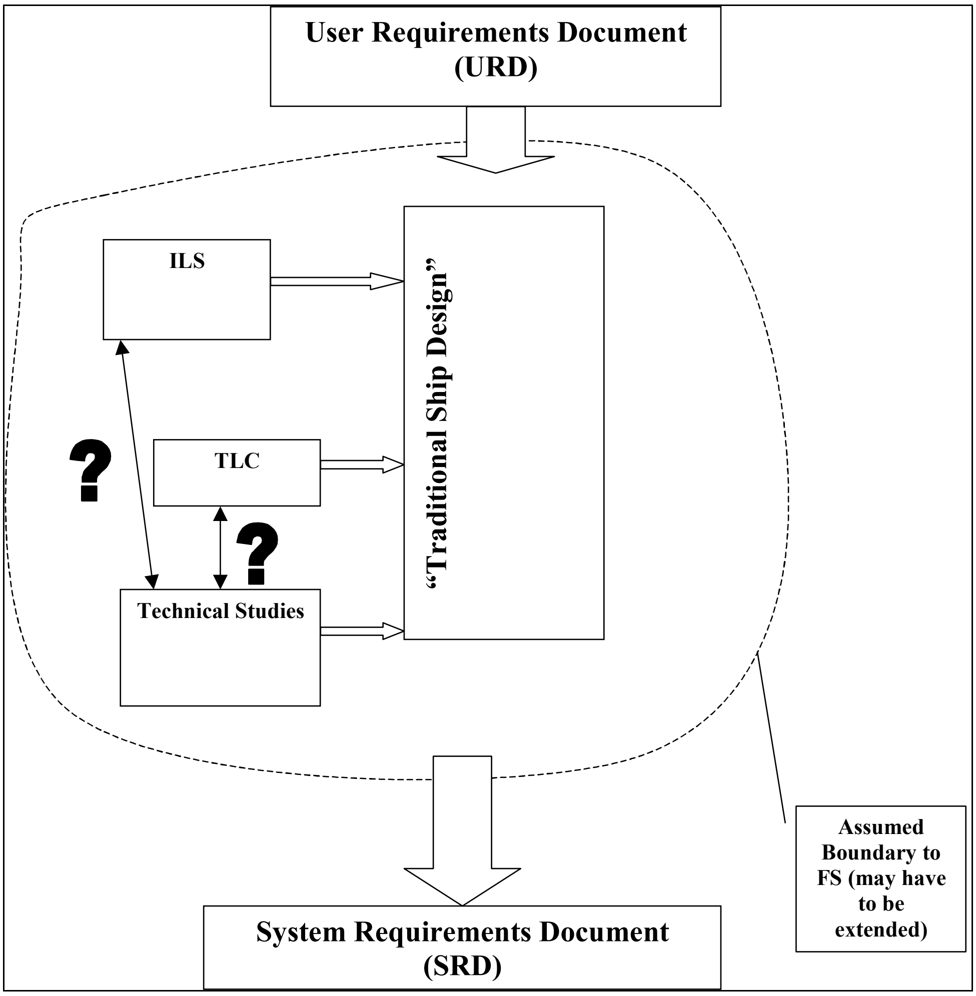

Figure 4 – Initial Assessment Phase Model

The question marks indicate unknown linkages between factors. Also, the factors shown in Figure 4 are for indicative purposes only, and do not represent the actual domains involved

Figure 4 was presented to members of the Defence Procurement Agency (DPA) at a meeting. Based on the information received during the meeting a refined model was created. This was based on the information that input and output into the feasibility study are not as clearly defined as shown in Figure 4. Figure 5 shows the iterative nature of not just the actual design cycle but of the assessment phase as a whole. The input into the assessment phase is not just the URD but also a high level SRD that develops which each loop.

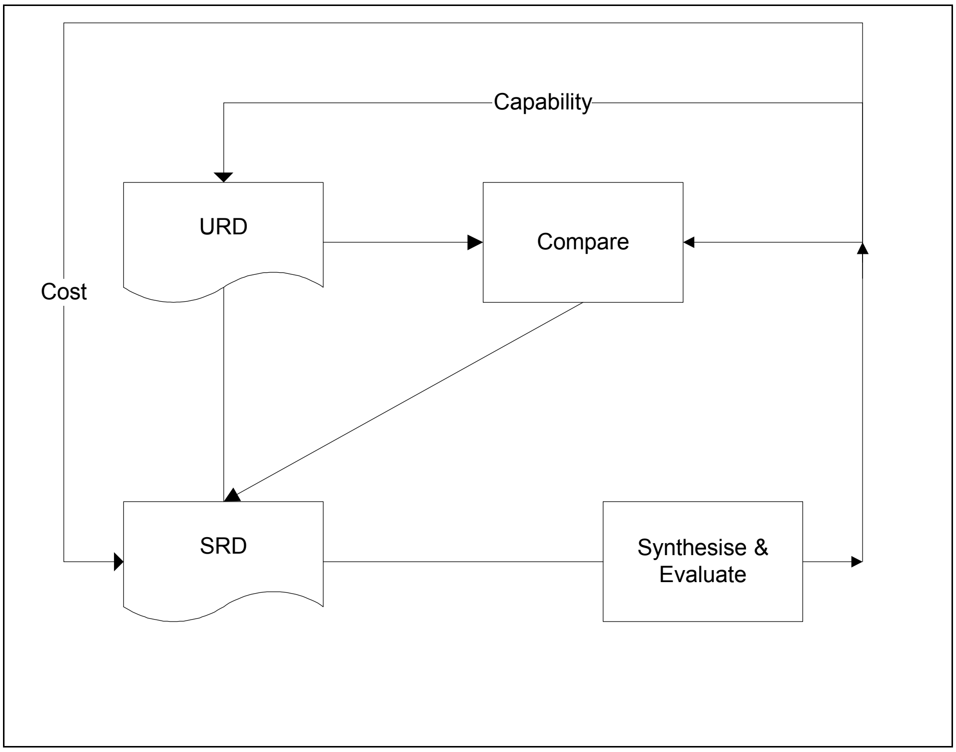

Figure 5 – High Level Feasibility Model

Again, Figure 5 is only indicative and it is not imperative that exactly 3 solutions are looked at during the assessment phase. However, the total number of distinctive variant concepts should be of a similar order of magnitude such as not to prolong the studies unnecessarily.

Figure 5 shows the high level of interaction required to derive the SRD and compare it to the URD. It also shows that the URD is not a given but does change with time if capabilities are no longer required or are not achievable given the budgetary constraints.

3.3 FINAL STRATEGY

The initial model revealed that it is necessary to understand the overall high-level integration of the model as well as the low-level management of the solution design. Due to the sponsor being a shipbuilder, and thus wishing for a practical solution applicable in a design office environment, the decision was made to mainly concentrate on the low-level aspects of the solution evaluation. However, an attempt will be made of proposing how the low-level management solution could be connected to the high-level requirements.
To fully understand the process three distinctive steps need to be carried out.

3.3.1 Early Stage Design Phase Identification

This phase of the work will investigate what the requirements for the early stage design phase are and the impact SMART procurement has on them. Most of this work has already been carried out in the literature review.

3.3.2 Interface Interaction

This part of the research will identify who and/or what the domains are which are involved and required during feasibility studies. It is proposed to use a combination of top-down analysis and bottom-up synthesis to verify the results. Several methods will be used including analysing existing design studies, carrying out design studies and interviewing key personnel at VT and the MoD to obtain some inherent but unpublished knowledge. The results from all these studies will be combined with published data and consolidated to provide an overall picture of the interactions and interfaces involved in feasibility studies.

3.3.3 Interface Management

Once the interfaces are identified it is necessary to investigate how to control and manage them. Again, a series of interviews will be carried out and the results will be combined with data obtained from design studies and published views.

An investigation will also be carried out into the high-level requirements. This will mainly consist of evaluating published information and combining it with data obtained during the design studies and from interviews.

3.3.4 Testing

A validation and verification process is required once all the interfaces are identified and a proposed management solution found. The found solution will be evaluated using a design study. The findings from the design study can then be used to determine whether the proposed model covers all necessary aspects of feasibility studies and highlight any missing interfaces and/or management processes.

4 INTERFACE INTERACTION

4.1 INTRODUCTION

This section aims to identify the “players”, termed domains for the purpose of this thesis, involved in feasibility studies. There are several articles highlighting some of the factors [1-3, 5, 10, 13, 24, 31-33] involved. These will be used to verify and validate the results obtained from the processes outlined in the research strategy.

4.2 EARLY STAGE DESIGN PHASE IDENTIFICATION

This part of the work has been covered in the literature review under section 2.4. The following is a brief reiteration of the findings.

The area of SMART related to early stage design studies is the assessment phase. During the assessment phase several designs are investigated and at main gate, see Figure 3, the most practical, cost-effective solution satisfying the user requirements is chosen. Apart from the traditional engineering domains it is necessary to include domains such as TLC and ILS. Also, the effect of changing requirements must be allowed for.

4.3 INTERVIEWS

An initial domain list was created based on the explicit domains existing within VT Shipbuilding. Explicit domains are those that are actual departments within VT such as structures. The list is based on domains involved with technical aspects of the design process. However, later developments of the list include commercial factors as well.

- Naval Architecture
- Hydrodynamics
- Electrical Design
- Engineering
- Structures
- Combat System Design
- Integrated Logistics Support
- Human Factors
- Quality Assurance
- Design Management

This list was then used to identify key personnel within VT. In most cases this meant approaching the line-managers of the various disciplines.

Interviews were used to gather information as it was felt that questionnaires would not provide the in-depth level of information required. Using interviews allows clarifying uncertainties without having to go back at a later date. Ideas and guidelines for questions were drawn up during meetings at VT.

The question list was revised several times. The final questions were constructed such as to allow for high-level answers but allowing for some top-down analysis. The final question list is attached in Appendix A. A presentation outlining the background to the research was prepared and shown to each interviewee before each interview. This was to ensure that interviewees knew about the context of the research.

Most interviews were recorded and a sample draft write-up is provided in Appendix B. Each draft write-up was distributed to the interviewee for approval.

4.3.1 Interview Analysis

The data obtained from the interviews was analysed under several aspects.

One part of the analysis investigated factors contributing to managerial problems. The results are shown in Figure 6.

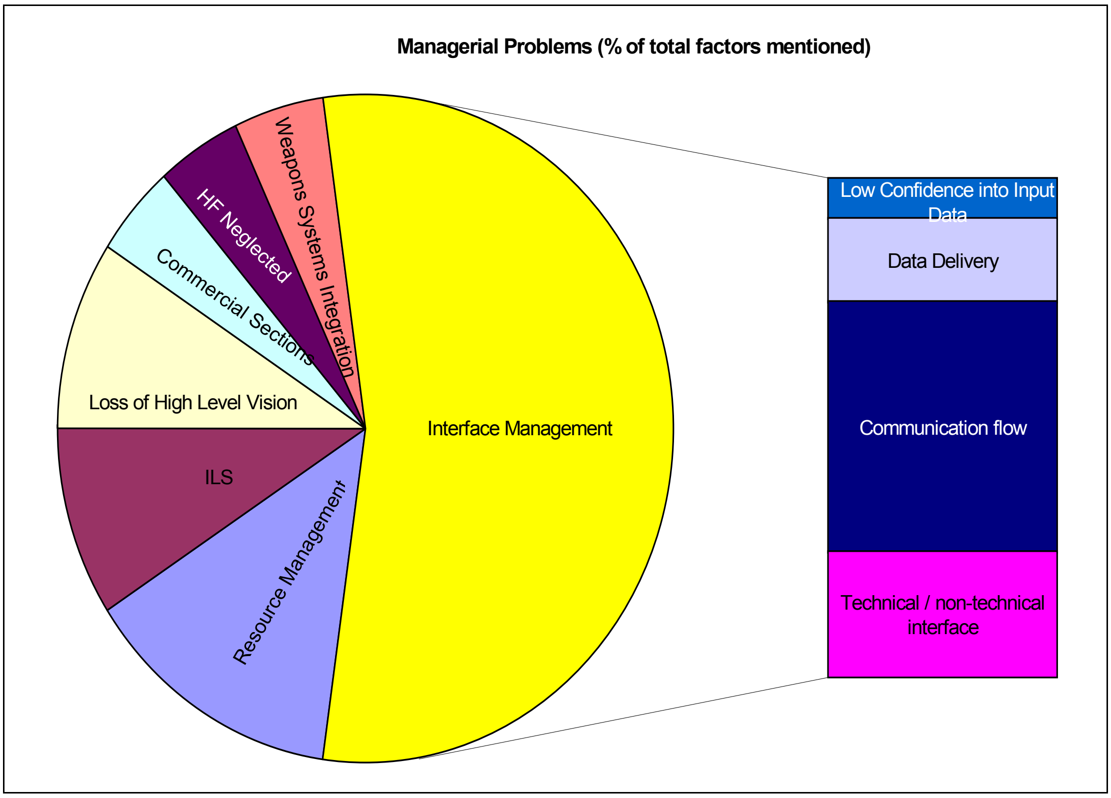

Figure 6 – Interview analysis chart

Figure 6 shows that the greatest perceived managerial problem, with ≈ 55%, is interface management. Interface management refers to any methods of controlling dataflow in and out from domains. This further proves the importance of the research to the company, as an improved knowledge of the process will lead to a better understanding of where the interfaces are. Once the interfaces are known it is then possible to improve the management of data flow across them.

The data for the chart is shown in Appendix C. To calculate the percentage values for each factor the overall number of factors mentioned was used.

4.3.2 Domain Connections

The data from each interview was used to construct spider diagrams for each domain. These show the input and output data, during feasibility studies, as specified by the interviewees. An example of these diagrams is shown in Figure 7.

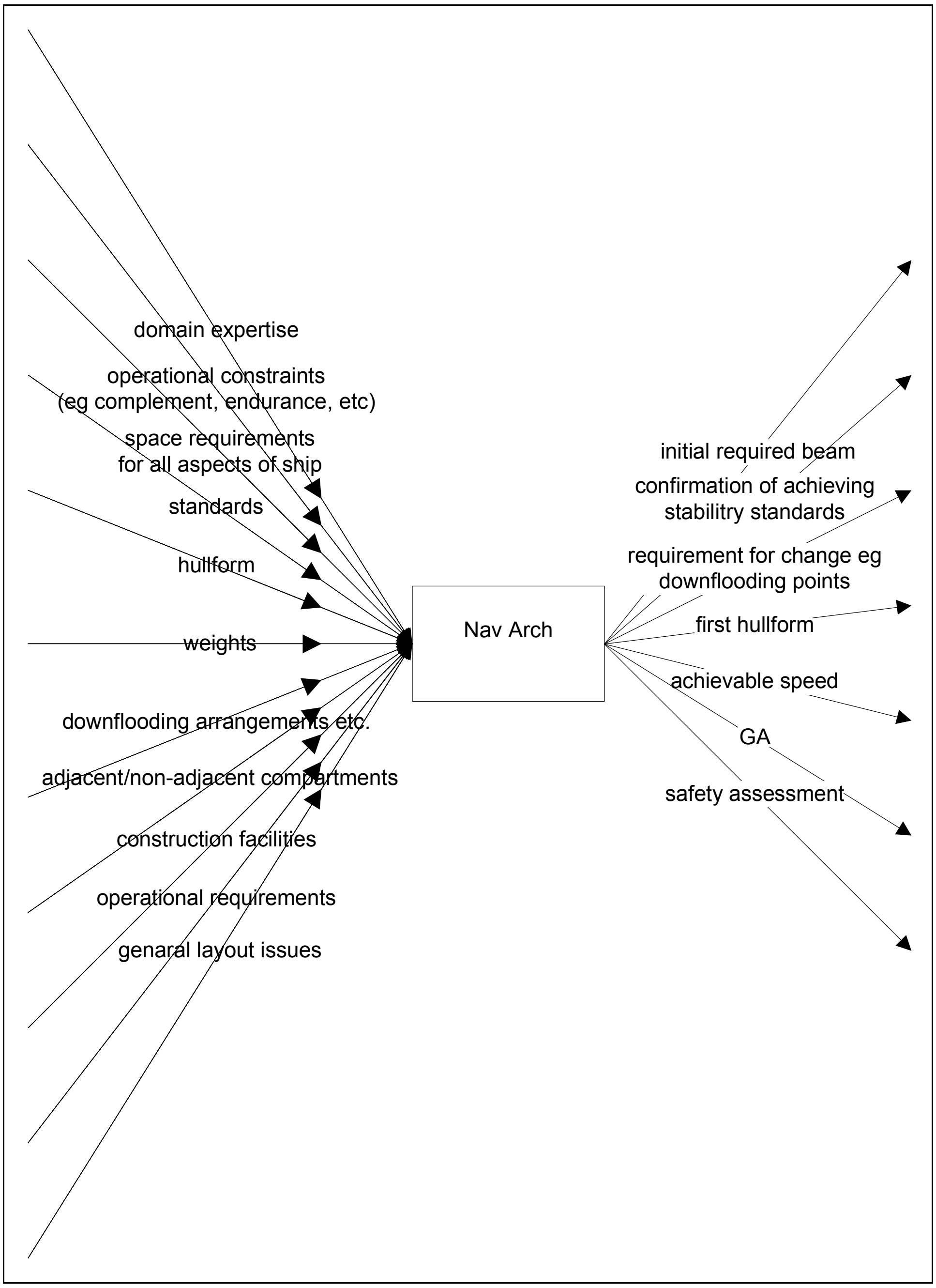

Figure 7 – Spider diagram Naval Architecture (Nav Arch)

Figure 7 shows the complexity and amount of data for the Naval Architecture domain. It clearly shows the array of data coming in and flowing out from the domain, ranging from operational constraints to hullform, and illustrates that domains are treated as black boxes for the purpose of this thesis. All other final spider diagrams are shown in Appendix D.

4.4 HIGH LEVEL INTERFACE CHART DEVELOPMENT

To further analyse the interactions between domains these spider diagrams were linked together. This means that if the output of a domain matches the input into another domain, explicitly and/or implicitly, then these two are linked.

Explicit links exist where the output of any domain matches closely to the input into another domain. An example of this is shown in Figure 8.

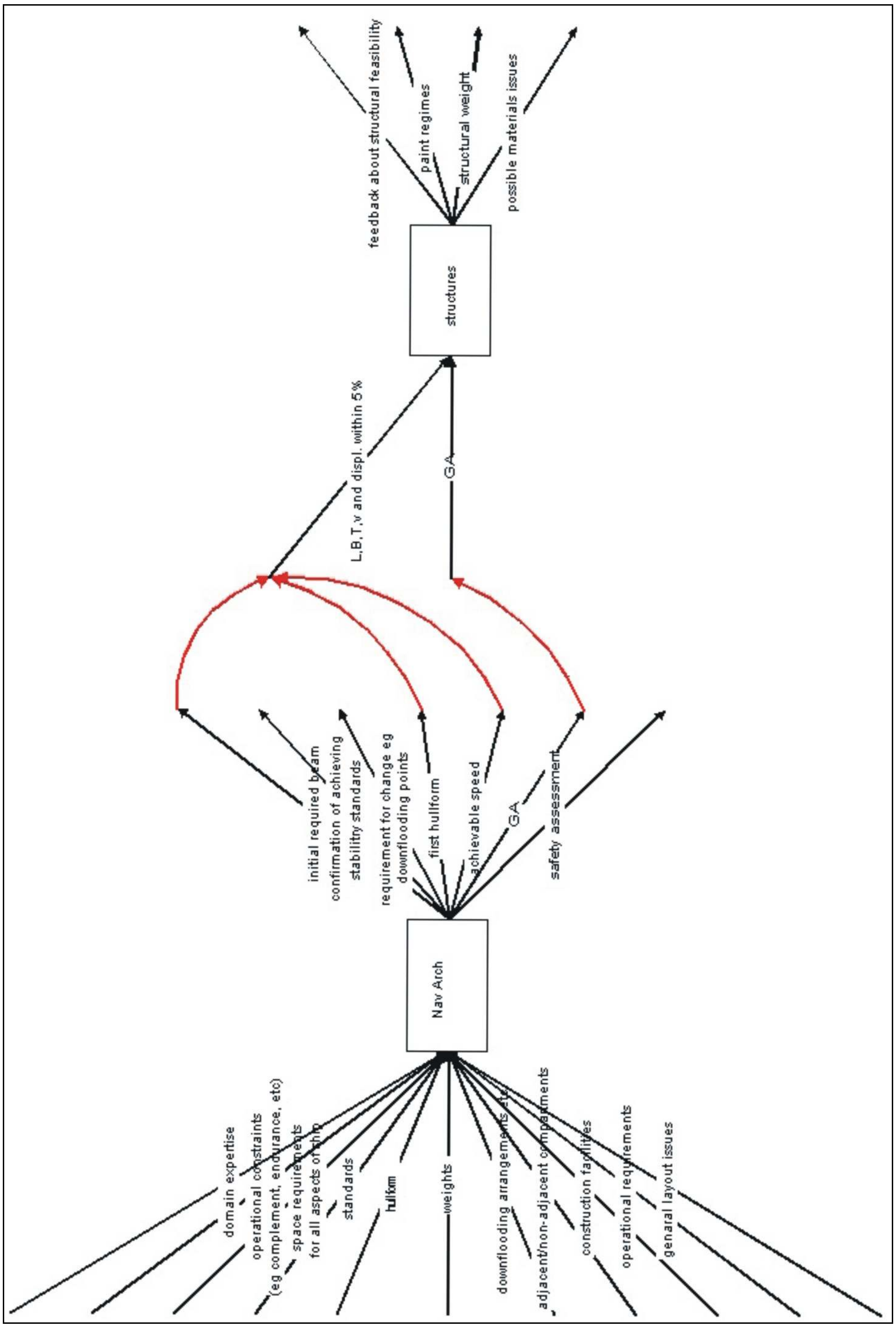

Figure 8 – Explicit Link Illustration

The method of implicit linking evolved as several domains specified output data that did not directly match any domain's input requirements. However, based on discussions with VT personnel and applying sound engineering judgement several links, such as the vibration link identified in Figure 9, were found. Figure 9 is an illustration of implicit linking.

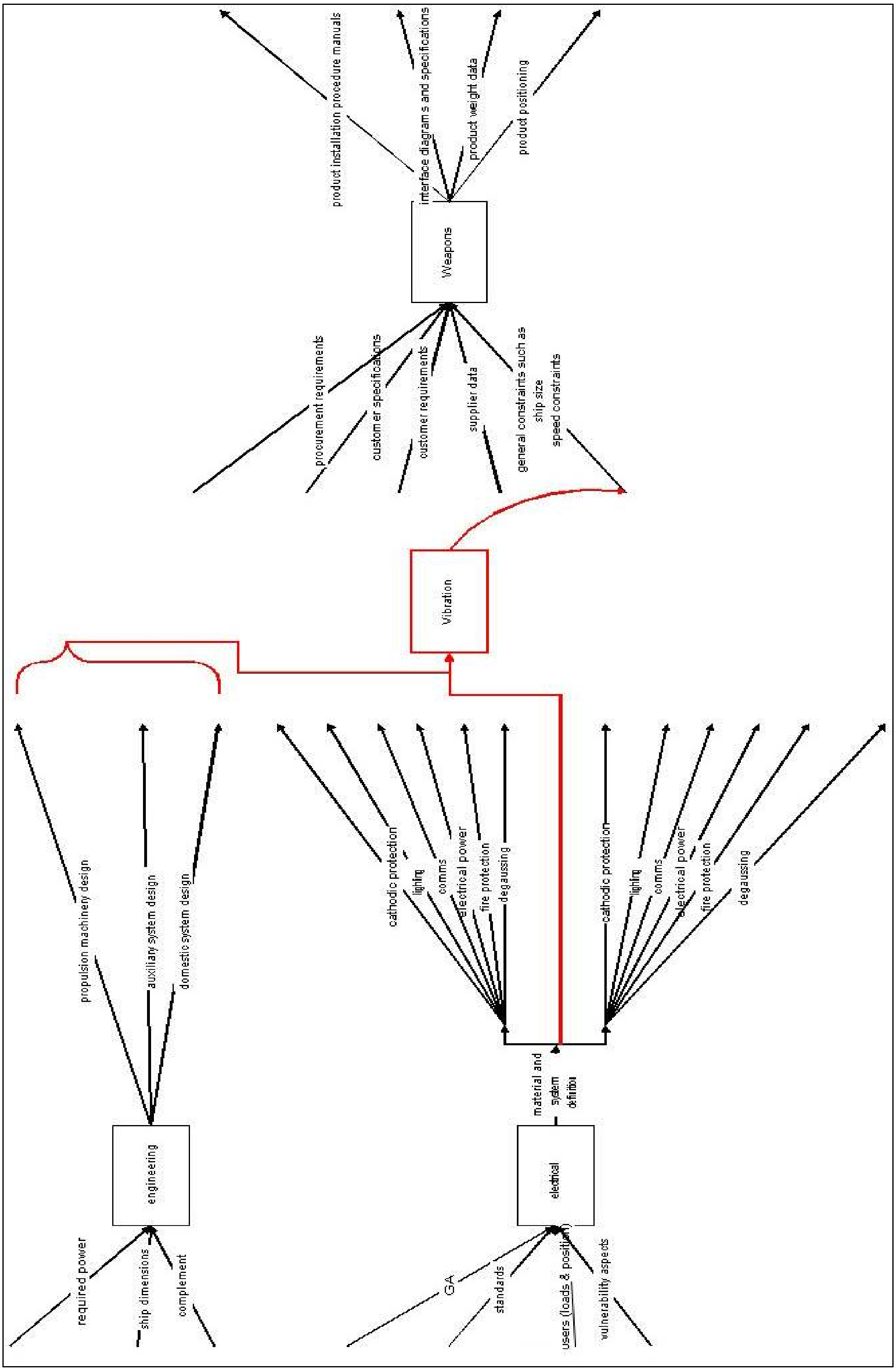

Figure 9 – Implicit Link Illustration

Connection diagrams were constructed using all the data available from explicit and implicit links as well as the redefined domain list. These diagrams show, for each domain, the input and output and respective associated domains. An example of this is shown in Figure 10

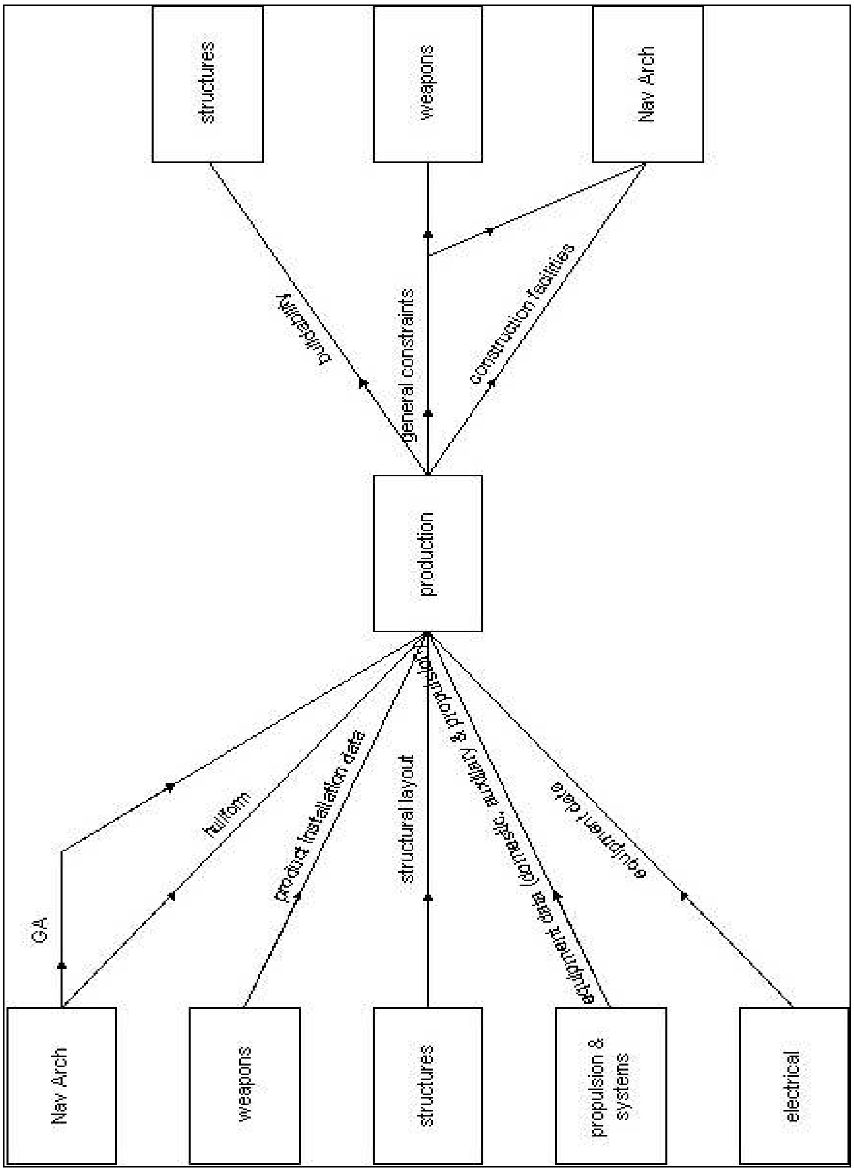

Figure 10 – Connection Chart Production

The figures for all other domain connections are shown in Appendix E. The connection diagrams were compared to data presented by Brown [1]. The input/output data extracted from the interviews matches some of the data presented in the 2-D interaction mesh [1].
The results from the spider and connection diagrams led to a revision of the domain list, see Table 1. The revised list includes the implicit domains. This is to say that some of the initial domains were amalgamated whilst others were split up. It is felt by the author that this allows for a more accurate description of the design process.

Naval Architecture
Weapon Systems
Integrated Logistics Support
Human Factors
Auxiliary, Domestic and Propulsion Systems
Electrical Systems

Structure
Production
Cost estimation
Aviation
General Vehicle Capability
Customer

Table 1 –Revised Initial Domain List

For example on the one hand Hydrodynamics was merged with Naval Architecture as this allowed for a more streamlined connection diagram without changing external connections. On the other hand the aviation domain was created as it was felt that this allowed for a more accurate representation of the actual design process.

Using the data displayed in the initial domain spider diagrams a first high-level interface chart was created. This is not based on detailed connections between domains, but rather on overall connectivity, see Figure 11.

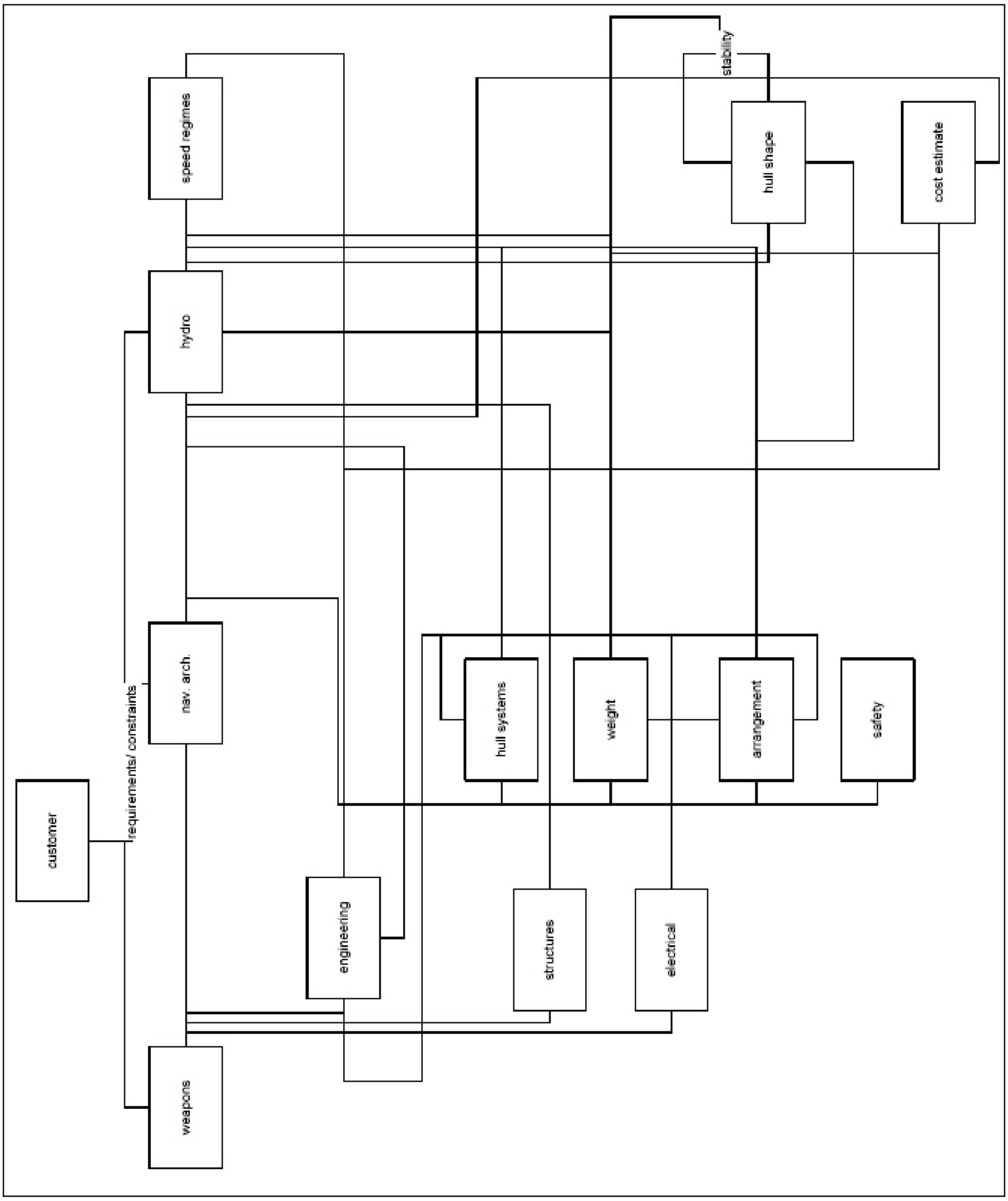

Figure 11 – High Level Interface Chart

The chart is simply a connectivity diagram and clearly shows the high level of complex interdependencies between domains. It is based on the domains as well as some main drivers, for example hull shape and therefore does not accurately represent the revised domain list. However, it provided a useful tool to avoid losing the "bigger picture".

4.5 INITIAL LOOPS

The next step involved combining the individual connection charts. This involved trying to identify loops and predecessors, whilst operating within the overall framework provided by the high-level interface chart.

As a result of the initial studies three loops were created. These three loops were presented in a three-dimensional drawing. The 3-D view was used to show that several of the activities can be carried out in parallel and that the process allows for data to be sent up/downwards as well as forwards. The 3-D view contains feedback loops and connections across several loops, see schematic shown in Figure 12.

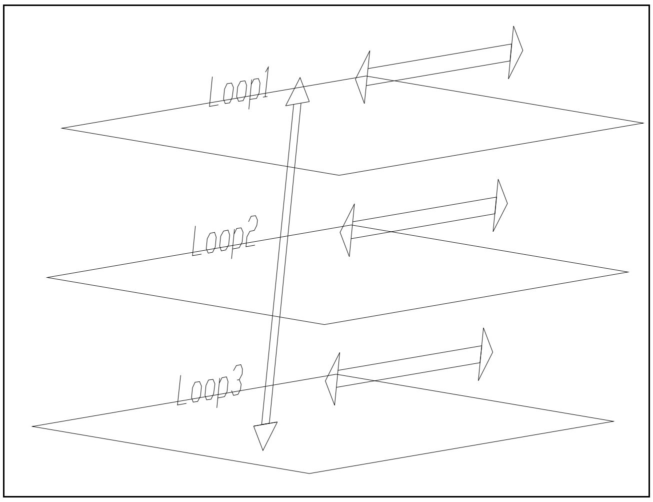

Figure 12 – 3D Schematic

The actual 3D view is shown in Appendix F. However, it was quickly discovered that the 3D representation proved too complicated in a day-to-day environment and was thus scrapped. The individual loops are shown in Figure 13, Figure 14 and Figure 15.

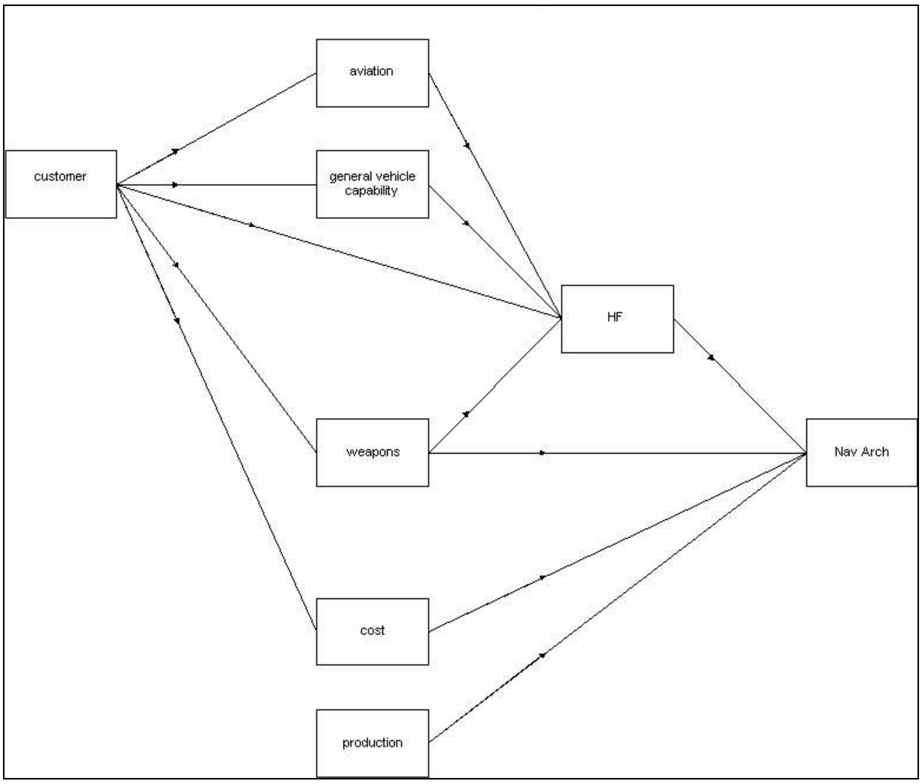

Figure 13 –Initial Loop 1

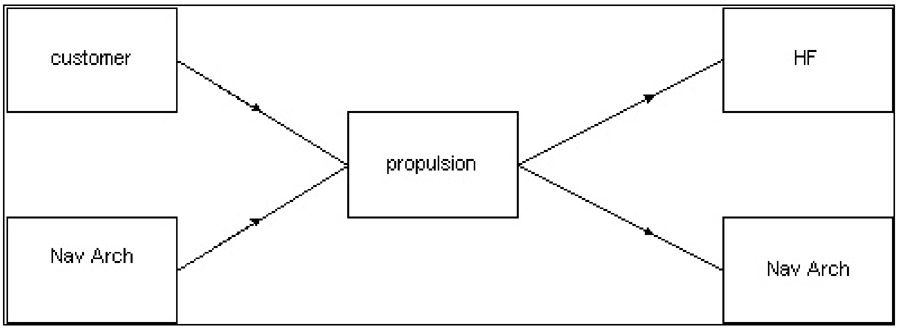

Figure 14 – Initial Loop 2

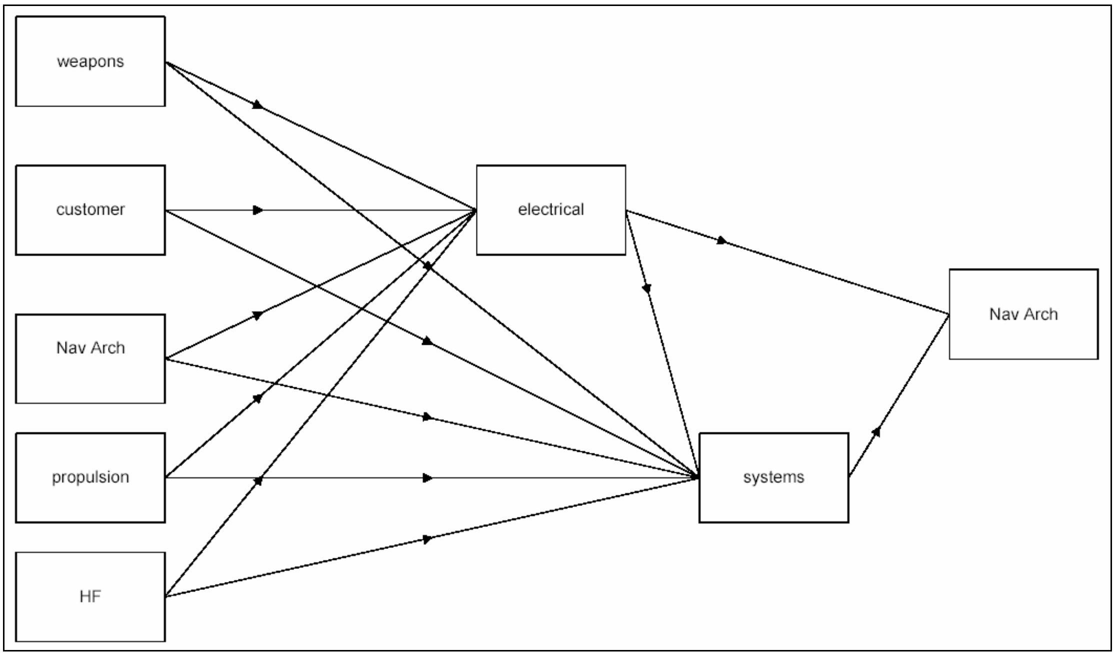

Figure 15 –Initial Loop 3

4.6 COMPARISON TO PUBLISHED VIEWS

To validate these initial results two comparisons were made with existing published data.

The first comparison used data published by Scott [34] and obtained with assistance from Vosper Thornycroft (now VT Shipbuilding). The Scott study used a bottom-up synthesis approach whilst the 3-D loops are derived using a top-down analysis approach. The results from the comparison are shown in Table 2.

Newcastle Study	3-D Loops
1st iterative loop is concerned with weapons system evaluation	Weapons – Customer interaction is contained on first loop
1st inside loop within major block contains hull form, propulsion and structural evaluation	Output of 1st loop is Naval Architecture and 2nd loop evaluates propulsion
2nd inside loop evaluates electrical systems, structure, hull form and domestic & auxiliary systems	3rd loop evaluates Naval Architecture, electrical systems and domestic & auxiliary systems

Major outside loop iterates Stability, Weight and Ship Size	3rd loop contains Naval Architecture output, which feedbacks into second loop (shown by dashed line in Figure 116)

Table 2 – Comparison 3D Loops with Newcastle Study [34]

The results from the comparative study are very encouraging. They indicate that the bottom-up, synthesis, approach taken by Newcastle derives similar results to the top-down analysis approach taken by this study.

Due to the good correspondence between the two, there is a high level of confidence that the added domains, for example human factors, are also placed correctly and inside the correct loops.

The view offered in the thesis provides a novel addition to the knowledge contained in the Newcastle study, as it is derived from a top-level analysis approach. Furthermore the thesis is based on actual dataflow information between domains and thus offers a management insight at a higher level than the work breakdown structure synthesis shown in the Newcastle work.

The second compared the loops to the traditional view of ship design as depicted by Andrews [35], see Figure 16 , and was used to determine whether any domains had been omitted and whether the ship design process was represented properly in the initial loops. Although the paper was written whilst the Downey cycle [4] was the procurement management plan in the UK, the data presented within the paper is still regarded as relevant as it is concerned with the actual ship design and not the procurement process.

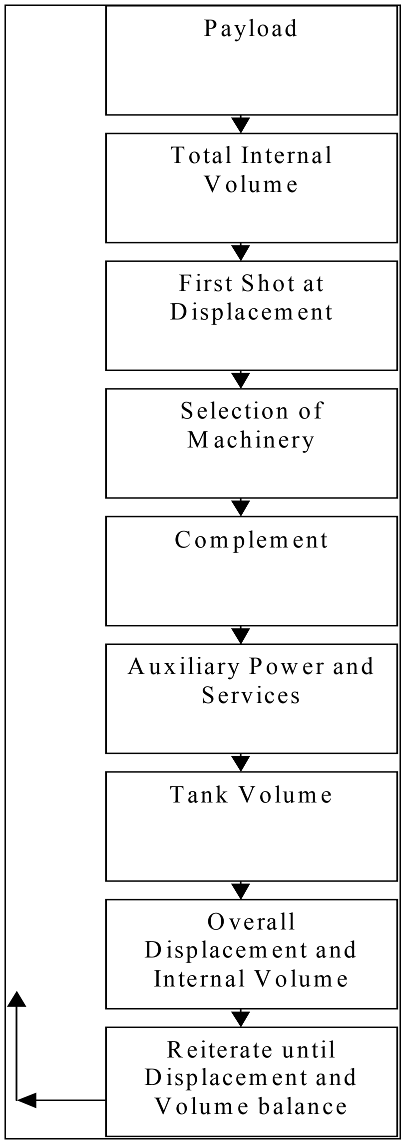

Figure 16 – Traditional approach to warship design

This traditional approach is outdated and too inflexible to cope with radical new designs [35]. However the domains described in Figure 16 were compared to the 3D loops to ensure no domains are omitted.

The first loop of the 3D loop covers payload, internal volume and first shot at displacement. The 2nd loop covers selection of machinery and complement. The 3rd loop covers auxiliary power and services, tank volume and overall displacement. Finally, the reiteration feature of Figure 16 is covered using the feedback loops in the 3D representation.

The results from this comparison indicate that all major domains are included and that the overall design process is described accurately.

Both investigations show that the initial loops appear to provide a good starting point for further investigations as no major omissions were found and the overall process seems to be described accurately.

4.7 DESIGN STUDIES

4.7.1 Introduction

This section describes the work carried out during two design studies carried out at VT and analyses their impact on the initial loop model.

Case studies are used to provide a more objective view of the design process opposed to the potentially subjective results from the interview analysis.

The first study evaluated the feasibility of a Fast Patrol Craft (FPC) whilst the second evaluated a concept study carried out as part of the Future Surface Combatant (FSC) program.

4.7.2 Fast Patrol Craft Study

4.7.2.1 Introduction

The main purpose of this case study was as a training exercise to gain an appreciation of what is involved in concept and feasibility design, as well as providing information on likely problems and interface interactions. The description of this study is more detailed in places than the other case studies to provide a representation of the type of work carried out during all case studies. The author of the thesis started with just the design brief and an existing hullform and carried out the actual design process.

4.7.2.2 Design Brief

The design brief for the study was to design an FPC capable of a high-sustained cruise speed, in excess of 30 knots (kts), with a sprint capability and a waterline length of less than 50m. The vessel is to operate in the Middle East off the coast of the Gulf States. The vessel is to have an endurance of 1000 nm and hence a mission length of approximately 1 ½ days.

All machinery is to be designed to allow for minimum maintenance and therefore commercial standards and ratings are to be applied as far as practical.

The vessel is to be manufactured from Fibre Reinforced Plastics (FRP).

CONFLICTING DESIGN REQUIREMENTS

This section outlines some of the conflicting design requirements based on the issued design brief.

1. The boat is to be of a high cruise speed and have an endurance of around 1-½ days. Most high-speed vessels have a very short endurance.
2. The vessel is to be of a length of around 50m. This implies that the vessel needs the armament typically associated with a vessel of 50m length, whilst most interceptor type vessels usually carry very little in way of armament.
3. The endurance requirement implies that the vessel needs to be of a round bilge construction to aid seakeeping capabilities. Most high-speed vessels are of a deep v form and have comparatively bad seakeeping performance.

4.7.2.3 Planned Scheduling of design steps

A very basic scheduling approach, loosely based on the initial loop model, was used to determine the required steps during the design process. This was mainly due to the fact that the study was meant as a learning exercise and hence a "learning by doing" approach was favoured. The planning resulted in the following order of steps

1. Hull material study
    a. Investigate the use of FRP on the 56m hullform.
2. Parametric study
    a. Provide a first estimate of parameters that meet the design brief
3. Initial Propulsion study
    a. Provide a first shot at propulsion machinery data based on the estimated parameters of the vessel
4. Reiteration of parameters
    a. Derive more refined parameters using data obtained from the propulsion study
5. First General Arrangement
    a. Identify required equipment and layout of vessel
6. Stability and performance check
    a. Ensure that the vessel meets the required stability standards and performance requirements
7. Reiterate General Arrangement
    a. Produce refined GA based on results of stability and performance check

The above schedule was only used as a rough guideline as it was anticipated that several problems might lead to a different approach being required.

The case study was purposefully constructed to be a very challenging design in order to highlight as many problems as possible.

By challenging design is meant that several aspects of the design brief are conflicting and/or have not been achieved before. Some of these challenges are outlined in section 4.7.2.2.

4.7.2.4 Material Concept Study

To better understand the implications of having an FRP hull a material concept study was carried out using an existing design; the baseline vessel used is the 56m Fast Strike Craft (Vita Class).
The original hull material of the vessel is steel and the effects of changing it to FRP were investigated.
The basic parameters of the vessel are shown in Table 3.

Length Over All (LOA)	56m
Length Waterline (Lwl)	52m

Table 3 – Basic Parameters for Vita FPC vessel

Other basic information is shown in Appendix G.

After discussions with VT staff the following changes were applied to the structure of the vessel to account for the change in material.

As a rule of thumb, obtained from the VT structures department, the change in material from steel to FRP produces a 40% reduction in weight. In the case of the 56m Craft, this only applies to weights in group 1, a list describing the weight groups is shown in 4.9.3.1. The bottom construction will most likely be single FRP layers, whereas the sides would be sandwich construction. The superstructure weights will stay roughly the same as it is constructed out of aluminium. The difference in construction between bottom hull and sides will most likely result in a slight reduction of the Vertical Centre of Gravity (VCG) of group 1; however this is neglected in this study due to difficulties concerning quantification.

Seats and supports are unchanged, as they may need additional strengthening if constructed of FRP, thus offsetting any potential weight loss. The VT structures department pointed out that there might be a small weight increase due to requirements for fire insulation. However this is also ignored, as weight increase can be avoided by using more exotic materials. These materials tend to be more expensive but provide the benefit of lesser weight increases.

Several factors influencing costs were also mentioned. These include factors such as paint schemes (FRP requires less paint maintenance) and electromagnetic screening, which is required in FRP structures.

Welding was deleted from the new weights table. Stern tubes and Sea Chest were reduced by 20% each. The rolling margin was kept to account for uncertainties in FRP manufacturing, based on information provided by VT Design Office staff. Manhole weight was reduced by 40%, thus applying the same reduction for both the main plating and stiffeners.

These changes were then applied to the existing weights data and the new weights were used to calculate the new centres of gravity for the vessel, see Appendix G.

These new lightship weights were used to evaluate the new full load condition. The weights and centres for the full load condition were taken from the inclining spreadsheet provided by the VT design department.

Using the hydrostatic data [36], the new trim and drafts were calculated. The relevant hydrostatics data for the nearest corresponding displacements and trim were taken from the hydrostatic tables.

Based on the position of the Longitudinal Centre of Flotation (LCF), the new draft at amidships, accounting for parallel sinkage and trim, was calculated. From the hydrostatic tables, the draft at LCF was then used to obtain a first iteration of the KM_t for both new lightship and new full load and also the Longitudinal Centre of Gravity (LCG) and the GM.
The results are shown in Table 4 and are with reference to the original hull.

	Lightship	Full Load
Displacement	-13%	-10.8%
VCG	2.7%	1.5%
LCG	-8.6%	-5.7%
GM	1.14	1.06

Table 4 – results of new hull material

Also, the trim of the new full load condition is almost level keel. The draft of the full load condition, when compared to the full load condition given in the stability booklet [37], has changed by –9.8%.

This draft change could have serious implications on propeller performance. However, no further investigation was carried out, as the actual propulsion configuration for the new craft had not been decided upon.

The results indicate that it is possible to use the 56m vessel as a basis for further calculations as the change in hull material has not created any significant stability issues.

4.7.2.5 Parametric Study

Performance estimates for the 56m hull were obtained from the hydrodynamics department based on the new displacement. A guideline applied within the hydrodynamics department suggests that the Froude Number (Fn) should be around 0.28 at cruise speed for a fast hull shape.

A resistance curve for the original hull was calculated. The original 56m hull was used because of the assumption that the weight lost due to the different hull material would be replaced by additional fuel tanks to increase endurance. The resistance estimate was based on the powering data provided in the sea trial documentation [38]. As the surface area of the hull (S) is not known, the resistance data is plotted as $C_t \times S$ versus Speed and is shown in Figure 17.

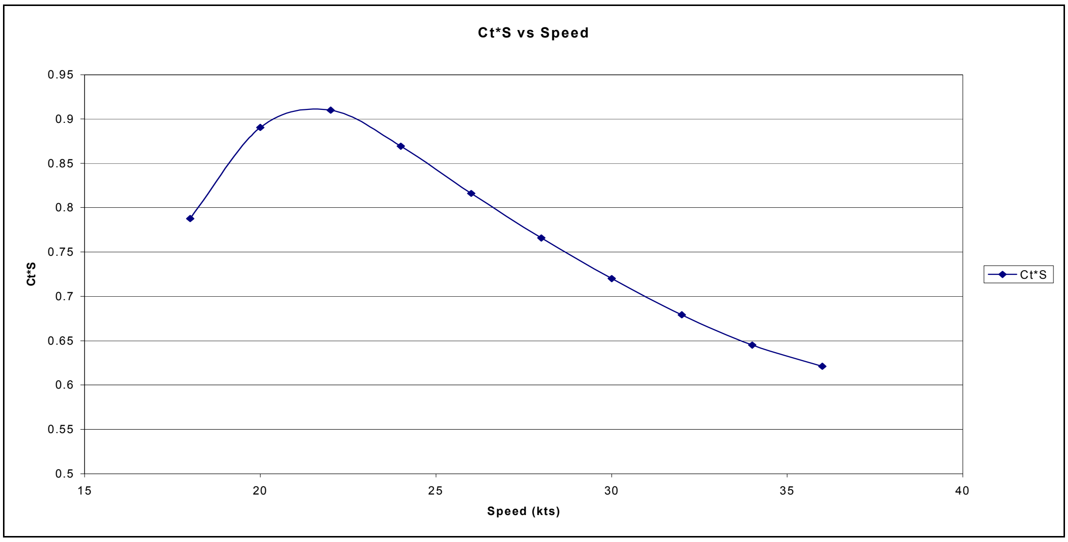

Figure 17 – Ct * S curve for modified FPC hull

Figure 17 indicates that speeds in excess of 25 – 30kts are past the resistance hump.

Using the specific fuel consumption of the engines [39], estimates were made to establish the approximate change in endurance for cruise speeds between 18 – 36kts. These results indicated that endurance could approximately be doubled for a cruise speed of around 30kts if the weight savings were offset by a higher fuel load.

Based on the above findings of possible high speeds and/ or increased endurance, the decision was made to further investigate the feasibility of a fast patrol craft capable of sustaining a high speed.

Based on a parametric study [40] investigating composite fast crafts the basic parameters for the design study were set as follows

Lwl	40 – 55m
Cruise Speed (V_c)	>30kts

The parametric study report [40] also contains several equations derived from regression analysis. These were used to determine a first estimate of how displacement varies with speed and endurance.

The regression equations are of the form

$$Weight = fn[x]$$

Equation 1

Where weight refers to the group weights under consideration and x can be any number of factors such as Lwl and range. The function itself is of an exponential format and takes the form

$$fn[x] = a(x)^b$$

Equation 2

Where a and b are factors determined using regression analysis based on existing ship data.

Using the results provided for the round bilge form in the parametric study [40], some graphs were plotted to further narrow down the choice of solution for the boat type required. The round bilge form was chosen due to its superior seakeeping performances [41] at high speeds over the hard chine craft.

The results indicate that a vessel of length 40m – 50m seems to be the most suitable to meet the requirements, see Appendix G.

4.7.2.6 Propulsion

The next step in the design process was the selection of the propulsion machinery.

Based on a review of similar vessel, the propulsion is to consist of two steerable waterjets coupled with a centreline booster waterjets. The steerable waterjets are to be powered by diesel engines and the booster waterjets are to be powered by a gas turbine.

Using information from similar vessels and after discussions with the VT Engineering Department the following engines were chosen

2x MTU 1163 73L	Diesel
1x TF100	Gas Turbine

Two power degradation rates were applied to the diesel engines. A 3% degrade was applied to account for the air intake and sea water temperature in the area of operation and a 15% reduction was applied to allow for maximum continuous operation during the cruise speed calculations.

A 20% degrade was applied to the gas turbine performance to allow for the temperature in the intended area of operation. The above figures were obtained from the VT Engineering department.

Using the data supplied by the manufacturers and applying the required degrades the following performance figures were calculated

Diesel Engines

Cruise rating = 5200 x 0.97 x 0.85
= 4287.4 kW

Gas turbine = 0.8 x 7409
= 5927.7 kW

The total available powers are therefore

Cruise rating = 2 x 4287.4
= 8575 kW

Max. rating = 8575 + 5927.7
= 16025 kW

Having downselected the engines choices the group 2 weights were refined. The weights of the diesels in the VT parametric study [40] were substituted with the weights of the diesels chosen for the new design. The group 2 weights used in the parametric study already contain items such as waterjets, turbine and gearboxes.

A simple model for the fuel consumption was developed to more accurately estimate group 8 weights and it is shown in Equation 3.

$$Fuel = a \times \frac{range}{V_c}$$

Equation 3

Where a is a variable based on Specific Fuel Consumption (SFC) and power output. The SFC of the engines was taken as constant and it was presumed that the generator sets (gensets) had the same specific fuel consumption as the diesel engines. The fuel consumption of the gas turbine is not taken into account, as only the cruise speed endurance is investigated.

The displacement for different lengths was then calculated using the regression equations provided in the parametric study report [40], combined with the refined fuel weights, engine weights and group 7 data. The results are presented in graph form, see Appendix G, together with cross plots of the length-displacement ratio, where

Length-Displacement Ratio = $\frac{L}{\nabla^{\frac{1}{3}}}$

The range of $l/\nabla^{1/3}$ is set to be 6.5 – 7. This matches the basis vessel value and corresponds with data provided by the VT hydrodynamics department. Applying higher cruise speeds resulted in lower displacements, due to the SFC and power output being fixed, as a higher cruise speed implies less time spend at sea for a given range. This decision was taken so that the approximate length was based on the ideal cruise ratings for the chosen engines.

The cross plots indicate that the vessel's length should be in the range 45m – 50m.

4.7.2.7 Reiteration of Parameters

The next step was to carry out a more detailed investigation into the vessel's size and shape. This was done using DSHIPSIZE, which is a VT developed and maintained program. It uses series data and regression data to derive a set of vessel parameters.

Again the results were plotted as displacement versus Lwl with cross plots of $l/\nabla^{1/3}$. DSHIPSIZE was used to calculate the displacements for ranges between 750nautical miles (nm) and 1500nm. Figure 18 shows a detailed graph for the design region.

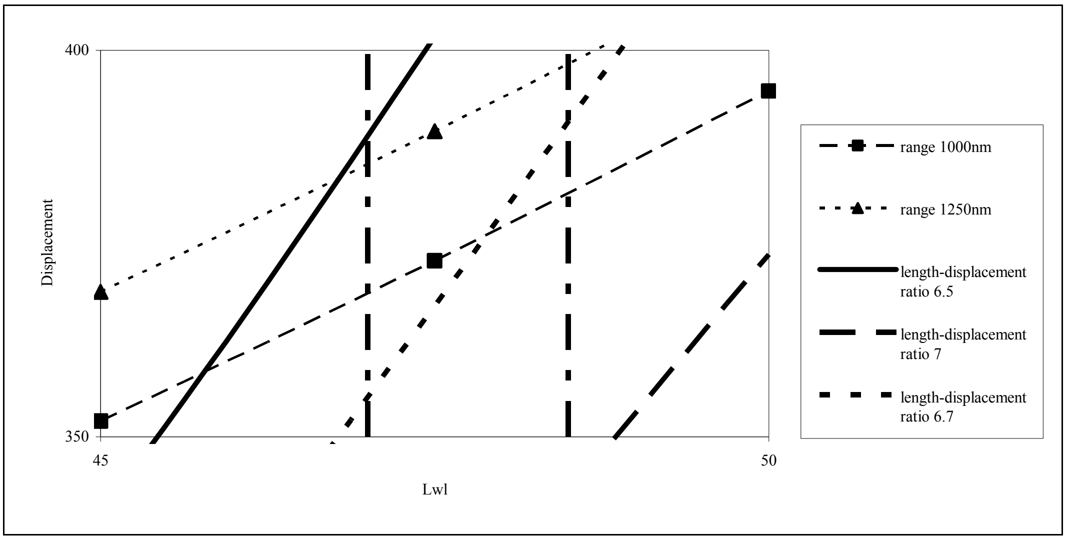

Figure 18 – Displacement vs. Lwl for modified FPC hull

From the graphs an Lwl of 48m is chosen as the starting point for further iterations.

Comparing the DSHIPSIZE results with other built vessels and scaling them accordingly, the following parameters were chosen as the initial dimensions.

Lwl	=	48m
Beam (B)	=	8m
Draught (T)	=	2.42m
$l/\nabla^{1/3}$	=	6.7
Displacement	=	377 tonnes
Cruise Speed	=	30kts

4.7.2.8 Time dependent log

This section describes the work carried out once the initial concept studies were completed.

The 56m MAXSURF model was shortened to match the presumed LWL at the design waterline of 2.4m.

As mentioned above the vessel is to be powered by waterjets. As a baseline for the design it was decided to use a configuration similar to the Rapid Response Boat (RRB), a VT concept design presented at Defence Systems and Equipment International (DSEi) 2003.

The RRB, which is capable of sprint speeds in excess of 50knots and has a LOA of 40m, is propelled by two steerable waterjets and a booster waterjet.
The waterjets used on the RRB are

2 x steerable waterjet	KaMeWa 100SII
1 x booster waterjet	KaMeWa 90BII

The hullform was adjusted several times to allow for the waterjets to be fitted. This included flattening the bottom of the hull nearer the transom and flattening the transom itself.

At this stage it was noted that due to the changes in the hull form, which was not geometrically similar to the 56m anymore, it would be necessary to re-evaluate the resistance and powering predictions. However, it was decided to leave these calculations until a first General

Arrangement drawing (GA) was obtained, as it was anticipated that several more changes to the hullform might be necessary.

The next step was the derivation of a first GA and the criteria influencing the layout of the vessel. The vessel is to be sub-divided to meet Naval Engineering Standard (NES) 109, now Defence Standard (DefStan) 02-109 [42], which stipulates a 2-compartment damage requirement. Due to the speed of the vessel it also needs to meet the International Maritime Organisation (IMO) High Speed Craft (HSC) Code [43], and particular attention needs to be paid to bottom raking damage.

The engine space envelopes were taken from the MTU manuals and a check was carried out to ensure the engines fit into the hull envelope.

The first design iteration was based on installing all the gearboxes in the aft of the vessel with the diesel engines being located in a forward machinery room. The connection between diesel engines and gearboxes would be via high-speed composite shafting.
This solution was discarded as there was not sufficient space in the aft machinery room to house both diesel engines and the gas turbine.

Also, the decision was made that the final propulsion solution iterations should allow for the vessel to be steered if one propulsion room was lost.

The next step of the design was concerned with determining crew numbers. This was necessary to determine how much space needed to be reserved for crew and hence how much space was available for alternative machinery configurations. The crew numbers are based on similar sized ships, with the data below obtained from VT.

Qatar 56m	35
Oman Offshore Patrol Vessel (OPV)	35
RRB	12 (not including Special Forces (SF))
Combattante I	24

After consultation with VT staff it was decided to have a crew of 25. The actual split for the crew is as follows

Junior Ratings (JR)	12
Senior Ratings (SR)	8
Officers (Off)	4
Commanding Officer (CO)	1

At this stage a decision was also made on the weapon payload of the vessel. Again this was based primarily on vessels of similar size. The minimum requirement was found to be a forward facing naval gun, such as the 40mm Bofors MK3, and a rear facing missile-gun combination, such as the Valkyrie or Raptor.

It was decided not to use modular cabins for the hull outfit. Modular cabins require too much space and are too heavy. On a small and weight sensitive design, such as this, they are far from ideal. The decision was therefore made to use flat pack cabins that can be arranged as required, thus fitting into the limited space, and keep the accommodation weight down.

A revised fuel calculation was carried out. For the fuel calculations a 105% fuel load was assumed, to allow for sprint speeds, and a 4.6% degrade was applied to allow for the surrounding temperatures. For the generators, a specific fuel consumption equal to the main diesel engines was assumed and the genset output was presumed to be 200kW. Using these figures a fuel consumption of 1.98t/hr was calculated. For a 1000nm range vessel this implies a required fuel storage capacity of 66t.

The frame spacing was set to 1500mm with the hull having transverse frames with main longitudinals. This was based on VT staff recommendations for similar vessels.

After several attempts to fit the diesel engines into the hull it became obvious that the chosen engines were too big for the size of vessel in question. It was therefore decided to investigate an alternative propulsion approach by switching from CODAG (combined diesel and gas) to COGAG (combined gas and gas).

Gas turbines have much higher degrades when subject to adverse environmental conditions, such as high intake temperatures. The first check was to ensure the gas turbines could still meet the powering requirements.

The degraded rating of each gas turbine is approximately 5400 kW, which is higher than the initially proposed diesel engines. This is based on a 10% degrade to allow for commercial use, a 5% degrade for intake/exhaust losses and a 3% degrade for gearbox losses. The gas turbine fuel consumption comes to 2.5 t/hr, resulting in approximately 83t of required fuel for a 1000nm range. However, the gas turbines are much lighter than the diesel engines at 1.5t each opposed to 20.4t each.

Using the space envelopes for 3 TF100 turbines and the information regarding redundancy and survivability a further iteration of the machinery layout was carried out. The intake and exhaust routes also had an effect on the location of the propulsion machinery, as they take up large amounts of deck area.

The investigation resulted in a proposal for an asymmetric machinery layout. The port gas turbine was located in the aft machinery compartment and the centre and starboard gas turbines were located in the forward machinery compartment. The two compartments were separated by a 6m compartment, thus satisfying NES109 minimum compartment length. This configuration provides steering ability if either of the two machinery compartments is flooded.

The genset requirement was determined as 120kW each, based on similar sized vessels and required endurance.

REVISED WEIGHTS ESTIMATE

Using the basis equipment data a revised weights estimate was calculated. The weights estimate was based on using the 56m hull but with the group 1 weights substituted with the results from the material concept study. The factors used for scaling are the ones normally applied by VT and are shown on the spreadsheet attached in Appendix G. The known weights were not interpolated but were input straight into the 48m weights sheet.

Once all the weights estimates were finished a weights sub-group comparison was carried out to evaluate the accuracy of the data. The weights were compared with data from the 56m, the RRB and a 49m waterjet concept based on the 56m. Based on these comparisons several sub-group weights were increased. The resulting weights and an estimate of their accuracies are described in more detail in Appendix H.

The LCGs and VCGs were estimated using layout data as far as available and scaling for all other values. These resulted in a revised lightship weights estimate for the vessel. The estimate contains a 10% margin on weight and a 5% margin on the VCG.

Lightship	VCG	LCG
260.153t	4.274m	20.15m fwd of aft perpendicular

A revised fuel estimate was carried out applying a 3% margin for structure and a 5% margin for unpumpable spaces. The revised fuel estimate is 2.58t/hr resulting in an 86t fuel requirement for a 1000nm range at 30 kts. Applying the margins resulted in 110 m^3 (93.5t) required fuel capacity.

The lube oil requirement was set at 1.5t and including margins came to 1.62t. The fresh water requirement was set at 120 l/person/day and including margins (3%for structure and 5% for unpumpable space) came to 4.54t. Both values are based on the advice received from senior VT ship designers.

Several iterations were carried out to decide on tank locations. Tank location was limited by the location of the machinery compartments as no tanks could be fitted under the machinery compartments due to space limitations. Also, fresh water tanks cannot be adjacent to fuel oil tanks.

A first stability check revealed that the vessel was not very stable at beam wind conditions. This, in combination with the limited space available, let to the vessel being widened and deepened within the maximum space envelope, i.e. the hull was made fuller.

It was later discovered that the beam wind criterion used in HydroMax overestimated the wind-heeling lever. However, this had no influence on the hull form, as all the equipment just fitted in, and hence there was no option of returning to the original shape.

Due to the changes in the hullform it was necessary to recalculate the weights estimate. The new lightship weights including margins were

Displacement	VCG	LCG
269.87t	3.654m	20.24m fwd of aft perpendicular

At this stage an error in the calculations was discovered. The entrained water of the jets had been omitted from the stability estimates, as it is part of the group 8 weights. It was decided to include them once a more detailed design was available.

REVISED PERFORMANCE CHECK

A resistance and propulsion check was carried out to ensure that the new shape still met the powering requirements before any further design decision could be made.

A manual check was carried out using the NPL High Speed Round Bilge Displacement Hull Series, see Appendix G. The results from this calculation indicated that an Effective power of 4.6 MW is required to maintain a cruise speed of 30 kts. This indicates that the chosen machinery satisfied the powering requirements and hence the design was progressed.

FIRST DETAILED GA

To construct the GA it was necessary to define the position of the watertight bulkheads within the hull. Using the originally proposed machinery layout it was found that the vessel did not meet the damage stability criteria of NES 109. Again, consulting VT staff revealed that the minimum compartment length stipulated by NES 109 is not suitable for small patrol crafts. It was therefore decided to allow the vessel to have a smaller minimum compartment length but keep the two-compartment damage requirement. This was backed up by the German Naval Standard, which dictates a minimum compartment length of 1.8m and the US Navy standard, which does not give a minimum compartment length but requires a damage of 15% Lwl to be applied anywhere along the hull.

The investigation of similar designs revealed that the vessel required an extension of the hull above the waterjets. This is to protect the jets whilst manoeuvring in port and also to maintain the required damage stability criteria.

The exhaust and intake routes for the gas turbines were the main design drivers for the deck layout. Proposed layouts included routing the exhausts along the centre line on the weather deck and along the side of the weather deck.

The original shear trim was removed to ensure access to the top of the gas turbines. This resulted in the proposal for a reverse shear on the vessel to accommodate the routings for the pipes. This was not deemed a satisfactory solution and hence an alternative arrangement was investigated.

Both side gas turbines were moved aft and the centre gas turbine was moved to the fwd machinery compartment. This was to allow the aft gas turbine exhausts being routed through the hull and hence only one exhaust having to be routed along the deck.

This proposal did remove the steering capability of the vessel if the aft machinery compartment was lost and hence a solution was sought involving small twin rudders. These were placed in between the centre waterjet and the steerable jet on either side with the steering gear being situated on a tween deck aft of the gas turbines.

The crew accommodation was designed using data from past designs, such as the RRB, 56m and 49m and consulting VT designers. Certain issues were driving the layout of the crew accommodation (not listed in order of importance)

1. Buffer between machinery and accommodation
    a. This resulted in stores and aux machinery being located in front of the main machinery compartment
2. WCs not to penetrate bulkheads but be adjacent to side shell
3. No bunks athwartships
4. No access to mess via other ranks' mess
5. Straight access way to optimise system routes and escape routes
6. As little dead space as possible

The superstructure design was constrained by the requirement to have a minimum 1000mm walkway either side of the superstructure, the 40mm gun in front of the superstructure, the stairway space envelope and the wardroom coinciding with parts of the galley below for a food hoist.

One of the requirements of the design was to carry a Rigid Inflatable Boat (RIB) on deck. The Rib chosen was a Pacific 22 from VT Halmatic, part of the VT Group. The Pacific 22 was chosen because of its inboard engine. The Pacific 22 cannot be stored athwartships and has to be launched by a davit due to its weight. This was not possible with the symmetric machinery arrangement and hence the design was changed back to the asymmetric machinery arrangement proposed earlier.

It was decided to route exhaust and intakes upwards through the deck. The exhaust funnel was shaped such as not to obstruct the inflow into the intakes. The exhausts were designed to be higher than the intakes so that exhaust fumes do not pollute the air sucked into the engines.

A more detailed weapon payload investigation was carried out. The factors influencing the position of the weapons are listed below

- All round firing arc coverage
- Located on a frame
- Sensor mounting (ideally located with gun so no extra sensors required on mast)
- Keep vcg as low as possible

The best compromise was found to be the 40mm Bofors forward of the superstructure, the Valkyrie or Raptor aft of the RIB and two General Purpose Machine Guns (GPMG) for close defence on the bridge wings.
The space underneath the 40mm was allocated as magazine space and a 750mm (half frame) cofferdam was constructed between magazine and accommodation. This is to comply with Lloyd's rules.

The bridge windows were raked forward to minimise glare and soiling from spray and birds. The emergency generator was placed next to the aft turbine intake by extending the intake casing transversely.

FURTHER WEIGHTS ESTIMATE & STABILITY CHECK

With most of the equipment determined and a first layout available it was possible to carry out a more detailed weights estimate. The weights estimate also included a calculation for the group 8 weights. The weights data was as follows

Lightship	VCG	LCG
257.7t	4.221m	20.28m fwd aft perpendicular

Again the tanks were rearranged to ensure the minimum immersion of the waterjets is 20% at all conditions. Also, the aft diesel tanks needed rearranging to be moved out of the way of the high-speed shafts.

The wind-heeling arm was calculated applying the guidelines in DefStan 02-109 [42], taking the projected areas from AutoCAD.

The stability check revealed that the vessel meets all stability criteria in the intact and damaged condition for both, full load and light seagoing.

As the vessel is a high-speed craft bottom raking damage needs to be considered. A more severe condition than the one required by the IMO HSC code was used. The stability of the vessel was assessed with the whole bottom being ripped away. This implies that all compartments are flooded to the tank top level (2.9m above baseline), with the exception of the two machinery compartments, which are flooded to the weather deck. The vessel passes the bottom raking case for full load and light seagoing. After the stability check was carried out the vessel was found to be non-compliant for the collision bulkhead. A collision bulkhead was added. However, no new stability check was carried out, as the additional watertight compartment will improve damage stability.

The layout was checked for emergency, system and storage routes. The emergency routes revealed that more hatches were needed. These were placed so that the IMO Safety of Life at Sea (SOLAS) [44] requirements were met. The system route check revealed that an air conditioning vent was missing. Creating a small compartment in the superstructure to house the vent rectified this. Mooring and lifeboat arrangements were also drawn up.

ALTERNATIVE PAYLOAD INVESTIGATION

With the design almost finished an alternative payload was suggested by the VT marketing department. A short anti ship missile system was installed on the vessel. The system used is the Daimler Polyphem, as it does not require any additional sensors. The missile system was placed at the aft end of the vessel and rotated at an angle such as not to damage any surrounding equipment during missile launch. This in turn led to the Valkyrie/Raptor being moved onto a pedestal on the bridge deck. The pedestal was required to maintain zero elevation clearance across the aft deck. A ready use locker for the Valkyrie/Raptor was installed in the pedestal, similar to the Single Role Mine Hunter (Sandown class) design.

The whip aerials were placed on the bridge wings to minimise radar black spots.

Once the alternative configuration was finished a weights check was carried out. The new weight data is as follows (including margins)

Lightship	VCG	LCG
260.393t	4.284m	20.28m fwd aft perpendicular

The change in VCG is about 3% and if margins are excluded then the new data is within the margins of the old data. Therefore no new stability check was carried out. The actual weights data including group 8 is shown in Appendix I.

FINAL PERFORMANCE CHECK

A final performance check was carried out. This was based on the model test data for the 56m hull. Using the actual turbine data and applying an Overall Propulsive Coefficient (OPC) between 0.65 and 0.7 the following results were obtained. The resistance data was based on a 2.4m design waterline.

At 45°C intake temp the vessel has a cruise speed of approximately 35 knots and a sprint speed of approx 45 kts. More detailed results are shown in Appendix J. To obtain the sprint speed two different approaches were used. One was a power trendline to extrapolate for higher speeds and the other was a polynomial trendline. A numerical check was also carried out using a spline interpolator form the hydrodynamics department. All results were in the same region.

Using the actual fuel aboard the vessel (93t) it was possible to carry out an endurance check, using an average power requirement. The following results were obtained for 45°C running at 35 kts

Mission time	35.9 hrs
Mission range	1220 nm

4.7.2.9 Design Summary

The final design checks prove that a working design has been developed. All design requirements have been met. The vessel is capable of a high cruise speed and has a sprint capability. This is ensured by using waterjets coupled to gas turbines. All applied degrades are for the required area of operation. The mission length is in excess of 1000nm and is approximately 1-½ days. The machinery has sufficient degrade margins applied to meet the minimum maintenance requirements. All machinery is accessible via removal hatches. The final GA is shown in Appendix K. The design waterline shown on the GA is at 2200mm above base to account for the actual waterjet position.

4.7.2.10 Conflict Areas

Several blind alleys were encountered during the designs. Some of the most important ones are listed and explained below.

- Engine Size
    - The initial selected engines did not fit into the hull.
- Engine location
    - Location is not just affected by the hullform but also by the deck layout. This is illustrated by the problems encountered during the layout and positioning of the RIB, Valkyrie/Raptor and Polyphem systems.
- Weapon location
    - Weapons need to be located low enough to minimise VCG impacts but high enough to provide coverage.
- System/Emergency/Storage routes
    - Routes need to be as straight as possible and have sufficient width for access

4.7.2.11 Description of FPC loops

To derive the impacts of the FPC study on the original loops it was necessary to translate the FPC findings into loops. The FPC loops were developed in several stages. During the first stage the time log developed in the FPC Design Description, see section 4.7.2.8, was used to construct a flowchart depicting the sequence of events. This flowchart is shown in Figure 19.

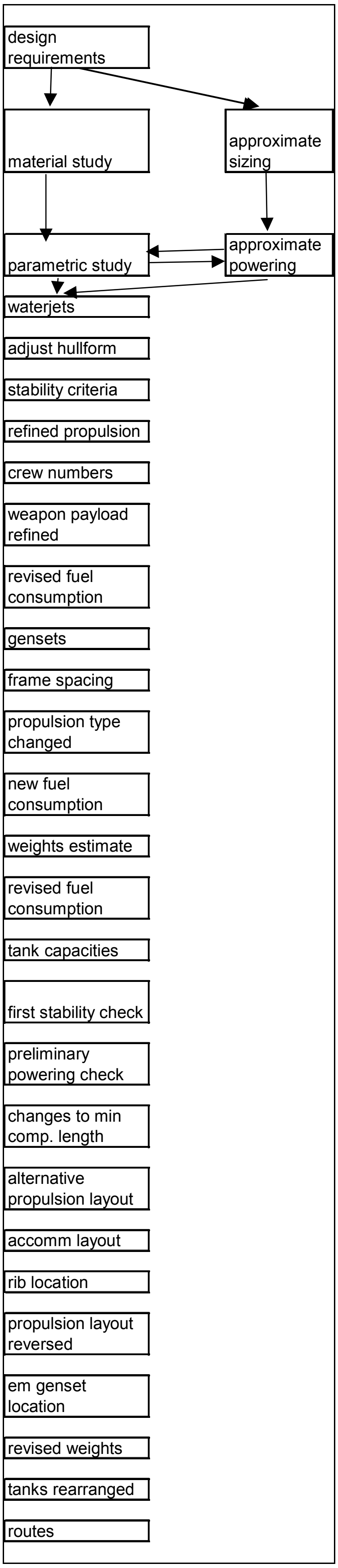

Figure 19 –FPC Sequence of Events

The process shown in Figure 19 was then translated. This means that the events described in Figure 19 were grouped under their respective domain headings. This was necessary to be able to draw a comparison to the initial loop model described in section 4.5. The resulting domain loops are shown in Figure 20.

F

Customer

structures	naval architecture	general vehicle capability	aviation	weapons	Cost	Production
naval architecture	propulsion					
propulsion						
naval architecture						
naval architecture						
propulsion						
HF						
weapons						
propulsion						
electrical						
structures						
propulsion						
propulsion						
naval architecture						
propulsion						
propulsion						
naval architecture						
naval architecture	propulsion					
naval architecture						
propulsion						
naval architecture						
naval architecture						
propulsion						
electrical						
naval architecture						
naval architecture						
systems	naval architecture	HF				
weapons						
weapons						
naval architecture	propulsion					
naval architecture	HF	systems	electrical			

Figure 20 –FPC Initial Loop Description

Finally the domains were consolidated. This means that wherever a domain appeared more than once in succession it was grouped into a single appearance. An example of this is shown in Figure 21.

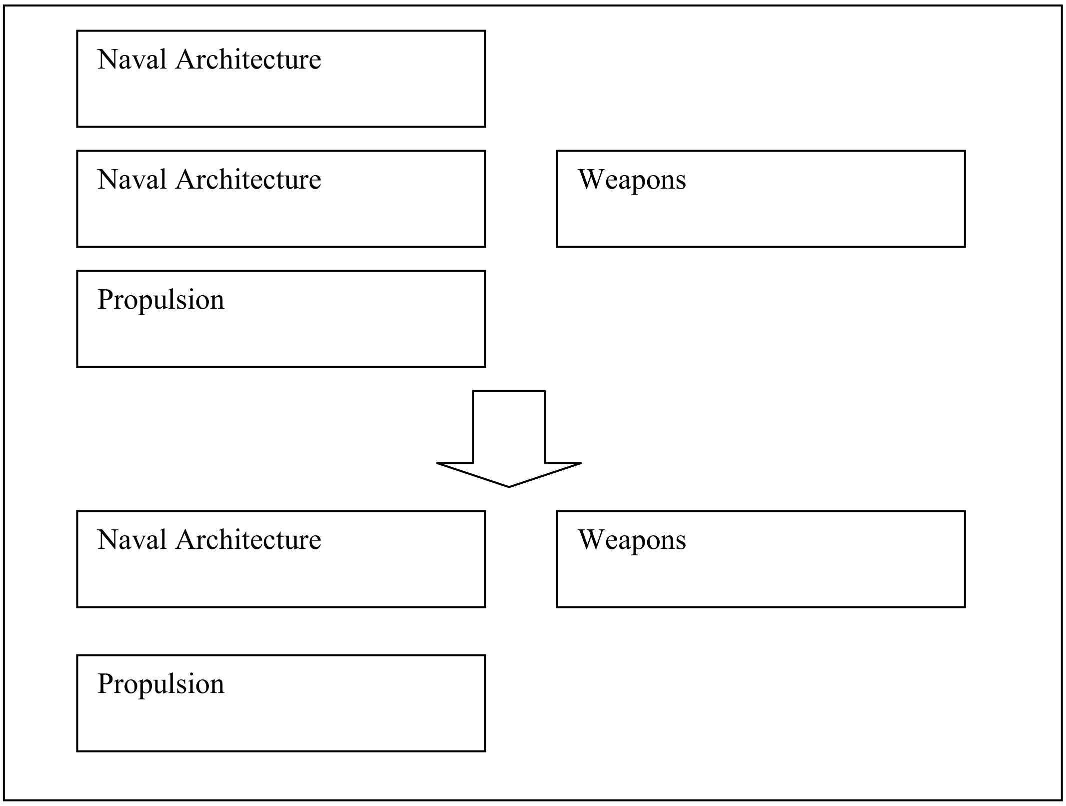

Figure 21 –Example of Consolidating Domains

The resulting flowchart is shown in Figure 22.

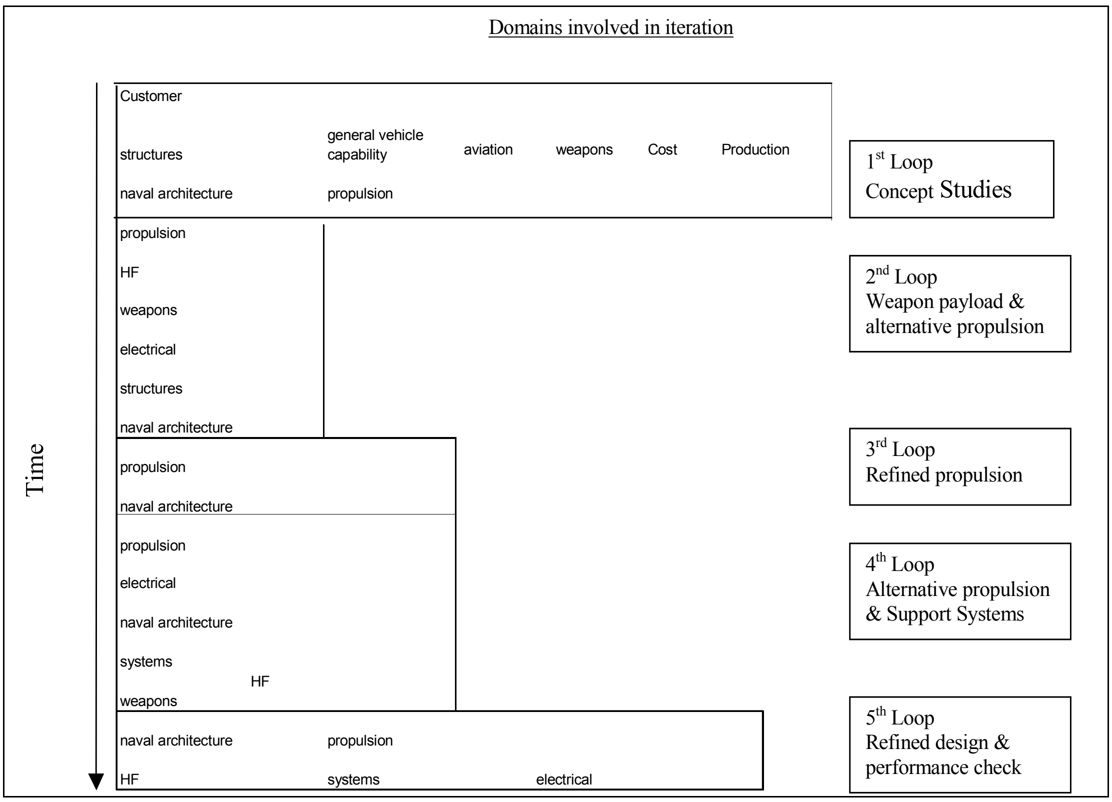

Figure 22 –FPC Final Flowchart

The first loop contains the parametric study and the material concept study. During the loop the first sizing and the basic parameters of the vessel are derived. The parent hullform of the vessel was chosen during this loop.

The second loop provides information about the weapon payload, the frame spacing and the electrical power requirements. It also contains a reiteration of the propulsion criteria based on a COGAG arrangement. At the end of this is loop is the first detailed weights estimate and a first stability check.

The third loop, shown in green, is mainly concerned with a reiteration of the propulsion machinery and the influence on the basic ship parameters. It finishes with a first accommodation layout.

The next loop, loop4, contains the reversal of the propulsion arrangement back to its original COGAG asymmetric arrangement. It also contains a more detailed weights estimate, tank arrangement and a system route check. Finally, the alternative weapon payload is investigated.

The final loop contains several smaller, but nonetheless important items. These are items such as mooring arrangements and lifeboats. The loop (and design) is closed by a final performance check to ensure the vessel meets the criteria outlined in loop 1.

4.7.2.12 Comparison to Initial Loop Model

The first FPC loop is very similar to the first initial model loop. It is used to determine a first shot at the basis parameters of the vessel. It can be argued that cost and production are included in the FPC loop as the vessel is based on an existing vessel to minimise cost and is within the boundaries of what VT can construct. The FPC loop 1 does not contain a first crew estimate. This is not investigated until loop 2. This seems a better practice than the solution suggested in the loop model as the crew estimate was largely based the size of the vessel. It is therefore proposed to carry out the crew estimate after the basis size of the vessel is determined.

The second FPC loop contains elements of the 2nd and 3rd model loops. If the FPC loop 2 was split up it might be possible to match it more closely to the model loops. This is attempted in the following section.

The main aim of the 2nd model loop is to give a more detailed analysis of the propulsion machinery arrangement. The FPC design contains a basic description of the propulsion arrangement at the start of loop 2. However, this is only based on data from previous vessels that were not designed to the same requirements and hence the 2nd FPC loop can be seen as a propulsion study by itself, if some of the other domains are isolated.

The weapons, electrical and structures domains of the vessel do not have to be carried out at this stage but can be moved further down the chart. This will then imply that the 2nd FPC loop is almost identical to the 2nd model loop. At this stage it is also noted that the structures domain, which is not included in the model loops, should be included on the 1st model loop. This is to ensure that a basic understanding of the required frame spacing is in place right from the start of the design process.

The 3rd FPC loop is mainly a check and control loop. It evaluates the powering and resistance data for the FPC and provides a first stability check. Having completed the design it is noted that this loop was not necessary at this stage and could have been moved further down the design process.

The 4th FPC loop investigates a revised propulsion layout. Other issues considered include an investigation into systems (domestic and auxiliary) and their routes. This corresponds closely with the 3rd loop of the initial model. Some of the items investigated had an impact on the layout of the vessel; the naval architecture domain in the loop covers this.

The 5th FPC loop is essentially another check and control loop similar to the 3rd FPC loop. The minor corrections that were required are covered in the 3D schematic by the provision of the feedback and iteration loops.

4.7.2.13 Recommendations for Initial loop model

In general it appears that the FPC loops match closely to the model loops. The correlation between the two is increased if the FPC loops are amended to allow for mistakes in the process. However some changes to the model loops are recommended. The initial crew estimate should be moved to the 2nd loop.
The 1st loop needs to contain the structures domain. This domain requires input from the naval architecture domain.
A control loop needs to be included to allow for the impact of the propulsion system on the topside design. It is therefore proposed to add weapons and general vehicle capability to loop 2.

4.7.3 Future Surface Combatant Study

4.7.3.1 Introduction

In a similar manner to the FPC study a time dependent log was created using data collected from all involved internal parties on the FSC project. The collected data was mainly in the form of design records and some background notes. Unlike the FPC study the FSC study is not a design study but rather an analysis of an existing design and its development cycle at VT.

The following section provides details of the design records used to obtain the interface model for the FSC study. The provided logs were isolated and did not always explain the impact on the overall design. Therefore all logs are written out below using the information contained within them and are then cross linked to each other. The background notes are shown in Appendix L to aid clarity.

The FSC design is based on a Trimaran hullform capable of fulfilling the MoD’s requirements for the Future Surface Combatant.

4.7.3.2 FSC Design Record

The following is a summary from the design logs as they were stored in the design log database. No dates are given but instead headings are given in time units. This is to allow for easier identification of time dependencies. The time units are derived from the original dates calculations were carried out. All dates were recorded and then sorted in ascending order and labelled time unit 1, 2 etc. In total 16 time units were created and they are shown in chronological order under the time dependent log.

NAVAL ARCHITECTURE

Initial design requirements were given and are detailed below
Time Unit 1

- Combat systems as outlined by weapons domain
- Flight deck and hangar for Merlin
- Possible extension for flight deck over aft working deck to allow for Chinook
- Aft working deck to carry pallets container or boats
- 2*amidships electric tractor pods
    - Associated generators to be placed where appropriate

- 1 aft gas turbine coupled to booster waterjet – exhaust routing already identified as a problem at this stage.
- Aim to optimise high cruising speed.
- Range 7000nm min.
- Endurance 30 days.
- Length approx 140m.
- Displacement target 4500 t.
- 100 crew envisaged.
- High survivability.
- Minimise structure above cross decks.
- Modularity essential.
- Future use spaces required.
- Production requirement – need to be able to pass through C and D locks to enable vessel to leave the dockyard.

Time Unit 2

- Deck heights decided upon.

Time Unit 3

- Basic parameters provided based on hydrodynamic performance.

Time Unit 4

- Based on a weights evaluation, incl. 12% design margin, the decision was made that the 145m hull has not enough buoyancy to support weight.
    - Hull was extended to 170m.
- Following the decision to increase the hull length the deck heights were scaled as well.
- A first damage stability assessment was carried out. It was found that the vessel failed the initial assessment. This resulted in increased sidehull length and added watertight decks in sidehulls. The added weights further increased the realisation that the 145m would not work.

Time Unit 5

- LWL of 170m discarded, as it would make design unattractive to RN. Design changed to 160m and instructions were given to try to achieve design balance.

Time Unit 6

- Confusion with regards to appropriate damage stability standards. Clarification obtained from MoD.
- Further weights increase noted.

Time Unit 16

- The aft helicopter deck was extended across the whole of the aft deck. This allows for operation of a Chinook and for operation of an Unmanned Air Vehicle (UAV).
- Some compartments at the aft end were rearranged to accommodate a hangar space for the UAV and for the operation of a towed sweeping array. Possible space conflict with extended flight deck.
- No walkway either side of the superstructure. To overcome this problem the superstructure was moved inwards on either side.
- Concerns over slamming loads led to the crossdeck structure being moved aft. This led to a complete redesign of the accommodation layout on 2deck, the reshaping of the front of the superstructure and loss of large open fore deck area, the latter designed for ammunition Replenishment at Sea (RAS).
- Redesign of the mast and funnel arrangement.

- A centralised stair tower was introduced. This led to simplification of some system routes. Only impact was reshuffling of some surrounding compartments.

ELECTRICAL

Time Unit 7

- The cable weight was based on proportional scaling of past vessel data. The length of the vessel for scaling purposes was 160m (changed hullform).
- The electrical equipment was estimated using data from Research Vessel (RV) Triton and Greek Fast Attack Craft (FAC).
- A preliminary switchboard weight was derived using data supplied by Rolls Royce.

Time Unit 8

- All electric propulsion was investigated and found to be not viable unless an arrangement similar to T45 is used.

Time Unit 14

- A baseline electric solution was created based on work carried out on the Greek FAC (similar crew and weapon load); solution does not include electric propulsion. Generators will change if all electric propulsion option is used.

Time Unit 15

- Slow speed electric propulsion weights were calculated.

Time Unit 14

- All electric propulsion weights were calculated.

WEAPONS

Time Unit 1

- An attempt was made to analyse the requirements for the FSC weapons system baseline. No exact requirements were given and thus the design was based on the draft URD and allows for flexibility to incorporate future design changes.
- The command system is based on the T45 design but the number of operator stations is based on the T23 adding 4. (T23=12 FSC=16)
- The communication system is based on T45 and scaled for the FSC.

STRUCTURES

Time Unit 7

- The estimated structural weights were scaled from 145m to 160m to allow for the change in dimensions.

AUXILIARY, DOMESTIC AND PROPULSION SYSTEMS

Time Unit 4 (estimated)

- Baseline design for propulsion system. This was based on the initial solution of pods for cruise and waterjet for boost. Twin waterjets had to be used, as the stern shape did not allow a single large waterjets to be fitted. This solution was discarded, as it was not feasible.

Time Unit 7

- Investigation into possibility of converting the pods to direct drive pods. This option limits low speed operation but significantly reduces weight.

- An investigation was carried out into the effect of reducing the cruise speed. The associated reductions in weights were calculated.

Time Unit 8
- An investigation was carried out into replacing the medium speed diesel engines with high-speed diesel engines for the electric propulsion solution. This was found to be unfeasible.

Time Unit 9
- A list was created of all the parts required for the auxiliary machinery of the vessel. Acoustic and Thermal signatures were noted for possible signature control.
- A detailed investigation of the fuel oil supply was carried out. The weights were calculated.

Time Unit 10
- Chilled water system was designed.

Time Unit 11
- A preliminary Heating, Ventilation and Air Conditioning (HVAC) system was designed for the purpose of weights evaluation.

Time Unit 12
- Thermal signature reductions were considered. The results of the study were some signature philosophies. None of these mentioned relocation of any equipment.
- Acoustic signature reductions were considered but no further action was taken as no actual acoustic data was known.

Time Unit 13
- An alternative propulsion arrangement was investigated. The idea was to replace the waterjets with controllable pitch propellers to avoid the stern shape becoming overly full.
- The impact of exhaust gases on helicopter operations was investigated. Helicopter operations should not take place whilst running at boost speed.
- A performance check was carried out to determine the endurance and range of the vessel at various cruise speeds. The powering figures used included an unspecified design margin.

4.7.3.3 Time Dependent Log

This section describes the modification of the above design records into a time-dependent log that can be used for further analysis and derivation of the interface model.

Time Unit 1
- Initial design requirements
- Weapons study results
- Production requirements (maximum build size investigation)

Time Unit 2
- Deck heights

Time Unit 3
- Basic parameters

Time Unit 4
- Failed damage stability requirement leading to increased weights
- Decision to change hull to 170m
- Deck heights scaled

Time Unit 5
- LWL set at 160m

Time Unit 6
- Problems with engineering weights
- Stability standard clarification
- Baseline propulsion system developed – later discarded

Time Unit 7
- Cable weights
- Electrical equipment weights
- Switchboards weights
- Structural weights
- Effect of reducing cruise speed
- Option of direct drive pods

Time Unit 8
- Electrical prolusion investigated – not viable
- Replace medium with high speed diesel engines –not viable

Time Unit 9
- Aux machinery
- Fuel oil supply system

Time Unit 10
- Chilled water system

Time Unit 11
- HVAC

Time Unit 12
- Thermal signature reduction philosophy
- Acoustic signature reduction philosophy

Time Unit 13
- Alternative propulsion arrangement using propellers for cruise and boost
- Impact of exhaust gases on helicopter operations
- Performance check

Time Unit 14
- Electric propulsion weights
- Baseline electric weights

Time Unit 15
- Slow speed drive weights

Time Unit 16
- Various options and alternatives investigated

To assess the accuracy of the time dependent log a comparison was made to the background notes. Comparing the background notes with the time dependent log indicates a good correlation. There appear to be some minor discrepancies with regards to the sequence of events regarding propulsion machinery decisions. However, the sequence of events described in the time dependent log is deemed sufficient for the purpose of the interface model derivation.

4.7.3.4 FSC Loop Development

Using the above data a flowchart was created detailing the actual sequence of events, see Figure 23.

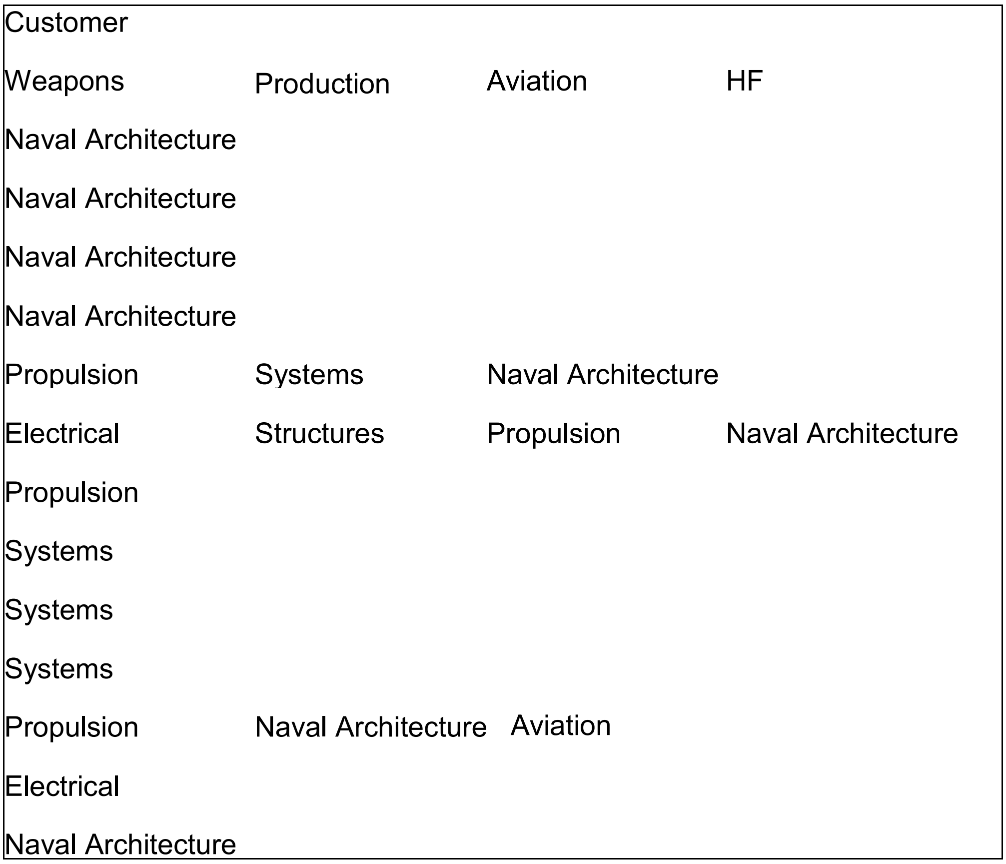

Figure 23 –FSC Initial Flowchart

A more refined version, where the domains are consolidated is shown in Figure 24.

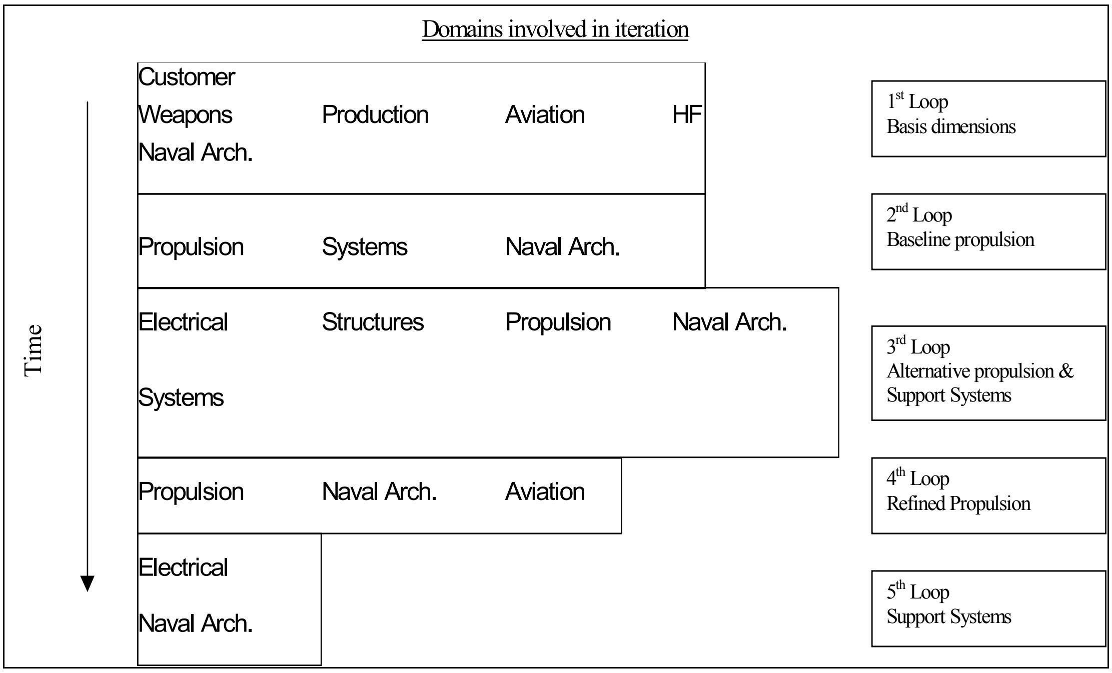

Figure 24 –FSC Final Flowchart

4.7.3.5 Comparison with 3D loops

Figure 24 is used for the comparison with the 3D loop. The consolidated flowchart is divided into several loops to aid comparison with the 3D representation.

The first loop is identical to the 1st loop of the initial model. The basic size of the vessel is determined from assumed customer requirements. The requirements had to be assumed as no URD has been published as yet.

The 2nd FSC loop investigates a baseline propulsion system. It also investigates issues arising due to errors in the engineering (propulsion, auxiliary and domestic systems) weights. This corresponds well with the model loop 2.

The 3rd FSC loop investigates several items. Most of these are in line with the model loops, however there are some discrepancies. Several alternative propulsion arrangements are studied during the 3rd FSC loop. This can be equated to the model loops by introducing a feedback loop linking propulsion loop 2 and propulsion loop 3 in the 3D schematic.

The 4th FSC loop is very similar to the 2nd model loop. The aviation domain is included as a basic check of the impact of exhaust fumes on helicopter operations is carried out.

The 5th FSC loop is similar to later parts of the 3rd model loop.

4.7.3.6 Recommendations for initial loop model

It appears that some time was lost on the FSC project due to the propulsion layout being unclear. It might have been advantageous if some work was not carried out until the actual propulsion layout was known.
Structures should be included in the initial model after loop 1, so that a value for structural weight is included in the weights estimate.

4.7.4 Combined effects on Initial Model

After the FSC and FPC studies were carried out a top-level loop was added. It was felt by the author that this would greatly enhance the management options available to a project manager and also provide a better model of the design process. The top-level loop is an attempt to include parts of the concept stage in the feasibility process. Figure 25, shows the initial proposal for the top-level loop.

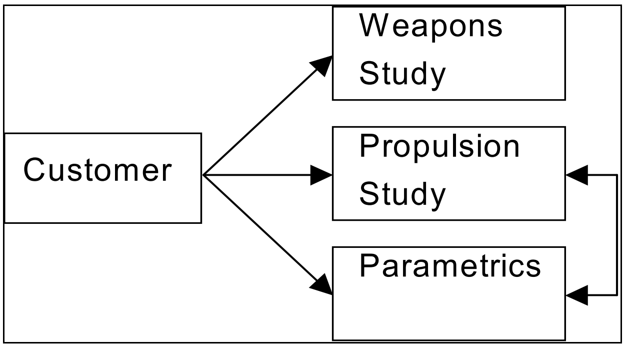

Figure 25 – Initial Model Top Loop

The results from the top level loop then feed into the original loops. Adding the top-level loop allows the manager to explore more radical ideas without the need of major redesign work.

4.8 FURTHER DOMAIN INVESTIGATIONS

4.8.1 Introduction

During the process of creating the flowcharts it became obvious that not enough was known about certain domains. Whereas the traditional technical domains, such as Naval Architecture, are investigated during the case studies, described in section 4.7, this is not necessarily the case for domains such as Human Factors, ILS and Production. To overcome this shortcoming more in-depth investigations into these domains were carried out. These studies were further necessitated by the need to include ILS as part of SMART procurement. The following sections provide an overview of the results from these studies. They also detail the derived impact on the loop model.

4.8.2 Production

The investigation of the production domain consisted primarily of an interview with the Design for Production Manager at VT.

Production has a major impact on the UPC and to be competitive on an international level it is vital that production costs are reduced.

Productivity is a function of design. The better a design is adapted for producability the cheaper the building costs are likely to be. There are several factors that influence producability and some examples are shown below

- Cable runs
- Cofferdam placement
- Deck layouts

It is important to design the vessel so that it is easy to split the hull into building blocks. System routes need to be as straight and simple as possible, and the same is true for access routes.

The earlier production is involved the easier it is to reduce production costs, by optimising the design for producability. An example of this is that it is much easier to connect equipment in the ops room using digital transmissions opposed to traditional analogue wiring. The material cost will increase, due to the additional digital converters, but the build time will reduce significantly.

He stated that the best way to improve design for producability would be by educating the designers. There is no need to consult production every time a change is made if designers are aware of producability implications. Some production decisions can be made up-front. However, production should be consulted for all major changes and at all review points.

There are several rules-of-thumbs for possible savings that can be made in design when considering the production inputs. The earlier during the process a change is made the more cost efficient it is. As an illustration the rule of “two” can be used, i.e. a change taking 8 days at berth takes approx. 4 days in the unit hall or 2 days on the shop floor or one day in the design office. These are only approximate but illustrate the point about early changes.

Production can absorb and free up margins depending on the decision. However, in general the trend tends to be to absorb design margins, e.g. cofferdams absorb space margin unless the design is lengthened.

4.8.2.1 Results

It appears that a more in-depth production phase is required up-front. A production input is required into the parametric study at the top study loop; this is to allow for hull-form implications and also provide information regarding planned building schedules and available berth space.

Production then needs to be included, as is the case, on the 1st loop to provide input into the Naval Architecture domain.

Production should then act as a general input to all domains but only become visible in the template at review points. This is to aid clarity.

4.8.3 ILS

4.8.3.1 Introduction

The report provides a summary and some interpretation of the notes from the MoD ILS reports. Several reports were used to gain an appreciation of the ILS requirements stipulated by the MoD. Most of these were taken from the MoD website.

It was found that many of the reports contained repeated information. It appears that the MoD does not have a centralised policy on the effects of ILS on ship design. This was highlighted by email correspondence received from the ILS helpdesk, which stated that ILS implications on ship design are normally considered by the platform Integrated Project Teams (IPT) and are not stored centrally.

To tie in with the overall aim of the research, i.e. to develop a methodology for early stage design, chapter 4.8.3 investigates the factors affecting ILS during the assessment phase, but also accounts for issues in late concept and early demonstration phase.

4.8.3.2 Domain Definition

To identify the impact of ILS on feasibility studies it is first necessary to define ILS as a domain.

"ILS is a disciplined approach to managing Whole Life Costs (WLC) that affects both MoD and suppliers. Its aim is to optimise WLC by minimising the support system required for equipment, through influencing its design for supportability and determining support requirements. The end result is supportable and supported equipment at optimum cost." [45]

The above quote is taken from the MoD guide on ILS and highlights some of the issues raised by ILS. It indicates that ILS is a multi-discipline domain and that ILS has to be started at an early stage of the project life cycle to effectively influence design.

A more detailed analysis of the tasks required to enable a successful implementation of ILS into the design cycle is provided in section 5.

There are several guidelines that formalise the policies relating to ILS. The disciplines and elements of ILS are outlined in DefStan [46]. This standard also details the factors associated with ILS and the related standards.

Reliability and Maintainability are two of the main drivers for support costs and they are managed by DefStan 00-40 through to 00-49.

The amount of data and policy strategies presented in the various DefStans is very large and hence only a general overview is given in this report.

As mentioned above the research concentrates on the ILS activities carried out during the assessment phase, the late concept and the early development phase of the Concept – Assessment – Design – Manufacture – In-service – Disposal (CADMID) cycle. These phases are considered to be roughly equivalent to feasibility studies, see section 2.4.

The work of ILS begins as soon as a military need has been identified and equipment concepts are being defined. This implies that ILS starts from the very beginning of the product life cycle.

Figure 26 shows the activities carried out as part of ILS as perceived by the MoD.

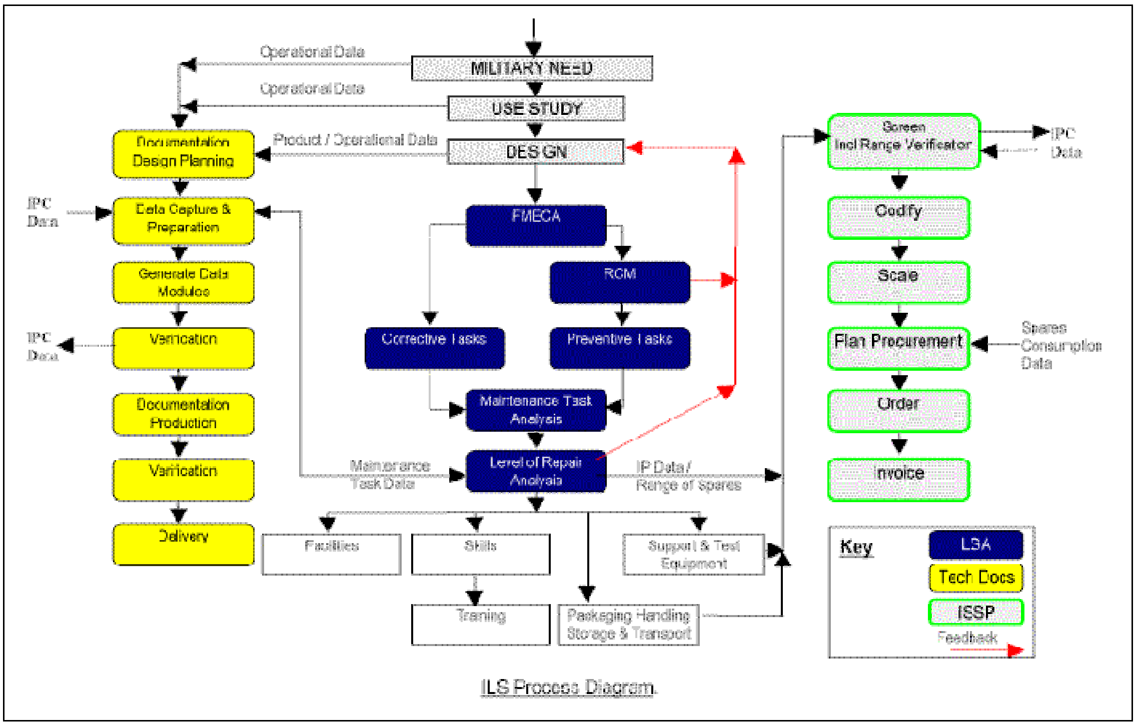

Figure 26 [47] –ILS Task chart

CONCEPT PHASE

ILS starts at the concept phase. At the end of the concept phase the support strategies and an outline support plan will be drafted. Within the URD reference will be made to supportability and availability requirements. A draft Logistic Support Analysis Plan (LSAP) needs to be developed and is part of the overall ILS plan and strategy. The LSAP contains information on how the LSA will be conducted. From a contractor perspective the important part is the creation of the Integrated Support Plan (ISP), which becomes the tenderer's principal ILS management plan.

During the concept stage the MoD will carry out the use study (Logistic Support Analysis (LSA) task 201) and will distribute it to the contractors. It is to be used for guidance only by the contractor. The use study will be continually updated by the MoD during the assessment stage.

The MoD will also distribute the Integrated Logistic Support Plan (ILSP) to the contractors. Again, this is not a contractual document but to be used for guidance by the contractors in interpreting the Statement Of Work (SOW).

The ISP is the most important part of the contractors bid in response to the Invitation To Tender (ITT).

ASSESSMENT PHASE

During the assessment phase the SRD is developed to satisfy the URD. During assessment the first "actual" support analyses are carried out.

The main activity of ILS during the assessment phase is described by LSA tasks series 200 and 300. Both of these series tasks carry on into the early demonstration phase. The aim of the assessment phase in terms of ILS is the determination of support requirements for the system solution [45].

The 200 series tasks include the above mentioned use study. They are designed to identify areas where design modifications could lead to improved supportability of the equipment. The desired outcome is to identify

- The way in which equipment is used and supported
- Opportunities for standardisation
- Existing and potential cost drivers
- Applicability of new technology

The information shown above is taken from the MoD ILS guidance notes.

The 300 series tasks are used to identify detailed trade-offs that can be performed once a more detailed design is available. Therefore they occur later during the assessment or early during the demonstration phase.

DEMONSTRATION PHASE

The relevant tasks carried out during the demonstration phase are already described in the section detailing the assessment phase tasks. Other tasks are carried out during demonstration but these are not relevant to the feasibility study process, as they require a level of detail not usually available during feasibility studies.

GENERAL TECHNIQUES

Several other techniques exist, which are applied throughout the project and not specific to any phase. These also have to be considered as they form part of the LSA and should be used during feasibility studies.

The most important ones are

- Failure Modes Effect and Criticality Analysis (FMECA)
- Reliability Centred Maintenance (RCM)
- Level of Repair Analysis (LORA)

FMECA

The aim of this analysis is to minimise maintenance requirements. Potential failures are identified and grouped under the following headings

- Cannot be removed through redesign but can be avoided through preventative maintenance
- Have a non-critical impact and are thus allowed to occur. Rectification is via corrective maintenance

RCM

RCM is used to assess the most cost-effective maintenance methods and should be combined with FMECA to avoid duplication of effort. All future maintenance strategies are to be based on RCM [48].

LORA

This is the term given to the analysis of determining the most suitable maintenance level for repairing equipment. LORA is divided into economic and non-economic sub-groups depending on the level of variables affecting the repair.

OTHER DOMAINS

There are other domains to be considered next to ILS such as human factors integration. However HF is not considered in this report as it is regarded as a separate domain for the purpose of this research and its implications are detailed in section 4.8.4.

Reliability and Maintainability is considered to be part of the ILS domain for the purpose of this study. This is in line with current policy at the MoD [45].

4.8.3.3 Data Storage

All data produced must be stored in the Logistic Support Analysis Record (LSAR). This is in the form of a relational database and ownership is with the relevant IPT. The implication of this for the contractor is that all data needs to be in a format accessible by third parties. The guidance notes provided by the MoD strongly emphasise that no data should be produced for data sake [45] to avoid overloading the system.

4.8.3.4 Maritime applicability

Having established the framework of important factors and studies during feasibility studies it is necessary to apply these to the maritime environment. This should allow for a more detailed integration of the ILS domain into the feasibility study framework, see chapter 3.

One of the main assumptions of the maritime support policy is that capabilities will be managed and supported on a pan-fleet basis [49]. This implies that the party responsible for the design and supportability of equipment needs to be aware of pan-fleet developments.

In term of ship design certain issues can be addressed during feasibility studies. These include

- Selection of equipment based on up front capital cost vs. through life support cost
- Frequency of service
- On board vs. on land maintenance
- Removal routes
- Access routes

Most of these could be solved if ILS was applied when equipment was being decided. This implies that ILS also communicates with procurement. Some of the studies and interviews at VT revealed that many of the aforementioned issues are considered by designers during feasibility studies but are not usually recorded explicitly. Therefore there is always the risk of designers omitting ILS requirements.

4.8.3.5 Tailoring

Tailoring is one of the major aspects of ILS under SMART procurement. It allows the workload to be adjusted based on the project requirements. If the customer specifies that he is more interested in up-front capital costs than TLC then it is possible minimise the activities carried out under ILS. On the other hand if the TLC is a priority then it is possible to maximise the activities carried out by ILS. This allows the shipyard to decide the required ILS strategy on a study-by-study basis and thus it is important to integrate ILS across the design process

4.8.3.6 Cost Implications

An increase in up-front capital expenditure is required to achieve a reduction in TLC. An increase of 10% in UPC can lead to a reduction of 20 – 30% TLC [50]. However, to achieve these TLC savings it is important the ILS works in close conjunction with procurement and design.

Also, it is important to make the bid-office and the sales department more aware of the activities carried out by ILS, as more and more customers require through life support solutions. As mentioned above, these increase UPC and hence marketing need to place more emphasis on reduced TLC.

4.8.3.7 Summary

The following outlines the effects of ILS on the methodology as seen by the author of this thesis. ILS should be applied at all stages of the design process. Similar to human factors, see section 4.8.4, it should be used as an input and advisory to other domains with regards to design issues. At design reviews a formalised ILS investigation should be included. For the purpose of the 3D process chart ILS should be shown at all review points.

One suggested solution to the ILS integration issue is an equipment database. This database already exists within VT and should be used on all future projects. This will allow the database to be populated with equipment specific ILS data and thus all designers can access information such as space envelopes. However only basic ILS information should be included in the design database to avoid information overload whilst the ILS domain should store detailed ILS information.

Another form of integration would be to use design guidelines. These could be distributed amongst design teams and their importance highlighted by giving seminars within the company. Currently, ILS chases up most of the data, and it is proposed that any future solutions should allow for design data to be shared with ILS. This will allow ILS to take preventative rather than corrective measures with respect to issues such as removal routes.

Any issues arising that can are not resolved during the design process would be addressed at the formal review point.

Ownership of ILS being observed should rest with the Integrated Logistics Department whilst the onus for provision of data should be on the individual domains.

Some up-front work is required by ILS to tailor the ILS tasks to the project. This can be carried out when the ILS domain starts on loop1. As mentioned above ILS would then run as an advisory to other domains.

4.8.4 Human Factors

4.8.4.1 Introduction

The section provides a summary of the findings from an in-depth investigation into the human factors domain. This investigation is necessary to more accurately determine the position of the human factors domain in the 3D model. The main emphasis of the investigation is on complement generation.

Most of the published literature is concerned with manning issues. Only one paper deals with general habitability concerns [51]. However, HF does encompass all areas of human-human and human-machine interaction [52].

4.8.4.2 Crewing

There are many factors influencing crewing requirements on vessel. Complement is a major TLC driver [53]. It is therefore important to have an effective crewing evaluation strategy in place for future feasibility studies. Complement has a direct impact on accommodation layout

[53], and hence the naval architecture domain. To allow for this it is necessary to have a first crew evaluation at the very first stages of the feasibility process. This implies that the crewing studies, as part of the HF domain, need to take place at the top-level loop, once the parametric study is completed, see Figure 27. To validate this assumption it is necessary to further investigate the drivers for crewing calculations.

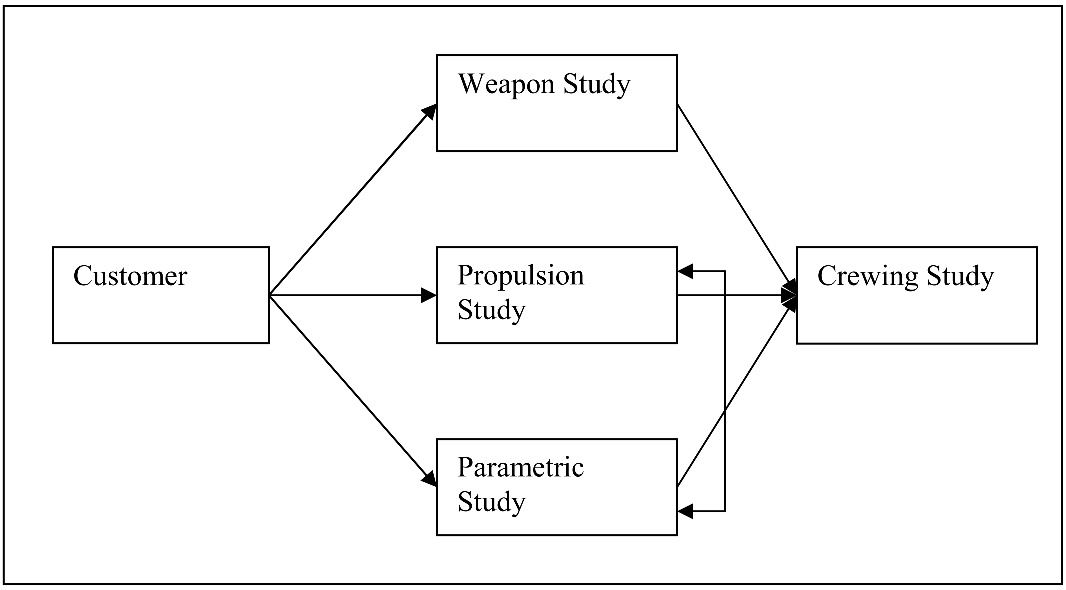

Figure 27 –Top Level Crewing Added

Crewing calculations are not concerned with complement reduction but with complement optimisation [53]. This is to say that the trade-off between cost of automation and cost of manning has to be considered. Two references [54, 55] discuss the impact of automation on crewing strategies but these tend to be outside the scope of this research as they investigate strategies across the RN as a whole. However, it should be noted that the issue of crewing and automation is not a simple one and many socio-technical factors, for example retention of personnel, have to be considered.

Wotton [53] identifies the main complement drivers as
- System Workload, System Manning and Complement
- Ship Design
- Ship Tanks, States and Conditions
- Operating Navy Manpower Structures

Wotton also describes the related factors that need attention at an early design stage. These are
- Size Estimates
- Equipment Fit
- General Arrangement
- Compartment Layout
- Equipment Manpower
- Personnel Support Manpower
- Whole Ship Task Manpower

By Whole Ship Manpower is meant tasks such as fire fighting and general damage control.

For HF to be worthwhile it has to be fully integrated into the design process [53]. HF cannot be treated as a simple add-on. The method proposed by Wotton [53] consist of 3 stages
1. Initial complement generation
2. Refined complement generation

3. Complement Validation

In section 5 an attempt is made to integrate some of the proposals made by Wotton into the 3D loops.

As mentioned previously there are many factors that need to be considered with respect to human factors. However, from the research it appears that crewing should be treated separately whilst the other factors can be considered as and when required. Other factors include amongst others habitability.

4.8.4.3 Habitability

Habitability is about living and work spaces [51] and thus of vital importance to the functioning of a warship. Several sources indicate that habitability issues, such as access routes, need to be accounted for at all times during the development of a vessel. However, some of them can be standardized, such as access space envelopes for machinery, and others depend on individual circumstances. As mentioned above all of the factors associated with habitability can be decided as and when the need arrives and thus there is no need for separate habitability studies during feasibility studies.
Some of the issues affecting warship habitability are outlined below. They further indicate that it is not necessary to carry out separate habitability studies during the design process. However, it may be of interest to carry out a habitability feasibility study but this would most likely be done by the customer to determine standards for future vessels.

- Galley needs to be close to mess areas
- No access to mess via other ranks' mess area
- Cabin size and habitability standard used can have severe impact on overall platform capability
- Access routes need to be as straight as possible
- No bunks athwartships
- Minimum walkway width
- Central stairway

4.8.4.4 Crewing Studies

This section provides a short description about the crewing study process as carried out by VT Integrated Logistics personnel. The VT Ship Workforce analysis is based on the waterfall method [56], and consists of five stages

1. Scenario Definition
2. Functional Decomposition
3. Functional Teams
4. Task Allocation
5. Crew Definition

Several scenarios are developed, that cover the ship's operational profile. These are then decomposed to identify the top-level functions required by the ship. The top-level functions are then allocated to interdependent teams and the tasks contained within each function are analysed. It is then possible to assign skill sets, and hence crew members to the required tasks. This allows for a crew definition to be established.

The study [56] indicates that the first crew estimate is solely based on basis parameters and operating profiles. No layout is known. This indicates that a first crew estimate can be carried out at the very top-level loop, using input data from the customer and the parametric study.

4.8.4.5 Results

Crewing studies are a dynamic issue as they become more detailed and accurate once actual equipment data is known. This ties in well with the 3D loops. A first high-level crewing study could be carried out at the top-level loop. HF should then act, as described above, as an input and advisory to other domains with regards to design issues. Once more equipment data is known, preferably after every completed design iteration, a more detailed study should be carried out. Again, this corresponds well with the iterative nature described by several references.

As mentioned in previous sections it may be necessary to investigate the use of an integrated database as means of tracking design decisions. In the case of human factors a simple control list should be made available to the project manager. This should entail a bullet point list of all factors involved such as space access envelopes.

Some observations at VT have revealed the impact HF can have on designs. Assigning inappropriate habitability standards affected the payload capacity of a vessel, as insufficient deck area was available.

The investigation has highlighted the importance of HF in a feasibility study context. It has shown that a possible solution is to treat crewing as a separate entity. Crewing should be carried out on the top-level loop and reiterated when more detailed data becomes available. HF in general should act as an input to design decisions to allow for suitable habitability standards etc.

4.9 PARAMETRIC SURVEY

4.9.1 Introduction

This section describes the development of a series of algorithms for predicting areas, weights and volumes for FAC and Corvette type ships. The corvette type ship equations are then used to analyse the effect of varying a range of parameters. The results are used to further refine the concept loop model. Some of the results are also used to derive some low-level management processes and guidelines, see section 5.1.2.4.

4.9.2 Equation Development Overview

When developing the equations it is important to note that the best mathematical fit to a given dataset may not be the most logical. It is more important to have a logical fit than to have a good mathematical fit. The steps taken to develop the trendlines are as follows

1. Develop logical hypothesis based on how the trendline is expected to behave
2. Fit trendline to datasets and evaluate fit
3. Refine hypothesis and re-evaluate trendline fit

The above-described procedure is seen as the best method of deriving a logical fit. In some cases certain datasets need to be excluded if the design presents anomalies when compared to similar vessels.

All equations are of the format

$Y = f(x)$

Where

$F(x) = ax^b$

Linear solutions can be modelled as two equations viz.

$Y_{linear} = Y_1 + Y_2$

$Y_1 = ax^1$
$Y_2 = ax^0$

4.9.3 Creation of Corvette equations

The development of the equations is separated into four distinctive areas:

- Weights
- Volumes
- VCGs
- Areas

The vessels used for the equation derivation are shown in Table 5. All vessels are VT designed.

Ship	Length between Perpendiculars
Oman OPV	89
Oman Corvette	76
Greece Corvette	102.4
FSC Corvette	118
River Class	73.6

Table 5 –Baseships for Corvette Equations

4.9.3.1 Weights

The weights equations are modelled at sub-group level, e.g. 12, 13, wherever possible. This is to ensure sufficient sensitivity when applying the equations in future concept designs whilst preventing localised anomalies dominating in the equations. The exception to this is sub-group 88, which is split into Lube Oil (LO), Fuel Oil (FO) and Fresh Water/Black Water/Grey Water (FW/BW/GW). For an overview of the weight groupings see Table 6.

Group Number	Group Name
Group 1	Hull Weights
Group 2	Propulsion Weights
Group 3	Electrical Weights
Group 4	Control and Communications Weights
Group 5	Auxiliary Systems Weights
Group 6	Outfit and Furnishings Weights
Group 7	Armament Weights
Group 8	Variable Load Weights

Table 6 –Weight Group Descriptions

The weights data, as far as applicable, is taken from the built-ship weight spreadsheets. Weights data from concept designs is treated with caution throughout the analysis.

Based on NES 163 [57] a first set of possible groupings for the weight sub-groups was established. These groupings were plotted against likely dominating factors. The groupings and influencing factors were modified until a best fit was found. In some cases this meant removing datasets if they were either of uncertain accuracy or of different design, e.g. a waterjet vessel amongst propeller vessels. Where this occurred a note is made under the relevant sub-group heading.

A margin of 10% is applied to groups 1 –7 on all non-built ships to account for the VT design and construction margin. This enables a more accurate comparison with the built vessels.

The equations provided in this section are based on the final groupings. In most cases several groupings were investigated and weight subgroups based on identical factors were grouped together.

GROUP1

Sub-group (SG) 19 is used within VT to account for items such as rolling margins and welding allowances. Therefore SG 19 is divided across 10/11/12/13/15, steel weight SGs, based on their respective weights. This allows for a more accurate comparison between individual groups.

Sub-groups 10/12/13/14

These weights are mainly dependent on the overall hull volume. As an approximation for hull volume the weights are plotted versus Length*Beam*Depth(D)*hull mat. Factor. The hull material factor is defined as follows

Steel	1
Aluminium Alloy	0.55
FRP	0.55

The data is shown in Figure 28.

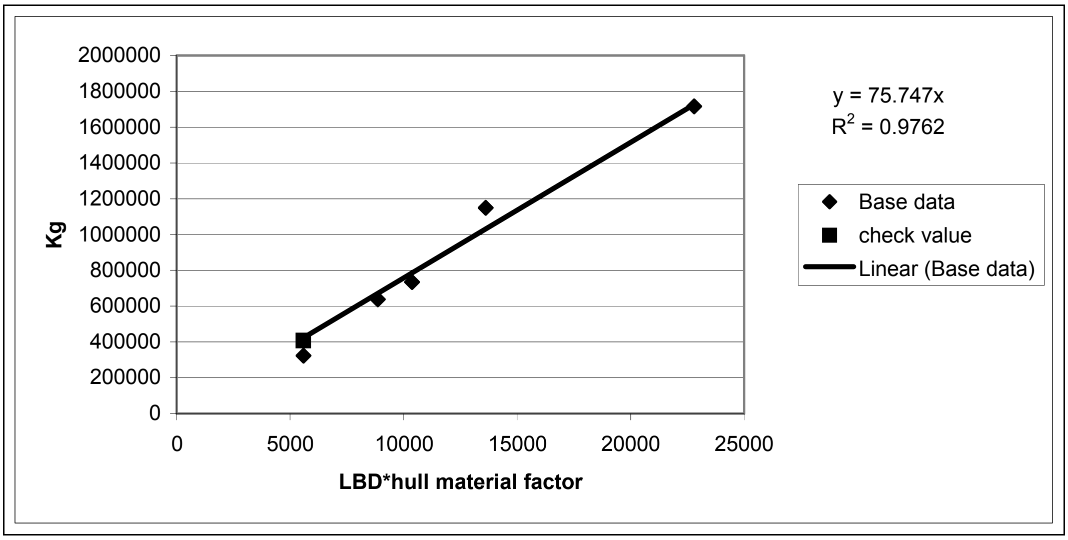

Figure 28 –SG 10/12/13/14 equation graph

The final equation is

Sub-groups 10/12/13/14= 75.747*LBD*hull material factor (1 steel, 0.55 aluminium and FRP)

Sub-groups 15/16

These weights are dependant on vessel length (shaft weights etc) and installed power (engine seats and supports). The data used is shown in Figure 29. Greece has been omitted from the data as the large power developed by the gas turbines distorts the dataset.

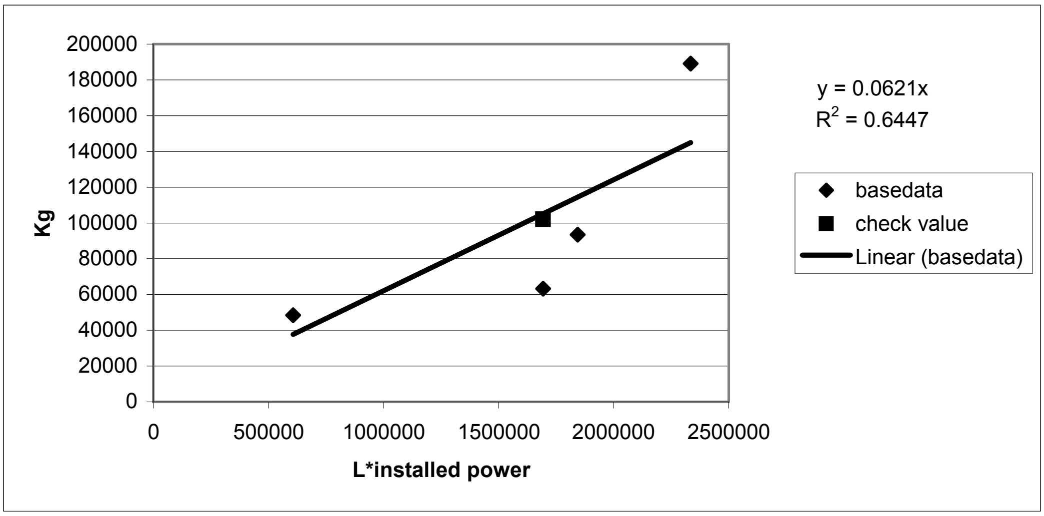

Figure 29 –SG 15/16 equation graph

The final equation is

Sub-groups 15/16 = 0.0621* Length (L)*installed power

Sub-group 17

Sub-group 17 weights are general structural castings not associated with propulsion and auxiliary machinery. They are therefore presumed to be dependent on L The data used is shown in Figure 30.

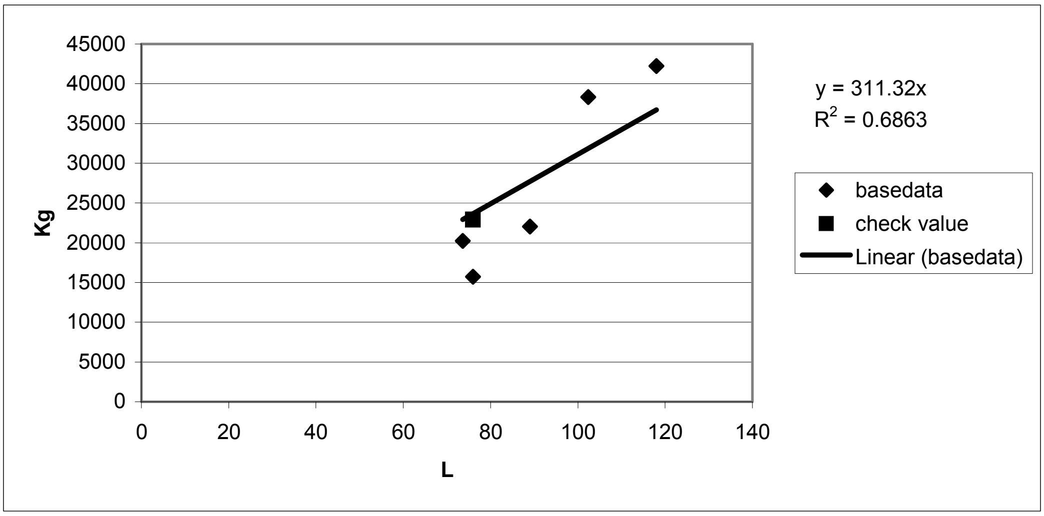

Figure 30 –SG 17 equation graph

The final equation is

Sub-group 17 = 311.32*L

Sub-group 11

SG 11 is split into vessels with hangar and those without. Overall vessel size is used as a base. Superstructure length ratio cannot be used as a base, as aft deck length is required for vessels with a flightdeck and the program does not allow for both to be entered.

The data is shown in Figure 31. The hangar equation has a constant, which is forced to equal a representative hangar weight taken from the Oman OPV. Also, the FSC has been taken out of the dataset as it has a completely different configuration to the other vessels.

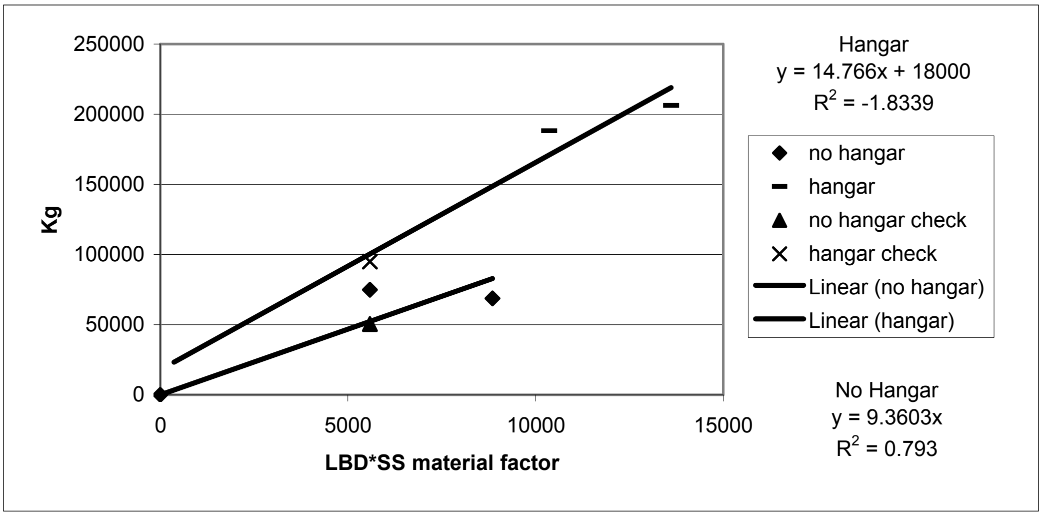

Figure 31 –SG 11 equation graph

The final equations are
Sub-group 11 hangar = 14.766*LBD*Superstructure material factor (SSmf) (1 steel, 0.55 aluminium and FRP)+18000
Sub-group 11 no hangar= 9.3606*LBD*Superstructure material factor (SSmf) (1 steel, 0.55 aluminium and FRP)

GROUP 2

Group 2 weights are not split into separate groupings. Some groupings were investigated but they were found to be dependent on power. The data is shown in Figure 32.

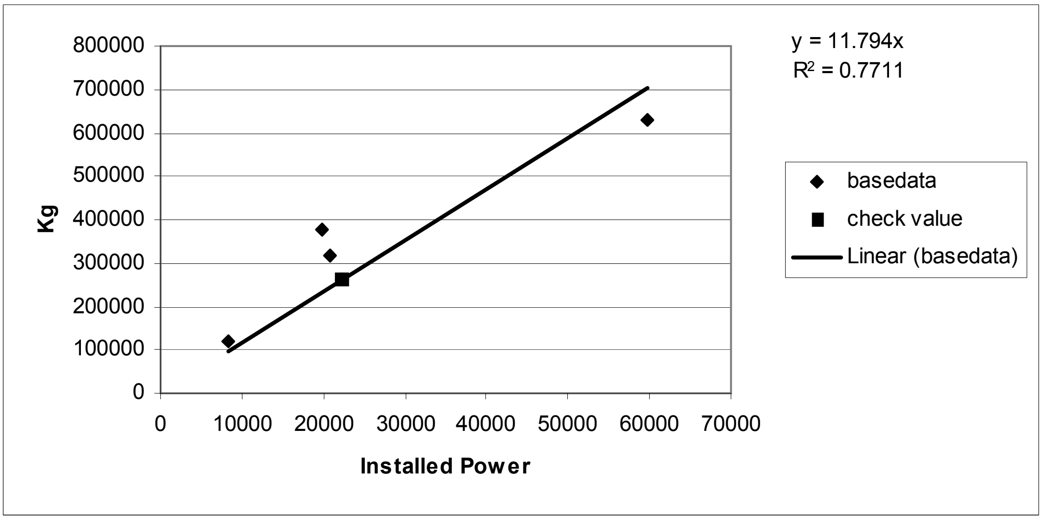

Figure 32 –Group 2 equation graph

The final equation is
Group 2 = 11.794*installed power

GROUP 3

Group 3 weights are not split into separate groupings. Similar to group 2, an attempt was made to split the group 3 weights into sub-groups but all sub-groups were found to be dependent on L^2 BD. L is squared, as the cabling weight is very dependent on the length of the vessel. The dataset is shown in Figure 33.

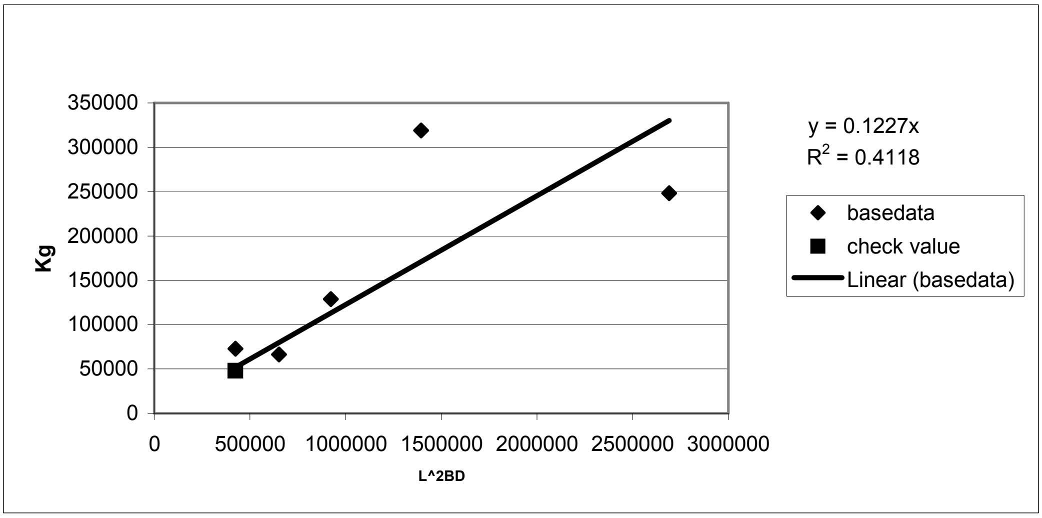

Figure 33 –Group 3 equation graph

The final equation
Group 3 = $0.1227*L^2BD$

GROUP 4

Sub-groups 40/41/42/45

These weights are mainly dependent on overall vessel size. The dataset is shown in Figure 34.

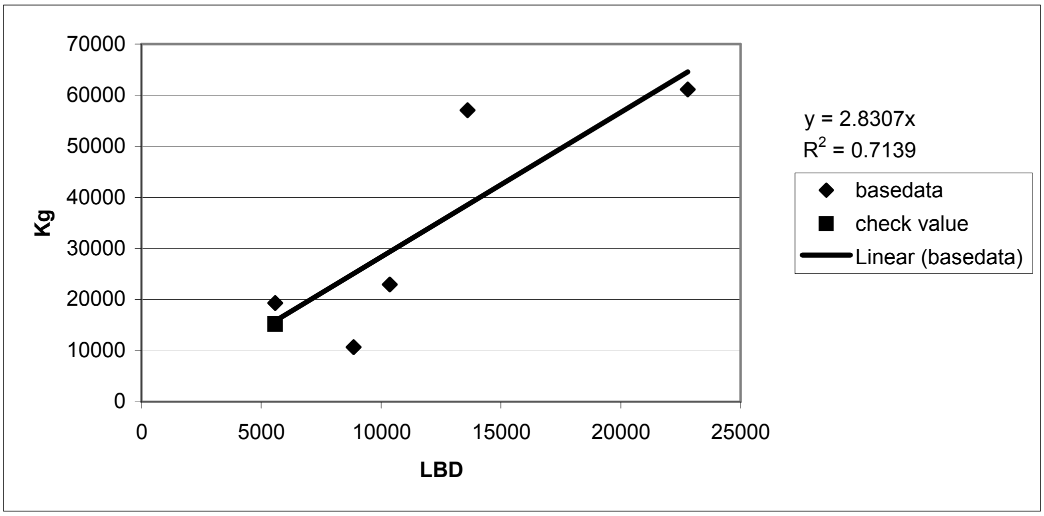

Figure 34 –SG 40/41/42/45 equation graph

The final equation is
Sub-groups 40/41/42/45 = 2.8307*LBD

Sub-groups 43/44

These weights are mainly dependent on weather deck length as the main influence is weapon fit. Weather deck length is not a variable available for the parametric program and thus a plot of 43/44 versus L is constructed and shown in Figure 35. River class and Greece have been taken out of the dataset, as they do not represent a typical weapon fit.

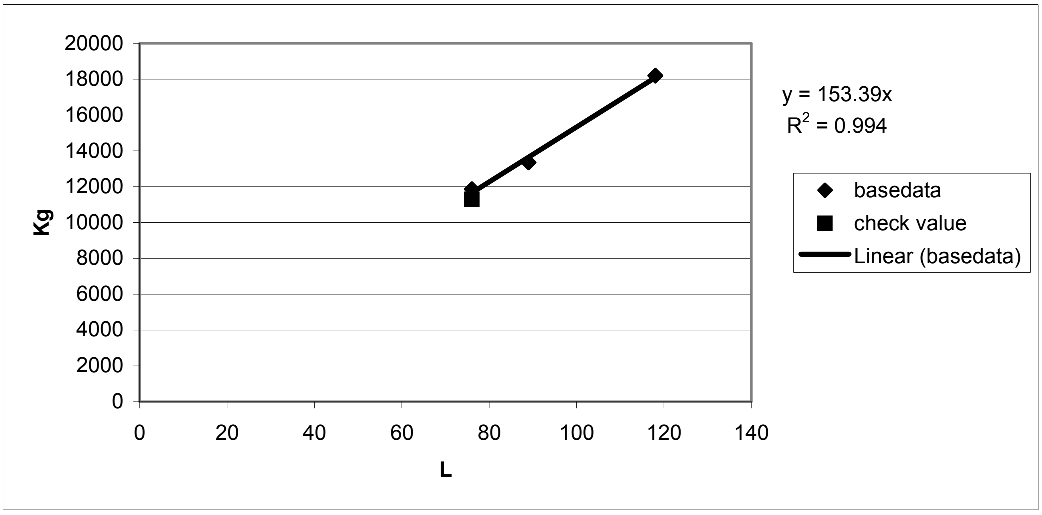

Figure 35 –SG 43/44 equation graph

The final equation is
Sub-groups 43/44 = 153.39*L

GROUP 5

Sub-groups 50/52/53

These SGs are based on overall vessel size. The dataset is shown in Figure 36.

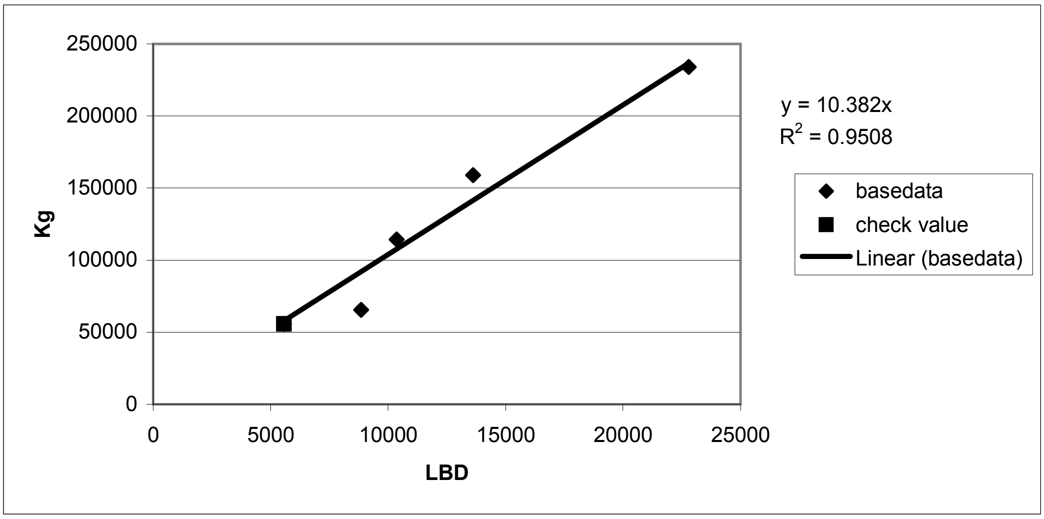

Figure 36 –SG 50/52/53 equation graph

The final equation is
Sub-groups 50/52/53 = 10.382*LBD

Sub-groups 51/58

These weights are thought to be dependent on the size of the vessel and the size of the engine. The main size factor is thought to be the length of the vessels. Greece has been omitted from the dataset as the large installed power distorts the dataset. The data is shown in Figure 37

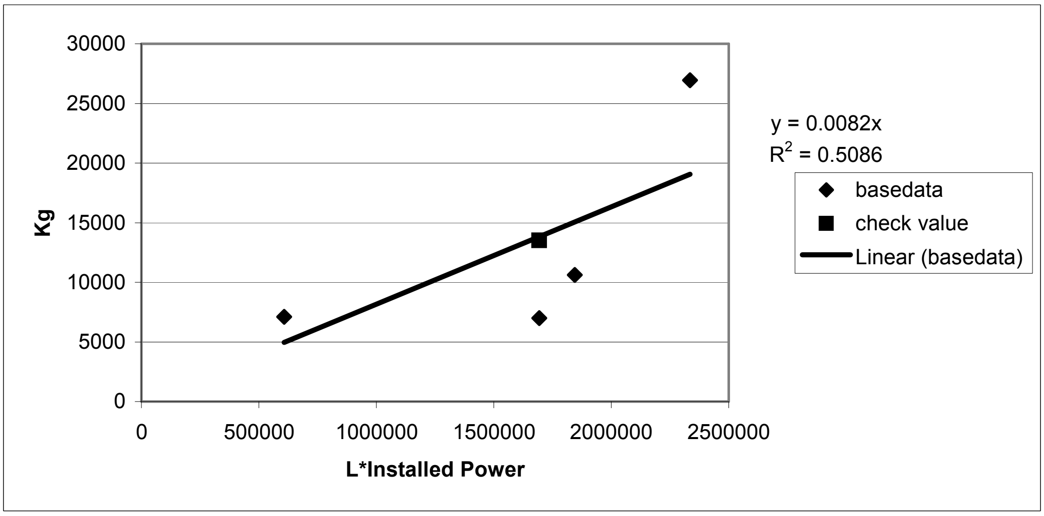

Figure 37 –SG 51/58 equation graph

The final equation is
Sub-groups 51/58 = 0.0082*L*installed power

Sub-group 56

This sub-group is presumed to be mainly influenced by overall ship size and crew numbers. However the investigation showed that crew number alone provides a very satisfactory fit. The data is shown in Figure 38.

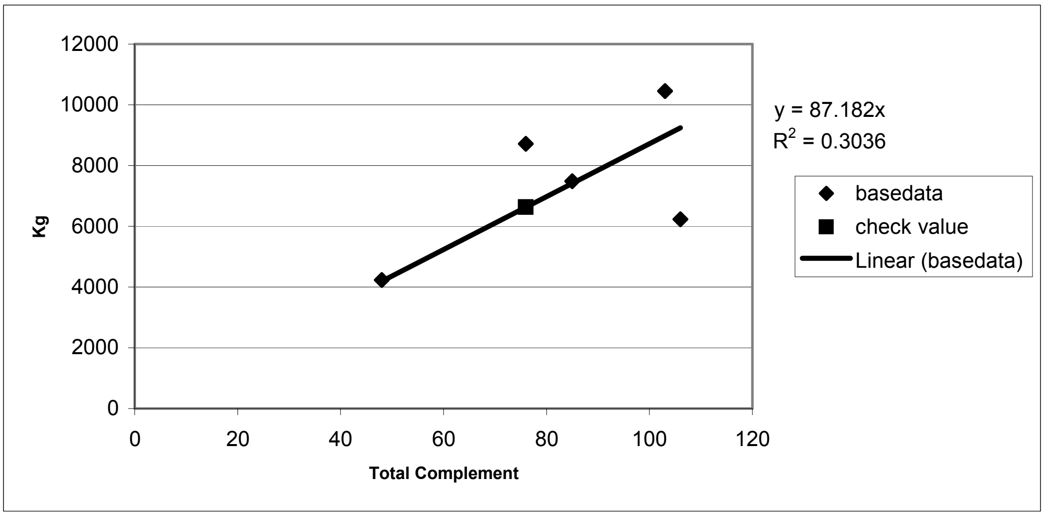

Figure 38 –SG 56 equation graph

The final equation is
Sub-group 56 = 87.182*total crew number

Sub-group 55

This SG is treated as a step function. The function is as follows

No Aircraft	=	0t
Flightdeck only	=	6.2t
Hangar	=	12.8t

GROUP 6

Despite 60/62/67 and 61/63/64/65/66/68 being dependent on the same factors, they are treated as separate equations as they are based on different vessels.

Sub-groups 60/62/67

These weights are based on vessel size. The dataset is shown in Figure 39. The FSC has been omitted, as it is a very "empty" hull.

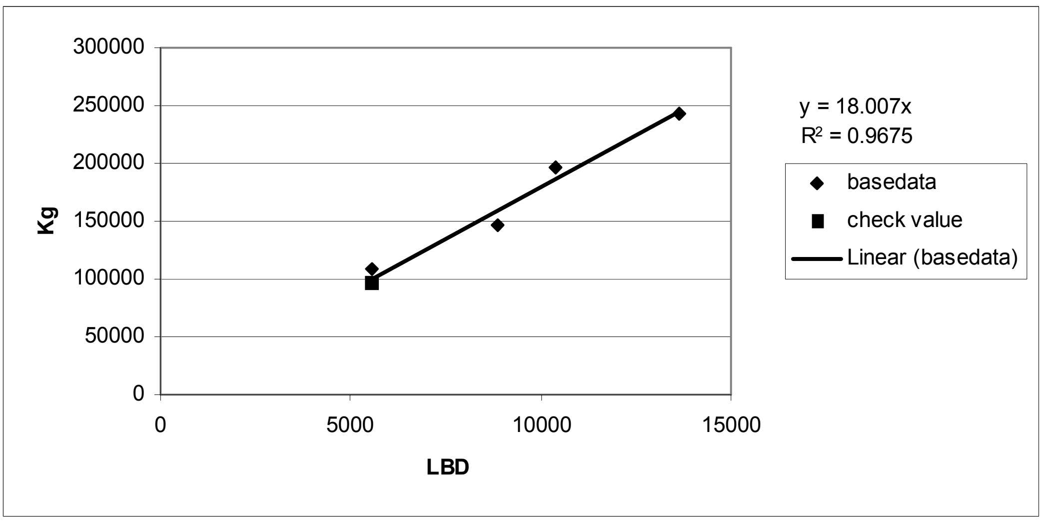

Figure 39 –SG 60/62/67 equation graph

The final equation is
Sub-groups 60/62/67 = 18.007*LBD

Sub-groups 61/63/64/65/66/68

As these sub-groups are crew related it is necessary to include crew as a factor in the parametric equation. Also, as most of the Nuclear, Biological, Chemical and Damage (NBCD) requirements are based in zones it is necessary to include length as a factor. However, for these size ships crew number is inherent in the total vessel size and therefore a satisfactory fit is achieved using L, B and D. All vessels are included and the data is shown in Figure 40.

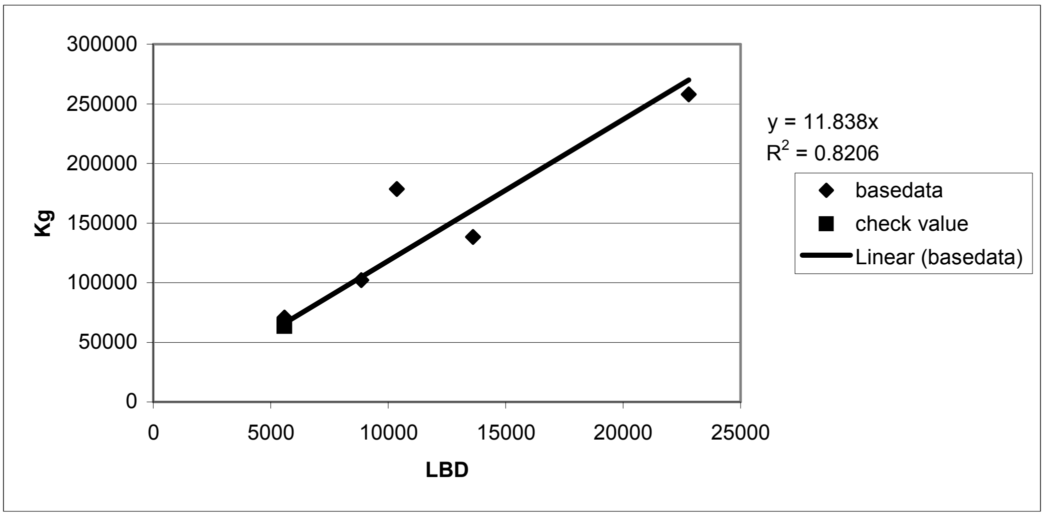

Figure 40 –SG 61/63/65/66/68 equation graph

The final equation is
Sub-groups 61/63/64/65/66/68 = 11.838*LBD

Sub-group 69

This is based on vessel size and endurance. The data is shown in Figure 41.

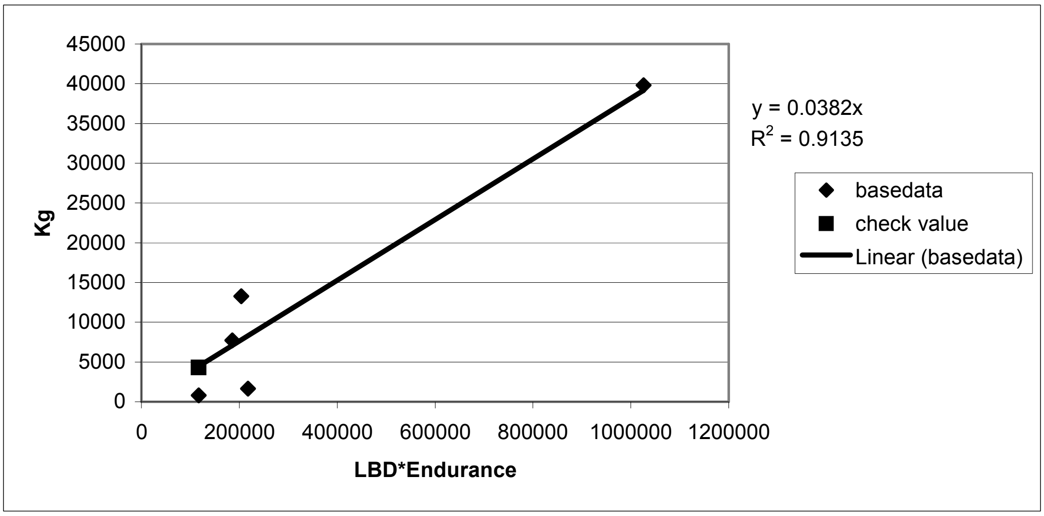

Figure 41 –SG 69 equation graph

The final equation is
Sub-group 69 = 0.0382*LBD*endurance

GROUP 7

Group 7 weights are a direct entry into the program as payload

GROUP 8

Group 8 weights are split into several groupings. Sub-group 88 is further divided into sub-sub-groups.

80	Crew
81/86	Ammunition/Weapon Stores
84/85	Stores
87	Operating Fluids
88	Liquids in tanks divided into:

- LO
- FO
- FW/BW/GW

Sub-group 80

This SG is based on crew numbers. The data does not account for embarked forces. The data is shown in Figure 42.

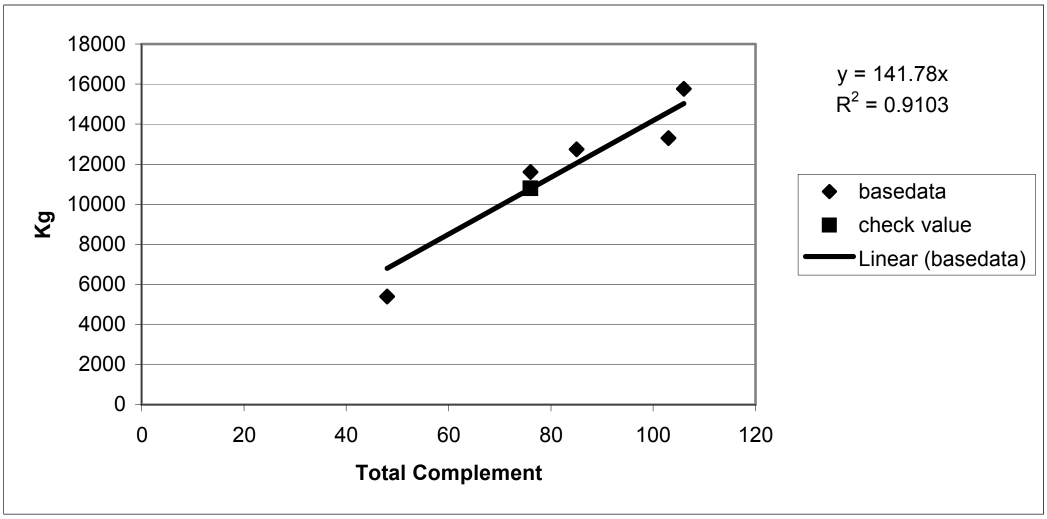

Figure 42 –SG 80 equation graph

The final equation is
Sub-group 80 = 141.78*Total Crew Number

Sub-groups 84/85

The number of crewmembers and the endurance of the vessel influence these weights. The endurance of the vessel is taken as specified in the design specifications and not just as cruise speed/cruise power. This is to account for periods of loitering and carrying out other operations. The data is shown in Figure 43.

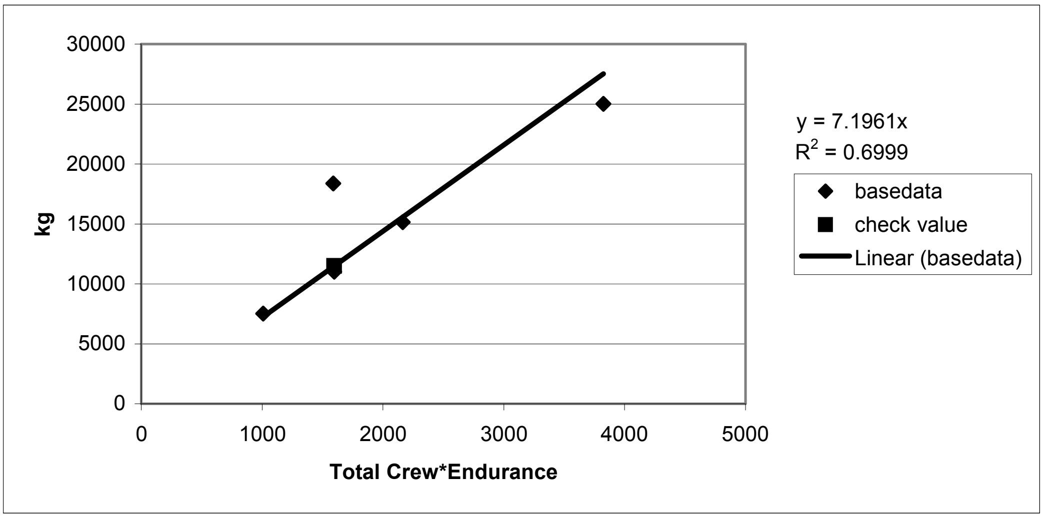

Figure 43 –SG 84/85 equation graph

The final equation is
Sub-groups 84/85 = 7.1961* total crew * nominal endurance

Sub-group 87

The operating fluids weights are plotted versus L*power. Length is included as an indicator of vessel size and power is included, as more powerful engines require more operating liquids. Again, Greece has been omitted as the large installed power distorts the dataset. River Class has been omitted as the stabiliser tanks distort the dataset. The graph is shown in Figure 44.

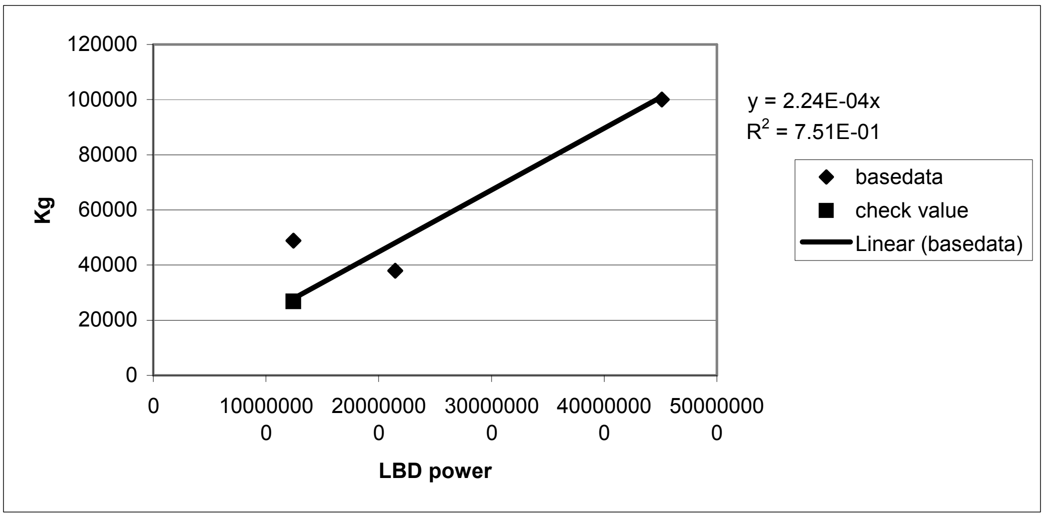

Figure 44 –SG 87 equation graph

The final equation
Sub-group 87 = 2.24E-4* LBD*installed power

Sub-groups 81/82/86/89/Avcat

These weights are treated as payload entries.

Sub-group 88

LO
This weight is dependent on installed power. The data is shown in Figure 45.

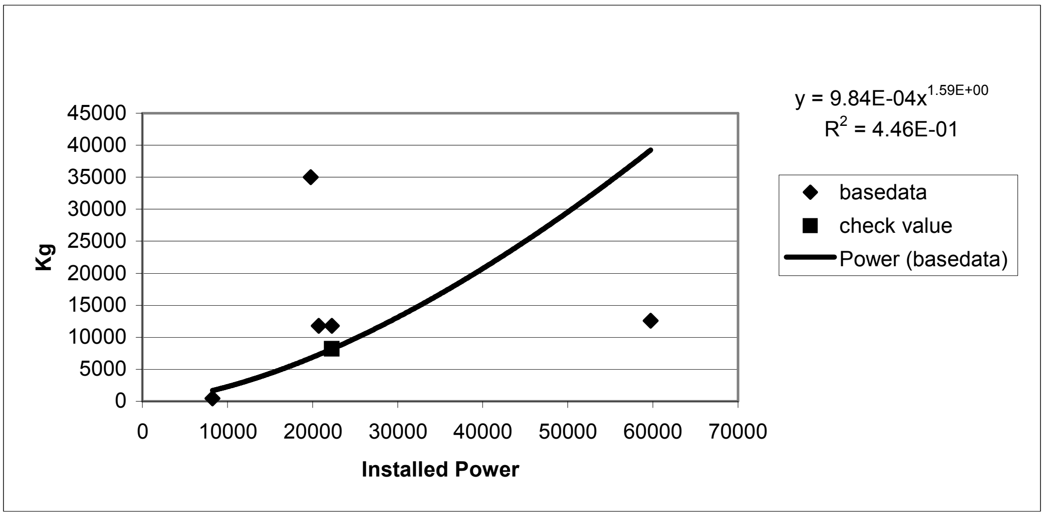

Figure 45 –SG 88 equation graph

The final equation is

LO = 9.84E-4*(installed power)$^{1.5914}$

FW/BW/GW

These are based on crew and endurance. The data is shown in Figure 46. The River class has been omitted as it carries a very large amount of water surplus to mission requirements. Embarked forces are included.

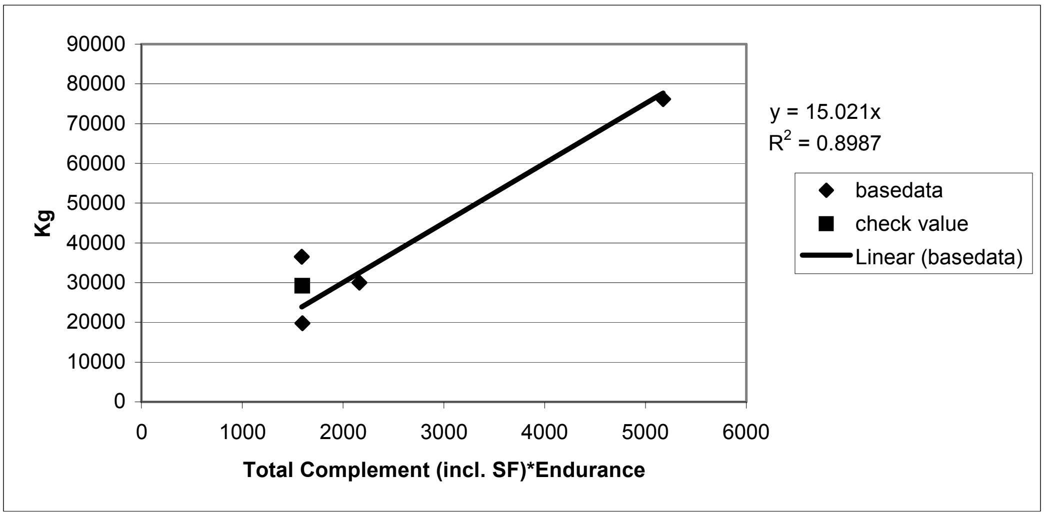

Figure 46 –FW/BW/GW equation graph

The final equation is

FW/BW/GW = 15.021* total crew * nominal endurance

FO

This is derived from first principles using the following equation.

$$FO = 1.05*(a*b*SFC_1*P_c*Range/V_c+a*b*SFC_2*G_c*Range/V_c)$$

Where

A	=	margin for structure (usually 3%)
B	=	margin for unpumpables (usually 5%)
SFC_1	=	SFC engine
SFC_2	=	SFC generator
P_c	=	Engine cruise power
G_c	=	Generator Cruise load
V_c	=	Cruise speed

A and b are considered to be equal and take account of a margin for unpumpables and a margin for structures within tanks. SFC is taken from existing ships books and a pessimistic value is used. The cruise power is taken from sea trials and the generator consumption rate is based on existing vessels. The factor of 1.05 has to be included to allow for 5% usable liquid remaining.

4.9.3.2 Volumes

As no tankage plans are available the volumes are taken as the fluid weights divided by their respective specific gravities.

FO	=	0.84
LO	=	0.89
FW/BW/GW	=	1
Avcat	=	0.788

VOIDS

The equation is used to estimate the amount of void space in the double bottom, as defined in DCONCEPT. DCONCEPT presumes a through deck double bottom (DB). Therefore the volume under the presumed double bottom deck is calculated from the section area curves. The volume contained within the engine room boundary and the fluid volumes are subtracted from the total value to calculate the void volume. The main factors influencing the equation are Lwl, as it determines the maximum available DB length, Pc, as it provides and indication of Engine Room (ER) length, and Pc*Range/VC, as it provides an indication of FO volume. The final equation is therefore

$$\text{Void} = 9.234707\text{E}9 * \frac{L}{P_c^{\,2} * \frac{Range}{V_c}}$$

The data used is shown in Figure 47.

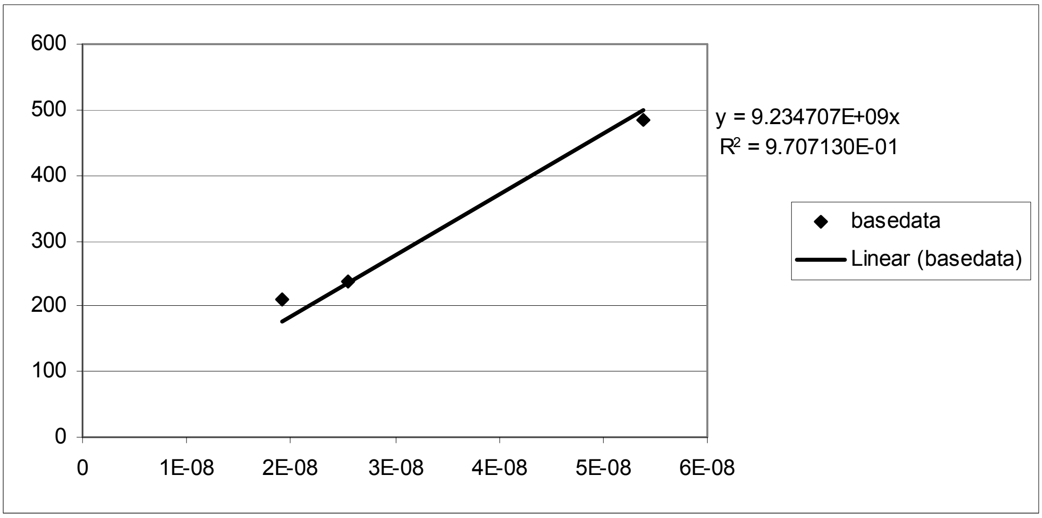

Figure 47 –Void Volume equation graph

4.9.3.3 VCGs

For the purpose of the program the VCGs are calculated at group level. A margin of 3% is added to all non-built ships to allow for the VT design and growth margin. For this investigation all VCG equations are made dependent on D only and the constant is forced to 0. This decision was made for logical reasons. Some curves gave a better fit if a factor such as L was included, however that would infer that the VCG would rise if the length of the vessel increased. As this is not a true statement the decision was made to only allow D as an influencing factor. The resulting equations are shown below and the corresponding graphs are shown in Appendix M.

Group	Equation
1	0.5121D
2	0.8117D
3	0.7252D
4	0.5935D
5	0.8712D
6	0.5354D
7	0.8043D
8	1.0779D
88	0.2205D

Table 7 –Corvette VCG Equations

4.9.3.4 Areas

DATA INPUT AND DEFINITIONS

A database was designed to store all relevant information. The database allows the user to extend it should more vessels be added. A set of pre-defined queries is included but the user is free to add more queries as required.

No sets of area data exist within VT for the vessels listed in Table 5. It is therefore necessary to measure the required areas from the GAs.

Several rules apply when measuring the areas of compartments. These are based on the way the parametric program is written. The rules are as follows

1. Only deck areas count – this infers that only the area of the deck the compartment is situated on is counted.

2. The engine room is not treated as a compartment but only its length and height are measured.
3. Compartments are regarded as having a nominal height of 1 deck.
    a. Aux. machinery compartments higher than 1 compartment are not measured. Where these are adjacent to the engine room they are counted as part of the engine room extent.
4. Only enclosed decks are measured. Where equipment on say 01 deck is not enclosed it is not measured.
5. Tween decks are counted as part of either the deck above or below depending on the design of the vessel.
6. Compartments in the aft superstructure (if existent) are recorded as being on 1 Deck.

Once the compartments are measured the need to be assigned to the relevant area groups and sub-groups. The area groups are split up as shown in the following list.

- Accommodation
    - JR
    - SR
    - Officer
    - Other
    - General
- Platform
- Crew Support (CS)
    - JR
    - SR
    - Officer
    - Other
    - General
- Access
- Vertical Access
- Operational

The type of compartments assigned to the relevant groups are shown below

- Accommodation
    - All compartments directly related to crew accommodation such as
        - Sleep
        - Wash
        - Baggage
        - Lockers
    - Where a WC is on the bridge it is included as part of the platform group
    - Trainee accommodation is included with the relevant ranks
    - Government Officers are treated as Officer accommodation
- Platform
    - All compartments related to the operation of the vessel but not exclusively to warfare and/or mission requirements
        - Electrical Equipment - Gensets, Switchboards, Emergency Generator, etc
        - Damage Control
        - Auxiliary (Aux) Machinery Room – see note above regarding deck extents
        - Air Conditioning
        - Sewage
        - Bridge

        - Ship Office
        - CO2 store
        - Garbage
        - Fore Peak Store
        - Chain Locker
    - The above list is not conclusive and more compartments can be added if required
- Crew Support
    - All compartments related to crew support such as recreational areas
        - Mess
        - Galley
        - Recreation
        - Laundry
        - Provisions
        - Cold Store
    - Areas are assigned to respective ranks
    - Communal areas across all ranks are stored under General, e.g. laundry
    - Where areas are shared between JR and SR these are assigned to JR with a note attached
- Access
    - All compartments and areas that provide horizontal access
        - Passageways
        - Lobbies
        - Airlocks
        - General Access
    - For passageways length and width are also recorded
    - The following rules are defined for the access area groups
        - If a passage is severally affected by vertical access than the passage width is taken as the width between passage boundary and vertical access extent, see Figure 48.
        - If a vertical access has no severe impact on the passage then the passage width is taken as the width between the passage boundaries. The total passage area is then the (passage length)*(passage width) – (vertical access area), see Figure 49.
- Vertical Access
    - All compartments providing vertical access between decks.
        - Stairs
    - Although hatches also provide vertical access they are only measured where they have a significant effect on the layout
    - Hatches and Stairs in way off the engine room or outside the superstructure are not measured
- Operational
    - All compartments related to carrying out the mission and warfare requirements of the vessel
        - Magazine
        - Gunbay
        - Operations Room (OPS)
        - Radio
        - Radar
        - Weapons Related Equipment
        - Missile Related Equipment
        - Kennels
        - Detention Rooms

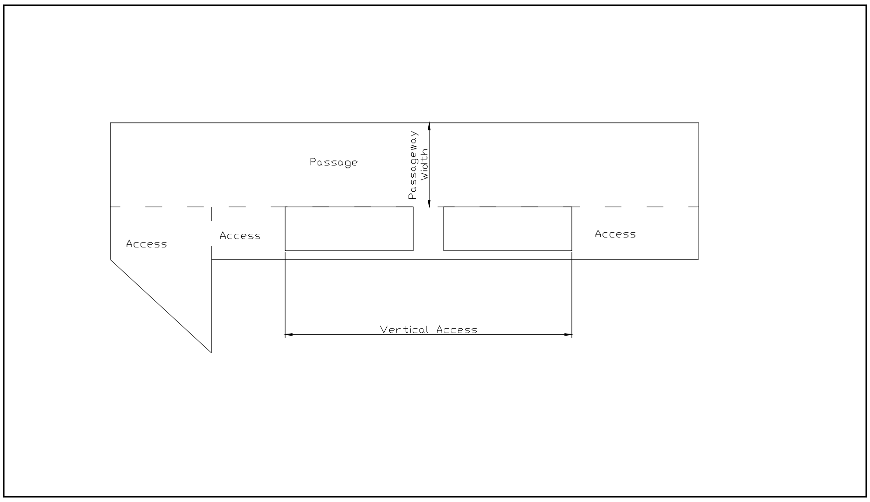

Figure 48 –Schematic interrupted Passagewidth

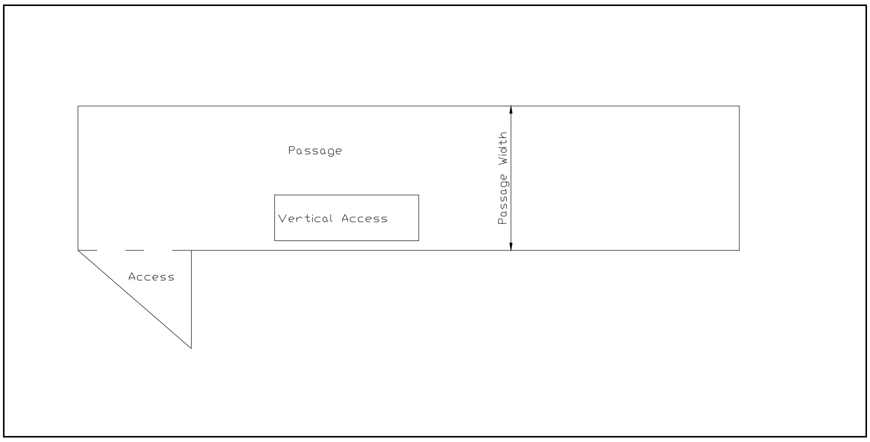

Figure 49 –Schematic uninterrupted Passagewidth

On almost all equations the decision was made to force the constant to 0. This was based on a logical assessment of the equations, for example if there is no crew on the vessel then there is no requirement for crew accommodation areas. Where the constant is not forced to 0 an explanation is given as to why. Almost all of the equations are of linear nature. This is to ensure a greater range of validity of the equations.

OVERALL AREA DISTRIBUTION

Before the basevessels were used a check was carried out to further determine their suitability with regards to the gathering of area data. Figure 50 shows the percentage distribution of the areas for each vessel.

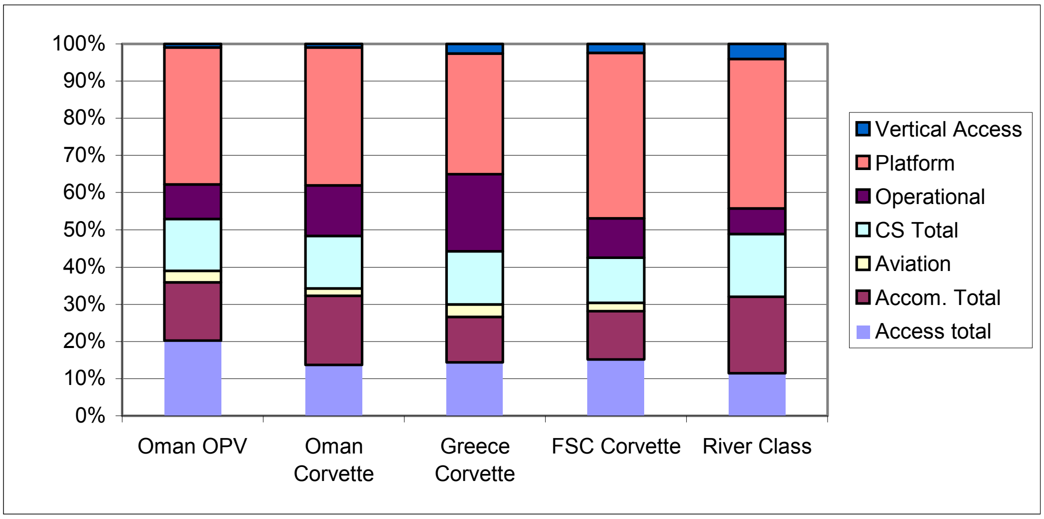

Figure 50 –Overall Area Distribution Corvettes

The graph does not show any major discrepancies and hence it seems plausible to use the recorded datasets for further analysis. This is based on the percentage allocations for each group being similar across all the vessels. It should therefore be possible to derive a sensible set of equations describing the area allocations.

ACCOMMODATION

For JR, SR and Officer accommodation two equations are developed to allow distinguishing between vessels with a generous space allowance (River and FSC) and standard space allowances.

JR

The JR accommodation is based on the total number of JR crew.
The graph in Figure 51 shows the trendlines used to establish the equations.

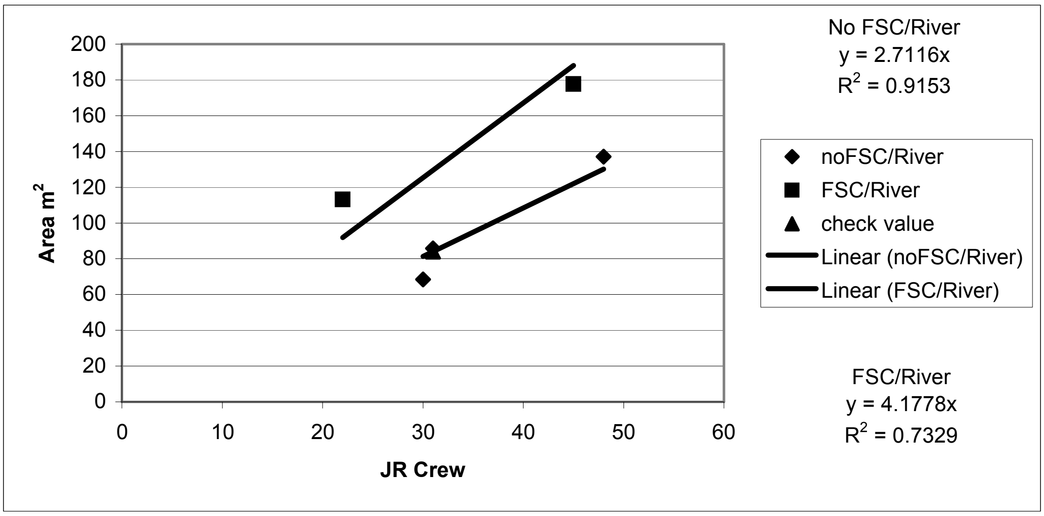

Figure 51 –JR Accommodation equation graph

The final equations are
Generous Space Allowance = 4.1778* JR crew number

Standard Space Allowance = 2.7116* JR crew number

SR

SR Accommodation is based on total SR crew numbers. Figure 52 shows the data used to establish the equations.

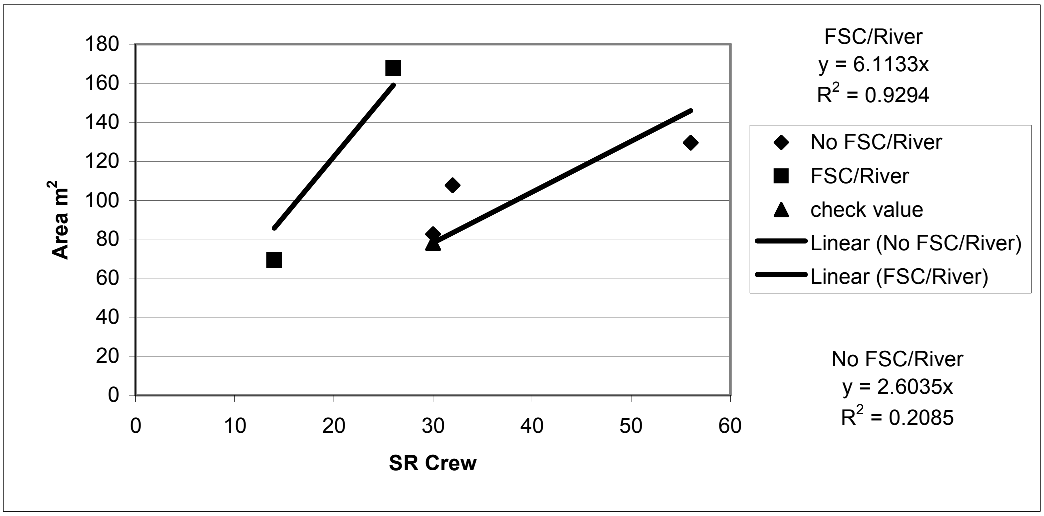

Figure 52 –SR Accommodation equation graph

The final equations are
Generous Space Allowance = 6.1133* SR crew number
Standard Space Allowance = 2.6035* SR crew number

Officer

Officer accommodation is based on total officer crew number. Figure 53 shows the data used to establish the equations.

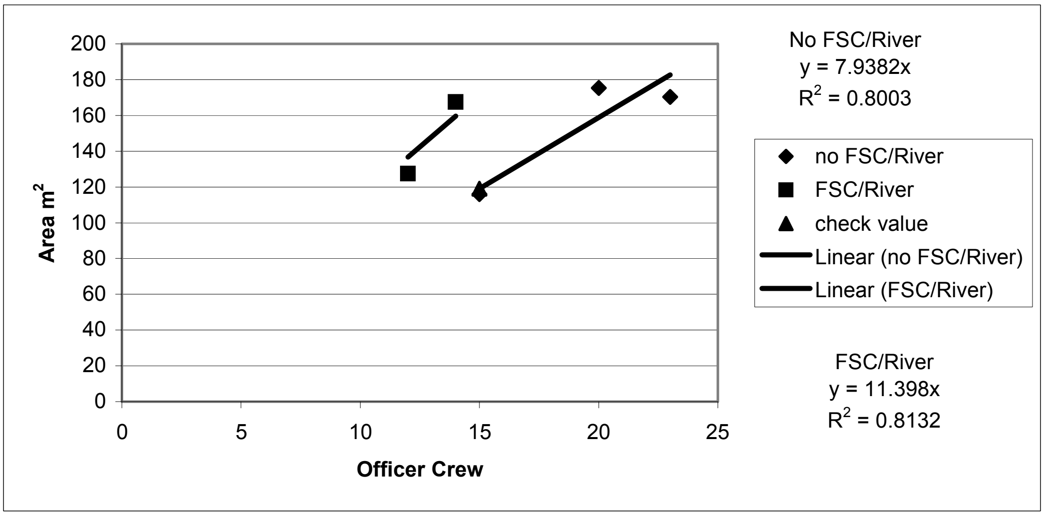

Figure 53 –Officer Accommodation equation graph

The final equations are
Generous Space Allowance = 11.398* Officer crew number
Standard Space Allowance = 7.9382* Officer crew number

Other

Only one data point is available for this category, as the FSC is the only vessel capable of carrying embarked crews. A simple linear equation is therefore used.
The equation is

Other Space Allowance = 2.4507x

Where
X = Embarked crew number

General

General Space allowance accounts for areas such as general changing rooms and wash facilities. It is based on crew density, i.e. LBD/crew. This is based on the presumption that the more spacious the vessel is the more the crew will benefit from it. Figure 54 shows the data used to establish the equation. Embarked Forces are not included in the total crew number.

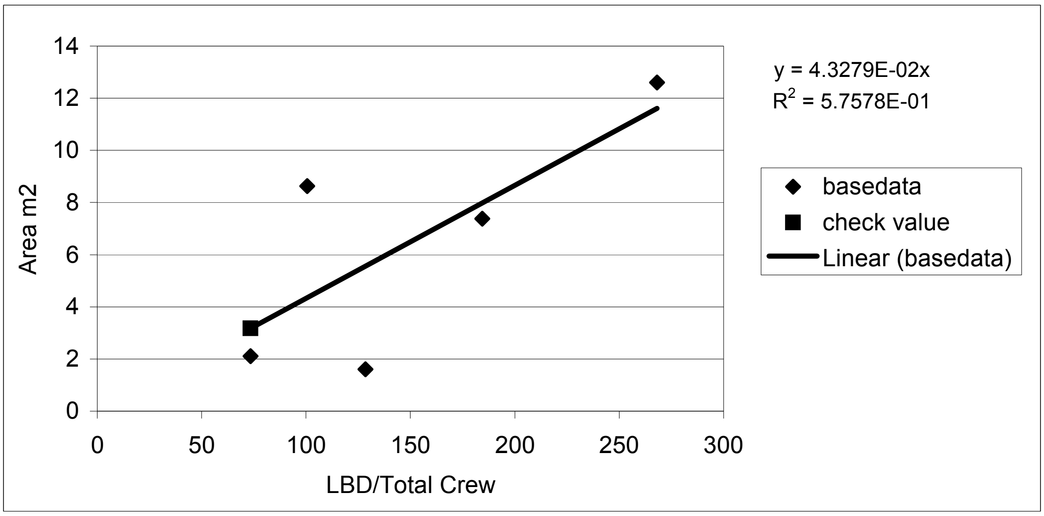

Figure 54 –General Accommodation equation graph

The final equation is
General Accommodation Area = 0.0433* LBD/total crew

ACCESS

The access equation is based on length and average walkway width. The access equation is a power curve. This is to account for the fact that as vessels get larger accessways start increasing more rapidly. Figure 55 shows the data used to derive the equation.

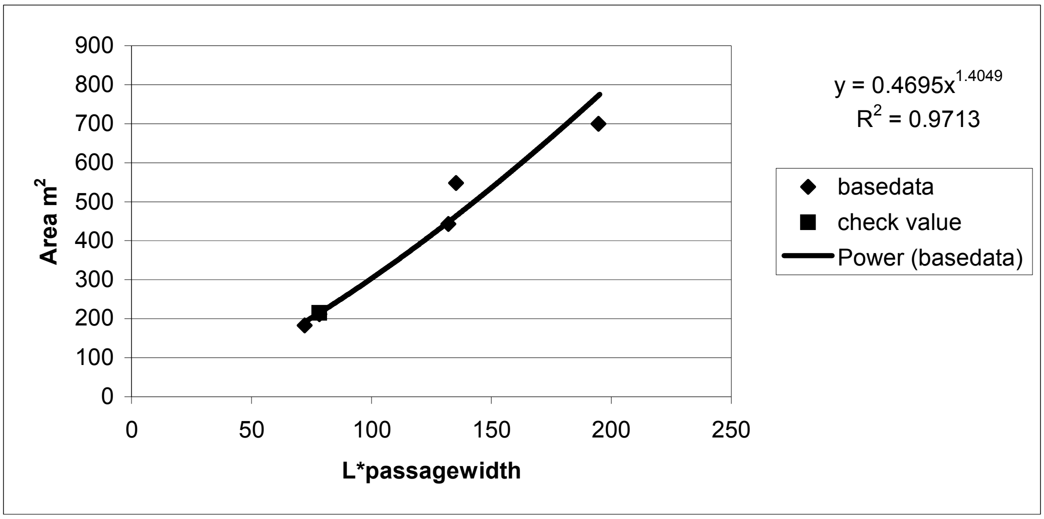

Figure 55 –Access equation graph

The final equation is
Access = $0.4695*(L*passagewidth\ (w))^{1.4049}$

AVIATION

Initially a straight-line equation was sought to model the aviation areas. However, based on the available data it was decided to use a step function. The hangar core area is not included in the aviation area as the program treats it separately. The final function is

No hangar	$0m^2$
Flightdeck only	$31m^2$
Hangar	$84m^2$

CREW SUPPORT

Greece has been excluded from the JR and SR graphs, as the available berths seem very large in comparison to vessels of similar size.

JR

CS JR is based on JR crew and √L. L is taken at a reduced power, as JRs are the last crew group to benefit if more space becomes available during the design process. The data used is shown in Figure 56.

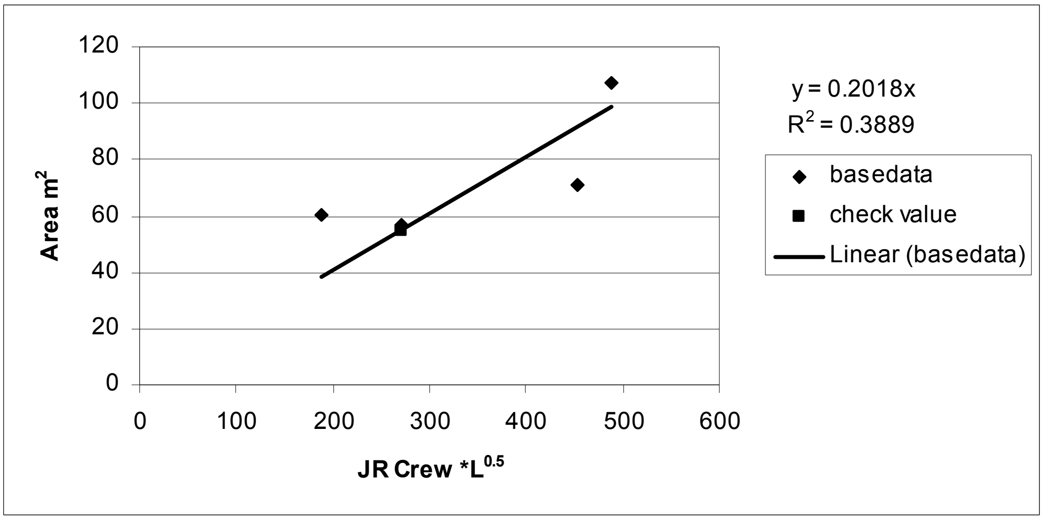

Figure 56 –JR Crew Support equation graph

The final equation is
CS JR = 0.2018* JR crew number * √L

SR

CS SR is based on SR crew number and L. L is included as rec. spaces increase with increasing vessel size. The data used is shown in Figure 57.

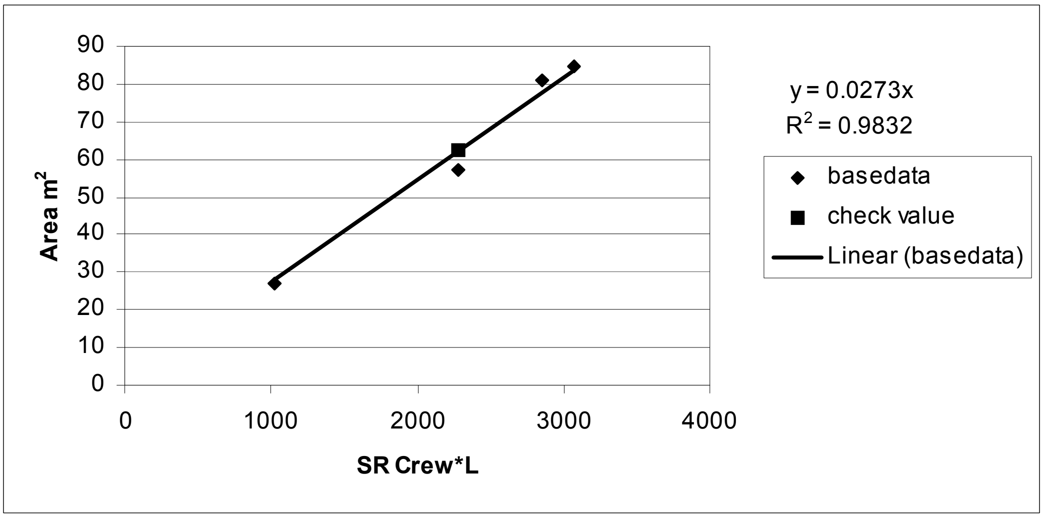

Figure 57 –SR Crew Support equation graph

The final equation is
CS SR = 0.0273* SR crew number * L

Officer

Officer CS is based on officer crew and L. The data used is shown in Figure 58.

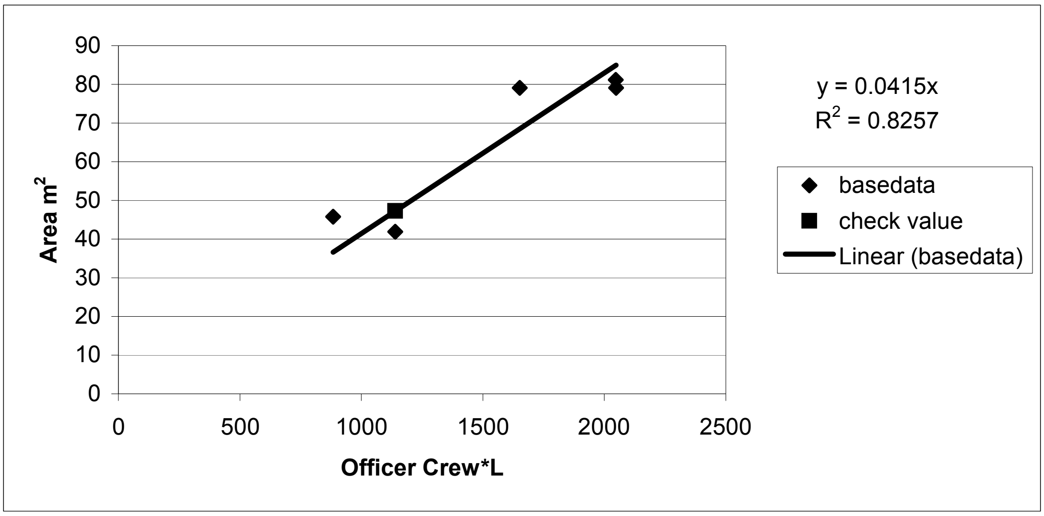

Figure 58 –Officer Crew Support equation graph

The final equation is
CS officer = 0.0415* Officer crew number * L

General

General CS is based on total crew number and L. The data used is shown in Figure 59. General CS does include a constant. This is to allow for minimum galley and provision areas. Embarked forces are included as they use facilities such as laundry.

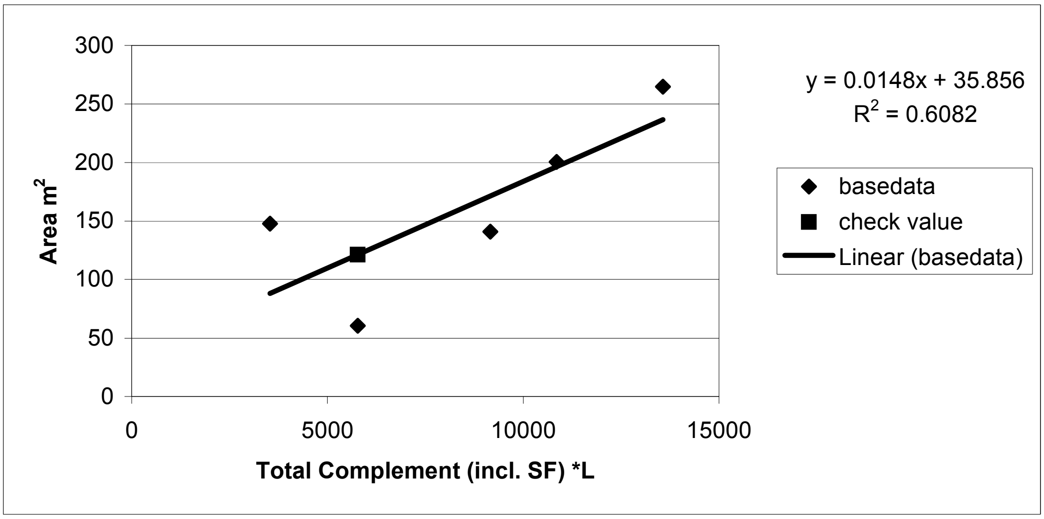

Figure 59 –General Crew Support equation graph

The final equation is
CS general = 0.0148* Total crew number * L +35.856

Other

Only one data point is available as FSC is the only vessel capable of carrying embarked forces. CS other is presumed to be dependent on Crew number only. The final equation is

CS other = 0.7717* Embarked Forces

OPERATIONAL

The operational areas are split into warships and OPVs. This is to allow for the reduced warfare capability of the OPVs. Operational areas are based on L and B. This is based on weatherdeck area being the most important factor with regards to weapon fit and thus associated areas. The data used is shown in Figure 60.

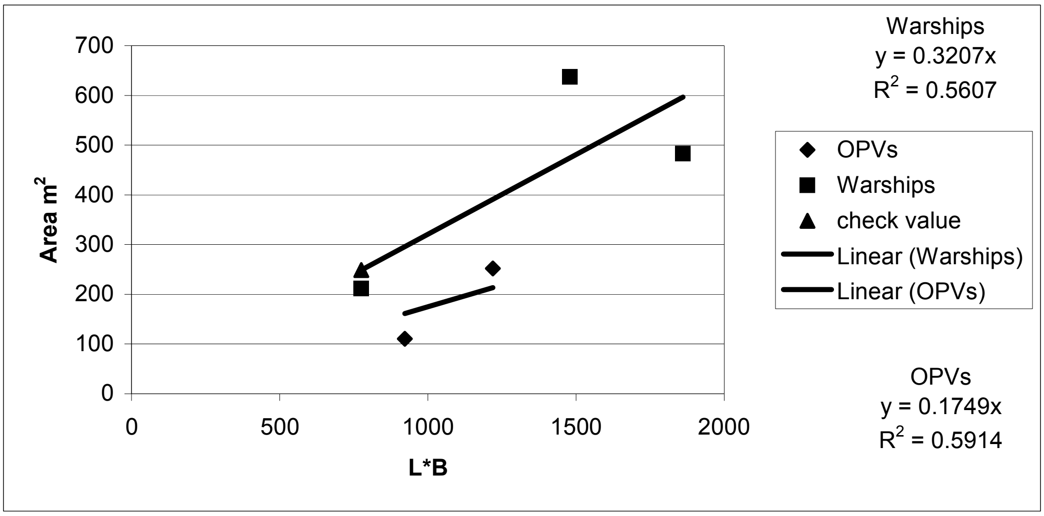

Figure 60 –Operational equation graph

The final equations are

Warships = 0.3207* L*B

OPVs = 0.1749* L*B

PLATFORM

The platform areas is mainly dependent on overall vessel size and hence L, B and D. The data used to derive the final equation is shown in Figure 61.

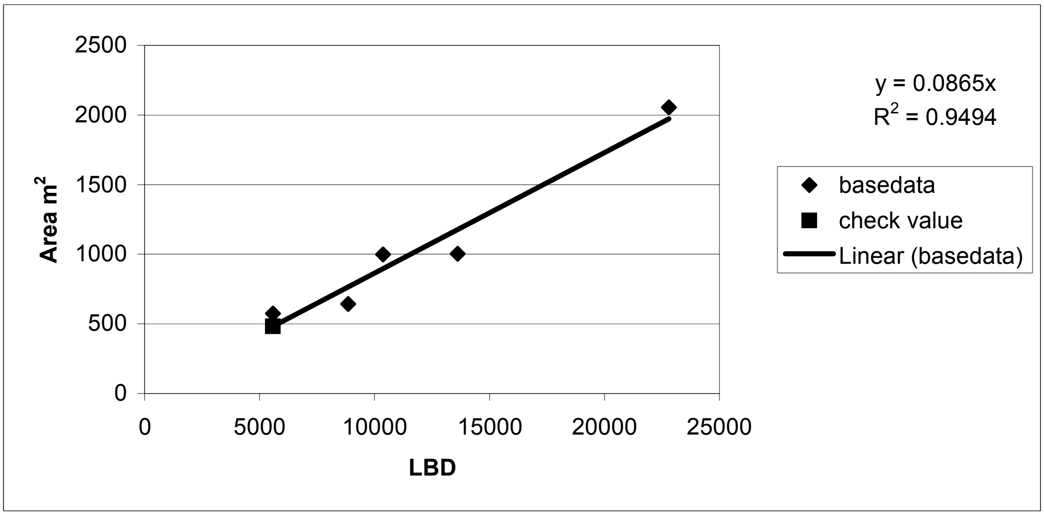

Figure 61 –Platform equation graph

The final equation is

Platform = 0.0865* LBD

VERTICAL ACCESS

This is based on size and number of decks. As number decks is not available as a variable D/deck height is used as an approximation. Also, L is found to be the overriding factor in relation to size. This is due to longer vessels having more than one main vertical access route. The data used is shown in Figure 62.

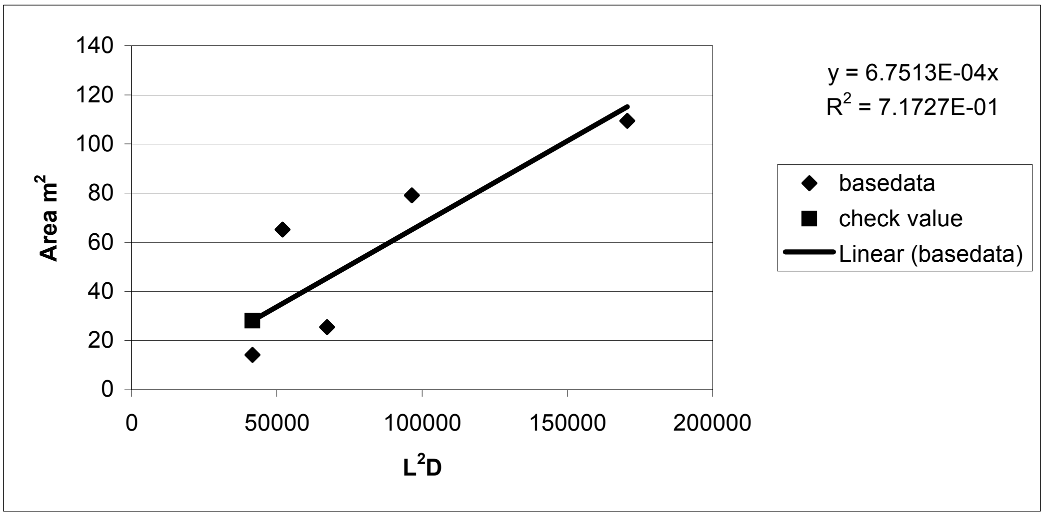

Figure 62 –Vertical Access equation graph

The scatter is due to the Oman corvette having no central stairwell, Oman OPV having one central stairwell, River having a central stairwell and some additional stairs in the accommodation quarters, Greece having a central stairwell and an additional stairwell in way of the hangar and FSC having several stairwells. The final equation is

Vertical Access = $0.000675 * L^2 * D$

4.9.3.5 Validation of Algorithms

An equation test spreadsheet has been developed. It allows the user to obtain the areas, weights, volumes and VCGs based on the vessel's specified input parameter, see screenshot Figure 63. This tool allows the user to specify the type of vessel, the required habitability standard and the aviation requirements. The spreadsheet then calculates the individual areas, weights, volumes and VCGs.

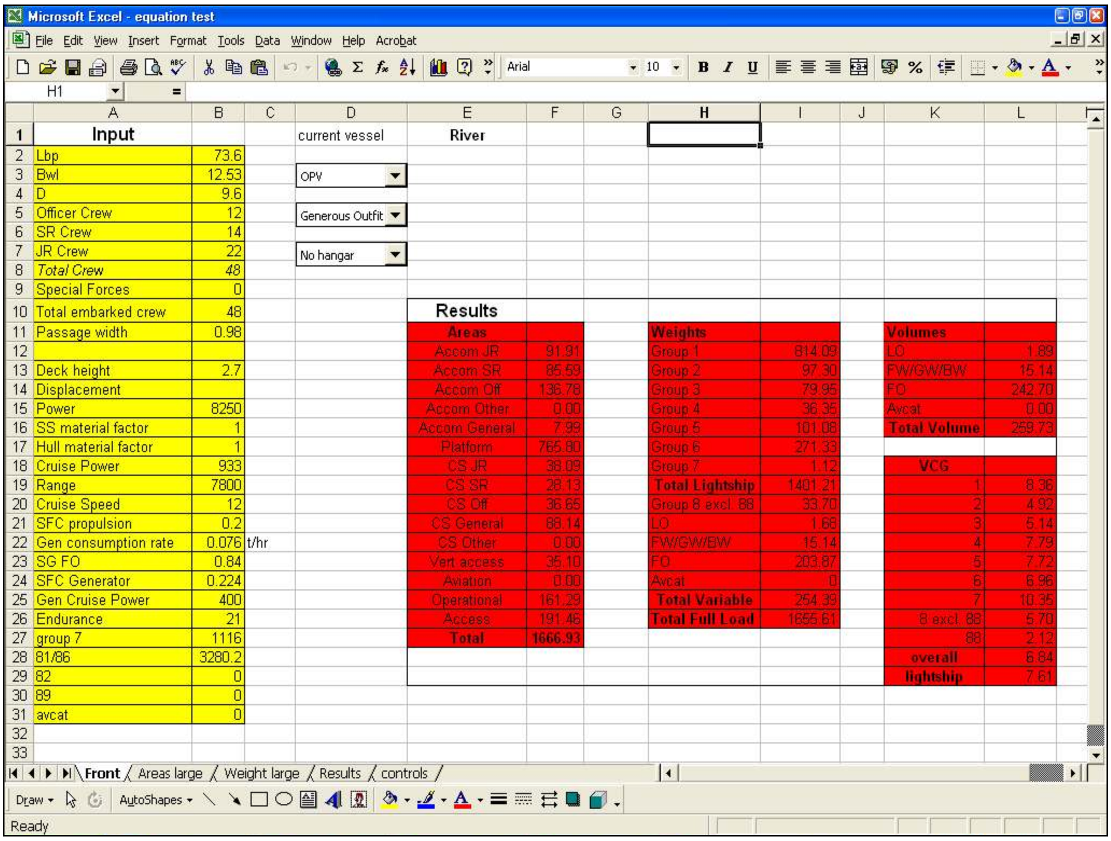

Figure 63 –Algorithm Validation Spreadsheet Screenshot

The test spreadsheet has been used to calculate the results for the 5 vessels used in the derivation of the equations. The comparison has shown that, although some detailed results are over/under-predicted by as much as 300%, the overall correlation is a good one, see Figure 64 and Figure 65. Based on the results from the validation process the equations are deemed sufficiently accurate for use in future designs and parametric investigations.

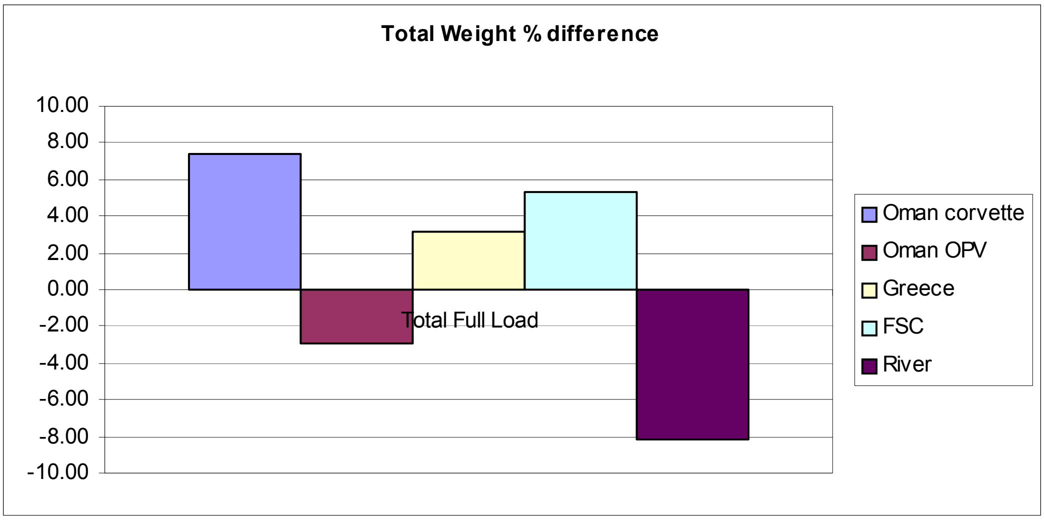

Figure 64 –Weight Comparison Basevessel to Algorithms

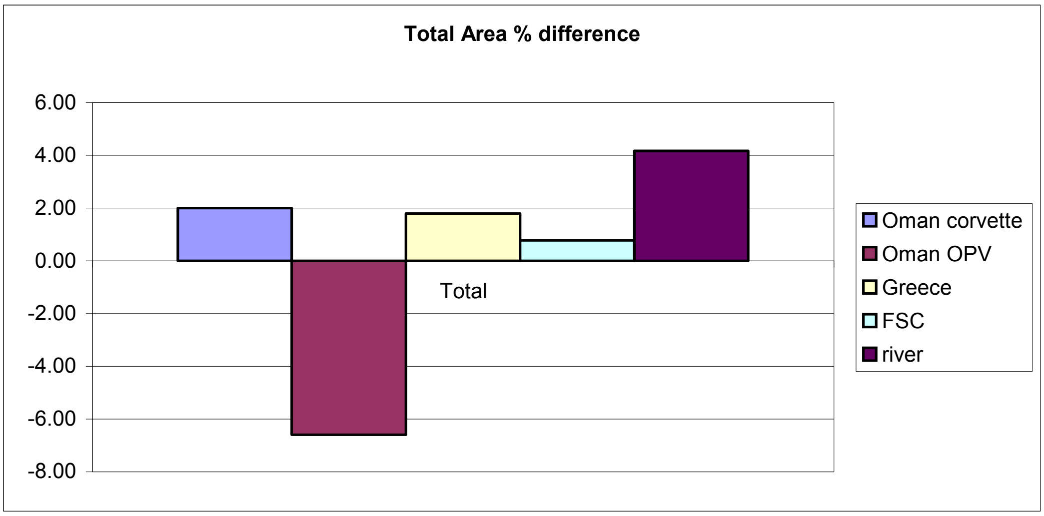

Figure 65 –Area Comparison Basevessel to Algorithms

A summary of all equations is shown in Appendix N.

4.9.4 Creation of FAC equations

The process described in section 4.9.3 for the corvette equations was repeated for a set of FAC type vessels. To aid clarity the results from these investigations are shown in Appendix O. As of the corvette equations, a set of equations was derived and validated for use in future designs and parametric studies.

4.9.5 Analysis of data

4.9.5.1 Introduction

The corvette equations were used to carry out a more in-depth parametric variation study. This decision was made, as the programme used in the analysis, DCONCEPT, did not cope well with the hard-chine hullforms of the FACs.

The analyses were designed to investigate the effect of a range of parameters on a chosen base vessel. The investigated parameters were chosen to reflect the usual design studies carried out when commissioning a new project at VT. The main reason for the survey was to aid the development of low-level management processes to control the feasibility study model. However, some results from the study were used to make changes to the loop model and therefore the study is described in detail here. The parts of the study used to aid the development of the interface management methodology are described in detail in the interface management section, see section 5.1.2.4.

4.9.5.2 DCONCEPT

DCONCEPT is an in-house VT developed concept design tool, which lets the designer change a variety of parameters and the program will output a balanced design. By balanced design the program implies that the design fulfils all the requirements given by the algorithms specified for area, weights, volumes and VCGs and also satisfies the specified stability criteria.

DCONCEPT is based on balancing the internal deck areas after specified blocks for engine rooms and double bottoms are reserved. The superstructure calculations work on a similar premise after a volume block for the hangar is specified. The program allows for the hangar to be integrated into the superstructure and does not just add it to the end of the superstructure.

DCONCEPT was chosen for its simple user interface and rapid setup capabilities. Whilst similar programs, such as PARAMARINE and SURFCON, require a great deal of pre-calculation setup, DCONCEPT simply requires an appropriate set of algorithms and base parameters. Also, as it is developed in-house at VT no expenditure was required from the research budget.

4.9.5.3 Base ship

The VT Multi Purpose Corvette (VTMPC) was chosen as the baseship. The vessel is currently in service with a foreign navy and therefore the confidence in the base weights and VCG data is as high as is possible. The VTMPC has an Lwl of 76m, which puts it firmly into the region considered for new designs.

During the evaluation of the baseship it became apparent that it would be easiest to model the GM as being a fixed value. This is due to the VTMPC having a very low GM and DCONCEPT being very beam sensitive. Also, the deck modelling used within DCONCEPT currently does not accurately represent the actual shape of the vessel above the waterline. This can lead to misleading results due to errors in the calculation of the wind-heeling lever.

The best fit obtained from DCONCEPT for the baseship is shown in Appendix P and a comparison of the percentage deviation from the actual vessel is shown in Figure 66. Figure 66 also provides a comparison of the DCONCEPT baseship with the best possible results based on the parametric equations. The graph indicates that the baseship created within DCONCEPT provides a suitable starting point for further parametric investigations. Care has to be taken when analysing the results as the DCONCEPT results overestimate the vessel’s area and displacement. However, the error is deemed to be within an acceptable boundary.

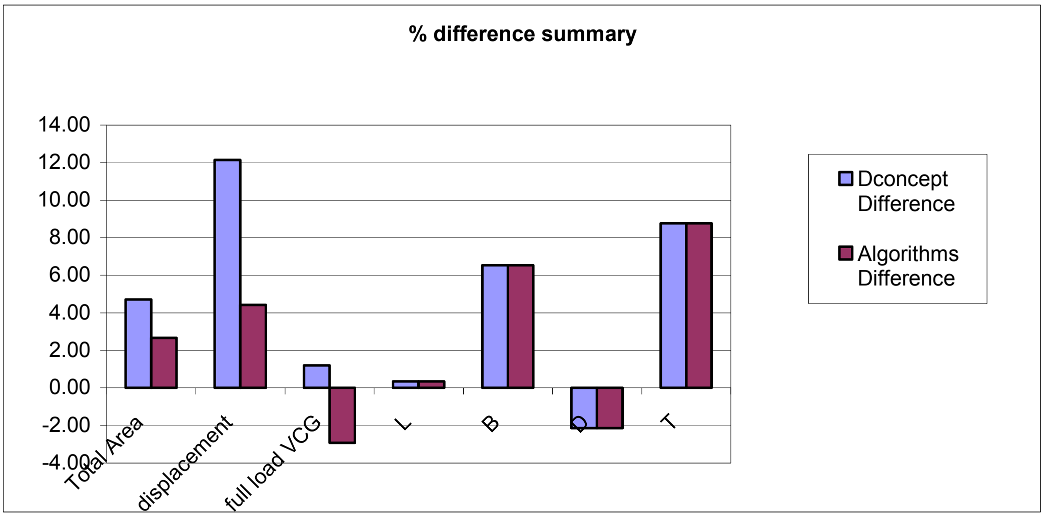

Figure 66 –Comparison Basevessel to Dconcept and to Algorithms

4.9.5.4 Limiting criteria

Before the analysis is started a set of constraints needs to be set up. This is necessary to help identify unsuitable solutions created by DCONCEPT. The constraints are based on existing vessels. A short description of each constraint is given below. All limits are calculated as follows:

Upper limit	-	uppermost value ever built +10%
Lower limit	-	lowermost value ever built –10%

L/B

This factor plays an important role in the determination of hydrodynamic performance figures. It is already used within the program routines and therefore no problems are anticipated in association with this factor.

B/T

This factor is important for seakeeping characteristics. It is used within the program routines, however some issues are anticipated as the hullshape used within the program does not accurately match some of the existing hullshapes.

L/D

This factor is used for structural considerations. It is anticipated that once the program stretches the vessel too much that longitudinal strength problems might occur.

L/FREEBOARD (F)

This factor is important for seakeeping characteristics. If too little freeboard is available then the vessel will not be suitable for its intended area of operation. At first a solution was sought comparing the actual L/F ratio with an L/F ratio where F was calculated using the US freeboard standard [60]. However, this proved unsatisfactory as the US standard is based on longer vessels.

The final solution is based on a linear equation based on the L/F ratios of several existing designs, see Figure 67. To include the baseship, the adjusted upper limit is set at approx. 18%. The lower limit is set at –10% to include all past designs.

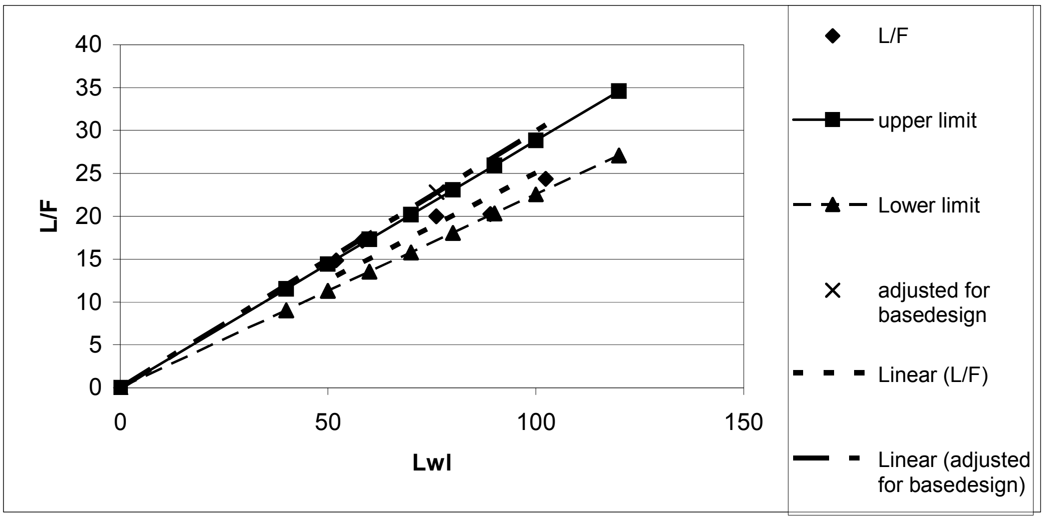

Figure 67 –Freeboard Criteria Derivation

The final equation for the adjusted upper limit is

Adjusted upper L/F = 0.29940 * Lwl

Table 8 gives an overview of the limiting values used. A table showing the vessels used to derive limiting values is attached in Appendix Q.

	L/D	L/B	B/T
max	11.13	8.93	3.60
min	7.67	5.87	3.16
max +10%	12.24	9.82	3.96
min -10%	6.90	5.29	2.84

Table 8 –Criteria Summary

All designs are compared to the limiting constraints. If a design falls outside the constraint boundaries it is flagged and a further investigation is carried out to determine whether a workable solution exists. This analysis is described in detail in section 5.1.2.4 as it is considered part of the interface management investigation.

4.9.5.5 Factor Investigation

Ten different factors were investigated. These factors were chosen during discussions with VT personnel and approved during meetings with academic staff at the University of Southampton. They were investigated across a range of values. Initially, most results were calculated using the parametric survey option of Dconcept. However, in some cases the results provided by the parametric survey proved inconclusive and in these cases alternative calculations, such as the design space option, are carried out. Where this is the case it is described in more detail under the relevant headings.

For each factor the reasons why it is investigated, the expected behaviour, results, implications and practical solutions are described. Only the summary results are shown, for a full list of tables see Appendix R (non-mitigating tables)

Whilst two in-depth papers already in existence discuss why certain types of ships end up with certain dimensions [58, 59], the investigation in this thesis is still necessary to assess what influence small changes have on a baseship in actual numerical terms. This data is required to populate the methodology and provide guidelines for designers.

CREW

Crew numbers are varied to investigate the effect of adding crew to the baseship. A second part of the investigation looks at the effect of changing the accommodation and outfit standard.
The accommodation standard analysis is necessary as more vessels are being built to commercial standards, which require a higher space allowance per crewmember.
The crew number analysis is required as it is common during designs that manning requirements change.

It is expected that with increasing crew numbers the overall size of the vessel will increase. This is due to the additional area required. It is not anticipated that the beam will increase by much but rather that the length will increase.

The overall trend for changing the accommodation standards is expected to be similar to adding additional crew but the step sizes are expected to be different.

To effectively investigate the changes it is necessary to run balanced ship calculations within Dconcept. This allows for the proper ratios of JR/SR/Off to be taken into account.

The crew cases run are as follows

Outfit	Standard	Standard	Standard	Generous	Generous	Generous
Total Crew	76	86	96	76	86	96
JR	31	35	39	31	35	39
SR	30	34	38	30	34	38
Officer	15	17	19	15	17	19

Table 9 –Crew Cases Summary

Results

The first part of the analysis is concerned with keeping the outfit as standard and increasing the crew number. As expected the beam stays almost constant and the length increases significantly. For every ten crewmember increase there is a corresponding increase in length of approximately 4m. This is illustrated in Figure 68.

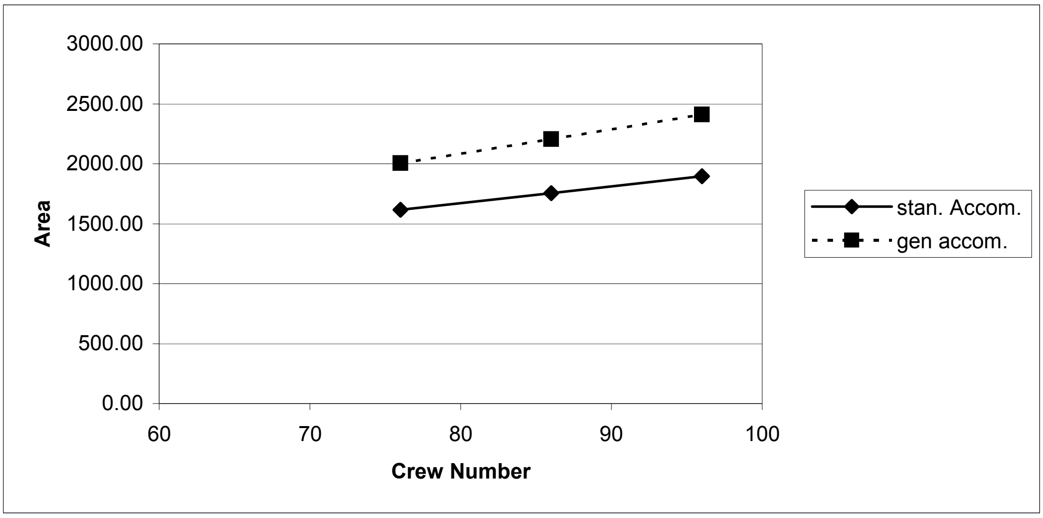

Figure 68 –Area vs. Crew

The required power also decreases as the L/B ratio increases with increasing complement. All results are within the constraints.

The trend for the generous outfit analysis is, as expected, very similar to the standard outfit. This is also shown in Figure 68. However, due to the step change in length when switching from standard to generous outfit, the design is outside the L/D constraint. The 96-complement condition exceeds the upper limit by more than 11%.

Implications

Adding crew has the expected effect on the baseship. However, increasing the length of the design has several practical implications. In reality it would be hard to justify any unused space within the design and thus the weight would increase, as more equipment would be added to fill the gained area. There are also UPC implications of increasing the overall ship size.
In reality a compromise would have to be made between trying to fit additional complement into existing space and redesigning large parts of the vessel. However, the analysis has shown the impact complement has on the design process and that crew numbers need to be decided on at a very early stage.

AFT DECK LENGTH

The aft deck length is varied to investigate the effect of changing requirements such as adding a larger helicopter and adding capabilities that require more aft deck working space.

It is expected that the vessel dimensions will increase with increasing the aft deck length, as less space is available for the superstructure.

The baseship aft deck length is 20.6m and the analysis is run for values from 18.5 – 27.5m in 1.5m steps. This is carried out using the parametric survey option within Dconcept.

Results

As expected the length of the vessel increases with increasing aft deck length. The relationship between increase in aft deck length and vessel length is almost 1:1. That is to say for every 1m added to the aft deck the Lwl increase by approximately 1m. However, this ratio starts to decrease once the vessel Lwl approaches 80m. The beam stays almost constant for all values of the aft deck length. This in turn increases the L/B with increasing aft deck length and thus decreases the required power. Figure 69 shows how the Lwl varies with increasing aft deck length.

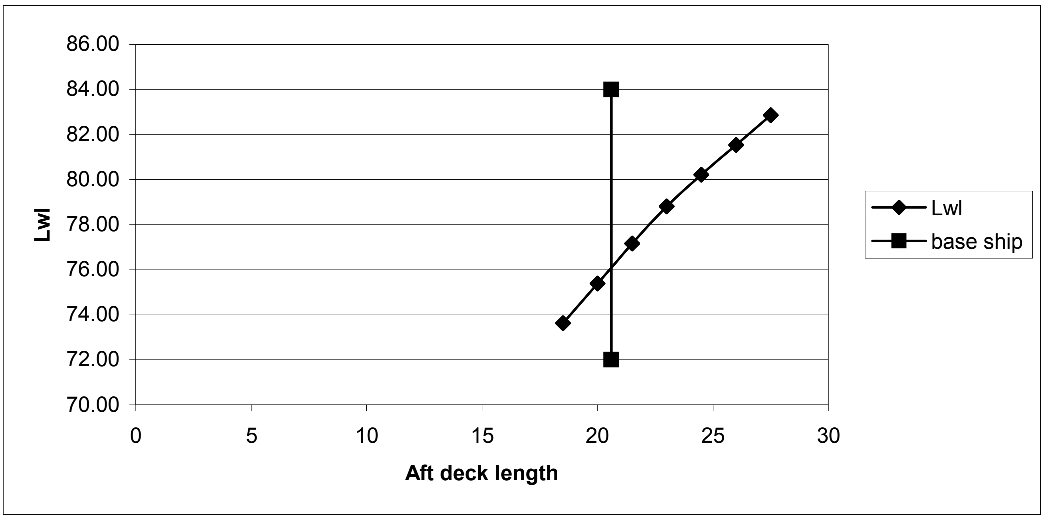

Figure 69 –Lwl vs. Aft Deck Length

The displacement increases by approximately 1% for every 1.5m increase in aft deck length. This is further illustrated by Figure 70.

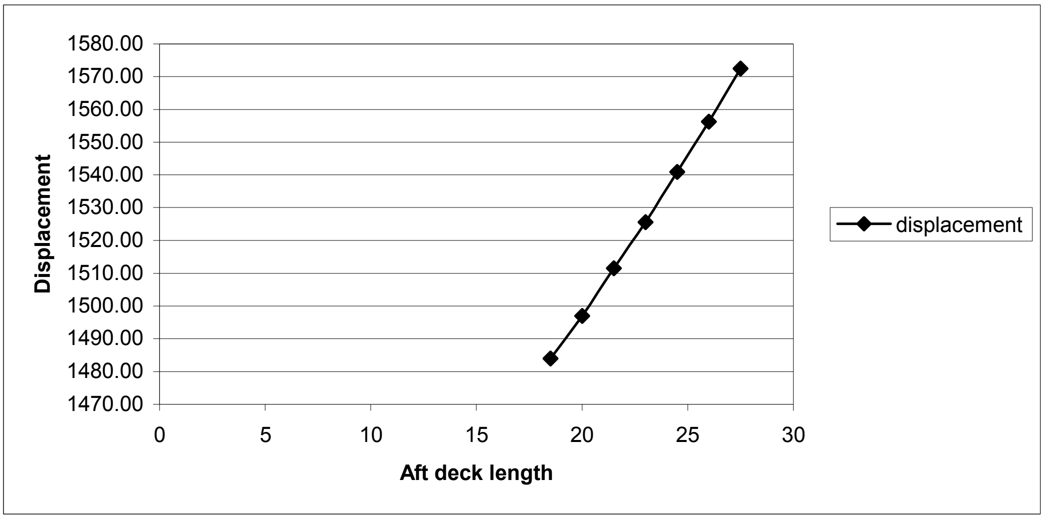

Figure 70 –Displacement vs. Aft Deck Length

Practical Solutions

The analysis shows that it is possible to increase the aft deck length of the vessel without major impacts on other factors. However, this is only true for small increases in aft deck length. If a major change in aft deck length is required it might be necessary to redesign the superstructure layout of the vessel.
The analysis shows that small changes in aft deck length requirements do not trigger major redesign decisions.

MATERIALS

This investigation analyses the effect of changing the superstructure material from steel to either alloy or composites. This would change the weight of the vessel and marginally decrease the displacement. It is anticipated that the beam should decrease slightly as the VCG decreases and thus the length should increase. However all changes are expected to be marginal.

To investigate the effect two balanced ship calculations are carried out, one with a SSmf of 0.555 (alloy/composite) and one at 1(steel = baseship).

Results

The first run of the analysis indicated that the Lwl decreases as the SSmf is changed to 0.55. This is not a feasible result, as the length of the vessel needs to be larger or equal to the baseship length, to avoid major redesign work. Therefore the design space calculation option is used and the results for the changed SSmf are obtained using linear interpolation with the baseship Lwl fixed.
As expected the VCG drops slightly and there is a corresponding decrease in the beam. The displacement decreases by approximately 30t and there is a corresponding drop in the required maximum power. This in turn leads to an increase in maximum speed by 0.5kts. There is a slight drop in the area of the vessel when compared to the baseship but this is negligible.

Practical Solutions

The analysis shows that changing the SSmf has a marginal effect on the dimensions of the vessel. However, the corresponding drop in required maximum power is a desirable outcome. In reality care has to be taken to evaluate the trade-off between increased speed and increased material cost.

HANGAR

This analysis consists of several parts. The first part investigates the effect of adding a hangar to the baseship. Two different hangar sizes are investigated to represent different helicopter requirements. Both hangars are of 7m beam and 2 decks high. Hangar length is varied between 15m and 18m. The hangar dimensions are based on other existing vessels.
The second part investigates adding organic helicopter support as well as the hangars. This implies an increased complement to support the organic aviation capability. For the non-organic support function no extra crew is required as the baseship already has non-organic support capability. For organic support an extra 6JR, 2SR and 2 Officers are required.

It is expected that just adding the hangars has a similar effect to increasing the aft deck length. But in addition the beam is also likely to increase as more weight is added above the weatherdeck.
Adding hangars and organic support capability should increase the dimensions even more as an additional ten crew are added.
In both cases a substantial weight increase is anticipated due to the additional required structure.

The cases are summarised in Table 10.

Support capability	Non-organic	Non-organic	Organic	Organic
Hangar length	15	18	15	18
Hangar beam	7	7	7	7
Hangar height	2 decks	2 decks	2 decks	2 decks

Table 10 –Hangar Cases Summary

All cases are calculated using the balanced ship calculation within Dconcept.

Results

Non-Organic
Adding the 15m hangar significantly increases the length to 85m and the displacement by 200t to 1720t. However, the increase in beam is marginal and thus there is a drop in required maximum power. However, the vessel is just outside the required L/F constraint. The actual drop in freeboard is only 4cm but the vessel length has increased significantly.

Increasing the hangar length by 3m to 18m increases the Lwl by a further 1m. The beam does not change. The displacement increases by a further 14t. Again the vessel is outside the L/F constraint.

The change in length is shown in Figure 71.

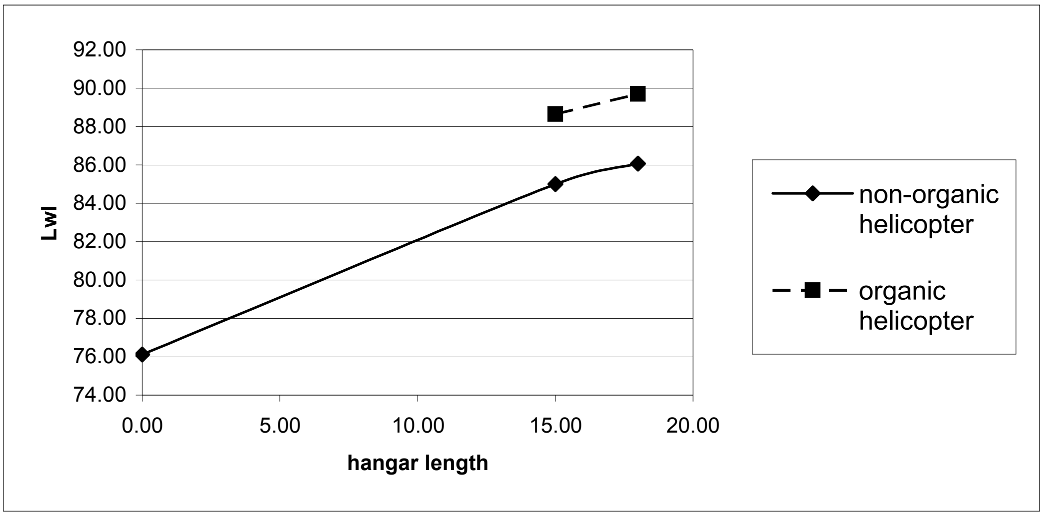

Figure 71 –Lwl vs. Hangar Length

Organic
Adding the organic support capability to either of the two hangars increases the length by a further 3.6m. This then leads to both organic hangar designs exceeding the L/D constraint. The organic support function also increases the displacement by a further 58t for both hangar lengths.

Practical Solutions

The results show that it is possible to add a hangar to the existing base vessel. However, this added capability is coupled to a significant increase in dimensions. The significant increase in length needs careful consideration, as it will increase the cost of the vessel and also trigger a complete change in vessel type and thus design.

AREA

This investigation analyses the effect of increasing the area margin. This has the effect of simulating increased space requirements on the baseship. The area margin is applied to all area equations and two parametric surveys are computed. The first runs for values from 0% - 15% in 2.5% steps and the second runs from 15% - 25% in 5% steps.
The investigation is necessary as it is very common during the design process to change space requirements.

It is expected that the overall dimensions will increase with an increasing area margin. It is also expected that a cut-off point exists beyond which the baseship cannot be extended but a new design is necessary.

It should be noted that the relationship between applied area margin and actual area increase is not necessarily 1:1. This is due to the complex iterative nature of the design calculations. The implications of this are described in the practical solutions section.

Results

The results are as expected. Increasing the area margin increases the dimensions of the vessel. However, the beam and depth stay almost constant. The Lwl increases linearly, for every 2.5% area margin increase there is an approximately 2.5m increase in Lwl. The displacement also increases in an almost linear fashion and for every 2.5% area margin increase there is an approximate 25t increase in displacement. The required power decreases with increasing ship size.

Up to and including 10% all designs are within the limits imposed by the constraints.

From 12.5% onwards the design starts exceeding the upper L/D limit, which indicates that the design would encounter structural problems.

Practical Solutions

The results behave as expected. However, it must be noted that applying a 2.5% area margin actually increases the area by 4.8%. This is most likely due to a complex set of interdependencies between the equation sets. The implication is that in reality the effects of the area margin seen in the analysis are not as profound and could be almost halved.
Increasing the area margin increases the overall dimensions of the vessel. However, care has to be taken when increasing the required area by more than 10%.

DECKHEIGHT

This study analyses the effect of changing the deckheight on the overall design. The main reason for changing deckheights is to improve the system routing of a design. This in turn will reduce the cost of the vessel up to the point where the increased depth adversely affects the design. Increasing the deckheight can also be used to increase the depth of a vessel if the freeboard becomes insufficient.

It is anticipated that increasing the deckheight will increase the depth of the vessel. This in turn will increase the beam, as the VCG will rise. Increasing the beam will decrease the length, as less length is required to create the same area. However, the length needs to stay equal to or greater than the baseship, as there is no change in complement or other requirements. The parametric survey option is used to determine for which deckheights the length decreases. For these deckheights the design space solution option is used and the results are interpolated with the Lwl fixed at the baseship Lwl. Where the Lwl is greater than or equal to the baseship Lwl the results from the parametric survey option are used.

The deckheight is varied from 2.3m to 2.9m in steps of 0.1m. The baseship deckheight is 2.35m.

Results

The results for 2.4 – 2.6 are interpolated from the design space calculations. All other results are taken from the parametric survey results.
As expected, increasing the deckheight increases the depth. For every 0.1m deckheight increase the depth increases by approximately 0.2m, which is corresponding with the vessel having 2 decks enclosed within the hull.

The beam increases with increasing deckheight. For every 0.1m deckheight rise (0.2m depth rise) the beam increases by 0.22m.

All values from 2.35m upwards are within the constraint limits. However, the increase in displacement, see Figure 72, leads to a reduction in the achieved maximum speed of approximately 0.5kts per 0.2m depth increase, see Figure 73.

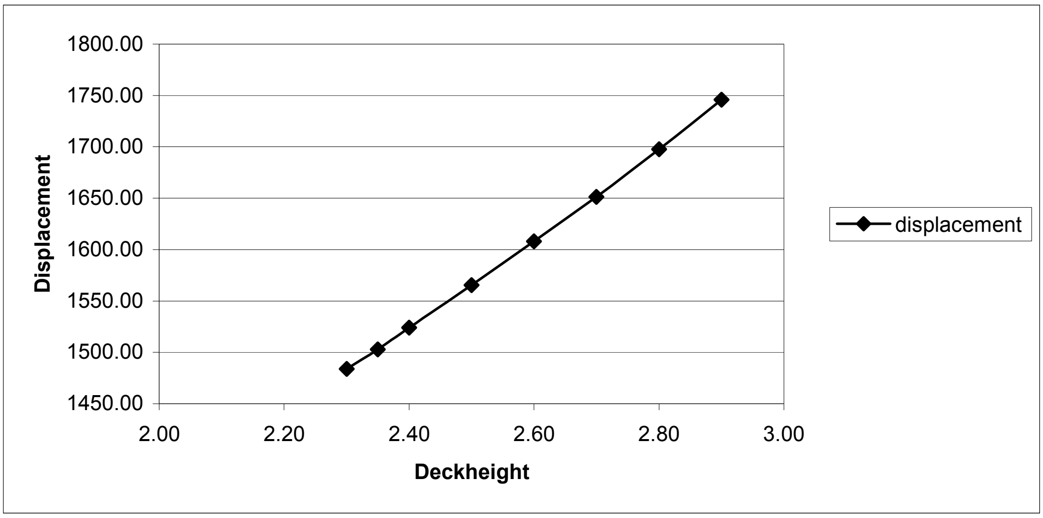

Figure 72 –Displacement vs. Deckheight

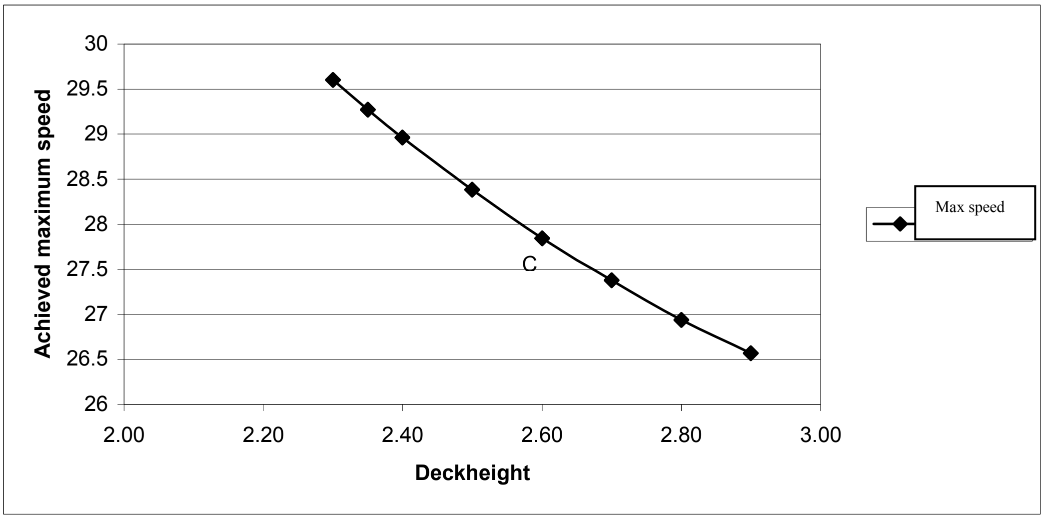

Figure 73 –Maximum Speed vs. Deckheight

Practical Solutions

The results clearly show the effect of increasing the deckheight on the overall design parameters. Careful attention needs to be paid to the powering requirements, as too large an increase in depth significantly reduces the achieved maximum speed. The analysis shows that it is possible to make minor (around 0.25m) adjustments to the deckheight without significantly altering the vessel's dimensions.

POWER

This analysis investigates the effect of adding a power margin to both, cruise and maximum power. This is a common occurrence during the design process and derives from varying power predictions due to changing dimensions. It is therefore very important to identify how the design responds to increasing power margins.

It is expected that increasing the power margin will increase the overall weight of the vessel as propulsion related weights will increase and the fuel oil carried will increase.

Similar to the area equations it should be noted that the relationship between power margin and actual power increase is not necessarily 1:1. This is due to complex interdependencies and the iterative nature of the design calculations. Increasing the power margin will increase the required powers, which in turn will increase the weights, which in turn increases displacement and thus increase the required power some more. The actual relationship is described in more detail in the practical solution section.

To effectively investigate the power margins it is necessary to adapt a different design approach. For all other factors the maximum power available is specified to be equal to the baseship design power. However, this caps the power and therefore the effect of increasing the power cannot easily be seen. This is not an issue for the other factor investigations as a comparison to the baseship is made using the actual achieved maximum speed. However, for the power margin investigation the available power is uncapped, i.e. set at 100 000kW, and therefore the investigation effectively looks at the power required to achieve the maximum specified speed of 30kts.

The power margins investigated range from 0% - 20% in 2.5% steps.

Results

As expected increasing the power margin increases the required power. The required power increases linearly and for every 2.5% margin there is an increase of approximately 950kW, which corresponds to 4%. The beam and depth both decrease marginally whilst the length increases with increasing power requirements. The increase in length is linear with an approximate increase of 0.38m for every 2.5% power margin, see Figure 74.

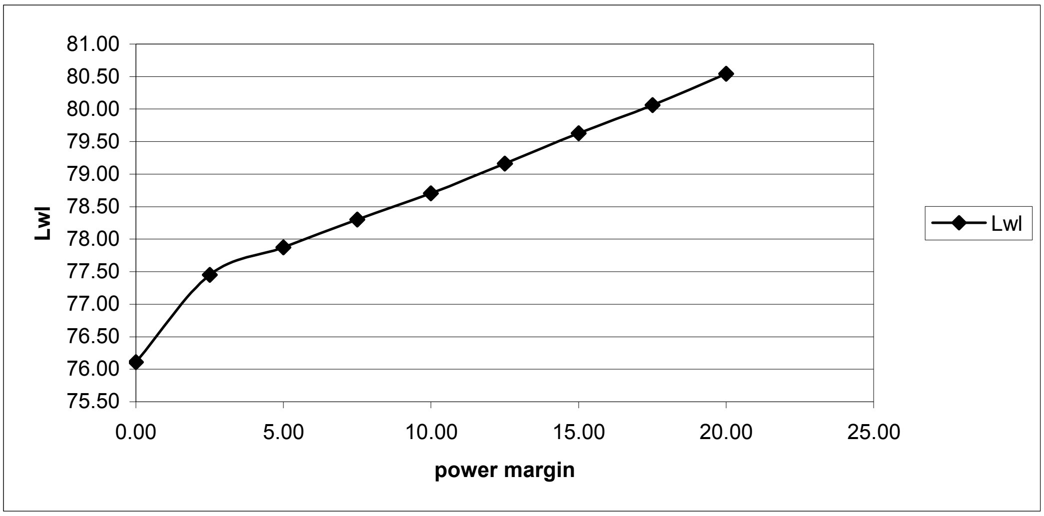

Figure 74 –Lwl vs. Power Margin

The initial drop in figure 11 is due to the 0% margin point being taken from the baseship, which is calculated using capped power settings.

As expected the displacement increase with increasing power. The rise is approximately 30t for every 2.5% power margin as shown in Figure 75.

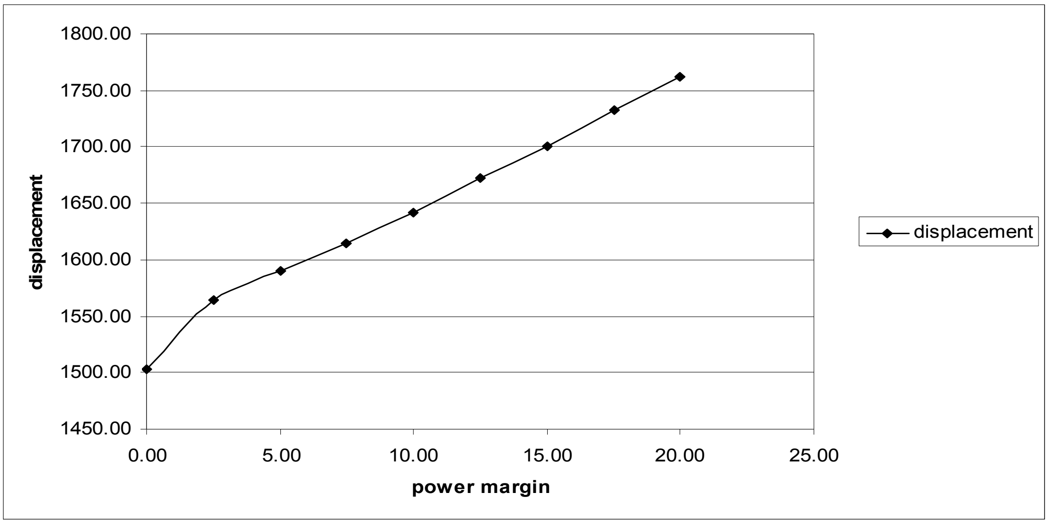

Figure 75 –Displacement vs. Power Margin

Again, the low starting point is due to it being taken from the baseship design.

However, all power margin values are outside the L/F constraints. This is because most of the weight associated with propulsion is very low down and therefore the vessel's draft increases without a corresponding increase in either length or beam.

Practical Solutions

The results show that the design is very sensitive to changes in the power margin. The resulting changes in dimensions are as expected.
Applying a 2.5% power margin results in an actual increase in power by about 3.8%. The impact of this is that in reality the effect of adding a power margin is not as severe as illustrated by the above results. This is partly due to the program treating the power available as elastic, whereas in reality this is a stepped function. It is not easy to make significant changes to the dimensions at a later stage of the design process and it is therefore important to determine the power values at a very early stage.

PASSAGEWIDTH

This investigation is carried out to investigate the effect of varying the mean Passagewidth. Increasing the Passagewidth increases the accessibility and also improves system routing. A trade-off needs to be made between increased material cost, due to increased dimensions, and lowered outfit cost, due to improved routing. It is therefore important to understand the influence of mean Passagewidth on overall dimensions.
It is expected that increasing the mean Passagewidth will increase the main dimensions, particularly length.
The Passagewidth is investigated over a range of values from 1m – 1.5m with steps of 0.1m.

Results

The results show that the beam and depth are almost unchanged. The length increases linearly at a rate of approximately 1.8m per 0.1m Passagewidth increase, see Figure 76.

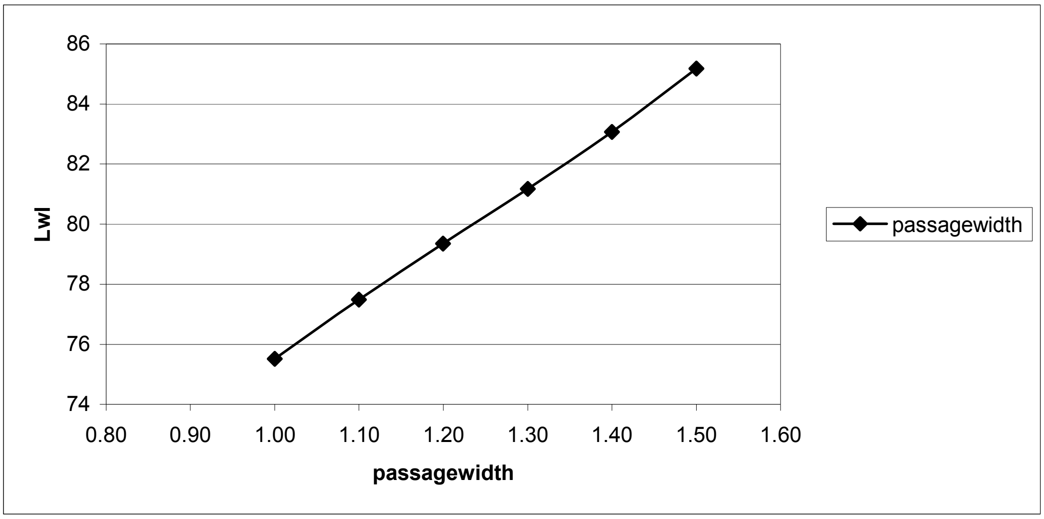

Figure 76 –Lwl vs. Passagewidth

The required maximum power decreases with increasing Passagewidth. This is as expected and similar to the results due to adding area margins.

Practical Solutions

The results show that increasing the Passagewidth has similar effects to adding the area margins. The results indicate that increasing the passagewidth is beneficial to the design, as it decreases the required power and increases the freeboard. However, in reality it is not feasible to make major changes to the principal dimensions at a later stage of the design process. The results show that it is possible to make minor adjustments to the passagewidth at a later stage but major changes will incur redesign penalties.

WEIGHTS

This study analyses the effect of adding a weights margin to the baseship design. This is one of the most common occurrences during the design process and it is therefore vital to understand the influence of changing the weights margins. The weights margins are only applied to weights of group 1-7 as group 8 weights are payload, crew or fluids related. Groups 1-7 are the construction weights.
It is anticipated that the relationship between applied weights margin and actual displacement should be 1:1. This is due to the vessel's displacement being based on the vessel's weight and there is no iterative weights equation.

All groups are investigated individually but only the combined groups 1-7 are analysed in detail. This is to accurately represent the design process currently used at VT.

It is expected that increasing the weights margin will increase the displacement of the vessel. This in turn should increase the required power and there might be a slight increase in dimensions.

The weight margins are varied from 0% - 12.5% in 2.5% steps.

Results

As expected increasing the weights margin increases the displacement of the designs, see Figure 77.

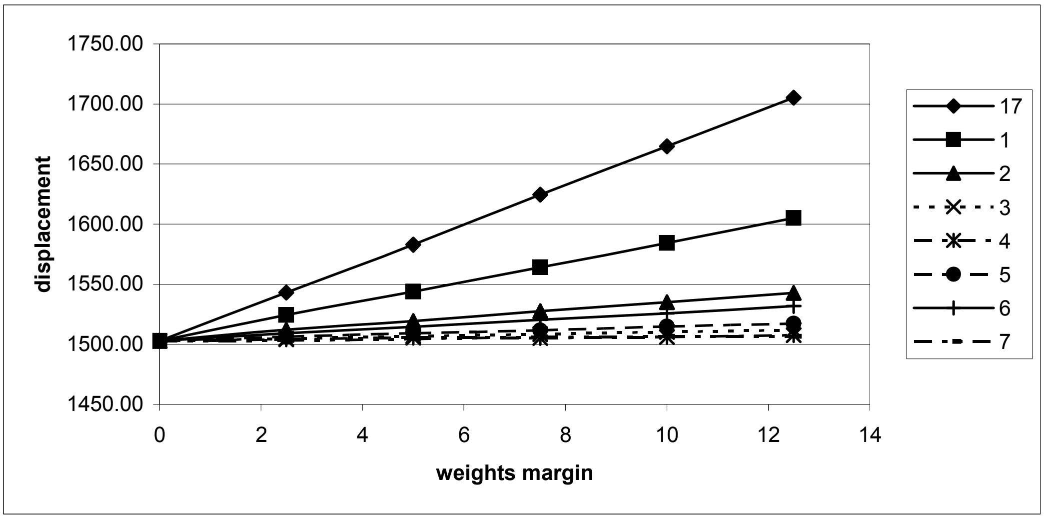

Figure 77 –Displacement vs. Weight Margin

The graph shows that for every 2.5% margin applied to groups 1 – 7 the displacement increases by approximately 2.5%. This is as expected.

The length increases with increasing weight margin, but the increase is very small, approximately 0.15m for every 2.5% margin applied to groups 1 – 7, see Figure 78.

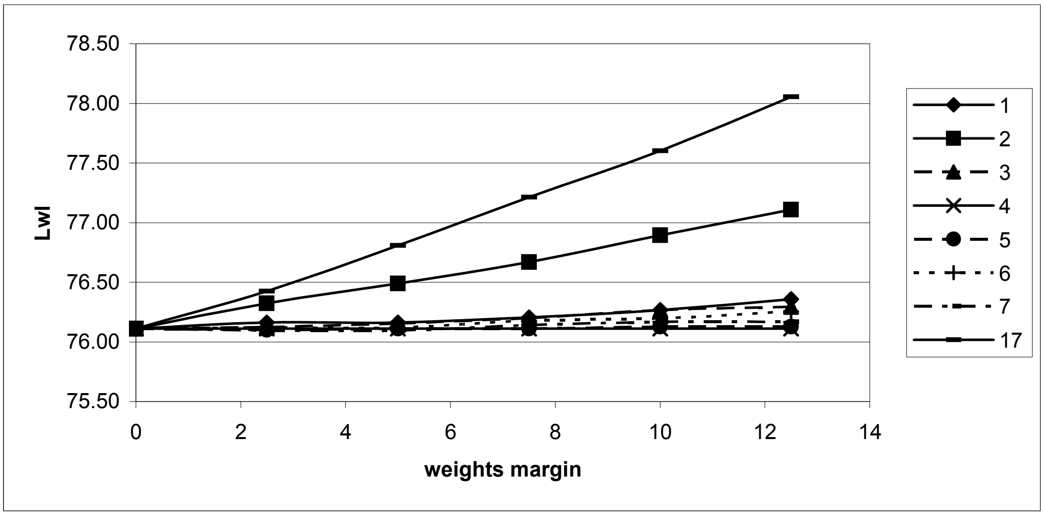

Figure 78 –Lwl vs. Weight Margin

Increasing the weights margin also changes the beam. When applied to groups 2, 3 and 7 the beam decreases slightly. This is due to these weights having a relatively low VCG. When applied to the remaining groups and across groups 1- 7, the beam increases slightly. Again the increase is minimal, see Figure 79.

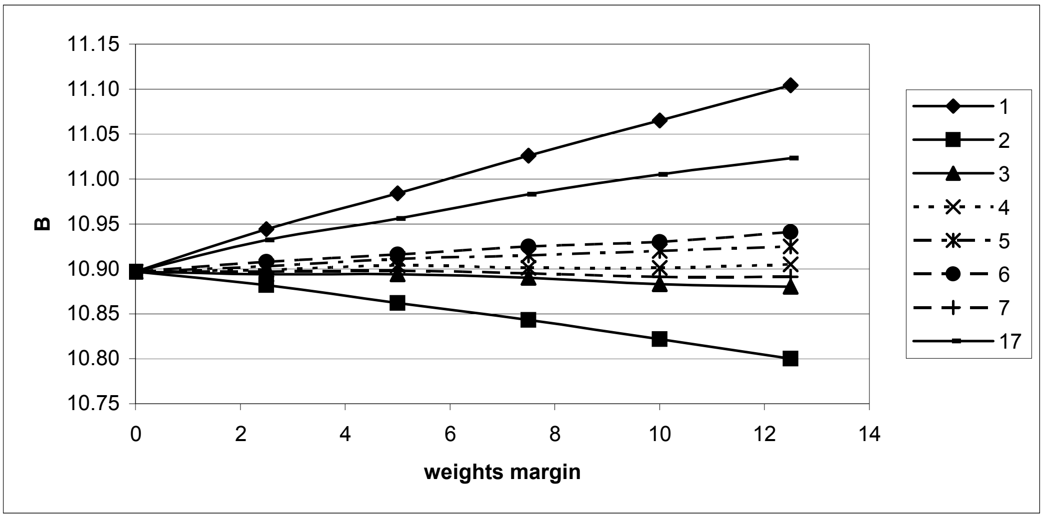

Figure 79 –B vs. Weights Margin

Increasing the weights margin also decreases the maximum achieved speed, assuming a capped maximum available power. Increases in the margins applied to individual groups 2 – 7 have little effect on the speed. Increases across groups 1 – 7 reduce the speed by approximately 0.3kts for every 2.5% weights margin increase.

Increasing the weights margin for groups 1, 2, 5, 6 and across 1 – 7 moves the design outside the L/F constraint. This is due to the heavier design requiring a deeper draft, as there is little change and beam and length.

Practical Solutions

The analyses show the effect of adding weights margin to the existing baseship. The effect is a small increase in dimensions coupled with a decrease in maximum achieved speed. The analyses show that changes in weight can have a significant effect on the achieved maximum speed as well as infringe on the freeboard requirements. Minor changes to the weights data can be incorporated into the design at a later stage but major changes will most certainly necessitate redesigns.

VCG

This study investigates the effect of increasing the VCG margins. This is a common problem during ship design, as items tend to go up in weight and thus shift the VCG up. Also, designs tend to be based on existing vessels and adding a bigger weapon payload, as is commonly the case in new designs, will increase the VCG.

It is anticipated that the relationship between VCG margin and actual VCG rise is not 1:1. This is due to the VCG equations being based on depth, which is dependent on many other factors.

Increasing the VCG margin should cause the vessel’s VCG to rise. This should increase the beam, which in turn should decrease the length. To keep the length >= baseship length the design space option in Dconcept is used. The results are interpolated with the baseship Lwl fixed.

The analysis is run for VCG margins varying from 0% - 12.5% in steps of 2.5%. The VCG margin is applied to groups 1 – 7 individually and to 1 – 7 combined. Group 8 is omitted from the analysis as the VCG margin is only applied to construction weights.

Results

As expected increasing the VCG margin increases the beam, see Figure 80.

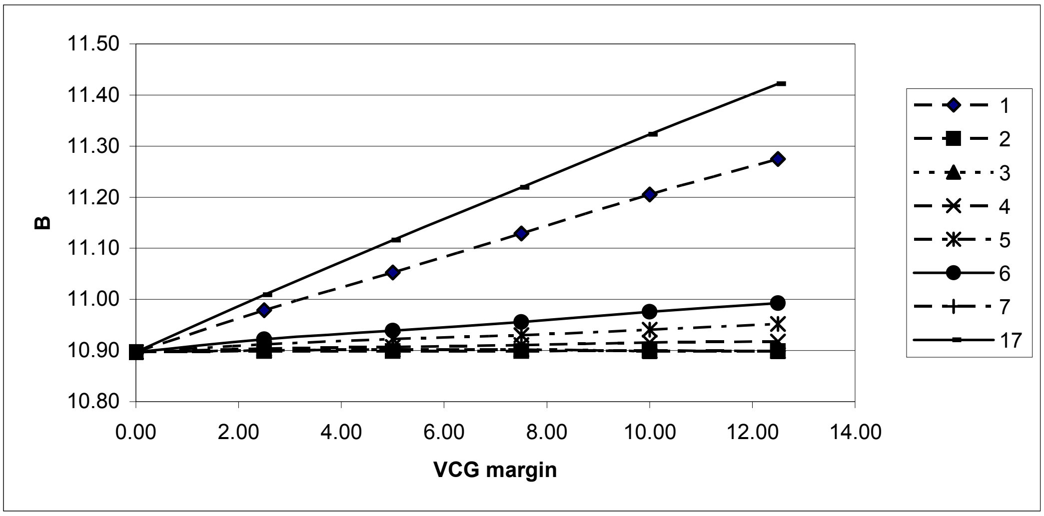

Figure 80 –B vs. VCG Margin

Increasing the VCG for groups 2 – 7 individually has only a marginal influence on the overall beam. Increasing the VCG across groups 1 – 7 increases the beam by approximately 0.1m per 2.5% VCG margin applied.

Due to the increase in beam, and Lwl being fixed, there is a corresponding rise in displacement of approximately 6t per 2.5% VCG margin increase applied across 1 – 7.

As expected the increase in displacement and beam leads to a reduction in achieved maximum speed, see Figure 81.

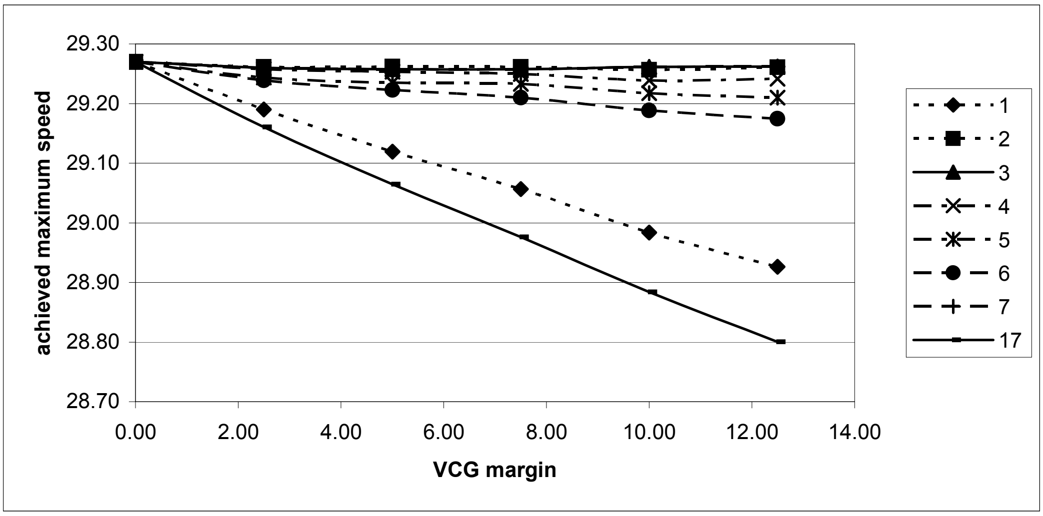

Figure 81 –Maximum Speed vs. VCG Margin

The drop in maximum speed corresponds to approximately 0.1kts per 2.5% VCG margin applied across 1 – 7.

There is an excess area associated with the designs due to Lwl being kept constant. This increases at a rate of $9m^2$ per 2.5% Vcg margin applied across 1 – 7.

All results are within the constraint boundaries.

Practical Solutions

The results show that increasing the VCG increases the beam. However, all observed changes are marginal. Care has to be taken with respect to the achieved maximum speed, as this is usually a critical value throughout the design process. Also, it is important to note that Lwl needs to be fixed to avoid redesigning the arrangement.

Applying a 2.5% VCG margin across groups 1 – 7 results in an approximate VCG rise of 1.6%. This implies that the actual influence of increasing the VCG margin is more pronounced than indicated by the results.

The results show that it is possible to allow for VCG rises, within reason, throughout most of the design process.

4.9.6 Impact on Loop Model

The results from the parametric study showed several factors potentially triggering major design changes. These are:

- Crew increase more than 10
- Any changes to the aviation requirements
- Area margin increases by more than 10%
- Deckheight increases exceeding 0.2m
- Power margin increases
- Weights margin increases
- Change from standard to generous outfit

The only one of these changes, which cannot be mitigated using a margin or which is not already included on the top loop, is the aviation domain. Human Factors and Propulsion are already included on the top loop and the parametric study covers items such as weight margins and dimension changes. Therefore, to reduce the risk of rework once the concept stage has passed the decision was taken to move the aviation domain from loop1 to the top-level loop.

It was also noted, that the weapons domain on the top-loop needs to be connected to the parametric study to provide equipment weight data. This is to avoid rework due to exceeding the weight budget.

The survey results further justified the decision to include naval architecture on all loops to allow for minor changes to be implemented.

4.10 CUSTOMER FEEDBACK

During discussions with the MoD and from feedback received from a paper submission, it became apparent that a closer integration of the customer domain was required. To ensure that the design is always up to date with the latest customer requirements, the customer domain has been included at each review point. This allows the designer to present the current solution to the customer and incorporate eventual requirement changes into the design.

4.11 SUMMARY

Combining all the results described in chapter 4, a refined interface model was constructed. This model was constructed in MS Visio and did not include a timeline. This decision was made, as it was felt that the inclusion of a timeline should be postponed until more detail about the required management processes was known. The model shows the input and output into each domain. Where an input/output is considered iterative, such as ILS with most other domains, this is illustrated by a dotted line connecting the domains. The model was designed so that no joint lines existed. Whilst this gives the model the appearance of wiring diagrams, it provides the most accurate description of the identified interface interactions. The four resulting loops are shown in Figure 82, Figure 83, Figure 84 and Figure 85. Cross-loop connectors are provided where a domain feeds into a different domain on a different loop. No cross-loop connectors are provided for domain to same domain connections across different loops.

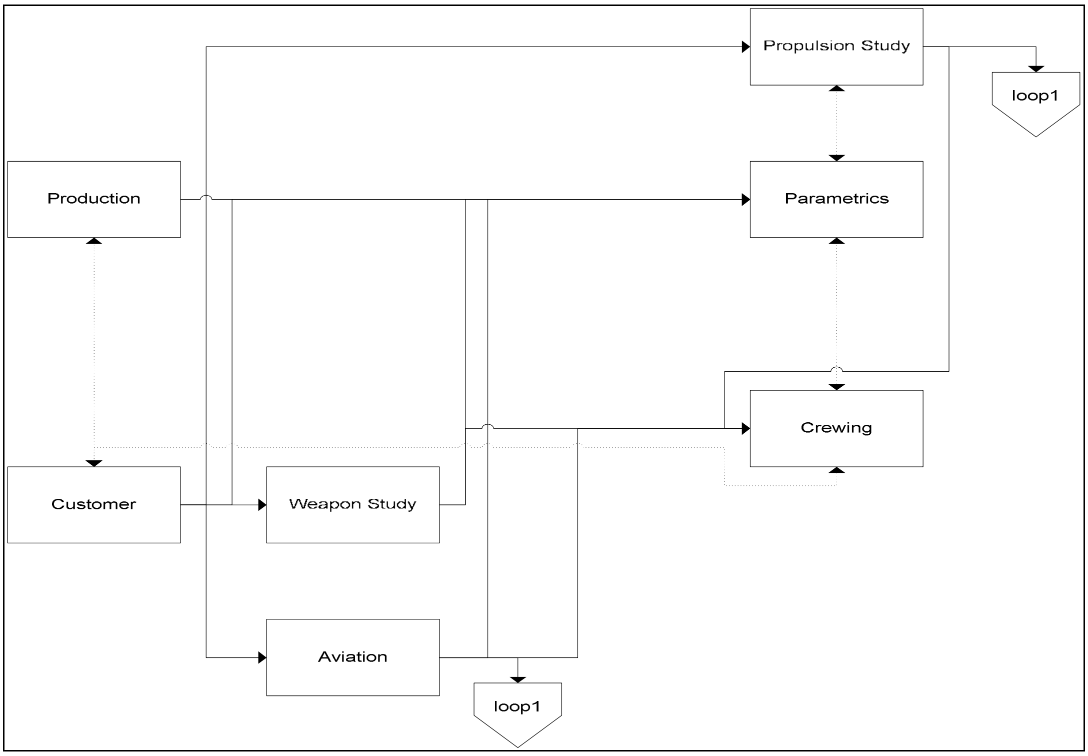

Figure 82 –Functional Top Loop

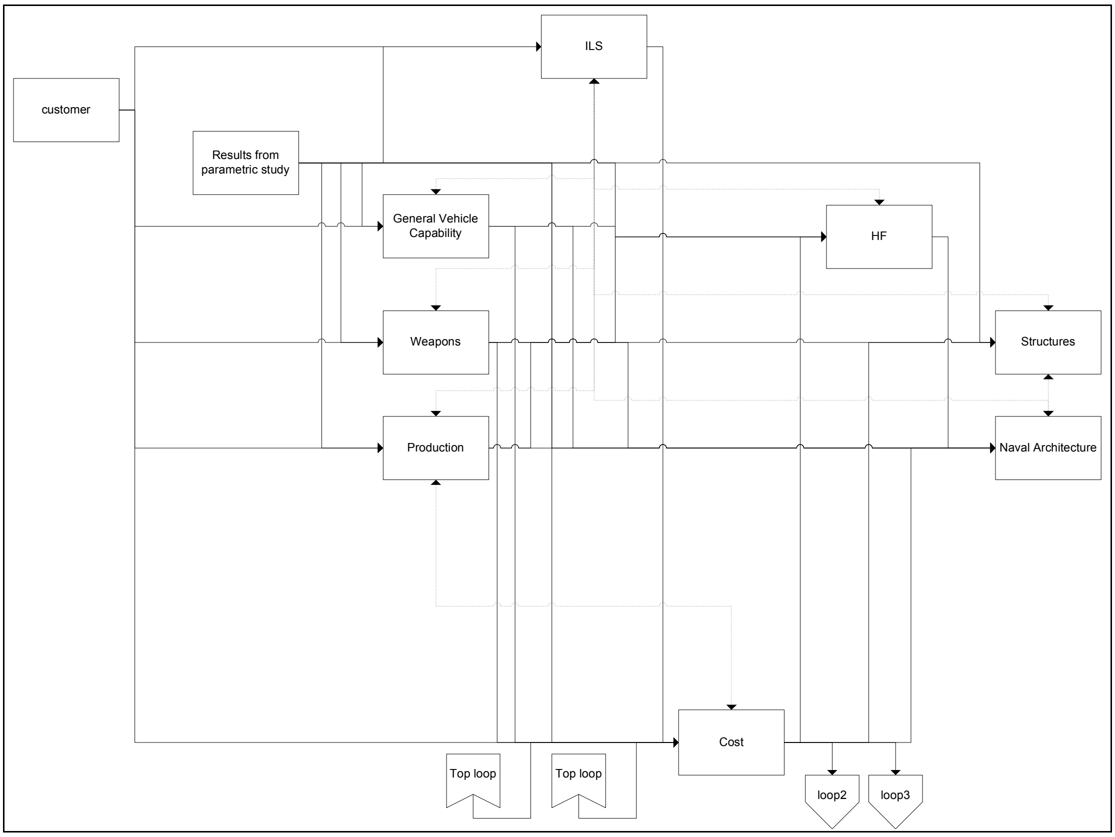

Figure 83 – Functional Loop1

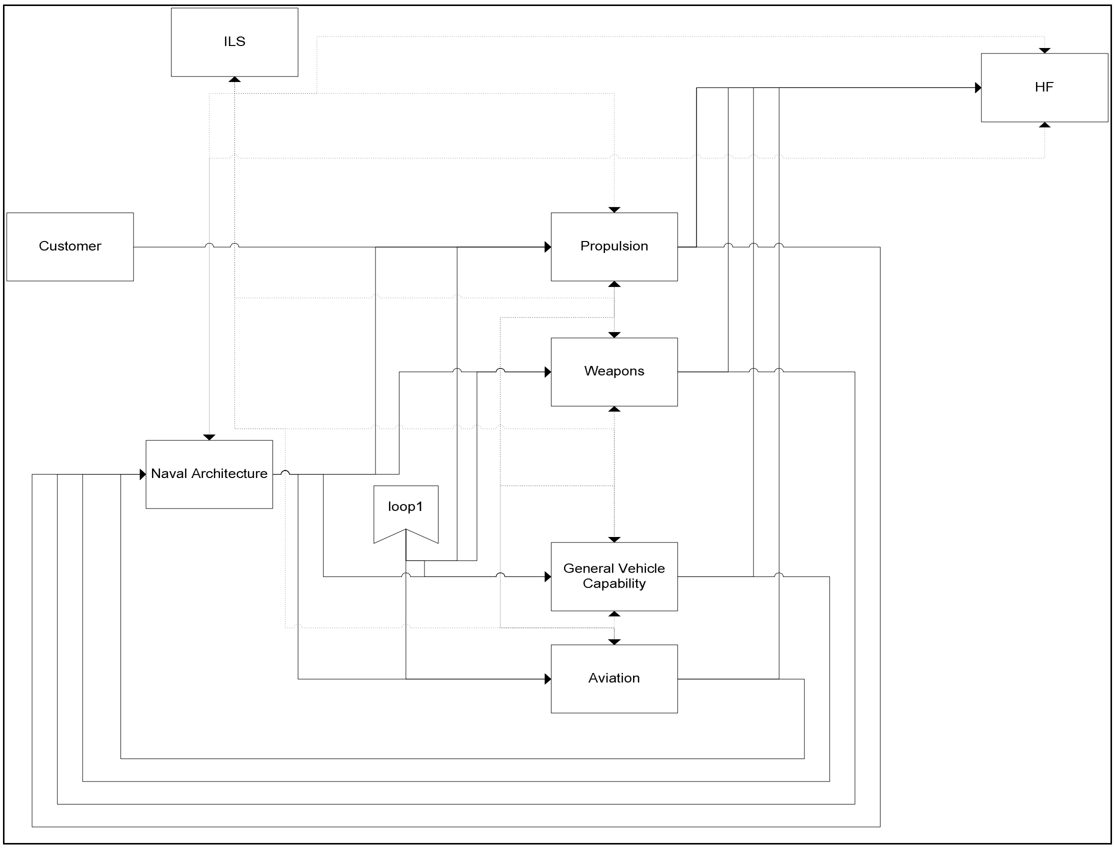

Figure 84 –Functional Loop2

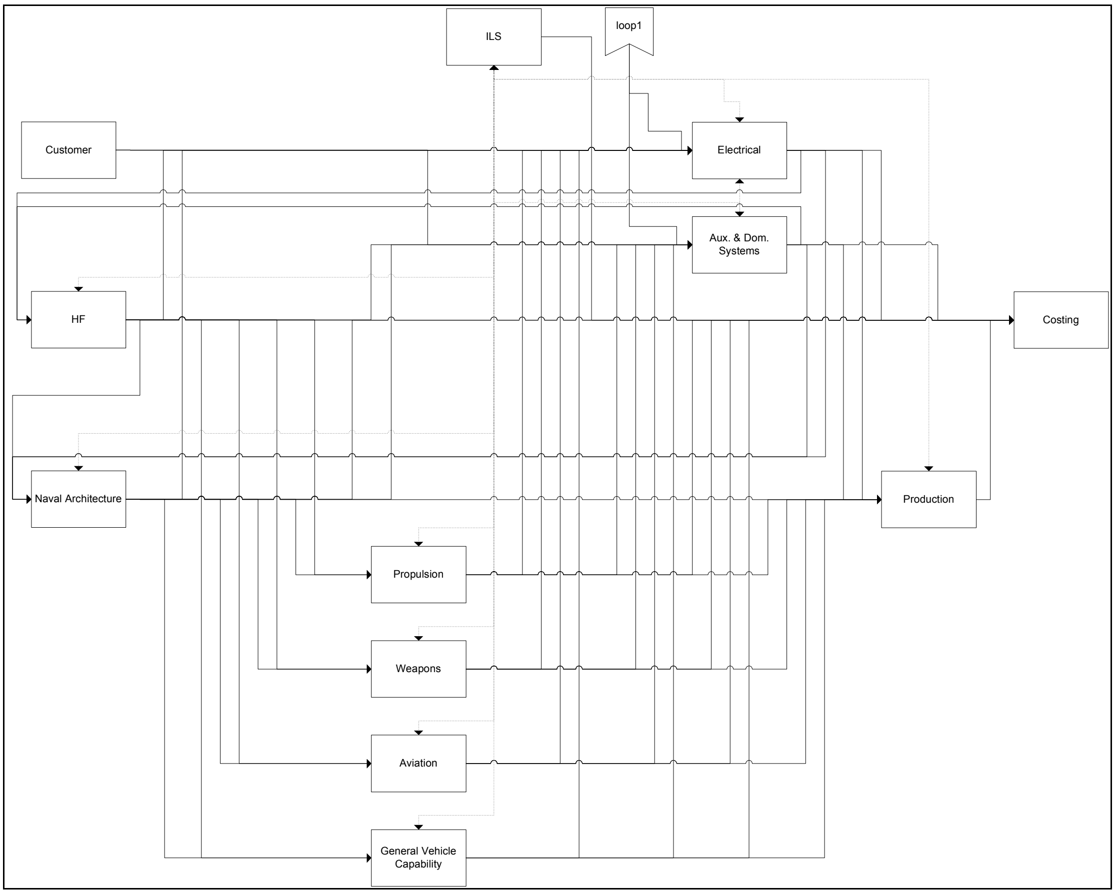

Figure 85 –Functional Loop3

The figures clearly show the complex nature of the interdependencies between the domains and also show that a different format is required to effectively manage the design process. The issue of interface management is described in detail in chapter 5.

5 INTERFACE MANAGEMENT

5.1 CREATION OF LOW-LEVEL MANAGEMENT TOOLS

5.1.1 Introduction

As mentioned in section 4.11, a different format for effectively managing the design process is required. After consultation with project managers and designers at VT, the decision was made to split the management suite into three parts.

The first part will provide a functional description of the data transferred between domains. This is in the form if the functional flowcharts shown in Figure 82, Figure 83, Figure 84 and Figure 85.

The second part is to provide a timeline for project managers based on the information gathered during the interviews and case studies, and also during further interface management research. This part will be stored in MS Project and will allow project managers to evaluate when domains have to be started by and which domains can run in parallel. It will also provide a tool to allow rescheduling of design activities when domains require time extensions.

The third part will be in the format of a user manual and for each domain will list the input and output required, the approximate timing of the input/output, the likely issues faced and possible mitigation measures. Both, project managers and designers can use the handbook.

The following sections describe the issues that need to be considered in order to derive a suitable management methodology and conclude by presenting the resulting Project schedule and user manual.

In order to successfully derive a working management methodology it is necessary to investigate the low level issues and how they can be resolved.

Many of the required low-level data have already been gathered during the interface interaction investigations. However, these are mainly actual input and output data and it is therefore important to identify critical events and to derive a set of tools to manage the dataflow.

5.1.2 Margins

5.1.2.1 Types of Margins

Consultation with VT staff and analysis of several references [6, 25, 31, 32, 61, 62] showed that margins are an important factor to consider.

Margins are of great importance in the ship design process, especially during feasibility studies. Due to the importance given to margins it was decided to further investigate margins and the way they can be managed. It is thought that a good understanding of margins and their management can greatly enhance the efficiency of feasibility studies. One option is to implement an appropriate margin policy [25, 32].

In 1975 Gale said “no subject is more likely to cause controversy… than that of margins” [61]. And with an ever-increasing emphasis on cost reduction [8] this is still applicable. Gale splits margins into three distinct regions

- Design and Construction margins
- Future Growth Margins

- Service Margins

Gale states that Design and Construction margin policies are very important during the design process, as they have to be tailored to each individual design study. Future Growth and Service Margins are either set by the Office of the Chief of Naval Operations (OPNAV) or the designer to allow for adaptability to changing requirements during the lifetime of the vessel. However, as this research concentrates on UK vessels being build under SMART procurement, it is necessary to identify margins used within British builds.

Brown [25] states that the margin policy is of key importance to the design as early as the concept stage. He classifies margins under the following headings

- Design and Build Margins
- Board Margins
- Growth Margins
- Other Margins

Brown's classification compares well with the one proposed by Gale [61]. Heather [31] gives a good description of future growth margins. On the subject of design and construction margins he only states that they "are self-imposed by the designer and under his control" [31]. This statement, along with the results presented in other references [25, 61, 62], leads to the conclusion that the types of margins that can be influenced by the designer are the Design and Construction (D&C) margins. Therefore the decision was made to concentrate the research on design and construction margins.

5.1.2.2 Margin Policies

Margin policies are difficult to determine and vary from design to design. However, Gale [61] suggests a two-stage approach to developing a D&C margin policy

1. Derivation of the required degree of assurance
    1.1. Take into account previous designs
2. Selection of specific margins for each characteristic based on the derived degree of assurance

This shows that in order to derive a margin management methodology it is first necessary to understand all factors involved in deriving the actual margins.

Garzke [32] states that D&C margins decrease during the design process. They should be chosen such that they are completely consumed by the time the ship is commissioned [25]. If they are not consumed they should be deleted prior to ship completion and delivery [61]. This indicates that D&C margins are used by designers to account for omissions and uncertainties, thus allowing for minor changes without the need for a design re-evaluation.

Another area of concern with regards to margin policy derivation is margin compounding and margin interaction [61]. Care has to be taken to avoid double counting margins [31]. Gale [61] provides the following example. If the margin for the shaft horsepower (SHP) is increased it will have a knock on effect resulting in an increased full load displacement. However, these weight increases will further increase the weight margin and in turn influence the SHP margin. This illustrates the need to communicate margins effectively between domains. Also, it provides further proof that all factors involved in deriving margins need to be understood before a margin management methodology can be proposed.

5.1.2.3 Interviews

Based on the positive results from the interview process regarding the domain interactions, it was decided to carry out the margin analysis using similar techniques. To identify potential interviewees and associated margins, it is first necessary to draw up an initial list of margins. It is anticipated that this list changes as more information is gathered. The initial list is based on previously published data [24, 31, 32, 61, 62] and is shown in Table 11.

Speed
Power at max speed
Power at sustained speed
Seakeeping
Endurance
Signatures
Manning
ILS (Maintenance Philosophy)
Weight
Space (volume)
Stability
Cost

Table 11 – initial margin list

This list was then presented and discussed at a meeting with representatives from VT and the University of Southampton. The amended list is shown in Table 12. It should be noted that the presented list is by no means extensive and only presents a sub-set of existing margins, as required for the purpose of the methodology.

Speed
Power at max speed
Power at sustained speed
Electric Load
Seakeeping
Endurance
Signatures: • Radar • EMF, Low frequency • IR • Acoustics
Manning
ILS
Weight
Space (volume)
Stability
Cost

Table 12 – amended margin list

Based on this list a set of interviewees was determined, many of whom took part in the interview process for the domain interactions and were thus familiar with the project. All interviewees were briefed at the beginning of the interview about the context of the interview in order to secure relevant answers.

As stated above, the interview process concentrated on D&C margins, their derivation, and how they interrelate. To figure out the interrelations the interviewees were asked to whom they communicate their margins. They were also asked about policies used for dealing with uncertainties within input data. This, it was hoped, would highlight any potential breakdowns of communication. A breakdown of communication could lead to double counting and compounding of margins. It also increases the risk of omitting margins.

A copy of the interview sheet is attached in Appendix S and shows that all interviewees were also asked about methods other than margins to account for uncertainties and assumptions. This was to identify methods other than margins but with similar purpose during the design process.

Several concerns were raised repeatedly during the margin interviews. These were mainly the communication and ownership of margins. This results ties in with the observations made in section 5.1.2.2.

A summary of the interview results is provided in Table 13.

Margin	Derivation and Techniques	Application	Typical Values
Weight	Mainly based on past experiences using regression analysis;	Required to allow for design changes and uncertainties in weight estimates	10 – 15% depending on novelty of design
Electrical Power	Power margin is applied to the result of the load analysis; Length of vessel has effect on cabling;	Power margin has direct implication on choice of gensets; margin is used to avoid having to choose a different genset	15 – 25%
Noise	Noise levels and targets are based on requirements; noise levels are calculated using software validated with years of noise data	Noise margin is used to ensure all requirements are met; noise levels are used to influence design changes;	Around 3dB per predicted value
Human Factors	Assumptions are made and all calculations are based on these, if assumptions change then crewing is re-evaluated; at the end of design cycle all assumptions should have been verified	Used to determine crew numbers as well as deck heights etc; Habitability and accessibility are investigated	
Seakeeping	Typically a proportion of the required performance criteria		
Speed	Combination of hydrodynamic, weight and power margins; sizing is constant compromise between level of technical risk and competitiveness of bid;	Used to insure against the risk of not meeting contractual speed	SHP – 5% Vs – 0.5kts
Endurance (SFC & Engine Power)	Based on experience	Used in case engine needs more fuel than expected to reach contractual speed	
Engine Power	Owned by engine manufacturer	Additional amount of	

		power to reach required speed	
Stability	Largely based on weights information	Used to protect design against failing stability criteria	
Space (Volume)	Qualitatively based on previous design experience	Ensure that all equipment fits	
Weapons	Based on received supplier data	Margins are not usually communicated; data is given to other domains as received	
Fuel volume margin	Set by the Engineering Department	Incorporated into Range and Endurance Calculation	5% tank structure, 3% unpumpables , 5% reserve
Manoeuvring		Ensure vessel meets stopping and turning criteria	Very large

Table 13 –Margin Interview Summary

Whilst the interview results suggest that there are several margins in use at VT it is also noted that the approach is not very formalised. Thus further work is carried out, described in sections 5.1.2.4, to derive a more formalised margin policy guideline.

5.1.2.4 Parametric Survey revisited

This section describes the measures investigated to mitigate for parametric changes that forced the base design outside the limiting criteria, as described in section 4.9.5.5. Again, only a summary of the results is described, for more detailed tables see Appendix T.

CREW

The step change in length when switching from standard to generous outfit forces the design outside the L/D constraint, see 4.9.5.5. The 96-complement condition exceeds the upper limit by more than 11%.

Extra Deck

To counteract the L/D limit being exceeded an additional investigation is carried out, which adds an extra deck. Initially the deck was added within the hull but this created problems due to the depth of the new design. The additional deck is therefore added to the superstructure. Again, the results follow the same trend as the standard outfit condition. All values are within the given constraints. However, due to the step decrease in length there is a required power penalty. The initial 76-complement design only achieves 26.45 kts. The achieved speed increases as the length increases but even in the 96-complement condition the vessel is still 0.5kts slower than the baseship.

HANGAR

The organic design exceeds the L/D constraints whereas the non-organic design exceeds the L/F constraints, as shown in section 4.9.5.5.
Three additional studies are carried out in order to determine suitable steps to bring the design within the limits imposed by the constraints. These are described in more detail in the following section.

Non-Organic – extra deckheight
This analysis looks at the effect of increasing the deckheight, as a way of increasing the depth, to increase freeboard and thus decrease the L/F. The results of the investigation are shown in Figure 86.

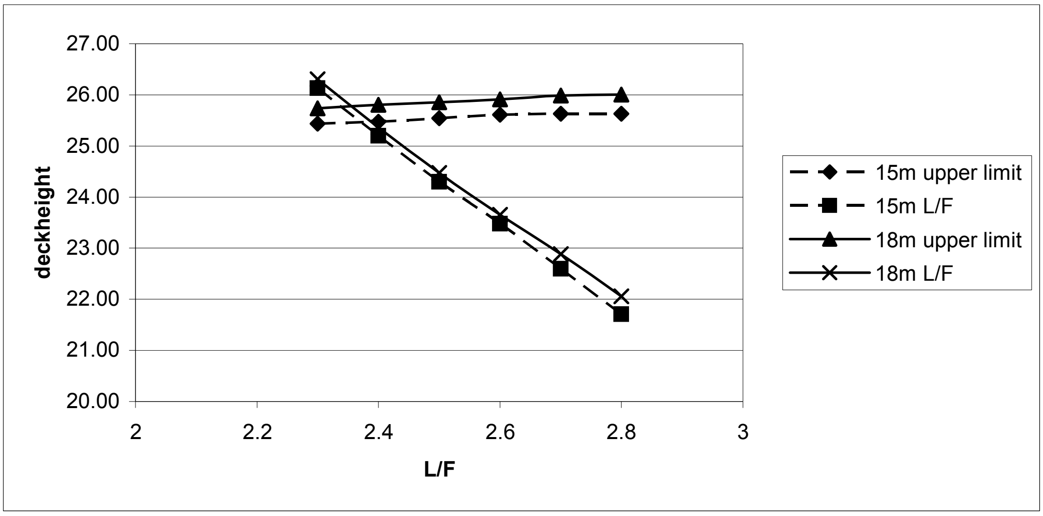

Figure 86 –Deckheight vs. L/F for non-organic helicopter

For both hangar lengths the investigation shows that only a minimal increase in deckheight, and therefore depth, is required to bring the design back within the constraints.

Organic – Extra Deck
This investigation studies the effect of adding an additional deck to the superstructure. This should reduce the length of the vessel and therefore bring the vessel back within the L/D constraints.

The results show that adding an extra deck significantly reduces the length of the vessel. However, the required maximum power rises sharply and thus the maximum achieved speed is reduced by approximately 3kts. Also, the designs now exceed the L/F constraints.

Adding an extra deck is therefore deemed to be an unsuitable solution to the problem poised by adding a hangar and organic support capability.

Organic – Extra Deckheight
This analysis is carried out to determine whether, similar to the non-organic hangar, a small increase in deckheight can bring the design within the constraints.

Increasing the deckheight increases the depth. This in turn leads to the L/D falling back within the limits. The L/F also decreases with increasing deckheight.

For the 15m hangar a deckheight increase of approximately 0.15m brings the vessel back within the L/D range. For the 18m hangar a further deckheight increase of 0.05m brings the vessel back within the L/D range.

In both cases L/D is the more critical factor.

AREA

From 12.5% onwards the design starts exceeding the upper L/D limit, which indicates that the design would encounter structural problems, as shown in section 4.9.5.5.

Extra Deck

This investigation is carried out to investigate whether adding an extra deck for area margins from 10% up to 25% brings the vessel back within the constraints.

Adding an extra deck in the superstructure and applying a 10% area margin decreases the Lwl by 10m when compared to the baseship, see Figure 87.

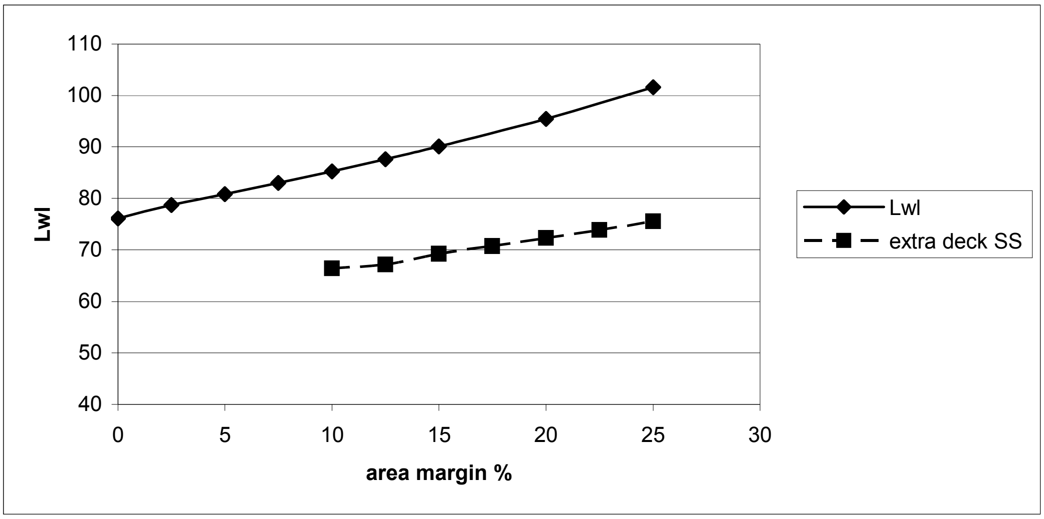

Figure 87 –Lwl vs. Area margin with added deck

The beam and depth decrease marginally whilst the Lwl increases with increasing area margin. All values are within the constraint limits. However, the additional required power leads to a reduction in achieved maximum speed. Again, as expected, the speed increases as the area margin increases due to the increasing length of the ship. At 25% area margin the maximum achieved speed is close to the baseship maximum speed.

POWER

As indicated in section 4.9.5.5, all power margin values are outside the L/F constraints. This is because most of the weight associated with propulsion is very low down and therefore the vessel's draft increases without a corresponding increase in either length or beam.

Two additional studies are carried out to determine ways of bringing the design back within the constraint limits.

Extra Area

The first additional study investigates whether adding extra area can reduce the L/F of the power margin designs. This hypothesis is based on the results from the area analysis, which shows that adding area increases the length and thus buoyancy of the vessel.

The analysis is run for power margins between 0% - 10% in 5% steps and area margins between 0% - 10% in 2.5% steps. The results are shown in Figure 88.

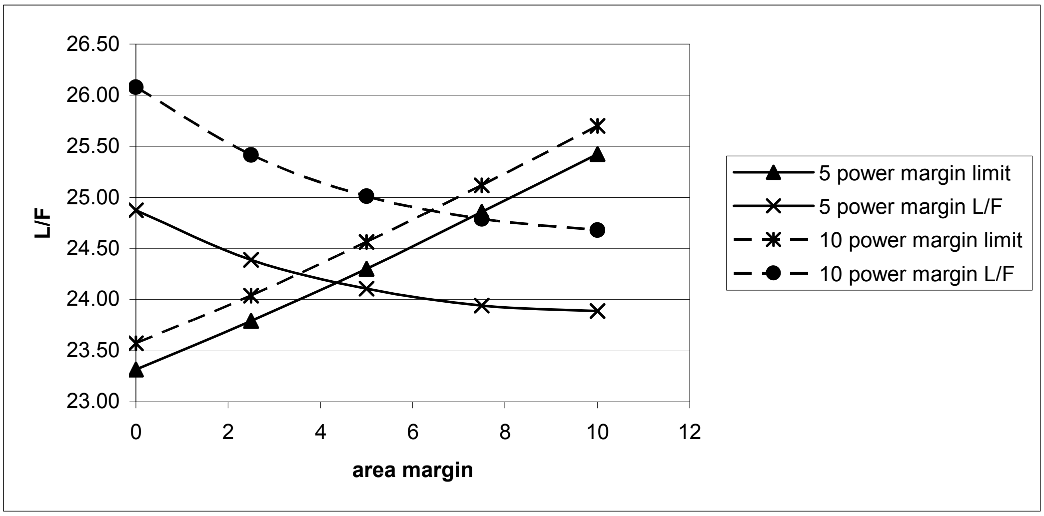

Figure 88 –L/F vs. Area Margin for varying power margins

Figure 88 shows that to bring the 5% power margin design within the constraints an area margin of approximately 4.5% is required and to bring the 10% power margin design within the constraints an area margin of approximately 6.5% is required. Adding the area margins also has the added benefit of reducing the actual required power.

Extra deckheight

This study investigates whether increasing the deckheight can reduce the L/F of the designs and thus bring them back within the constraint limits.

It is based on the results form the deckheight analysis, which shows that increasing the deckheight decreases the L/F with only some minor changes to the beam.

The results are shown in **Figure** 89.

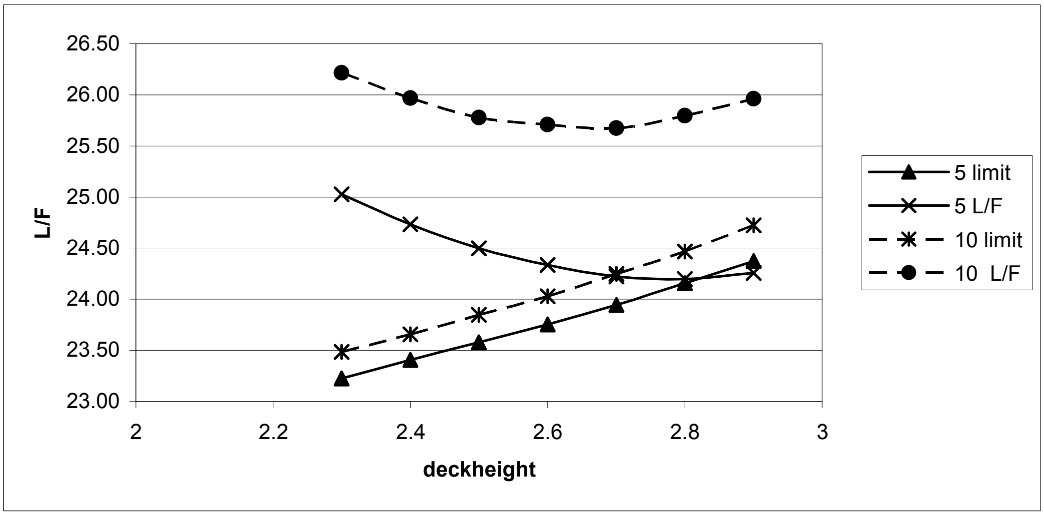

Figure 89 –L/F vs. Deckheight for varying power margins

Figure 89 shows that increasing the deckheight decreases the L/F. However, due to the increase in beam the required power increases even more, which in turn increases weight and draft and therefore reduces freeboard. The 5% power margin design requires an increase in deckheight of almost 0.5m, which corresponds to an increase in depth of 1m. It is not possible to bring the

10% power margin design within the constraints using the range of deckheights used in the calculations.

WEIGHTS

Increasing the weights margin for groups 1, 2, 5, 6 and across 1 – 7 moves the design outside the L/F constraint, as shown in 4.9.5.5. This is due to the heavier design requiring a deeper draft, as there is little change and beam and length.
To investigate ways of bringing the design back within the constraints two additional studies are carried out. These studies only look at the effect of applying the weights margin across groups 1 – 7.

Extra Area
This study investigates the effect of adding extra area margins as well as applying the weights margin. Increasing the area margin should increase the dimensions and thus increase the buoyancy, which in turn should reduce the required draft.
The analysis is run for weights margins from 0% - 10% and area margins from 0% - 10%. The results are shown in Figure 90.

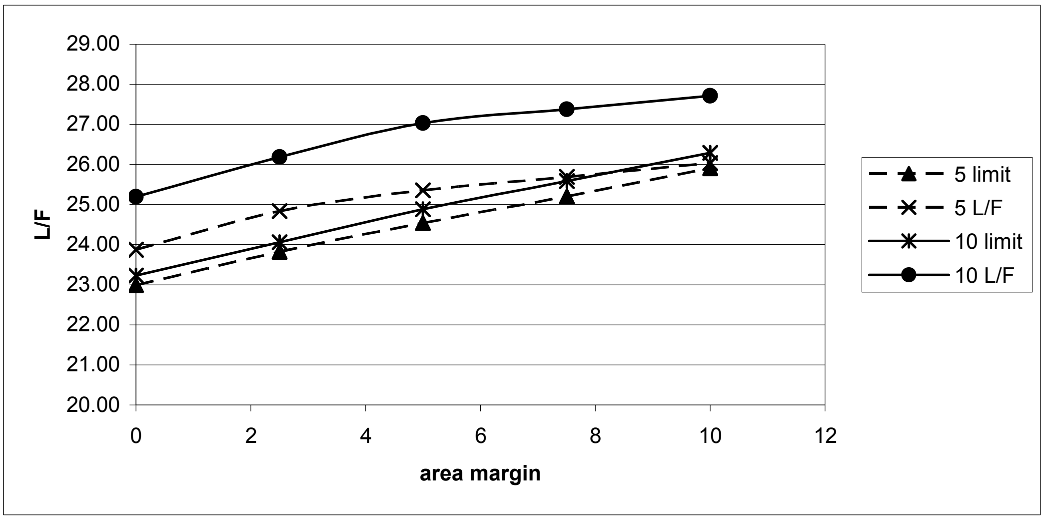

Figure 90 –L/F vs. Area Margin for varying weights margin

The results show that adding the extra area margin reduces the L/F. However, the effect is not as profound as desired and a large area margin is required to bring the L/F back within the constraints.

Extra Deckheight
This study investigates the effect of increasing the deckheight as well as applying the weights margin. Increasing the deckheight should increase the depth and thus result in more available freeboard. However, increasing the deckheight will also decrease the maximum achieved speed. The deckheight is increased from 2.3m – 2.9m and the weights margin is varied between 0% - 10% across groups 1 – 7. The results for L/F are shown in Figure 91.

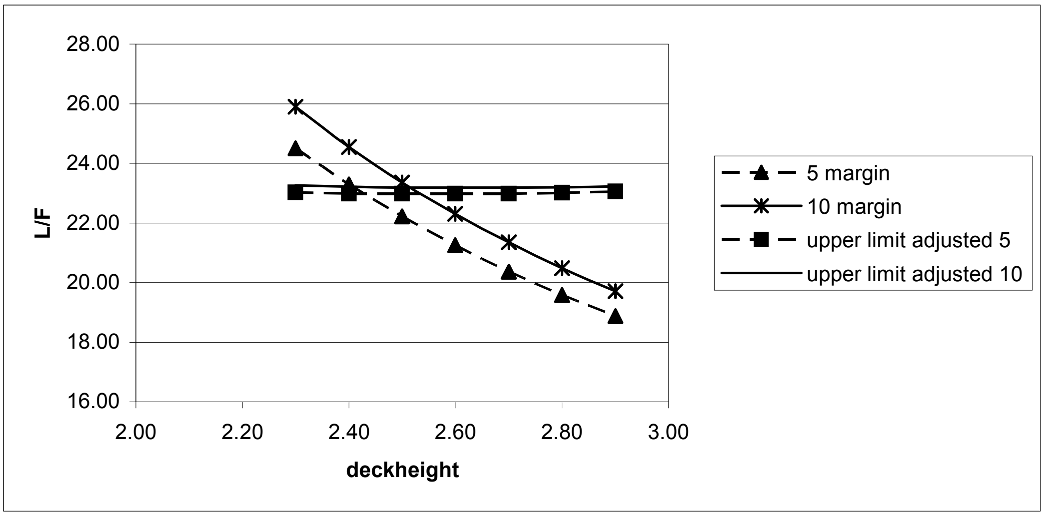

Figure 91 –L/F vs. Deckheight for varying weights margins

The results show that small changes in deckheight bring the design back within the constraints. For the 5% weights margin a deckheight increase of approximately 0.1m from the baseship is required and for the 10% weights margin a deckheight increase of approximately 0.2m from the baseship is required. The corresponding losses in maximum speed are 1.4kst and 2.5kts respectively, see Figure 92.

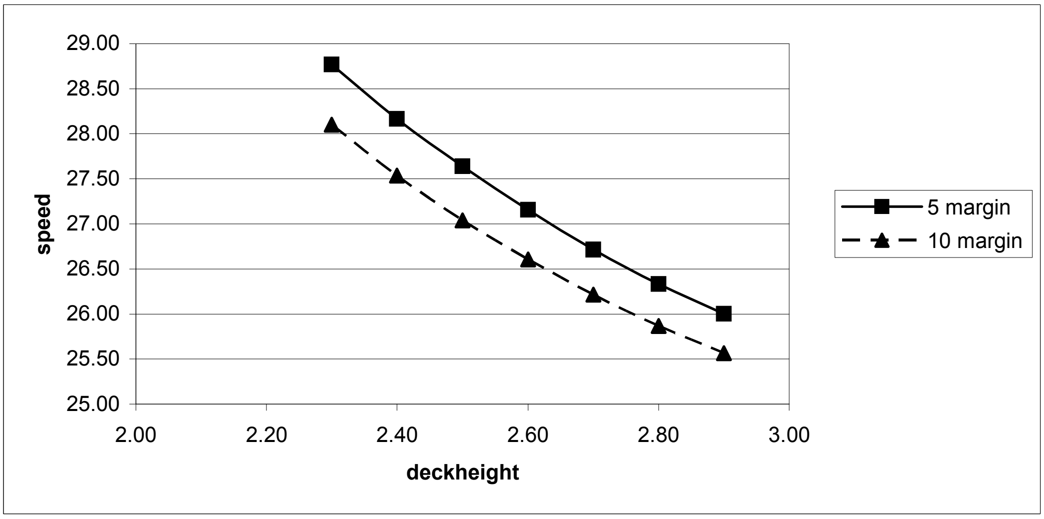

Figure 92 –Maximum Speed vs. Deckheight for varying weights margins

For both, the 5% and 10% weights margin case, the length increase is marginal but there is a significant increase in the beam, see Figure 93.

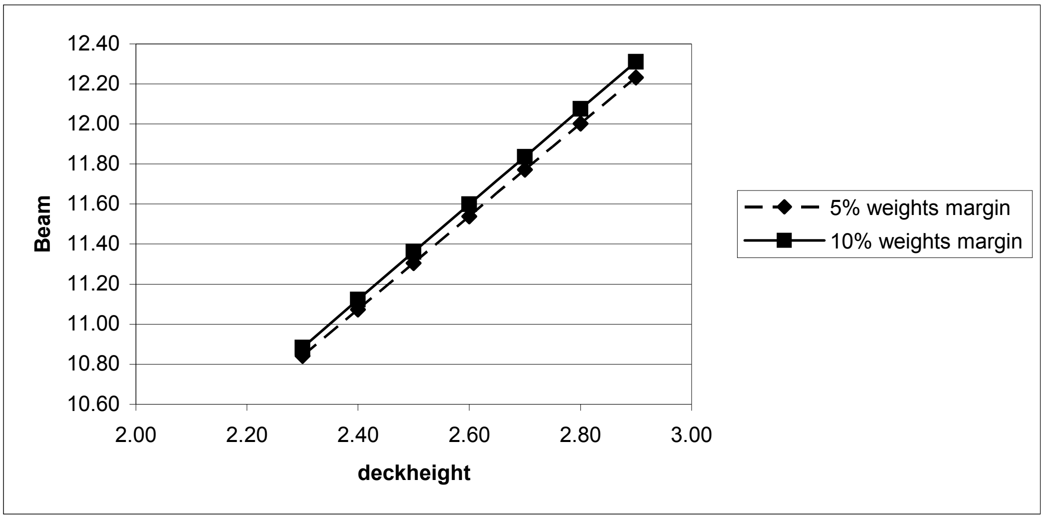

Figure 93 –B vs. Deckheight for varying weights margins

SUMMARY

The above results have shown some ways of mitigating for factors that have pushed an existing design outside the limiting criteria. When deriving the final margin policy an evaluation needs to be made of how likely a design change is going to be, the impact it will have and thus the appropriate size of the margin required.

The design changes and corresponding mitigating factors are summarised in Appendix U.

5.1.2.5 Implications

Having carried out an investigation into margins it is possible to combine the published results with the interviews and the results from the parametric survey to derive a basic set of margin guidelines. Some of the data for the parametric survey, which is not used in the margin guidelines, is used in the final creation of the user manual to provide the designers with input as to regarding mitigation measures for common design changes.

The final margin policy guidelines are shown in Table 14.

Domain	Margin	Value	Notes
Electrical	Power Margin (hotel and peak)	15 – 25%	Based on experience. Will be set internally by the electrical department. No real need to communicate to all other domains. However, information from weapon domain is required to set appropriate margin. In all electric propulsion vessels

			a closer collaboration with propulsion and Naval Architecture is required.
Individual Domains (but Naval Architecture responsibility)	Noise Margin	3dB	Naval Architecture needs to take responsibility for this margin as it mainly affects the layout of the vessel
Propulsion	Fuel Load	Consists of: • Unpumpables 1.05 • Structure 1.03 • Fill levels 1.05 • Several other factors	Several margins are included in Range calculations; All margins are already accounted for in propulsion spreadsheet
Human Factors	Crew	• Critical if value exceeds more than 10 (for corvette type ships) • Not usually a numerical margin	Effects overall vessel layout
Human Factors	Habitability Standard	• Critical if made more generous at later stages • Not usually a numerical margin	Effects overall vessel layout
Aviation/Naval Architecture/Weapons/General Vehicle Capability	Aft deck length	Not a margin but increase of more than several metres requires weatherdeck redesign (for corvette type ships)	
Aviation	Hangar	No margin can be used; it is a yes/no decision	Major implications on design
All (but responsibility with Naval Architecture)	Internal Space	• Used to allow for customer requirement changes and issues not covered by other margins	

		• Impacts on L	
Naval Architecture	Weights Margin	5 – 15%	Size of margin depends on experience and similar boats built
Naval Architecture	Speed (cruise and max)	0.5kts; 5% SHP	Size of margin depends on experience and similar boats built
Naval Architecture	VCG	3 – 5%	Size of margin depends on experience and similar boats built
Naval Architecture	Deckheight	Need to allow for system runs	
Naval Architecture	Passagewidth	Need to allow for system runs and habitability concerns	

Table 14 –Margin Summary

5.1.3 Communication

The interface and margin interviews both showed the need for effective communication between domains. It is anticipated that the user manual will improve communication between domains, by clearly defining each domain's responsibilities.

5.1.4 Review meetings

This section provides information about the review processes used to control the design process and most of the data contained therein is taken from discussions with VT managers and designers and a lessons learnt report from an actual project [20]. There are two types of review meetings, informal and formal ones. Any domain can request an informal meeting. The decisions of that meeting need to be recorded and must be circulated to all domains. Any informal decisions will be approved at the formal meetings. These need to be held at crucial points during the design cycle. Obvious times to hold formal review meetings are between loops. However, it is up to the Project Manager to decide on the formal meeting regime, based on the requirements of each project.

As a suggestion it is proposed to have a full review meeting after each loop is completed. These meetings should also involve the customer or at least the customer should be informed of the result of the review meeting. This is to allow for any requirement changes and to avoid unnecessary rework due to an unsatisfied customer. All changes recommended during the review meeting need to be communicated to the relevant domains and should be implemented, as far as is possible, before progressing on to the next loop.

5.2 SUMMARY

Having established several different methods of controlling and communicating the low level detail, it was possible to create a user manual for designers and project managers as well as a time dependent MS Project version of the loop model. The loops are based on the information described in chapter 5 and the control methods are taken from chapter 6. The user manual issued to VT contains the information about review meetings and margin policies; see 5.1.4 and

5.1.2.5, as well as a description of each domain. The domain descriptions, including changes made as a result of the test and validation study, are shown in Appendix V and the MS Project loop model is shown in Figure 94.

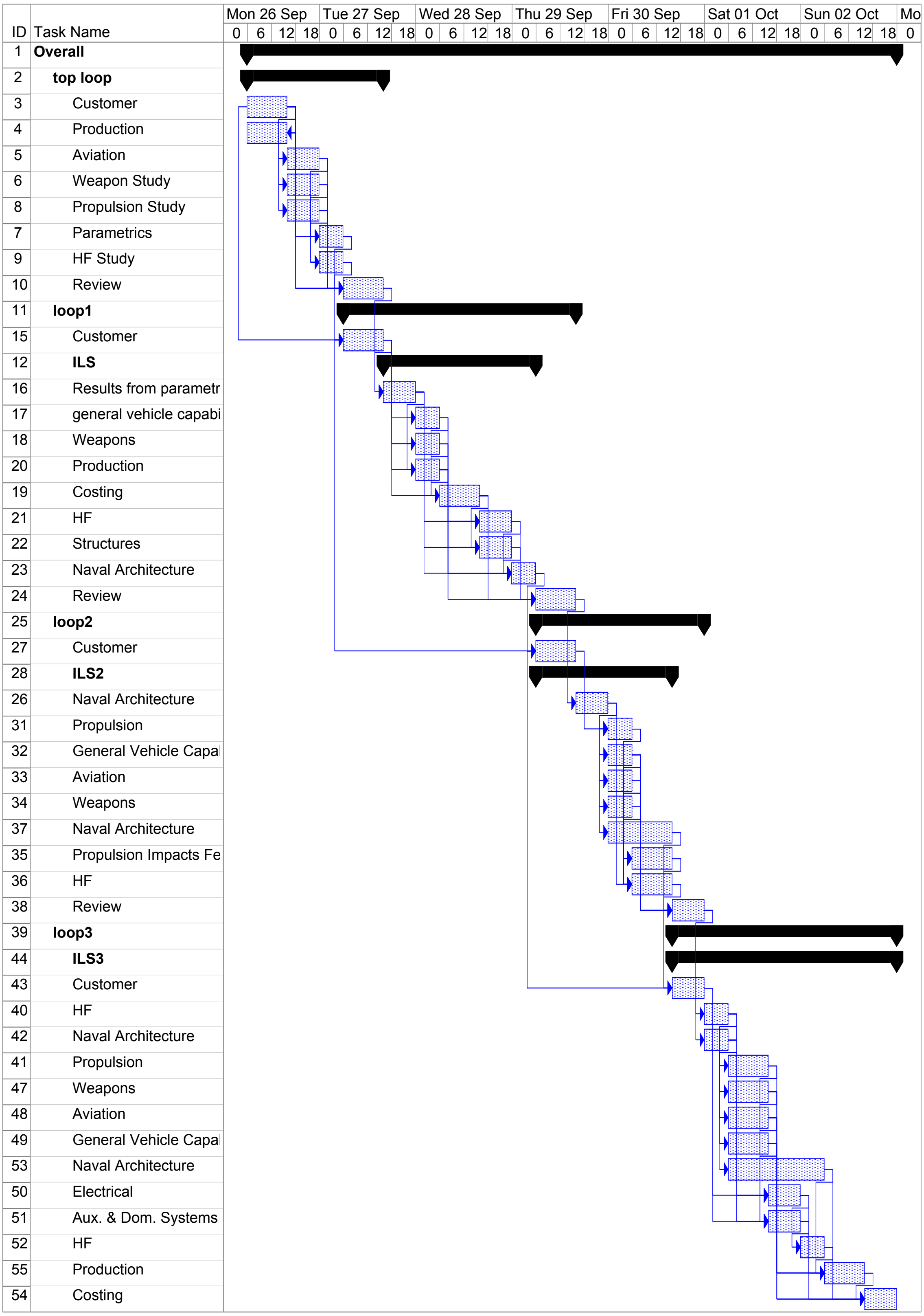

Figure 94 –Project Schedule pre-Validation

6 TESTING OF RESULTS

6.1 INTRODUCTION

In order to validate the derived methodology, comprising of the user manual, Project schedule and the functional flowcharts, it was tested on a concept design study. The aim of the study was to design a Trimaran OPV following exactly the outline given in the proposed programme. Notes were made if a deviation from the programme was required and the amount of rework was used as an indicator of the accuracy and validity of the methodology.

The only existing engineering data available at the start of the study was a hullform outline based on the Research Trimaran Triton. All other work was carried out by the author, similar to the FPC study.

As a rule of thumb it can be said, that the less rework required, the more likely the programme is to improve the design process.

6.2 TRIMARAN STUDY

6.2.1 Design log

This section contains a time dependent log of the activities carried out during the design study. To improve overall readability only summaries are provided under each domain heading. The actual level of detail applied during the study can be seen from the GA in Appendix W.

The following outlines the base requirements the design had to achieve. Many of these are based on an existing VT design.

- Speed
    - 25 kts - Max
    - 12 kts - Cruise
- Range 6000nm
- Endurance 28days
- Crew 44 standard + 30 embarked forces
    - Officers 10
    - Senior Ratings 14
    - Junior Ratings 20
    - Special Forces 30
- Weapons
    - 25mm fixed gun mounted forward of superstructure
    - 2 x GPMGs 0.5 calibre
- Helicopter – Merlin (preferred)
    - Organic Support – Hangar
- Container Storage Capability
- Cargo Crane(s)
- 2 x 7.3m RIBs
- Displacement not exceeding 2200t
- Towing (preferably up to 1500t load)
- High crew habitability standard
- Generators (taken from similar ships)
    - 3 x 250kW
    - Emergency generator 1 x 170kW

The next 4 sections describe the results derived from carrying out the steps as described in section 5.2.

6.2.1.1 Top Loop

Production Study

- An investigation of maximum allowable build size and permissible floor loadings in the berth was carried out.

Aviation Study

- An outline of required dimensions and facilities was drawn up for the required level of support.

Weapon Study

- The outline weapon fit was defined to match the requirements.

Propulsion Study

- Using existing trimaran designs a first estimate of the required installed powers was calculated.
- Conventional shafts were chosen as the preferred propulsion method.
- A range of engine supplier was chosen

Crewing Study

- A first estimate of the required complement was derived using previous designs and the weapon and aviation requirements.
- The habitability standard was decided to be generous to match the requirements.

Parametric Study

- A review of suitable base design was carried out.
- A first weight guesstimate was based on a previous trimaran study.
- A revised weights analysis using a different cruise speed (15kts) was carried out.
    - 1790t

Propulsion

- Initial estimates showed that maximum speed is achievable with 7036kW Effective Power (Pe) for 100m LBP.
    - This is the worst-case scenario and corresponds to 11.7MW Pi (OPC 0.6).
        - The engines were changed but this resulted in issues with the cruise speed.

Parametric

- The weights estimate was revised using the new engine weights (1783t)

Propulsion

- The OPC was changed to 0.5, after consultation with hydrodynamic experts.
- For cruise speed engines should not go below 30% of max rating
    - Alternative engines required

Parametric

- A first length was derived to match the weights estimate (110.5m)

Propulsion

- New power prediction justified use of revised engine choice (Caterpillar 3616)
    - Engine can go down to 20% of max. rating for min continuous operation (0.6Pe per engine)

Parametric

- New weights estimate carried out (1778t)
- New length derivation (LBP 110m)
- New performance figures worked out:
    - At 6MW Pe (both engines max cont.) = 26.24 kts
    - At 0.6MW Pe (one engine min cont.) = 13.98kts

Propulsion

- Chosen engine dimensions investigated:
    - L 5872mm
    - B 1871mm
    - H 3541mm

Parametric

- First attempt at positioning engine rooms within hull envelope
    - More gearbox data required to proceed.

Propulsion

- First propeller diameter estimate calculated using base vessels and actual engine data.
    - Twin screw each approximately 2m.

Parametric

- The hull main coefficients were evaluated to determine whether the design is sized correctly.
    - Cb 0.471
    - Cp 0.594
    - Cm 0.794
    - Cw 0.747
    - Beam (waterline) 8.44m
    - L/B 13.04
    - $l/\nabla^{1/3}$ 9.37
- Comparison with other trimarans and 25kts monohulls appears favourable

Propulsion

- Base propeller diameter increased to 3m after re-evaluating performance criteria.
- Propeller clearance of approx 20% diameter tip to tip required.
- Tip – hull clearance required to be approximately 25% of the diameter (but can be as low as 20%)

Parametric

- Initial estimates indicated that the propellers can be fitted under the transom.
- Revised weights estimate of 1811t (+33t) to account for increase in dimensions and reduced powering requirements
- The parametric fit was investigated to ensure the increase dimensions do not push the vessel outside the envisaged envelope
    - No issues were identified.

Propulsion

- A revised powering estimate was carried out
    - New cruise speed is 13.7kts and new max speed is 25.9kts

Parametric

- A first estimate of the double bottom height was carried out
- Possible further engine arrangements were investigated

    - Engines need be inclined to achieve suitable fit.

Propulsion

- Alternative propulsion arrangements were investigated
    - A comparison between one shaft trailing during cruise and both shafts turning during cruise was carried out
    - Trailing shaft increases running costs by approximately £30000 pa, see Appendix W
    - No maintenance issues identified with trailing shaft

Parametric

- First estimation of required areas using the equations derived from corvette type ships, see Appendix W. This was deemed accurate due to the fact that a trimaran is essentially a monohulls with outriggers.
    - Approximately 2200m^2 required

Structures (deviation from programme)

- Investigation into required stiffening due to increased depth.

Parametric

- Deckheight decided upon (2.6m below weatherdeck)
- Hangar size to support Merlin is L18.09 B8.66 H5.6 min.
- Side access to foredeck past superstructure required
    - Superstructure to be lined up with side-hull bulkhead

Propulsion

- Intake deck cut-outs for intakes and exhausts are approx. 3m^2
    - Silencers are approximately 1800mm diameter and 5000 – 7500mm length

Parametric

- Superstructure deckheight set at 2.8m

Propulsion

- Gearbox option with cross clutch received from RENK (Germany)
    - Allows either engine to run both shafts for cruise and both engines to run for max speed.

Parametric

- Bridge needs to provide full visibility fore and aft as well as down past the side hulls for berthing and boat operations.

Propulsion

- A first estimate of the gearbox dimensions received

Parametric

- Available areas excluding ER compartment were estimated
4Deck (DK)	390 (not including side hulls)
3DK	580 (not including side hulls)
2DK	1140 (extended through cross deck)
1DK	420 (includes hangar and gun platform)
01DK	240
02DK	approx. 180
Total	2950
- No issues were identified

- A first basic layout was created in AutoCAD
  - Engine rooms do not extend into cross deck
- A revised weights estimate showed that grp1 weights are 243t heavier than originally predicted – this was carried out in close co-operation with structures.
  - Revised deep-deep displacement is 2057t (incl. margins) (4.15m draft)
  - Dimensions do not need to increase to support added weight

Propulsion

- A revised performance estimate was carried out using the new displacement
  - Deep-deep
    - Max – 25.4
    - Cruise – 13.5
  - Half load
    - Max – 25.8
    - Cruise – 13.7

Parametric

- The margin policy was derived
  - Weights
    - 5% on group 1-7 design margin
    - 2% on group 1-7 construction margin
  - VCG not yet set – likely to be around 3 – 5%
  - Engineering
    - 3% structures
    - 5% fill levels
    - 5% unpumpables
  - Power
    - Vessel required to reach 25kts max. (This currently corresponds to 0.8kts margin @ half load)

Crewing Study

- No changes to original estimates

Review

- The following issues were identified as requiring clarification
  - There was some uncertainty about the stability criteria to be used
    - Use stability criteria applied to Triton and check bottom damage based on HSC
    - 2compt damage in main hull and 6m gash length in side hulls
    - Stability check not required until end of loop1 but information needed to derive approximate bulkhead positions.

6.2.1.2 Loop1

Customer

- No changes in customer requirements
- Stability criteria confirmed
  - Defence Standard 02-109 to be applied
  - Bottom damage based on HSC

Results from Parametric Study

- All data received from top-level loop

ILS

- The ILS philosophy for the vessel is centred on providing shore based support. This implies that all major equipment requires removal routes.
- Removal of engine room 2 equipment could be an issue – possibly remove through hangar
- Removal of engine room 1 equipment through opening in Flightdeck in front of hangar door

Electrical (deviation from programme)
- Generators could be placed in front of engine rooms

Auxiliary & Domestic Systems (deviation from programme)
- Zoning policy agreed
    - Provide Air-conditioning (Aircon) units for each major division on each deck.

General Vehicle Capability
- Initial Data for RIBs and cranes taken from a previous VT design
    - For the RIBs use VT Halmatic Pacific 22s
- No additional crew numbers identified
- No specific removal routes required
- Cranes were identified as not sufficient due to large outreach required on trimaran design.

Weapons
- No changes in customer requirements
- Forward gun to be placed on a pedestal to allow reasonable arcs of fire. Pedestal is sufficient to include RU locker. Magazine should be located below weatherdeck to increase protection from incoming fire.
- No additional crew numbers identified
- No specific removal routes required
- GPMG and ammunition stored in lockers near mountings on bridge deck.

Production
- No items identified that could cause major production issues
- At this stage a draft build strategy would be agreed and an updated cost estimate would be communicated. This was not done due to time and resource constraints.

ILS
- A first estimate of ILS costs would be calculated based on the support philosophy and major equipment selection. Again this was not done due to time and resource constraints.

Costing
- A first cost estimate would be carried out.
- Most major equipment has been selected but the actual estimate was not carried out due to time and resource constraints.

Human Factors
- Based on information from other domains there is no need to revise the crewing estimate. 44 crew + 30 embarked forces.

Structures
- Frame spacing set at 1500mm and allowable bulkhead positions were derived.

Naval Architecture

- ER bulkheads were moved to allow for 1500mm frame spacing.

ILS

- Moving engine bulkheads has impact on generator room removal routes – an alternative solution is required

Naval Architecture

- A first estimate of floodable length and subdivision was obtained for the centre hull.
- For first estimate of side hull subdivision the same number of bulkheads as for the main hull was used.
- A VCG estimate was calculated and based on known locations and scaled on D.
    - VCG margin (4%) applied to group1-7 only.

Structures

- The aft cross deck joint was moved to align with the bulkhead.

ILS

- Alternative removal route for generators were considered:
    - Through superstructure (not ideal)
    - Through forward bulkhead
    - Through aft bulkhead and into engine room
    - Through deck into hangar
- Preferred solution is through deck and into the hangar.

Naval Architecture

- A first estimate of the required tank volumes was calculated
    - FW 54.1
    - FO 234.3
    - Avcat 27.5
    - LO 0.6
    - GW 54.1
- The collision bulkhead position was determined using DNV Naval Rules
- Damage control deck set to be 2deck
- Revised weights estimate carried out using all available data for group 8 estimates (2069t)
- Minor change to deep-deep VCG by 1cm to 8m
- Intact stability passed for deep-deep
- Damage stability investigation revealed that increased subdivision in the side hulls is required
- Raking damage passed and no double bottom is required
- An LCG estimate was calculated
- The longitudinal bulkhead was removed and replaced by transverse bulkheads, some of which do not need to extent all the way across. This was checked for cross-flooding issues and none were identified.

Review

- No issues were identified and the design was passed to progress onto the next loop.

6.2.1.3 Loop2

Naval Architecture

- The GA was updated and prepared for transfer to all other domains.

Propulsion
- A Preliminary funnel arrangement was designed with exhausts and intakes on opposing sides to avoid air contamination.

General Vehicle Capability
- An investigation into crane solutions was carried out and two options were considered.
  - 1 large crane mounted amidships
  - 2 smaller cranes mounted on either side of the vessel.
- The 2-crane solution appeared to be favourable as it allows greater flexibility

Weapons
- Desired crane solution requires the gun pedestal to be moved forwards.

Aviation
- Propulsion layout does not interfere with Flightdeck operations.

Propulsion Impact Feedback
- An alternative funnel design was derived to ease the integration of compartments around the hangar.

HF
- No further crew are required
- No accommodation to be placed directly above propulsion machinery

Naval Architecture
- A first detailed internal layout was designed based on modular cabin sizes used on a previous VT design.

ILS
- Major equipment removal routes need to be kept clear from obstacles such as modular cabins.

Naval Architecture
- Hangar compartment layout designed.
- A revised weights estimate was carried out using the 2 crane solution
  - Lightship 1749.79t
  - VCG 9.12m (10cm rise)
  - LCG 52.46m fwd AP
- A revised stability check was carried out
- All conditions pass including bottom raking
- New power prediction checks were carried out to reflect the increased weights
  - Vc 13.4kts
  - Maximum Speed (Vm) 25.2kts
- An initial escape arrangement was designed and integrated into the layout

Review
- Some issues were identified that needed to be rectified before moving onto the next loop:
  - Naval Architecture: Some minor layout changes were required.
  - Propulsion: A bow thrusters was incorporated into the design.
  - Aviation: A minor layout issue regarding the Avcat pump module was resolved.
  - ILS: The removal routes for the forward engine room were modified.

6.2.1.4 Loop3

Customer
- No changes in customer requirements were identified.

HF
- There were no identified habitability issues.
- Crew numbers remain unchanged.

Naval Architecture
- The GA was updated.

Propulsion
- No changes required to engines or propulsion room layout.

Weapons
- No issues identified
- No changes to chosen weapons

Aviation
- Some minor changes to the internal hangar arrangement were required to allow for propulsion emergency exits – no impact on overall aviation capability
- Helicopter operations from ships other than aircraft carrier (HOSTAC) guidelines obtained and transferred to Naval Architecture for integration into final GA

General Vehicle Capability
- No equipment changes identified.
- Final cranes chosen. Design provided by NME and are of Knuckle boom type (NKB 245 SE1)

Electrical
- Generators need to be moved into engine rooms to allow for more efficient space usage

ILS
- New generator removal routes are required – No issue for aft engine room however fwd engine room is underneath galley and mess areas

Naval Architecture
- Minor changes made to mess area layout to accommodate new removal routes.

Electrical
- Electrical distribution room on each deck required
- No major changes are required to the overall design
- No extra manpower is required
- All major equipment can easily be removed

Auxiliary and Domestic Systems
- Auxiliary system compartment required near keel.

Naval Architecture
- Fuel tank layout changed to allow access for auxiliary pipes

Auxiliary and Domestic Systems

- Auxiliary and Domestic machinery compartment were split over two decks to allow for better maintenance accessibility.
- The aircon arrangement was defined in more detail.

Naval Architecture

- Some minor layout changes were implemented to integrate aircon plants.

Auxiliary and Domestic Systems

- The main aircon plant on 1deck needed to be moved closer to passageways to minimise routing complications.

Naval Architecture

- The aircon plant was moved.

Auxiliary and Domestic Systems

- The Aircon arrangement for the switchboard room was designed.

HF

- There are no changes to the final complement calculations
- There are no unresolved habitability issues

ILS

- All removal routes are as required

Naval Architecture

- All equipment has been fitted into the arrangement
- The RAS arrangement was designed and consists of a fixed RAS station integrated into the back of the gun pedestal.
- No changes to lightship and group 8 weights.
- Lightship LCG moved to 52.36m (due to moving generators into engine rooms) – no trim issues identified.
- No changes in performance estimates.
- All tanks transferred into GA.
- GA completed for review.

Review

- No major changes are required

Production

- No final production study was carried out due to time and resource constraints.

Costing

- No final cost estimate was prepared due to time and resource constraints.

6.3 SUMMARY

The study showed that it is possible to carry out a successful design study using the information supplied in the programme manual and associated charts. Unlike the previous studies, no final flowchart is provided, as the study followed the programme manual and any required deviations from the programme were noted.

A summary of the final TOPV parameters and the final GA are shown in Appendix W., which also contains a summary of the weights spreadsheet.

As mentioned above the study highlighted some required changes to further optimise the programme structure. These are described in more detail as follows:

- For new concepts with little historical data there is the need to include structures on the top level loop.
    - This became apparent when insufficient data was available to determine suitable deckheights. Structures needed to be consulted to determine the likely stiffening requirements. Also, including structures on the top level loop for radical designs allows for a more accurate weight prediction, as required during the trimaran study.
- Stability standards need to be confirmed before the end of concept loop.
    - This is a necessary requirement as it allows the designer to determine the likely subdivision of the vessel and thus aid the development of the internal layout. Although no stability checks are carried out until the end of loop1 it is still desirable to agree the standards to be used, to minimise the risk of having to re-design parts of the vessel to pass the stability checks.
- Tank estimates need to be completed by the end of loop1 for high speed vessels to assess raking damage.
    - Without a first tank estimate it is not possible to carry out an accurate raking damage check, as it would be difficult to determine any eventual double bottom requirement.
- High level electrical and auxiliary domains need to be included on loop 1 to determine zoning policies and desired position of generator rooms.
    - It was found during the study that it is very important to determine the location of the generator rooms as early as possible. This allows the ILS domain to determine the required removal routes, if needed. Not including the electrical domain at this stage could have serious impacts on the internal layout.
    - The air-conditioning zoning policy needs to be decided at this stage to allow for sufficient space in each zone for air-conditioning plants. These reserved spaces need to be adjacent to major routes and passageways and also have routes for intakes.
- The importance of escape route arrangements needs to be noted in the programme manual.
    - The study showed that escape arrangements can have a serious effect on the internal layout. These effects were mainly related to escape hatch arrangements and dead-end corridors.
- The design of the RAS station needs to be included in the programme manual.
    - The study showed that the RAS requirements can lead to some design changes. No major issues occurred on the trimaran study, due to the space available, but on smaller designs the RAS station may need closer attention.
- GA to stay as rough sketch until loop3 otherwise any redesign work requires extensive effort
    - During the trimaran study a reasonably detailed GA was prepared during loop1. This led to extensive re-design work anytime a minor change to the layout was made. Keeping the GA as a rough outline would minimise the required rework.
- The importance of the system routes needs to be included in the programme manual.
    - During the study some internal layout changes were necessitated due to passageways and associated system routes being inadequate. System routes should be kept as straight as possible throughout the vessel.
- The importance of visibility from the bridge needs to be included in the manual.
    - The superstructure design of the study highlighted an important issue. Due to the breadth of the trimaran it is very difficult to observe berthing and boat operations unless the superstructure extends all the way to the deck edge. Also,

full visibility fore, for loading and weapon operations, and aft, for helicopter and boat operations, is required.

The above recommendations show that the main change to the programme structure is the inclusion of the high-level auxiliary domain and the high-level electrical domain on loop1. Structures will not be added on the top-loop but instead a note will be made in the programme manual to advise designers of any likely issues, when working on novel designs. All other recommendations present minor changes and can be incorporated into the programme manual.

Some other findings were made when the actual programme structure of the trimaran study was analysed. Throughout the study the project schedule was regularly updated to accurately represent the durations of individual domain activities. Upon completion of the study the schedule revealed that Naval Architecture is the overall design integrator.

This resulted in the removal of some of the naval architecture predecessors in the MS Project schedule to allow the project manager to manually extend Naval Architecture to match other domains' durations and also ensures that the domain runs in parallel with all design activities from loop2 onwards. The aim was to ensure that Naval Architecture could be extended in the MS Project Schedule without other domains automatically shifting, whilst still maintaining the overall integrity of the schedule. These steps had to be taken to allow for the rigidity of the links allowed in MS Project, i.e. start-start, finish-finish and finish-start. The revised schedule was tested extensively to ensure that any possible extension of any domain accurately represented the process.

7 FINAL PROGRAMME STRUCTURE

7.1 FINAL LOOP MODEL

The Validation study, 6.3, showed that some changes were required to update and refine the existing programme structure, described in 5.2. The only items concerning the functional flowchart and the project schedule are the inclusion of the electrical and auxiliary domain on loop1. All other items were integrated into the programme manual, see Appendix V. The changed loop1 functional flowchart, including electrical and auxiliary & domestic systems is shown in Figure 95. All other loop charts are unchanged and are shown in Figure 82, Figure 84 and Figure 85.

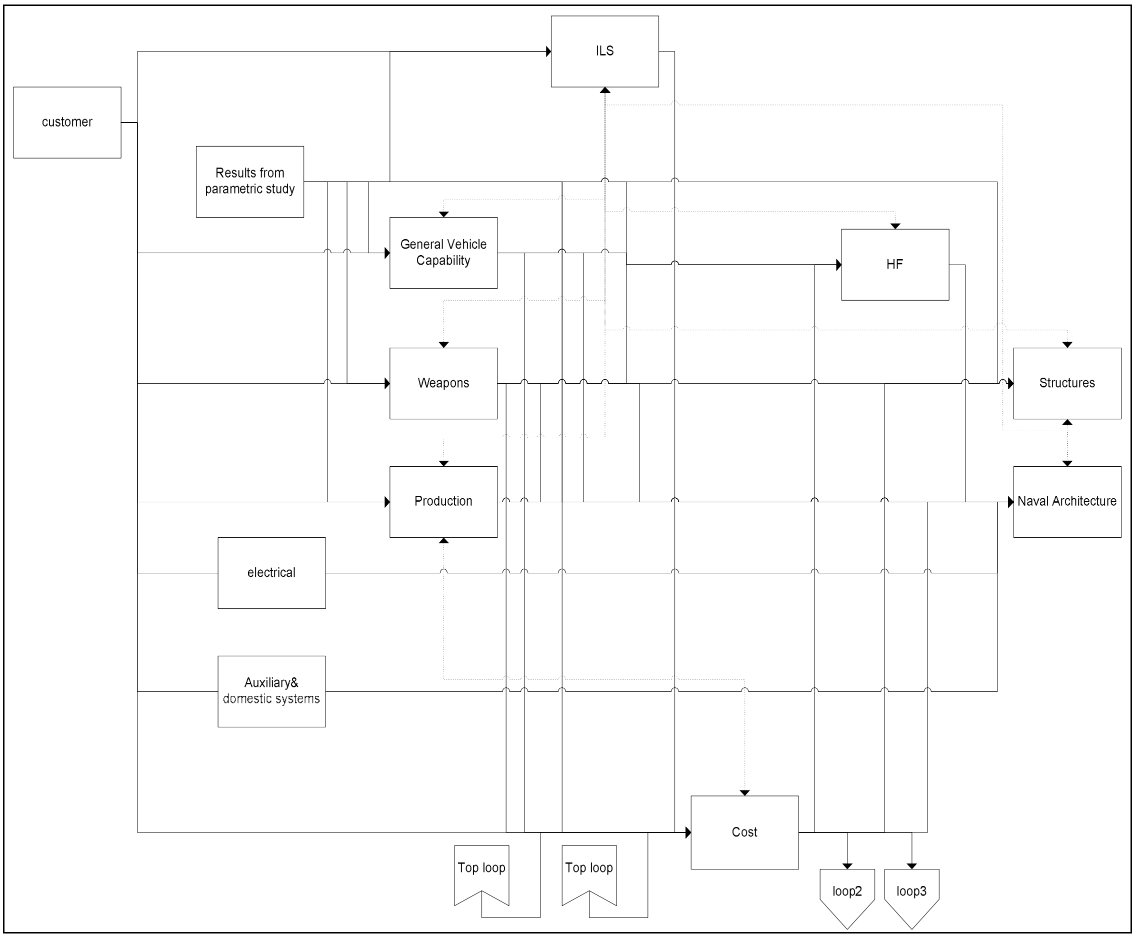

Figure 95 –Amended and Final Functional Loop1

The final resulting MS Project schedule is shown in Figure 96. This figure was created using the results from the TOPV study in combination with the previous schedule in Figure 94. The actual timings were reduced to unit times, in this case a nominal working day. Naval Architecture was increased to ensure it runs in parallel with all other design activities from loop2 onwards, see 6.3. Finally the working calendar was changed to 24 hours/7 days to allow for greater flexibility and also to provide a more accurate representation of the process, without weekend breaks.

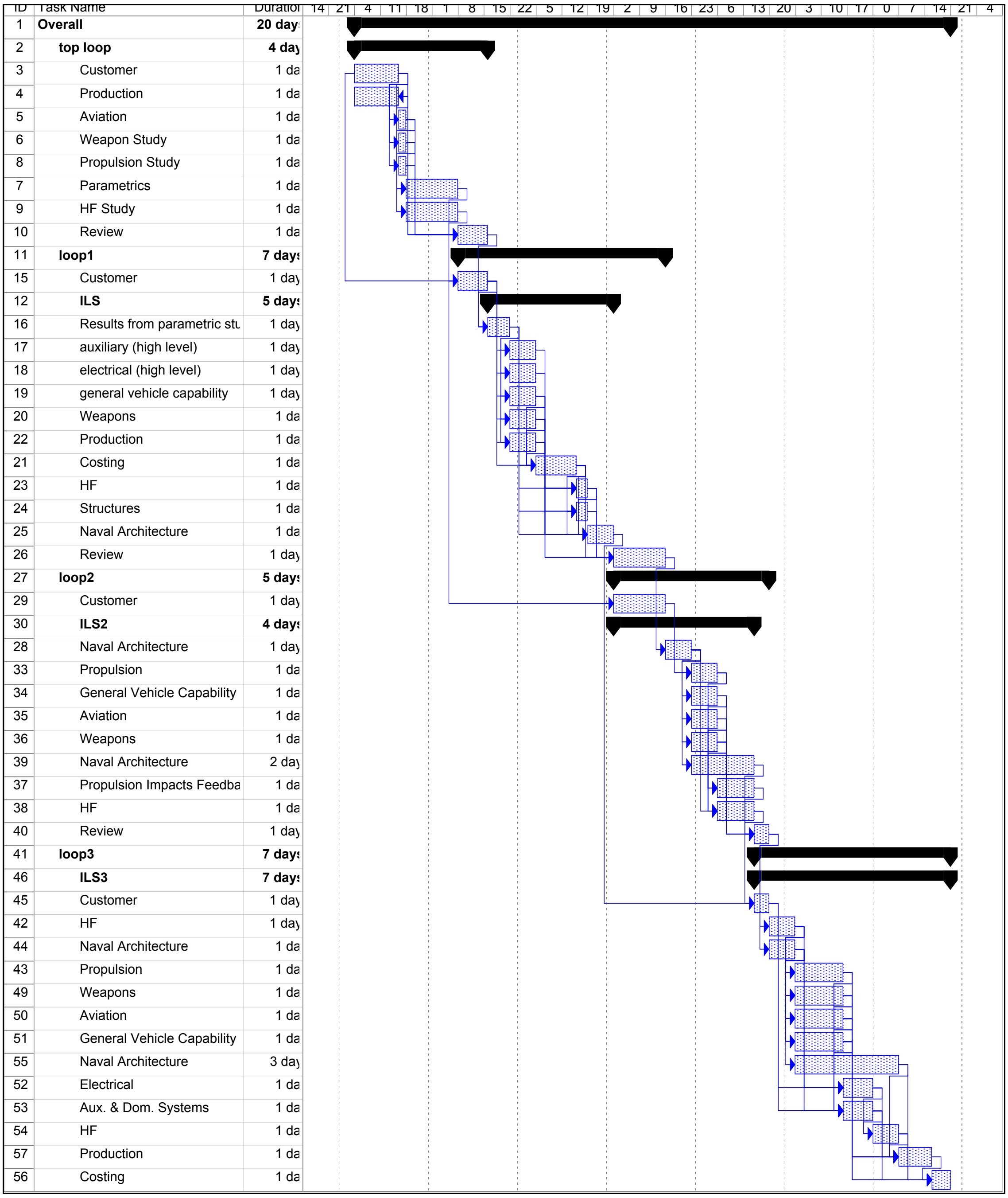

Figure 96 –Project Schedule post-Validation (final)

The following sections provide a summary description of the work carried out on each loop. For a more detailed description of each activity see the programme manual attached in Appendix V, where all tasks numbers refer to Figure 96.

7.1.1 Top Loop

At this stage a first estimate of the likely weapon configuration and aviation capability is carried out. A short production study is also carried out to determine a possible build philosophy. A parametric study in conjunction with a propulsion study is used to determine the high-level propulsion arrangement and establish some baseline parameters. The aim of the HF study at this stage is to identify likely crew numbers and required standards of habitability.

7.1.2 Loop1

This loop is used to refine the concept solution determined in the top-loop. Also, the general vehicle equipment, such as cranes etc., is determined. In addition, a first cost estimate is carried out and, if relevant, budget levels are set. The iterative loop involving structures and naval architecture revolves around bulkhead locations, frame spacing and weights estimates.

7.1.3 Loop2

During this design stage a more detailed propulsion configuration study is carried out and its impact on the overall layout is evaluated. The naval architecture domain is used as the design integrator. The propulsion impact feedback task is used to allow for required changes to the overall propulsion configuration due to conflicts with other domains.

7.1.4 Loop3

The final loop of the design is mainly concerned with refining the overall design. All major domains are included at the start to ensure the latest equipment data is used. The iterative loop involves the electrical and auxiliary & domestic systems domains. Naval architecture as overall design integrator is also included. The aim of the iteration is to determine positions for electrical equipment and auxiliary & domestic systems such as air-conditioning units. At the end of the loop is a final cost estimate based on a more detailed production cost calculation.

7.2 HIGH LEVEL INTEGRATION

An attempt was also made to integrate the final low-level methodology, consisting of functional flowcharts, project schedule and programme manual, into the high-level systems engineering process, described in 2.3. The proposed solution places the programme structure along the strands of the V-diagram, see Figure 97, between the URD and SRD. This also allows for the potential integration of the requirements database [14] by placing it on top of the programme structure. This solution also allows the manager to tailor the project schedule to the required level of detail. For example at an early stage several top-loops could be run to determine a range of designs.

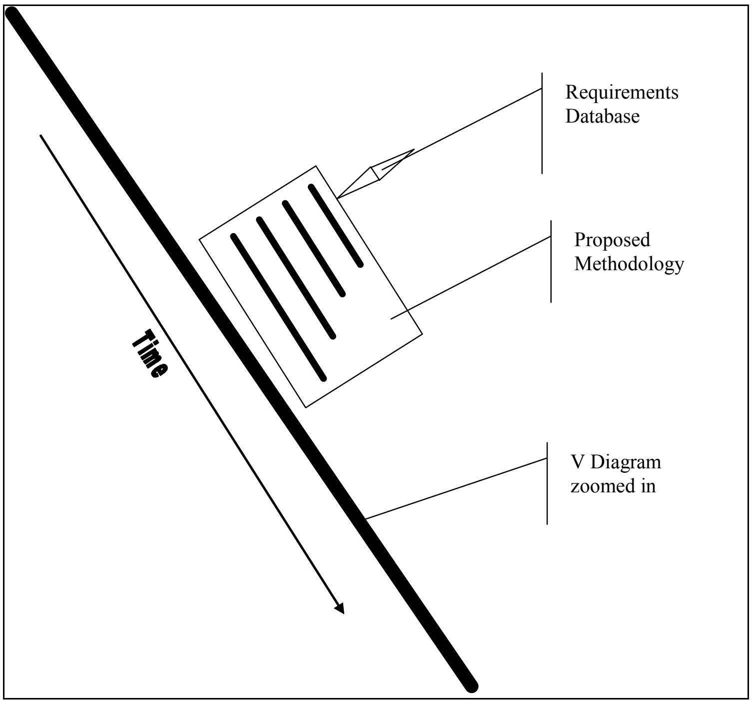

Figure 97 –Possible High-Level Integration Schematic

8 DISCUSSION

8.1 INTRODUCTION

This chapter provides an overview of how the investigations fit together and outlines how the various studies have contributed to this thesis.

As outlined in the research strategy, see chapter 3, the research was split into three main parts together with one testing and validation section.

8.2 RESEARCH AREA

The first part was concerned with identifying what feasibility studies are and how they are influenced by the implementation of SMART procurement. This was mainly accomplished through a literature review. It was found that although SMART does not explicitly define feasibility studies, the assessment phase of the new procurement cycle can be regarded as the new equivalent. It was also found that the new procurement cycle requires a much greater emphasis on TLC and ILS and that these need to be carefully integrated into any proposed management methodology. Finally, it was also found that it is necessary to consider some aspects of the concept and demonstration phase, in order to determine a workable solution capable of passing main gate.

8.3 INTERFACE INTERACTION

Once the research area was clearly defined the next major step was to research the interface interaction. The aim of this part of the research was to identify all required parties and to determine the data being transmitted via these parties. Several different studies were carried out to complete this part of the research.

The first study was based on a series of interviews with senior management personnel at VT. This was aimed at unlocking some of the inherent knowledge contained within the company. One of the major issues encountered during the interviews was to convince people to set aside time for the interviews. However, by ensuring a transparent process and allowing interviewees to review the interview write-ups, a good rate of participation was achieved.

The interviews were used to construct a visual depiction of the current process at VT. This depiction also featured implicit connections that were not named during the interview process and found to exist during the interview analysis, see section 4.3.2. Finally, the derived flowcharts were compared to previously published studies and a good correlation was found and thus the flowcharts were used as the basis for the final methodology derivation.

To further refine the initial model, two case studies were carried out. One investigated the issues and processes involved when designing a small, high-speed craft, whilst the other investigated a large, frigate type ship. The aim of the studies was to gain an objective insight into the ship design process to complement the subjective knowledge gained from the interviews. The main problem encountered throughout the study was to locate and access previous design data.

Both studies found that, whilst the initial model provided a reasonable description of the design process, some changes with regards to the scheduling of certain activities was required. In particular the impact of the propulsion domain on the initial layout was noted and a top-level loop was included in the management model. The studies also highlighted the importance of keeping a detailed design record

During the case studies it became apparent that certain domains required further in-depth investigations, namely Production, ILS and HF. Theses studies consisted of a combination of literature reviews and interviews. Similar to the original interviews the process was kept as transparent as possible to ensure a good rate of participation.

The production study showed that it is necessary to include production on the top level loop to ensure the designers follow best-build practices and also to allow for the integration of the project into the overall shipyard build program.

The ILS study resulted in ILS being included as an iterative domain on all loops providing feedback with regards to items such as removal routes, maintenance philosophy and equipment accessibility.

The HF study showed that a first complement estimate needs to be carried out at the top loop and re-evaluated at all subsequent loops. HF also needs to investigate the habitability impact of layout and general design decisions throughout the process.

The final step of the interface interaction involved the development and use of a parametric study. The main aim of the study was to identify any potential stop-events and to ensure that these were allowed for at the earliest possible stage in the loop model.

A series of algorithms was derived to model weights, VCGs, volumes and deck areas for corvettes and fast attack craft. The main problem encountered was that many of the input data was difficult to fit to linear equations. Linear equations were chosen to ensure a sufficient range of validity when applying the algorithms. Only the corvette equations were used in the parametric study as the program struggled to cope with the FAC hullforms.

The results highlighted that the aviation domain needed to be included on the top level loop, as it was identified as a stop-event that could not otherwise be mitigated.

8.4 INTERFACE MANAGEMENT

Having identified all interfaces and their interactions the third major step of the research investigated methods of managing the interfaces and the dataflow across them.

An in-depth literature review into existing management techniques was carried out and it was found that margins play a great role throughout the ship design process. It was therefore decided to derive a margin policy guideline that could be integrated into the final management methodology.

Initially a set of interviews was carried out to make explicit the inherent knowledge contained within the company. This resulted in a first list of margins used within VT. This list was amended and complemented using the information found in the literature.

Finally the previous parametric study was revisited and analysed to develop a series of mitigation guidelines. A set of limiting design criteria was developed and used as design boundary conditions. The parametric study was used in order to determine what changes in parameters made the design exceed the boundary conditions and what changes could then be made to bring the design back within the boundary conditions.

The results were used in conjunction with the margin list and a refined margin guideline table for corvette type vessels was derived.

A communication and review meeting policy was also outlined to complement the derived margin policy and aid project managers in controlling the interfaces.

8.5 OVERALL METHODOLOGY

Having established the interfaces, interactions and their devised potential management tools the next step of the research set out to combine all findings and devise a workable management methodology.

It was decided to split the methodology into three parts and use readily available MS Office ™ programs. This should allow for a relatively easy deployment of the methodology at any shipyard and also simplify any future updates and changes to the overall programme.

The first part of the methodology is in the form of functional flowcharts. These represent all dataflow connections between domains but do not include a timeline. Most of this data came from the interface interaction studies. A timeline was also included by using a simplified project schedule, which was constructed using the information provided in the functional flowcharts and then refined using the earlier case studies.

Finally a user manual is provided. For each domain, this manual lists the interacting interfaces, the type of data exchanged, the time criticality of any dataflow, as well as possible problems, and associated mitigation recommendations. The data in the user manual combines the results from the interface interaction studies with the interface management research.

8.6 TESTING AND VALIDATION

To ensure the integrity and accuracy of the developed methodology a testing and validation study was carried out.

The study was based on designing a trimaran OPV and all the steps in the methodology were meticulously followed. This was to test the methodology's adaptability and its accuracy. Any required deviations from the original methodology were noted and incorporated at the end of the study.

The study showed that no major changes were required to the methodology and that the combination of using three different formats provided a useful tool for designers and managers. Some minor changes were required and these were integrated into the final methodology.

9 CONCLUSIONS

9.1 INTRODUCTION

This chapter outlines the results from the individual studies and also summarises the overall methodology results. Suggestions for further work are also outlined.

9.2 INTERFACE INTERACTION

The thesis has proposed how feasibility studies can be interpreted under the SMART procurement cycle. It has shown that the assessment phase can be seen as the equivalent to feasibility studies for the purpose of shipyard design management.

The interviews carried out during the interface interaction study made explicit a large volume of knowledge inherent within the company. They also provided a further insight into the complexity of the research area. Furthermore the thesis has shown that the top-down analysis approach arrives at almost the same results as the bottom-up synthesis approach used in previously published literature, see section 4.6.

The results from the case studies have highlighted the importance of the propulsion domain on the overall vessel design and layout. Furthermore, it has been shown that this is applicable to both, large and small vessels.

The ILS study has shown that this domain is of increasing importance and needs to be managed as an integral part of the design process and not just as an add-on. This also applies to the HF domain.

The thesis has developed a set of rules that can be used to determine area equations for vessels ranging from small fast attack craft to large corvette and frigate type vessels. Furthermore, a set off rules for weight, volume and VCG equations has been developed and this will allow any future algorithms to be compatible with the algorithms developed in the thesis.

Both the FAC and corvette algorithms have been tested and have been found to provide an accurate mathematical description of certain design parameters. The developed test spreadsheets allow designers to quickly evaluate novel ship designs taking into account factors such as habitability and aviation support.

A ship parameter database has been developed, which contains information on areas for a range of vessels built at VT Shipbuilding.

A set of limiting values has been derived that can be used as boundary conditions for future corvette designs and patrol vessels. These limiting criteria provide a sufficient boundary during concept evaluations, as they contain factors such as longitudinal strength, in the form of L/D, and freeboard evaluation, in the form of L/F.

The parametric survey has determined some important guidelines for future ship design. The survey has shown that a decision about the required aviation capability has to be taken at the very beginning of the design process as it is not possible to add increased aviation capability at a later stage.

The survey has also shown that it is not possible to increase the habitability standard once the basic parameters are set. Equally, any complement increase of more than 10 crew, for a corvette type vessel, can not be implemented without detrimental effects on the chosen habitability standard or increasing the overall parameters of the design.

9.3 INTERFACE MANAGEMENT

This thesis has highlighted and collated the existing, published views on margins and combined them with the knowledge inherent within the company. It has succeeded in making explicit the knowledge contained within VT Shipbuilding. It has also identified that design and construction margins are the most suitable for use during the SMART assessment phase.

The work carried out in the parametric survey has provided numerical ranges for potential mitigation measures during corvette designs.

The combination of literature review, interviews and results from the parametric survey has led to the development of a margin policy guideline. The guideline provides information about the type of margins that are required and available .It also details their appropriate numerical ranges and provides information about critical values and design decisions. An example of a critical design decision is the aforementioned change in habitability standards, see 9.2.

Furthermore, the thesis has outlined a simple system of holding review meetings and thus communicating critical decisions.

9.4 OVERALL METHODOLOGY

The thesis has shown that using a three part management methodology suite allows a designer and/or manager to carry out even complex design studies.

The developed functional flowcharts provide an in-depth insight into the dataflow across the interfaces. The developed project schedule is presented in 24hr time units and thus can be easily adapted to any working scheme depending on company circumstances. Finally the word manual provides a detailed overview of all the factors relevant for each domain at each stage of the design process.

The methodology developed in this thesis provides a novel approach to managing early-stage warship design. The originality of the methodology lies in its dissemination of practical data and its detailed description of what data needs to be transferred to what domain at what stage. It also provides a clear description of where the ownership of data and processes is situated. Furthermore a novel, yet easy to follow process has been devised by combining readily available software packages and separating functional data from time dependent data. The novelty of the methodology lies in its simplicity whilst being able to describe a very complex engineering challenge.

The testing of the methodology has proven that it is well equipped to deal with complex projects, thus it provides an appropriate tool for novice designers, as a step-by-step guidance, and experienced project managers, as a reference tool, alike.

The thesis has also shown how the methodology could potentially be integrated into the overall high-level management of the procurement process.

9.5 SUMMARY

The research set out to develop a methodology for managing feasibility studies in an MoD context. Combining case studies with academic research and attempting to unlock the inherent knowledge contained within the shipbuilding industry have resulted in a programme consisting of three parts: a functional flowchart description, a project schedule and a guidance manual. It is believed that the programme provides an accurate depiction of the design process and allows the user to reduce the rework during the design process. The methodology also acts as a reference tool for both designers and managers.

As stated in the objectives the final methodology provides a description of the early stage design process and how it functions. This methodology provides a step-by-step guide and its use of readily available software packages enables it to be easily deployed within VT and other design offices, if required.

The methodology clearly defines ownership of data and the responsibility of domains. This allows all domains to work more effectively by creating an open and transparent design process.

The validation study has shown that the programme structure is suitable for use in a design environment. The combination of the MS word manual, functional flowcharts and overall project schedule has proven successful. The programme has coped well with a demanding an novel design concept.

The various components of the programme should allow any designer to take over the project management role for a feasibility study. The study has also shown that it is relatively easy to alter the programme should this be required. In its current form it is most suitable for Fast Attack Craft and Corvette type ships, however the validation study has shown that it is also capable of dealing with novel ship types.

Overall, the research has outlined many of the factors that influence feasibility studies in the modern procurement environment.

It is believed that the thesis makes explicit many of the views and knowledge inherent within the shipbuilding and ship design community and which are often taken for granted.

9.6 FURTHER WORK PROPOSALS

9.6.1 Integrated database

During the research it became apparent that it is necessary to provide an efficient tool to capture and trace the data transmitted across the interfaces. Deploying an integrated database across all disciplines could do this. The database has to be easy to use, as designers appear to be reluctant to utilise them. This is based on observations made whilst at VT. The database should allow any domain to access decisions and data by other domains, thus further opening up the process and improving transparency.

A basic database was set up during the research and was deployed on a concept design study at VT. However, the design was stopped at a very early stage and thus no conclusions could be drawn from the investigation.

9.6.2 High-Level Integration

If an integrated database is designed then further research should be carried out into how to connect it into the overall procurement process. A short description of a likely integration into the high-level procurement process is given in 7.2, and this could be used as a starting point for any further work.

9.6.3 Graphical User Interface

Whilst the developed methodology can be used and deployed easily across a company network, due to it consisting of standard office programmes, an investigation should be carried out into providing a one-solution interface. This should link all constituent parts of the programme together and thus make it easier to be accepted by design and management staff.

9.6.4 Parametric Surveys

An investigation should be carried out into whether a version of DCONCEPT, or a similar tool, has been developed that can accommodate FAC type hulls. If this is the case then a parametric survey, using the developed algorithms should be carried out. This could then be used to update the user manual and insert a section detailing FAC specific issues.

It is also proposed that any future research includes the development of new algorithms so that the user manual can continually be updated.

9.6.5 Sub-Domain Investigations

Throughout the thesis sub-domains have been treated as black boxes, as the emphasis has been on data input and output and not on the actual work carried in the sub-domains. It is proposed that future research should investigate the sub-domain level and thus provide an even lower level management insight for designers than described in this thesis. This should complement the methodology by further integrating all levels of management into one set of procedures and processes.

10 APPENDIX A

- **Output**:
    i. What are the objectives of your domain?

    ii. What are you trying to achieve?

- **Input**:
    i. What input (ie what data) do you need to achieve your objectives?

- **Linkages and staging:**
    i. When do you require your data?

    ii. When do you deliver your objectives?

    iii. When would you like your data?

    iv. What are the main managerial problems (time-management, working with other sections etc.)?

    v. What domains do you deal with (internal as well as external)?

- **System as seen from sub-system subjective view:**
    i. Where do you see yourself within the system? (Reiterate theoretical model)

Figure 98 –Interview Sheet

11 APPENDIX B

Interview Nick Pattison
Date: 27/05/2002
Version: Draft for correction

His domains are Naval Architecture and Safety. The work of his domains can be split up into several groups. These groupings are outlined below and are also illustrated in the attached files.

- Naval Architecture related groups
    - Basic Naval Architecture
        - Stability
        - Hydro
        - Weights
    - Arrangement
        - Spatial
        - Standards / Performance
    - Hull Systems
        - E.g. weatherdeck (mooring)
        - Boats
        - RAS
        - Lifesaving
        - Insulation / linings / deck coverings etc
        - Furnishings
- Safety
    - Ensure safe operability

General input to compute and produce the output includes basic operational or performance requirements such as speed. Also required is a set of standards, either derived or specified, e.g. for sustainability the volume of the stores and fuel is required.

The required inputs, linkages and time related stages are outlined in the attached files. The linkages for the arrangement process are not included as this domain group is linked to lots of different processes. It is not linked to

- Generic training of equipment
- Command system functionality
- Preservation / painting
- Colour scheme

Regarding managerial problems it can be said that most of these are to do with accuracy and timeliness of supplied data. This is true for all the processes in the naval architecture domain.

The naval architecture domain is a central domain where most of the design coordination work takes place.

Figure 99 –Sample Write up

12 APPENDIX C

Interface Management	12	54.5%
Resource Management	3	13.6%
ILS	2	9.1%
Loss of High Level Vision	2	9.1%
Commercial Sections	1	4.5%
HF Neglected	1	4.5%
Weapons Systems Integration	1	4.5%
Data Delivery	2	9.1%
Low Confidence into Input Data	1	4.5%
Communication flow	6	27.3%
Technical / non-technical interface	3	13.6%
	22	100.0%

Table 15 –Perceived Managerial Problems

13 APPENDIX D

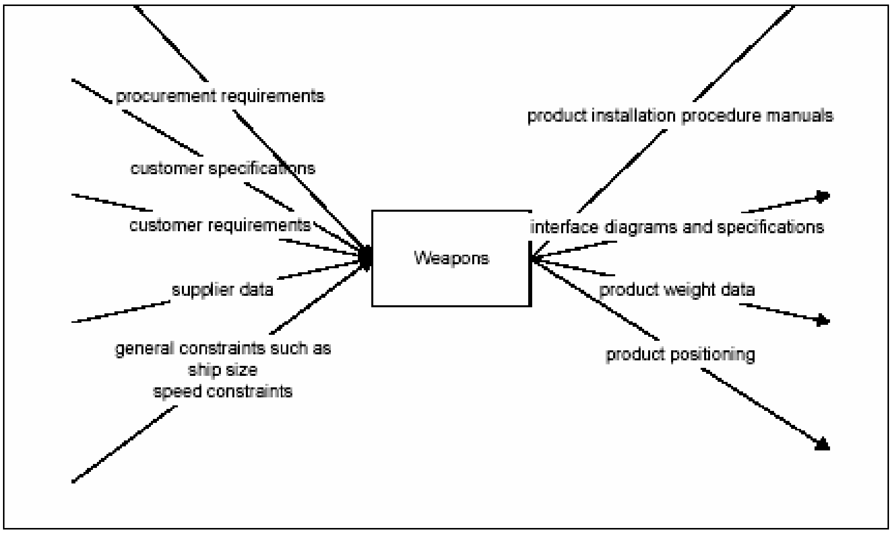

Figure 100 – Spider diagram weapons domain

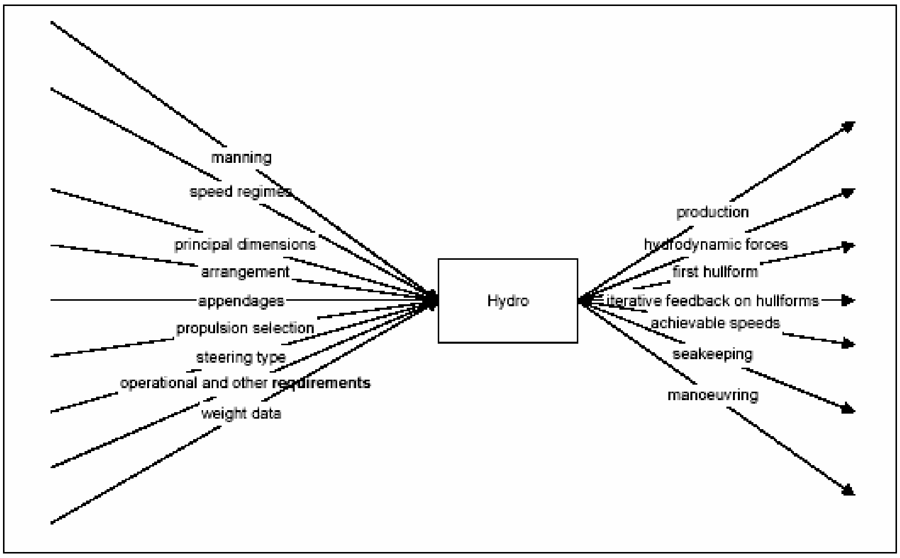

Figure 101 – Spider diagram Hydrodynamics domain

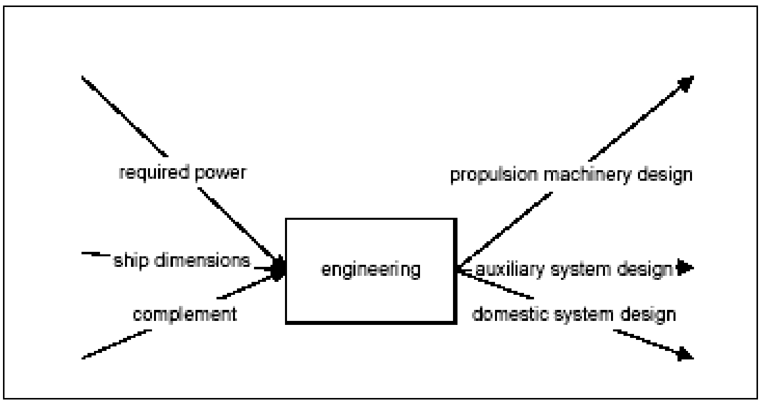

Figure 102 – Spider diagram Engineering

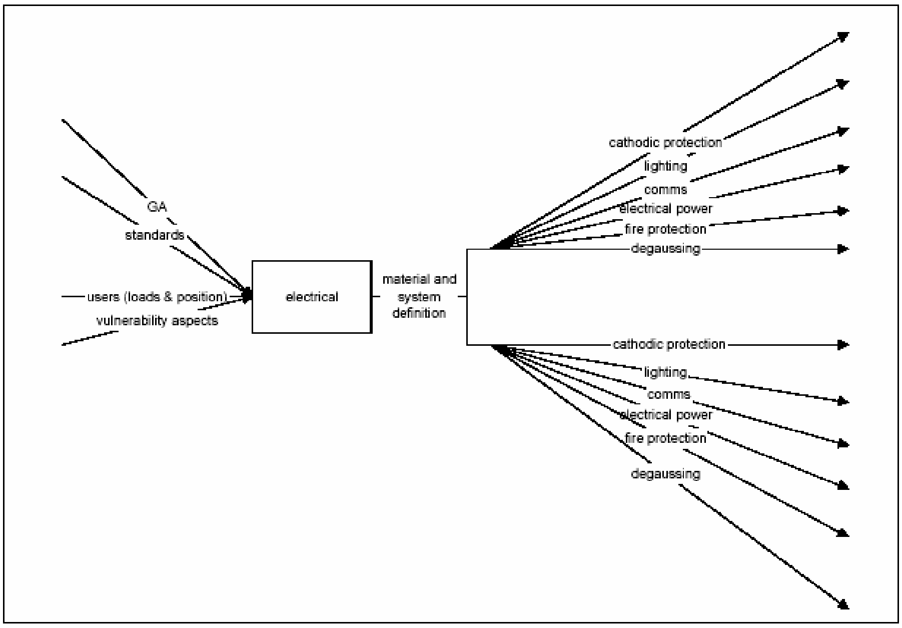

Figure 103 – Spider diagram electrical

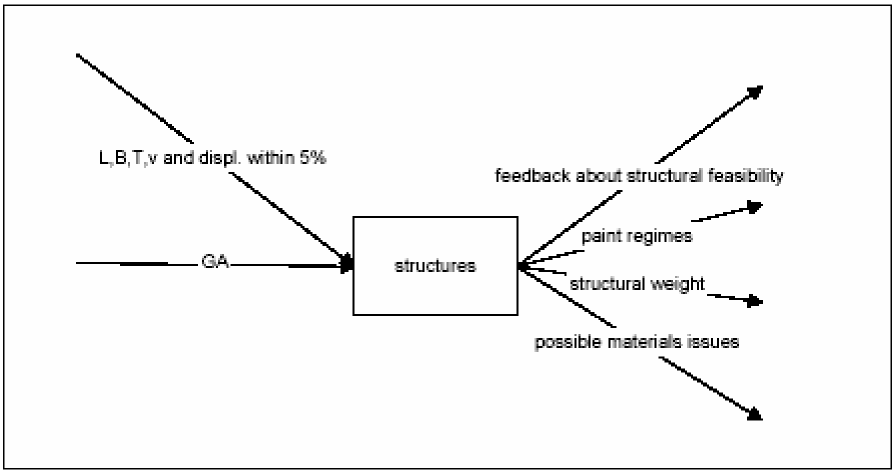

Figure 104 – Spider diagram structures

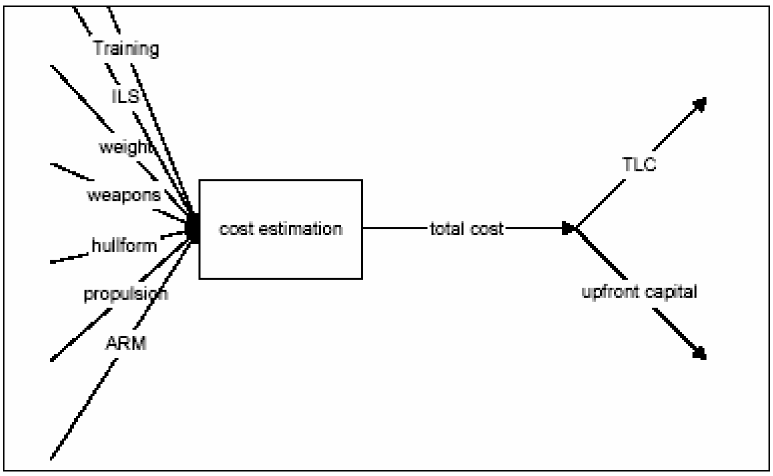

Figure 105 – Spider diagram cost estimation

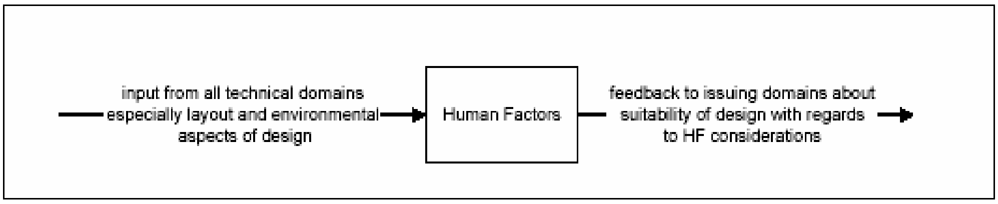

Figure 106 – Spider diagram human factors

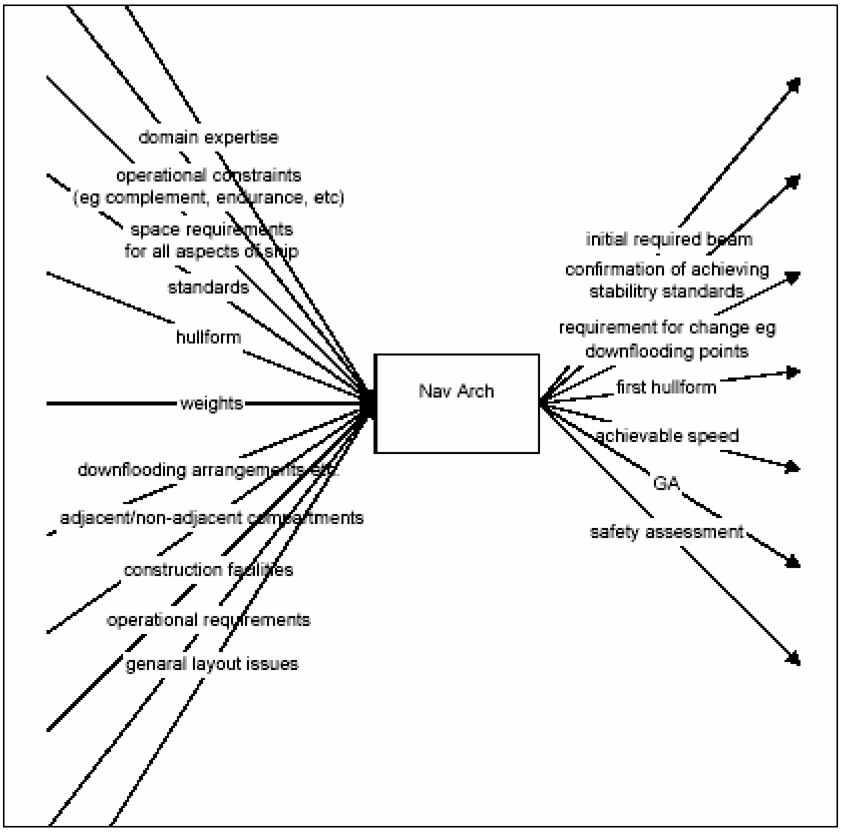

Figure 107 – Spider diagram naval architecture

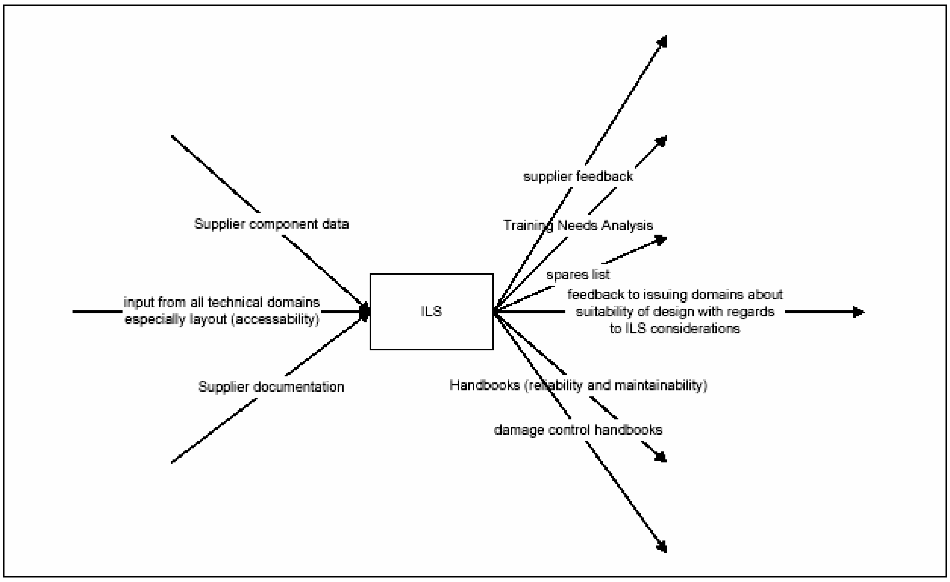

Figure 108 – Spider diagram ILS

14 APPENDIX E

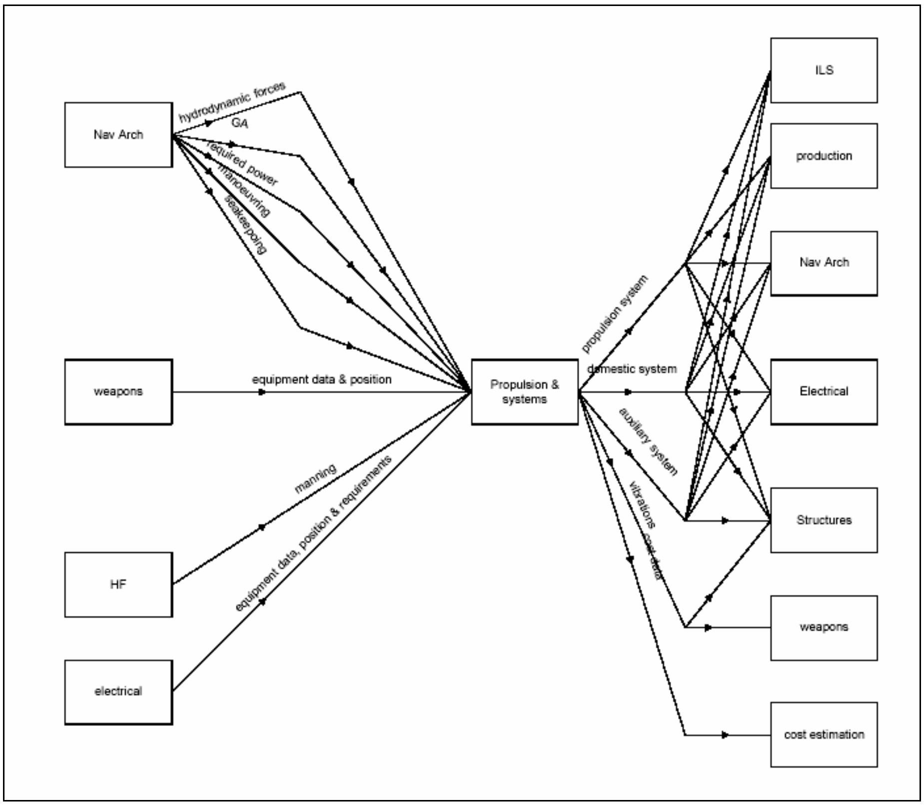

Figure 109 – Connection diagram Propulsion and Systems

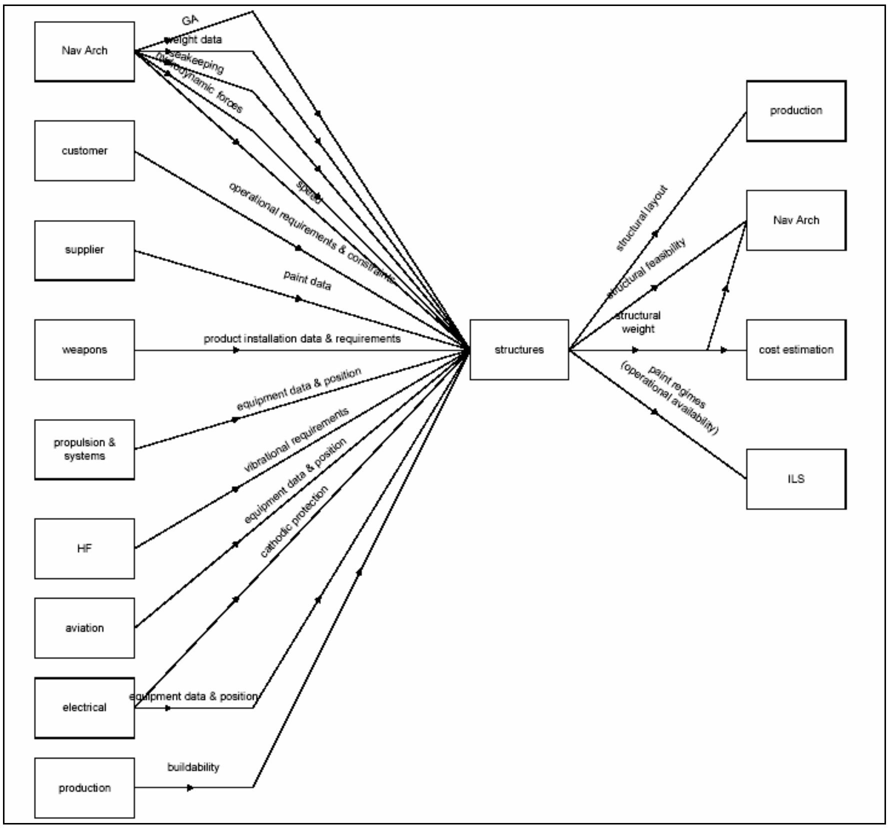

Figure 110 – Connection diagram Structures

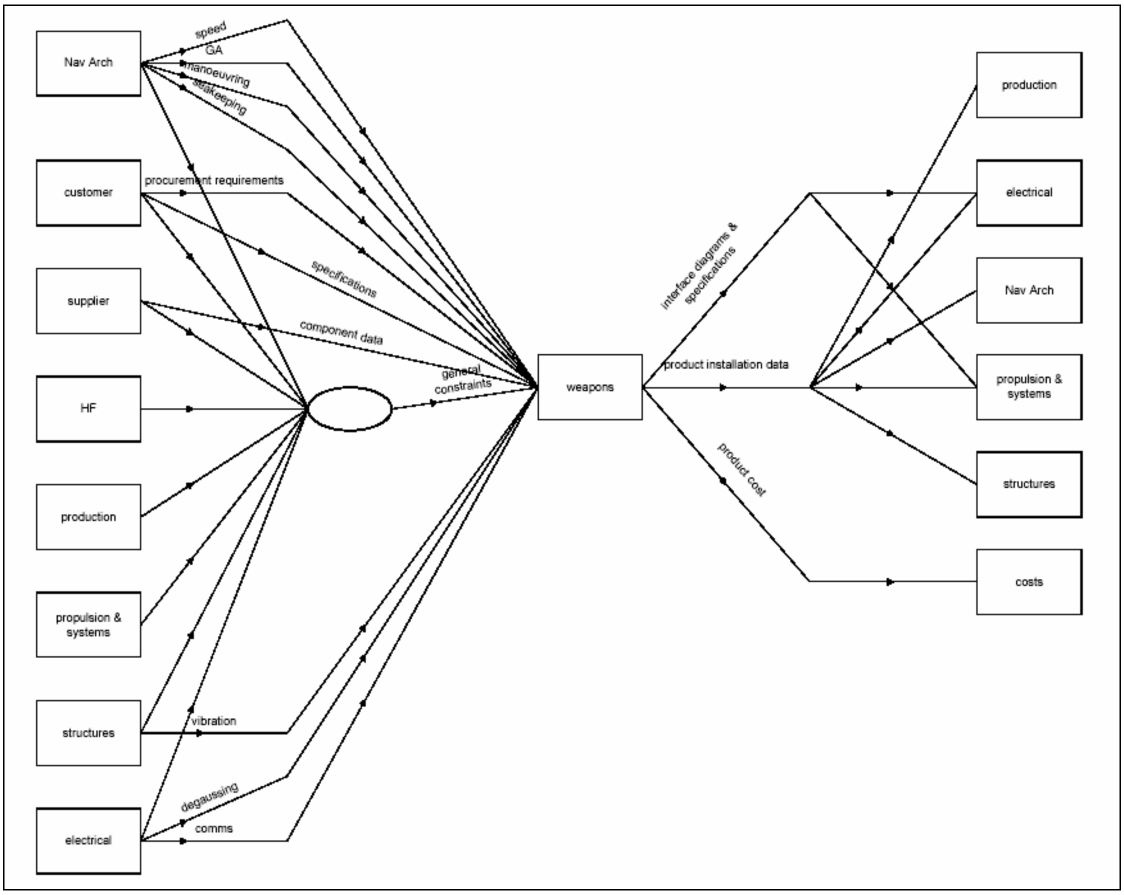

Figure 111 – Connection diagram Weapons

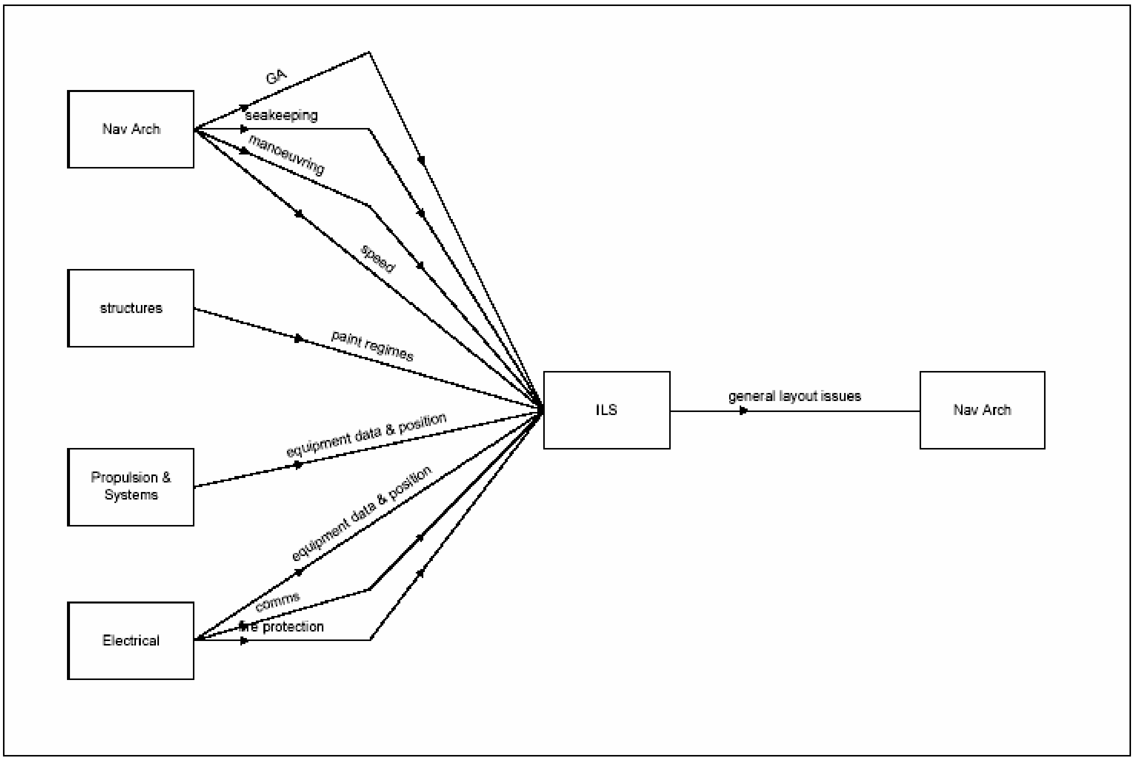

Figure 112 – Connection diagram ILS

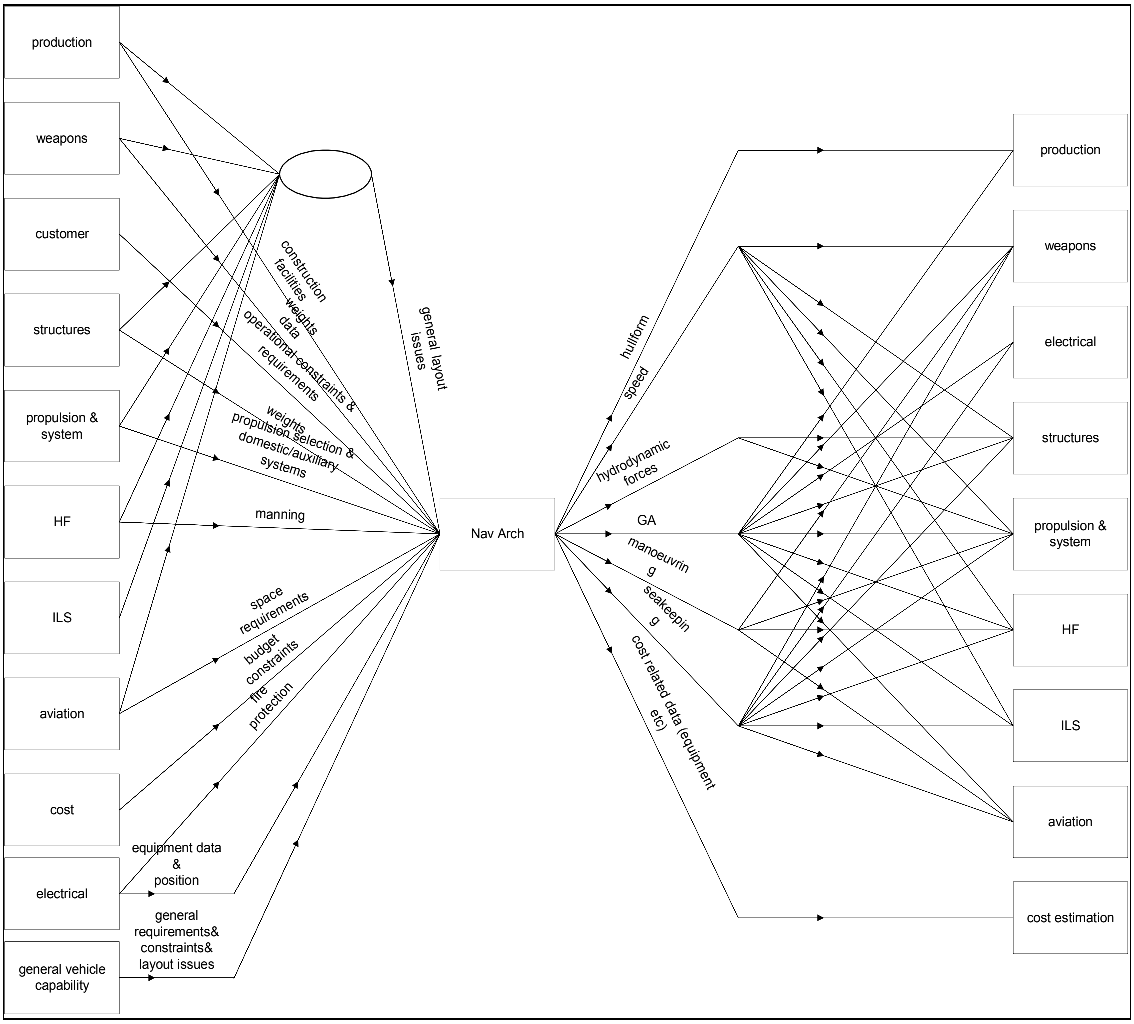

Figure 113 – Connection diagram Naval Architecture

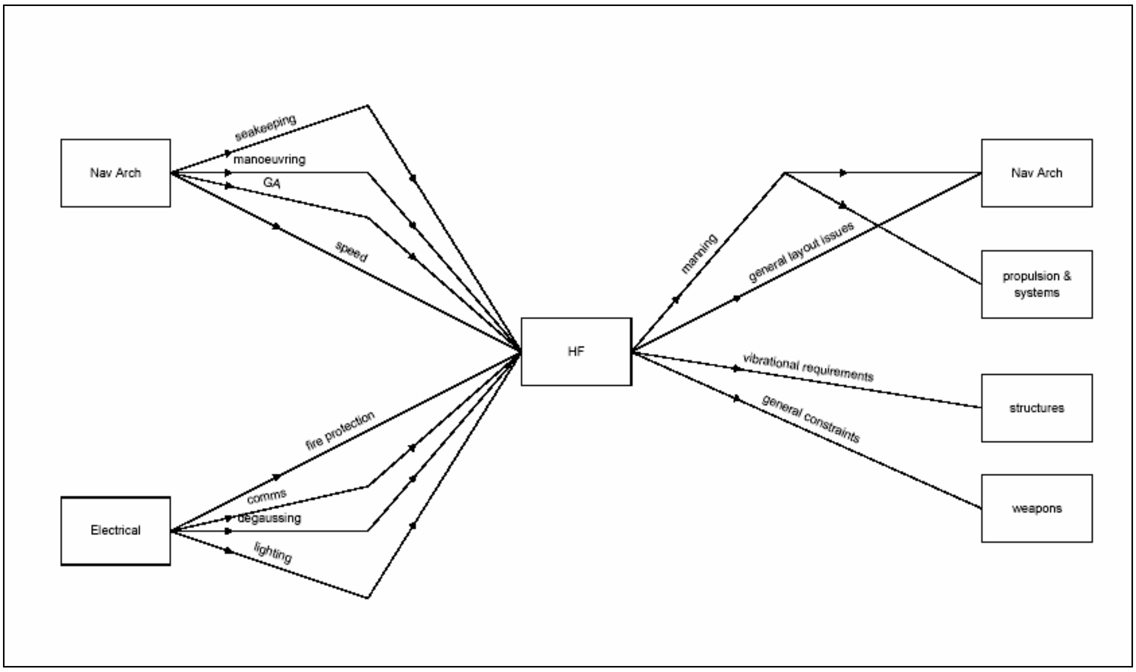

Figure 114 – Connection diagram HF

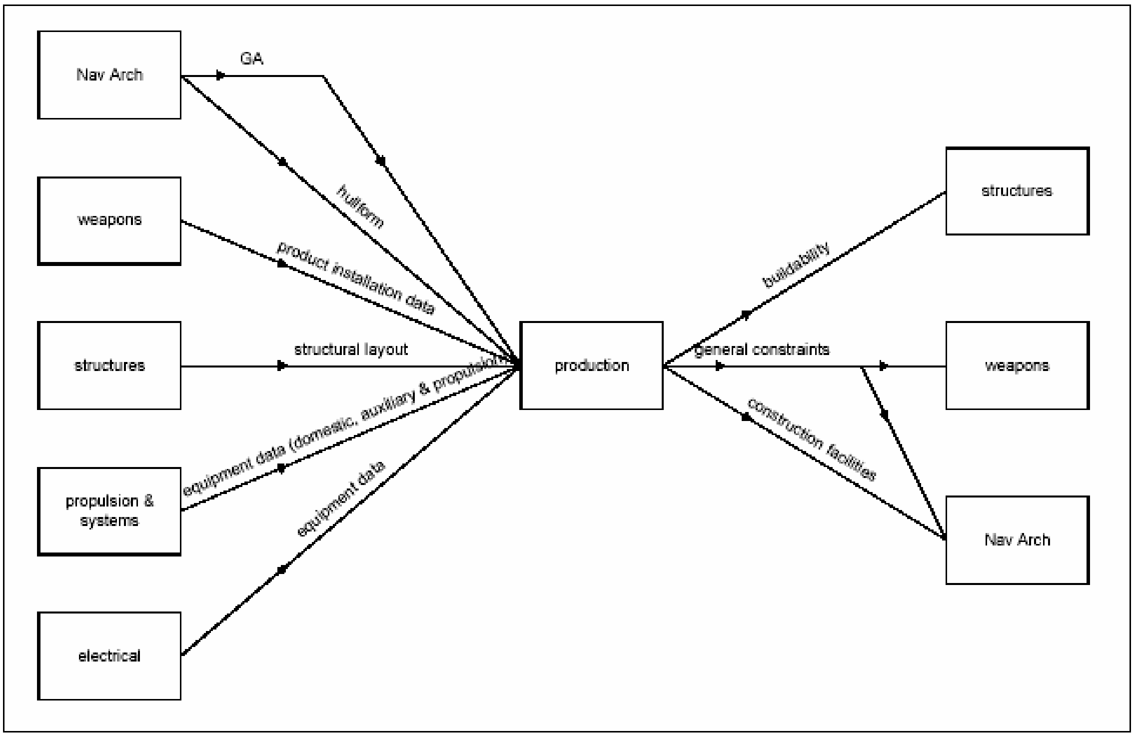

Figure 115 – Connection diagram Production

15 APPENDIX F

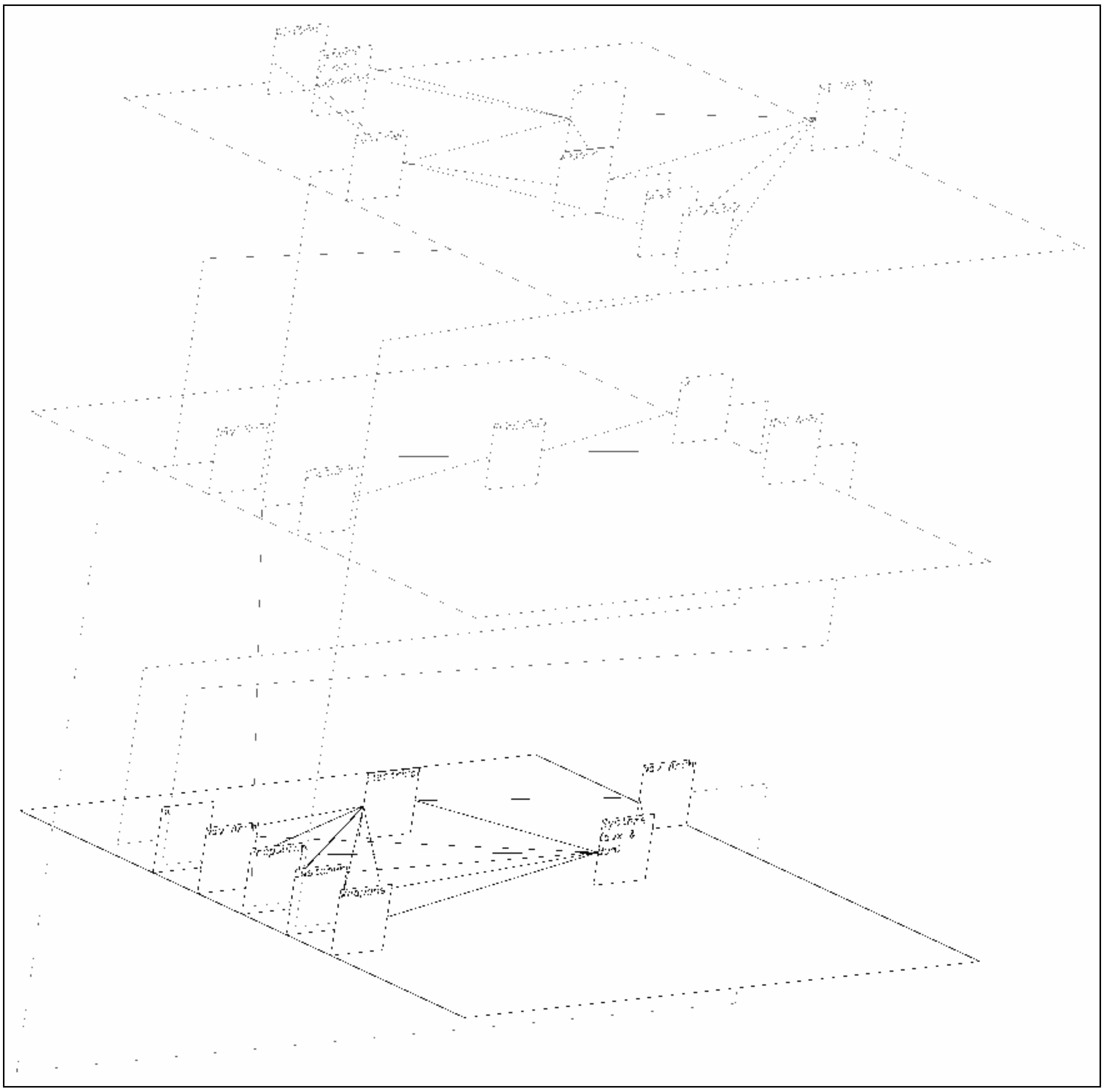

Figure 116 -3D Representation

16 APPENDIX G

LBP	52	m
LOA	56	m
LWL	52	m
Lightship displacement	382,806	kg
VCG	4.15	m
LCG	-3.59	m
TCG	-0.01	m

Table 16 –FAC Baseship Parameters

	WEIGHT kg	LCG M	VCG M	TCG M	reduction
100 HULL PLATING	21537	-1.35	2.84	0.00	40%
101 HULL LONGL. & TRANSVERSE FRAMING	17868	-3.72	2.42	0.00	40%
102 INNER BOTTOM PLATING	1883.4	6.36	1.32	0.00	40%
120 MAIN TRANSVERSE BULKHEADS	6715.8	-2.75	3.51	0.02	40%
121 LONGITUDINAL BKHDS	306.6	-11.61	2.38	0.00	40%
122 OTHER STRUCTURAL BULKHEADS	1009.8	-2.34	4.36	0.22	40%
130 MAIN DECKS	22192.2	0.02	4.97	0.00	40%
143 MANHOLES	285.6	3.73	1.59	-0.08	40%
172 SEA CHESTS	694.4	-6.33	0.98	0.15	20%
174 STERN TUBES	1008	-14.37	1.16	0.00	20%
190 WELDING	0	-1.36	4.07	0.00	100%
199 ROLLING MARGIN ON PLATE TOLERANCE	-6921	-0.19	3.75	-0.01	0%
total changed items	**66579.8**	**-1.86**	**3.34**	**0.01**	

Table 17 –FPC Group1 Weights

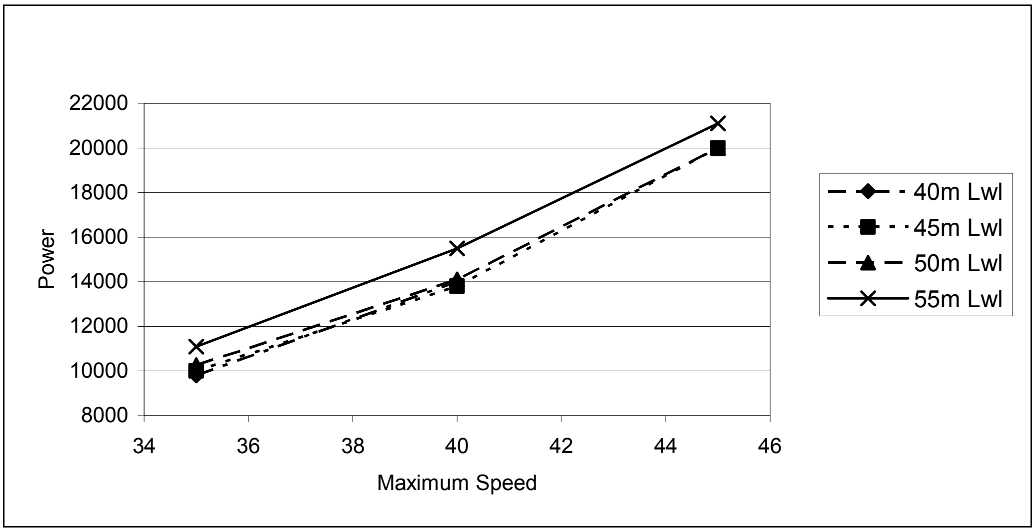

Figure 117 –FPC Initial Parametric Study

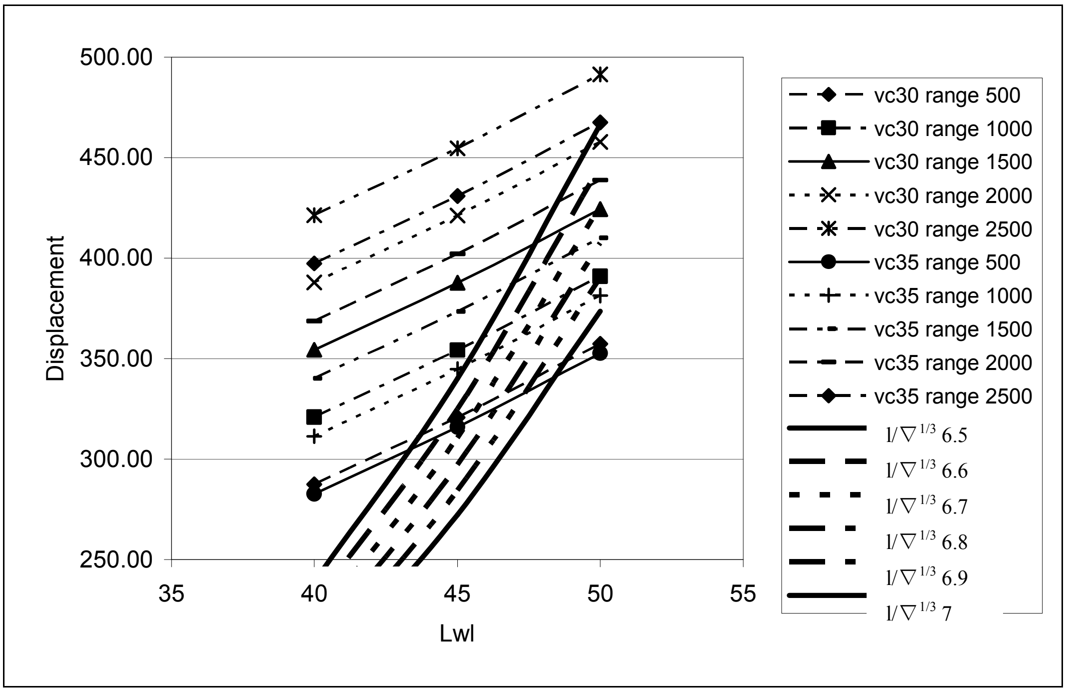

Figure 118 –FPC Preliminary Sizing

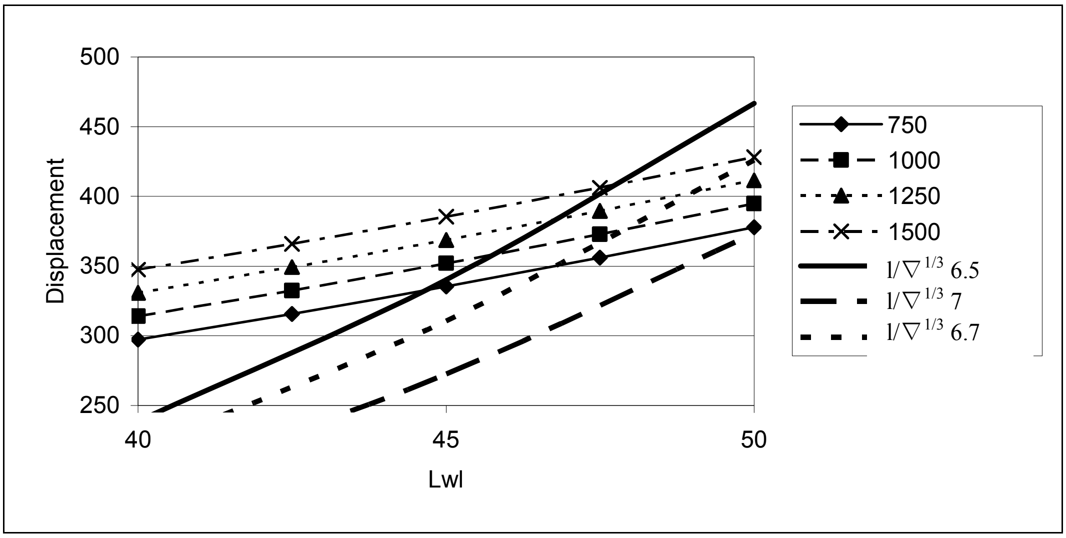

Figure 119 –FPC DSHIPSIZE Sizing

48m weight estimate (56m derivative)

issue 1 - 06/20/02

Concept 48m rocket			Qatar 56m		
Loa	52.00	compliment 25	Loa	56.00	compliment 35
B	8.30		B	9.00	
D	5.40		D	6.00	
Shp_n	17218		Shp_p	14000	
kW_n	240		kW_n	460	
kg_n	250,000		kg_p	387,400	

	Scaling				Concept 48m rocket			Qatar 56m		
	Weight		VCG		Weight	VCG	VMOM	Weight	VCG	VMOM
Description	rule	factor	rule	factor	kg	m	m	kg	m	m
HULL										
100 HULL PLATING	L(B + 2D)	0.84	D	0.90	18,189	0.00	0	21537		
101 HULL LONGL. & TRANSVERSE FRAMING	L(B + 2D)	0.84	D	0.90	15,091	0.00	0	17868		
102 INNER BOTTOM PLATING	LB	0.86	D	0.90	1,613	0.00	0	1883.4		
110 SUPERSTRUCTURE PLATING	B	0.92	D	0.90	3,811	0.00	0	4132		
111 SUPERSTRUCTURE LONG & TRANS FRAMING	B	0.92	D	0.90	1,089	0.00	0	1181		
112 SUPERSTRUCTURE DECKS & FLATS	B	0.92	D	0.90	4,549	0.00	0	4933		
113 SUPERSTRUCTURE BULKHEADS	B	0.92	D	0.90	2,052	0.00	0	2225		
114 SUPERSTRUCTURE HANGAR	INPUT		D	0.90	0	0.00	0			
116 SUPERSTRUCTURE ARMOUR & PROTECTION			D	0.90	0	0.00	0			
120 MAIN TRANSVERSE BULKHEADS	LBD^2	0.69	D	0.60	4,658	0.00	0	6716		
121 LONGITUDINAL BKHDS	LD^2	0.75	D	0.90	231	0.00	0	307		
122 OTHER STRUCTURAL BULKHEADS	$(LBD^{2+}LD^2)/2$	0.72	D	0.90	730	0.00	0	1010		
123 FUNNEL	Vol. Ratio	0.92	D	0.90	0	0.00	0			
130 MAIN DECKS	LB	0.86	D	0.90	19,004	0.00	0	22192		
140 BRIDGE WINDOWS SIDELIGHTS & SCUTTLES	LB	0.86	D	0.90	343	0.00	0	400		
141 WATERTIGHT & GASTIGHT DOORS & HATCHES	L	0.93	D	0.90	1,710	0.00	0	1842		
142 ESCAPE HATCHES & SCUTTLES	L	0.93	D	0.90	223	0.00	0	240		
143 MANHOLES	L	0.93	D	0.90	265	0.00	0	286		
151 SEATS & SUPPORTS FOR GROUP 1 ITEMS	LB	0.86	D	0.90	0	0.00	0			
152 SEATS & SUPPORTS FOR GROUP 2 ITEMS	LB	0.86	D	0.90	1,019	0.00	0	1190		
153 SEATS & SUPPORTS FOR GROUP 3 ITEMS	LB	0.86	D	0.90	1,141	0.00	0	1332		
154 SEATS & SUPPORTS FOR GROUP 4 ITEMS	LB	0.86	D	0.90	4,942	0.00	0	5771		
155 SEATS & SUPPORTS FOR GROUP 5 ITEMS	LB	0.86	D	0.90	1,045	0.00	0	1220		
156 SEATS & SUPPORTS FOR GROUP 6 ITEMS	LB	0.86	D	0.90	871	0.00	0	1017		
157 SEATS & SUPPORTS FOR GROUP 7 ITEMS	LB	0.86	D	0.90	2,134	0.00	0	2492		
160 RUDDERS & SKEG	L	0.93	D	0.90	4,910	0.00	0	5288		
164 BILGE KEEL	L	0.93	D	0.90	0	0.00	0			
165 STABILISING TANKS (INCD. IN 102,120 & 121))	L	0.93	D	0.90	0	0.00	0			
170 SHAFT BRACKETS	INPUT	1.00	D	0.90	3,166	0.00	0	3166		
173 ANCHOR HAWSE PIPES & NAVEL PIPES	INPUT	1.00	D	0.90	303	0.00	0	303		
174 STERN TUBES	INPUT	1.00	D	0.90	1,008	0.00	0	1008		
175 SEA TUBES	INPUT	1.00	D	0.90	694	0.00	0	694		
190 WELDING	L(B + 2D)	0.84	D	0.90	0	0.00	0			
191 WEIGHING ADJUSTMENT	LB	0.86	D	0.90	0	0.00	0			
192 BOLTING	LB	0.86	D	0.90	572	0.00	0	668		
ROLLING MARGIN	LB	0.86	D	0.90	-5,927	0.00	0	-6921		
PROPULSION										
221 GAS TURBINES	Shp	1.23	D	0.90	0	0.00	0			
222 PROPULSION DIESEL ENGINES	Shp	1.23	D	0.90	0	0.00	0			
224 PROPN UNITS CONTROL EQUIPMENT (INTEGRAL)	INPUT		D	0.90		0.00	0			
225 CLUTCHES GEARING FLEX COUPL & TURN GEAR	INPUT		D	0.90		0.00	0			
226 MACHINERY SPACE LIFTING GEAR	INPUT		D	0.90		0.00	0			
240 SHAFTING	$Shp^{1/2}$ x L	1.11	D	0.90	0	0.00	0			
241 PROPULSORS INC ACT RUDDERS	INPUT		D	0.90		0.00	0			
242 SHAFT BEARINGS & STERN TUBES	INPUT		D	0.90		0.00	0			
243 TORSIONMETRES & BRAKES	INPUT		D	0.90		0.00	0			
251 SUPPLY SYSTEM	kg_p x $(Shp)^{1/2}$	0.72	D	0.90	0	0.00	0			
252 EXHAUST SYSTEM	kg_p x $(Shp)^{1/2}$	0.72	D	0.90	0	0.00	0			
271 COOLING WTR SYSTEM FOR PROPN UNITS	kg_p x $(Shp)^{1/2}$	0.72	D	0.90	0	0.00	0			
280 COMBST FUEL OIL SERV SYST TO PROPN UNITS	kg_p x $(Shp)^{1/2}$	0.72	D	0.90	0	0.00	0			
290 LUB OIL SYSTEM TO PROPN UNITS	kg_p x $(Shp)^{1/2}$	0.72	D	0.90	0	0.00	0			
ELECTRICAL										
302 DIESEL GENERATOR SETS	kg_p x kW	0.34	D	0.90	0	0.00	0			
310 MAIN SUPPLY EQUIPMENT	kW x Loa	0.48	D	0.90	1,770	0.00	0	3,654		
311 DISTRIBUTION EQUIPMENT	kW x Loa	0.48	D	0.90	846	0.00	0	1,746		
312 GENERAL SERVICE CONVERSION EQUIPMENT	kW x Loa	0.48	D	0.90	1,315	0.00	0	2,714		
313 PORTABLE APPARATUS SYSTEM (EQUIPMENT)	kW x Loa	0.48	D	0.90	0	0.00	0			
320 CABLING	kW x Loa	0.48	D	0.90	6,921	0.00	0	14,285		
321 GLANDS & CABLE SUPPORT EQUIPMENT	kW x Loa	0.48	D	0.90	1,842	0.00	0	3,803		
330 GENERAL LIGHTING SYSTEM INC EMERGENCY & CEREMONIAL	LBD/100 x Complemen	0.55	D	0.90	459	0.00	0	834		
331 EMERGENCY LIGHTING SYSTEM	LBD/100 x Complemen	0.55	D	0.90	0	0.00	0			
332 CEREMONIAL LIGHTING	INPUT		D	0.90	175	0.00	0	175		
334 EARTHING	INPUT		D	0.90		0.00	0			

Table 18 –FPC Weights 1/2

CONTROL & COMMUNICATIONS										
400 GYRO & OTHER COMPASSES	LBD/100	0.77	D	0.90	287	0.00	0	373		
402 NAV AIDS & DIRECTION FINDING EQUIP.	LBD/100	0.77	D	0.90	7	0.00	0	9		
403 LOGS	LBD/100	0.77	D	0.90	37	0.00	0	48		
404 WIND SPEED & DIRECTION INDICATING SYSTEM	LBD/100	0.77	D	0.90	22	0.00	0	29		
405 NAVIGATION RADAR	LBD/100	0.77	D	0.90	209	0.00	0	271		
406 VIEWING DEVICES	LBD/100	0.77	D	0.90	151	0.00	0	196		
407 CHRONOMETERS	LBD/100	0.77	D	0.90	0	0.00	0			
408 PLOTTING & CHART TABLES	LBD/100	0.77	D	0.90	73	0.00	0	95		
409 NAVIGATION LIGHTS ETC	LBD/100	0.77	D	0.90	68	0.00	0	88		
410 BROADCASTS	LBD/100	0.77	D	0.90	349	0.00	0	453		
411 RICE EQUIPMENT	LBD/100	0.77	D	0.90	0	0.00	0			
412 SOUND REPRODUCTION EQUIPMENT	LBD/100	0.77	D	0.90	0	0.00	0			
414 TELEVISION RADIO & CINEMA EQUIPMENT	LBD/100	0.77	D	0.90	72	0.00	0	94		
415 ALARMS AND WARNINGS	LBD/100	0.77	D	0.90	0	0.00	0			
416 NBCD WARNING SYSTEM	LBD/100	0.77	D	0.90	50	0.00	0	65		
418 RUDDER ANGLE INDICATORS	LBD/100	0.77	D	0.90	0	0.00	0			
420 SHIP CONTROL CONSOLE	LBD/100	0.77	D	0.90	370	0.00	0	480		
421 SYSTEMS CONSOLES	LBD/100	0.77	D	0.90	0	0.00	0			
423 RUDDER CONTROL SYSTEM	LBD/100	0.77	D	0.90	1,067	0.00	0	1,384		
425 MOVEABLE STABILISER & CONTROL SYSTEM	INPUT		D	0.90	2,392		0	2,392		
427 TANK STABILISATION SYSTEM	LBD/100	0.77	D	0.90	0	0.00	0			
428 MACHINERY CONTROL SYSTEM	LBD/100	0.77	D	0.90	610	0.00	0	792		
430 SURFACE/AIR WEAPON CONTROL SYSTEM	INPUT		D	0.90	698	0.00	0	698		
431 SURFACE/SURFACE WEAPON CONTROL SYSTEM	INPUT		D	0.90	6,739	0.00	0	6,739		
432 SURFACE/ANTI-SUBMARINE WEAPON CONTROL SYSTEM	INPUT		D	0.90		0.00	0			
435 WEAPON AND SURVEILLANCE RADARS	INPUT		D	0.90	5,155	0.00	0	5,155		
436 SONARS	INPUT		D	0.90		0.00	0			
437 CENTRALISED WEAPON SYSTEM	INPUT		D	0.90	29	0.00	0	29		
438 ELECTRONIC WARFARE SYSTEM (EW)	INPUT		D	0.90	2,142	0.00	0	2,142		
440 DEGAUSSING SYSTEM	INPUT		D	0.90		0.00	0			
441 CATHODIC PROTECTION SYSTEM	LBD/100	0.77	D	0.90	240	0.00	0	311		
442 ZINC PROTECTORS	LBD/100	0.77	D	0.90	0	0.00	0			
444 EARTHING	LBD/100	0.77	D	0.90	0	0.00	0			
450 RADIO COMMUNICATION SYSTEMS	LBD/100	0.77	D	0.90	2,490	0.00	0	3,231		
451 UNDERWATER TELEPHONES & ECHO SOUNDERS	LBD/100	0.77	D	0.90	94	0.00	0	122		
452 VISUAL SIGNALLING EQUIPMENT	LBD/100	0.77	D	0.90	97	0.00	0	126		
453 SIRENS AND WHISTLES	LBD/100	0.77	D	0.90	15	0.00	0	20		
454 SATELLITE COMMUNICATIONS	LBD/100	0.77	D	0.90	0	0.00	0			
AUXILIARY SYSTEMS										
500 AIR CONDITIONING PLANTS	Accom+LBD/100	0.74	D	0.90	2,596	0.00	0	3,506		
501 CHILLED AND TEPID WATER SYSTEM	INPUT	1.00	D	0.90		10.70	0			
502 A/C & MECH. VENT SYSTEM (EX MMS-508)	Accom+LBD/100	0.74	D	0.90	3,624	0.00	0	4,894		
503 FREE STANDING AIR CONDITIONING UNITS	Accom+LBD/100	0.74	D	0.90	0	0.00	0			
504 NATURAL VENTILATION SYSTEM	Accom+LBD/100	0.74	D	0.90	0	0.00	0			
505 REFRIGERATION PLANT & EQUIPMENT	Accom	0.71	D	0.90	675	0.00	0	945		
508 AIR CONDITIONING & VENT SYSTEM IN MMS	Accom+LBD/100	0.74	D	0.90	1,446	0.00	0	1,953		
510 MAIN FUEL FILLING HEATING & TRANS SYSTEM	LBD/100	0.77	D	0.90	715	0.00	0	928		
511 AUXILIARY FUEL SYSTEMS	INPUT	1.00	D	0.90	0	0.00	0			
520 SEA WATER SYSTEM	LBD/100	0.77	D	0.90	1,054	0.00	0	1,367		
521 SEA WATER FIRE FIGHTING SYSTEM	LBD/100	0.77	D	0.90	1,584	0.00	0	2,055		
522 FLOODING AND SPRAYING SYSTEMS	LBD/100	0.77	D	0.90	0	0.00	0			
523 PRE-WETTING SYSTEM	INPUT	1.00	D	0.90	348	0.00	0	348		
524 BALLASTING TRIMMING AND DRAINAGE SYSTEM	LBD/100	0.77	D	0.90	0	0.00	0			
525 SEA WATER/FRESH WATER COOLING SYSTEM	LBD/100	0.77	D	0.90	771	0.00	0	1,000		
526 DISTILLING PLANT SYSTEM	LBD/100	0.77	D	0.90	336	0.00	0	436		
527 FRESH WATER SYSTEM	LBD/100	0.77	D	0.90	609	0.00	0	790		
528 ROD GEARING	LBD/100	0.77	D	0.90	0	0.00	0			
530 HP AIR SYSTEM	LBD/100	0.77	D	0.90	946	0.00	0	1,228		
531 LP AIR SYSTEM	LBD/100	0.77	D	0.90	0	0.00	0			
532 AIR BREATHING SYSTEMS	LBD/100	0.77	D	0.90	147	0.00	0	191		
533 CONTROL AIR SYSTEMS	INPUT	1.00	D	0.90	0	0.00	0			
537 GAS FIRE EXTINGUISHING SYSTEMS	INPUT	1.00	D	0.90	688	0.00	0	688		
556 AIRCRAFT LIQUID SYSTEMS	INPUT	1.00	D	0.90		3.30	0			
558 AIRCRAFT ELECTRICAL SYSTEMS	INPUT	1.00	D	0.90		16.00	0			
560 SEWAGE DISPOSAL SYSTEMS	Accom+LBD/100	0.74	D	0.90	1,303	0.00	0	1,760		
561 WASTE WATER DISPOSAL SYSTEM	Accom+LBD/100	0.74	D	0.90	418	0.00	0	564		
562 GARBAGE DISPOSAL SYSTEM	Accom+LBD/100	0.74	D	0.90	0	0.00	0			
580 MAIN LUB OIL FILLING & TRANSFER SYSTEM	LBD/100	0.77	D	0.90	444	0.00	0	576		
OUTFIT & FURNISHINGS										
600 ANCHORS CABLES WINCHES FAIRLEADS ETC	(LBD/100 + kg)	0.65	D	0.90	3,072	0.00	0	4,761		
601 GRDRAILS STANCHIONS RIGGING AWNINGS ETC	L	0.93	D	0.90	1,611	0.00	0	1,735		
602 LADDERS AND FITTINGS	LD	0.84	D	0.90	407	0.00	0	487		
603 NON STRUCTURAL WALKWAYS	LB	0.86	D	0.90	2,889	0.00	0	3,374		
604 MISCELLANEOUS FITTINGS	LB	0.86	D	0.90	82	0.00	0	96		
610 POWERED & NON POWERED BOATS	INPUT		D	0.90	1,138	0.00	0	1,138		
611 DAVITS & HANDLING EQUIP FOR BOATS	INPUT		D	0.90	2,160	0.00	0	2,160		
612 LIFERAFTS LIFEJACKETS STWGES FLOATS ETC	complement	0.71	D	0.90	394	0.00	0	552		
620 MINOR BULKHEADS & DOORS (MAIN HULL)	LBD/100	0.77	D	0.90	1,004	0.00	0	1,303		
621 PARTITIONS AND LININGS (MAIN HULL)	LBD/100	0.77	D	0.90	1,736	0.00	0	2,253		
622 EXTERNAL & INTERNAL PAINT	LBD/100	0.77	D	0.90	3,179	0.00	0	4,125		
623 DECK COVERINGS (MAIN HULL)	LB	0.86	D	0.90	1,615	0.00	0	1,886		
625 ACOUSTIC INSULATION (MAIN HULL)	LBD/100	0.77	D	0.90	2,567	0.00	0	3,331		
626 THERMAL / ACOUSTIC INSULATION (MAIN HULL)	LBD/100	0.77	D	0.90	0	0.00	0			
630 FURNISHINGS & FITTINGS IN NAVAL STORES	LB	0.86	D	0.90	538	0.00	0	628		
631 FURNISHINGS & FITTINGS IN VICTUALLING STORES	LB	0.86	D	0.90	0	0.00	0			
632 SPARE GEAR STOWAGES	LB	0.86	D	0.90	0	0.00	0			
633 FURNISHINGS & FITTINGS IN ALL OTHER STORES	LB	0.86	D	0.90	0	0.00	0			
640 FURNISHINGS FOR OFFICERS ACCOMODATION	complement	0.71	D	0.90	1,649	0.00	0	2,308		
641 FURNISHINGS FOR CREWS ACCOMMODATION	complement	0.71	D	0.90	2,400	0.00	0	3,360		
642 FURNISHINGS FOR HEADS & BATHROOMS	complement	0.71	D	0.90	727	0.00	0	1,018		
650 FURNISHINGS FOR OFFICES	Accom+LBD/100	0.74	D	0.90	43	0.00	0	58		
651 FURNISHINGS FOR SICK BAY & DENTAL SURGERIES	complement	0.71	D	0.90	0	0.00	0			
653 FIRST AID EQUIPMENT THROUGHOUT SHIP	complement	0.71	D	0.90	14	0.00	0	20		
655 FURNISHINGS FOR OPERATIONAL SPACES	Accom+LBD/100	0.74	D	0.90	301	0.00	0	406		
658 FURNISHINGS FOR LOBBIES & PASSAGEWAYS	LB	0.86	D	0.90	17	0.00	0	20		
660 EQUIPMENT FOR GALLEYS PANTRIES ETC.	complement	0.71	D	0.90	721	0.00	0	1,009		
661 WATER COOLERS DARS ICE CREAM MCHINES ETC	complement	0.71	D	0.90	216	0.00	0	302		
662 FURNISHINGS FOR LAUNDRY	complement	0.71	D	0.90	132	0.00	0	185		
663 EQUIPMENT FOR WORKSHOPS & REPAIR SPACES	LBD/100	0.77	D	0.90	64	0.00	0	83		
670 MINOR BKHDS & DOORS (SUPERSTRUCTURE)	Vol. RatioB ratio	0.92	D	0.90	416	0.00	0	451		
671 PARTITIONS AND LININGS (SUPERSTRUCTURE)	Vol. RatioB ratio	0.92	D	0.90	0	0.00	0			
672 EXTERNAL & INTERNAL PAINT (SUPERSTRUCTURE)	Vol. RatioB ratio	0.92	D	0.90	0	0.00	0			
673 DECK COVERINGS (SUPERSTRUCTURE)	LB	0.86	D	0.90	0	0.00	0			
675 ACOUSTIC INSULATION (SUPERSTRUCTURE)	Vol. RatioB ratio	0.92	D	0.90	1,340	0.00	0	1,453		
676 THERMAL / ACOUSTIC INSULATION (SUPERSTRUCTURE)	Vol. RatioB ratio	0.92	D	0.90	0	0.00	0			
680 PORTABLE FIRE FIGHTING EQUIP (EXC 521)	LBD/100	0.77	D	0.90	732	0.00	0	950		
681 DAMAGE CONTROL EQUIPMENT	LBD/100	0.77	D	0.90	273	0.00	0	354		
682 NBC EQUIPMENT	LBD/100	0.77	D	0.90	0	0.00	0	0		
690 RAS HIGH POINTS & TRIPODS	INPUT		D	0.90	0	0.00	0			
692 CRANES & OTHER NON PORTABLE LIFTING APPLIANCES	INPUT		D	0.90		0.00	0			

Table 19 –FPC Weights 2/2

displ	495												
Vs	Vs m/s	Pe 56	Rt 56	Ct 56	Rn 56	Cf 56	Cr 56	Cr geo	Rn geo	Cf geo	Ct geo	Rt geo	Pe geo
20	10.28	1995.652	194.1296	0.0083338	534560000	0.001657	0.006677	0.0066769	493440000	0.001674	0.008351	165.0872	1697.097
25	12.85	3594.252	279.7083	0.0076849	668200000	0.00161	0.006075	0.0060747	616800000	0.001627	0.007701	237.8822	3056.786
30	15.42	5115.85	331.7672	0.00633	801840000	0.001573	0.004757	0.0047565	740160000	0.001589	0.006346	282.261	4352.464
35	17.99	6659.997	370.2055	0.0051894	935480000	0.001543	0.003646	0.003646	863520000	0.001559	0.005205	315.11	5668.83
40	20.56	8593.619	417.9776	0.0044858	1.069E+09	0.001518	0.002968	0.0029678	986880000	0.001533	0.004501	355.9086	7317.48

Figure 120 –NPL Performance check

17 APPENDIX H

17.1 WEIGHT SUB GROUP COMPARISON

Several sub groups were compared to establish the accuracy of the weights estimate for the 48m Fast Patrol Craft (FPC).
Comparisons were made with the RRB concept, the 49m Qatar concept, and the 56m Qatar Fast Attack Craft (Vita class).

17.2 GROUP1

No group 1 weights were compared. The weights derived for the 48m hull are based on a material concept study which derived the hull weight of the 56m FAC if it was constructed of FRP. These weights were then scaled using the scaling factors provided by the weights department. It is believed that these weights give a good approximation of the hull weight for the 48m boat.

17.3 GROUP 2

Group 2 weights have not been scaled. The weights for group 2 have been taken from the RRB design and been amended for actual used equipment.

17.4 GROUP 3

Group 3 weights were scaled from the 56m FAC. The weights for the gensets are based on two Volvo D7ATA gensets and data taken from the RRB weights spreadsheet for the emergency generator.

17.4.1 Group 31x

These sub group weights were compared using electric load as a baseline. Data for electrical loads were available for the 56m and the RRB designs.

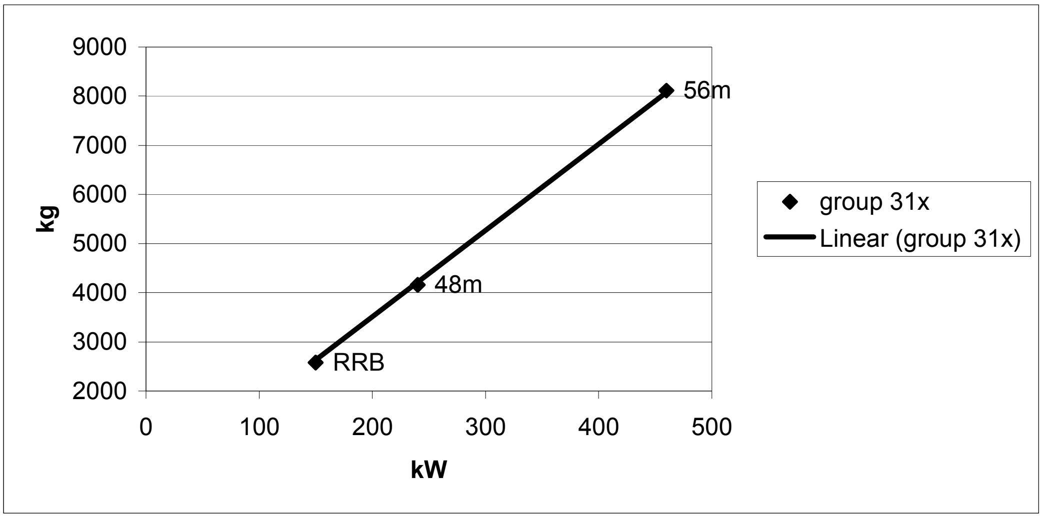

Figure 121 –SG 31 weight check

The graph indicates that the 48m weight is slightly underestimated.

17.4.2 Group 32x

KW x LOA was used as a baseline. Again the only results available were the 56m and RRB designs.

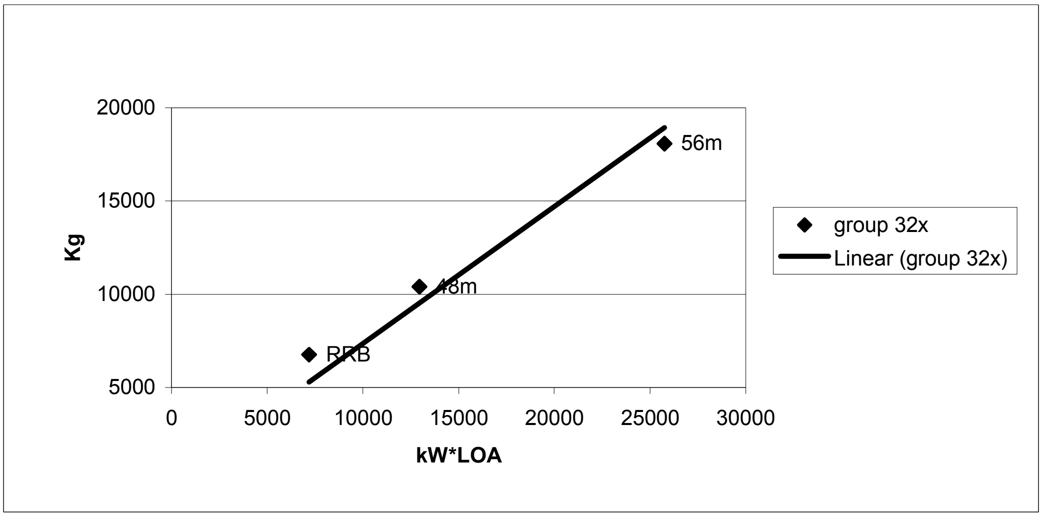

Figure 122 –SG 32 weight check

The 48m weights appear to have been overestimated but the deviation is minimal.

17.4.3 Group 33x

The baseline used is the product of block volume and complement, i.e. LBD/100*complement. Data was available for all vessels.

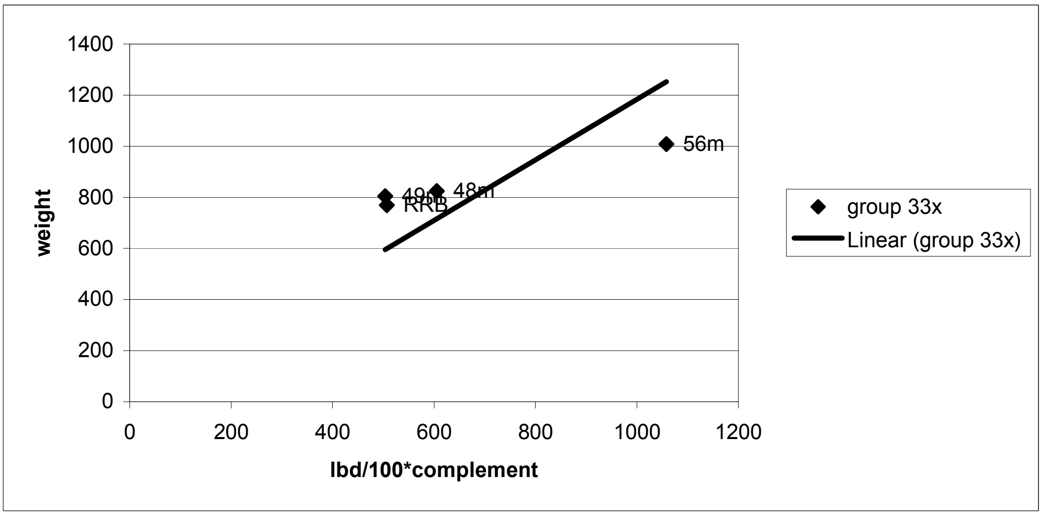

Figure 123 –SG 33 weight check

The weights for the 48m vessel appear too high. However, the real difference is only of a magnitude of approximately 300kg.

17.5 GROUP 4

Group 4 weights were all scaled from the 56m FAC data.

17.5.1.1 Group 40x

Weights were compared using a baseline of block volume LBD/100.

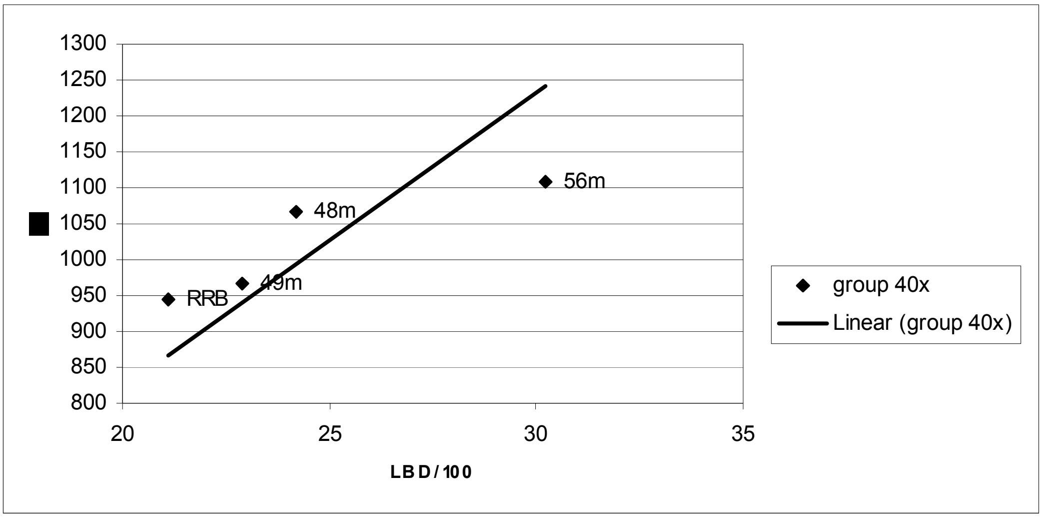

Figure 124 –SG40 weight check

The 48m design is underweight.

17.5.2 Group 41x

Weights were compared using a baseline of block volume LBD/100.

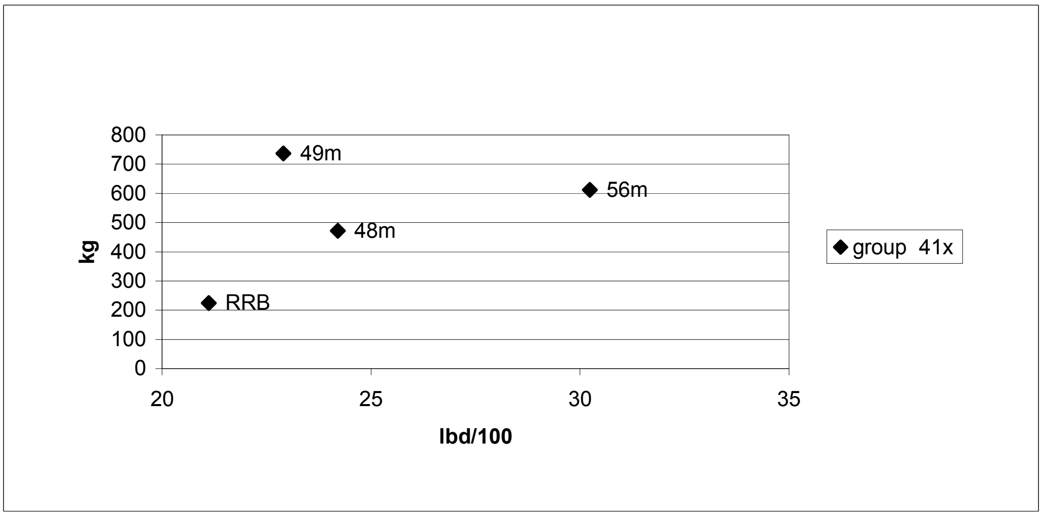

Figure 125 –SG 41 weight check

Either the 49m design was too heavy in its estimate or the RRB was too light. The first case would indicate that the 48m design is about 200kg too light the latter would indicate that the 48m design is about 100kg too heavy.

17.6 GROUP 5

Again weights were scaled from the 56m design.

17.6.1 Group 50x

Weights were compared using a baseline of LBD/100 + complement.

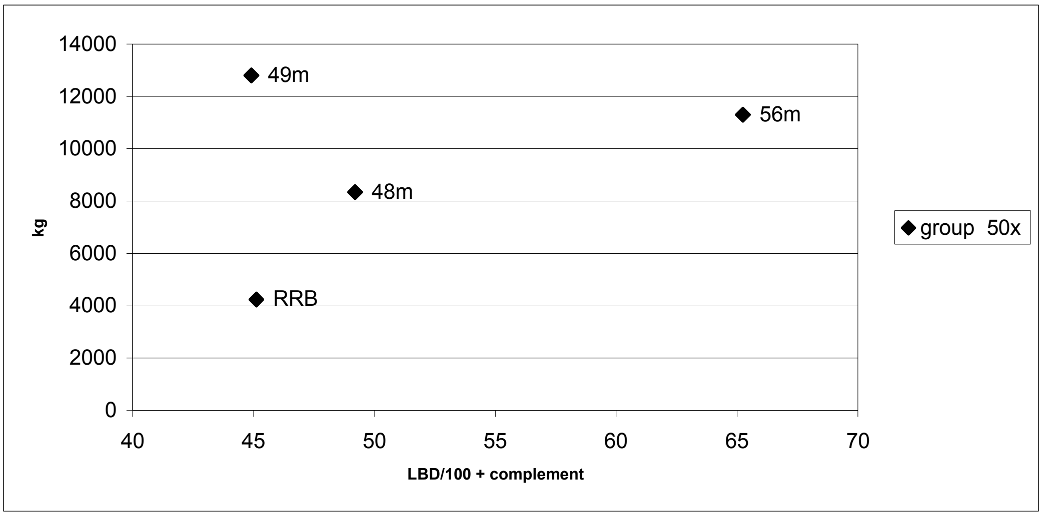

Figure 126 –SG 50 weight check

Again, care has to be taken to decide whether the 49m design is overweight or the RRB is underweight. However, the RRB weights appear more reliable as it is highly unlikely that the 49m design weights are higher than the 56m weights. This then leads to the conclusion that the 48m weights are fairly accurate and mainly need refining to allow for actual equipment data.

17.6.2 Group 52x

The baseline used was LBD/100.

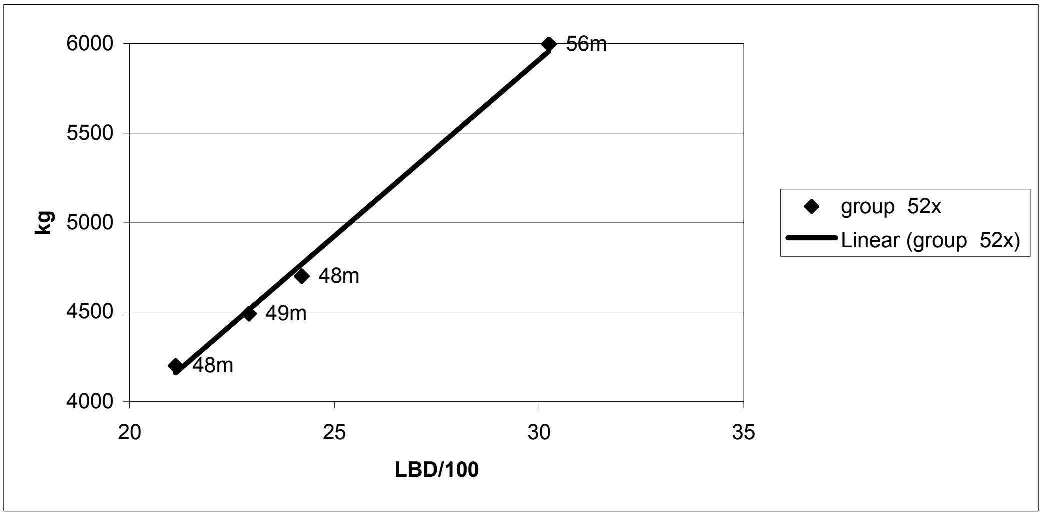

Figure 127 –SG 52 weight check

The graph indicates a very good fit.

17.6.3 Group 53x

The baseline used is LBD/100

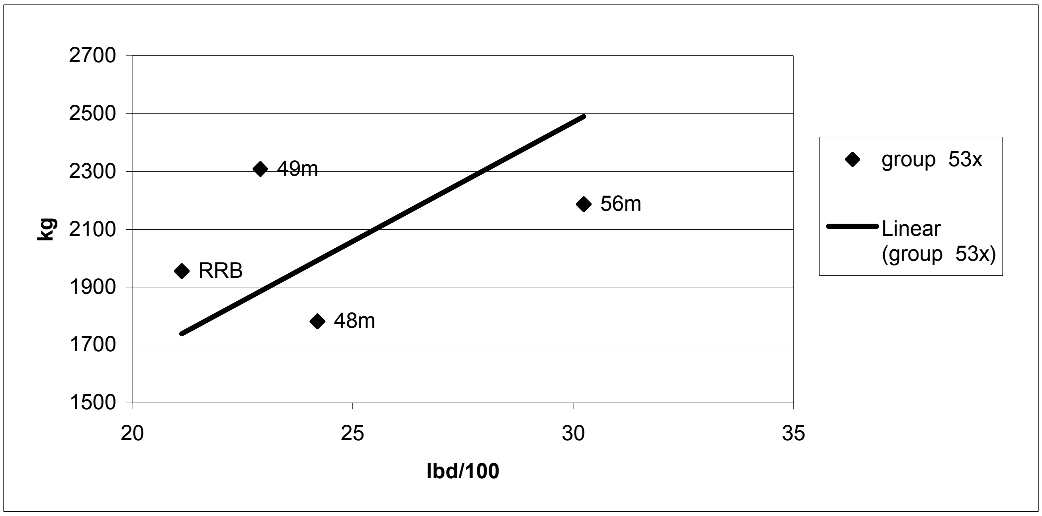

Figure 128 –SG 53 weight check

Again it appears that either the RRB or the 49m weights are inaccurate.
The 48m weights estimate is underweight.

17.7 GROUP 6

17.7.1 Group 62x

The baseline used is LBD/100

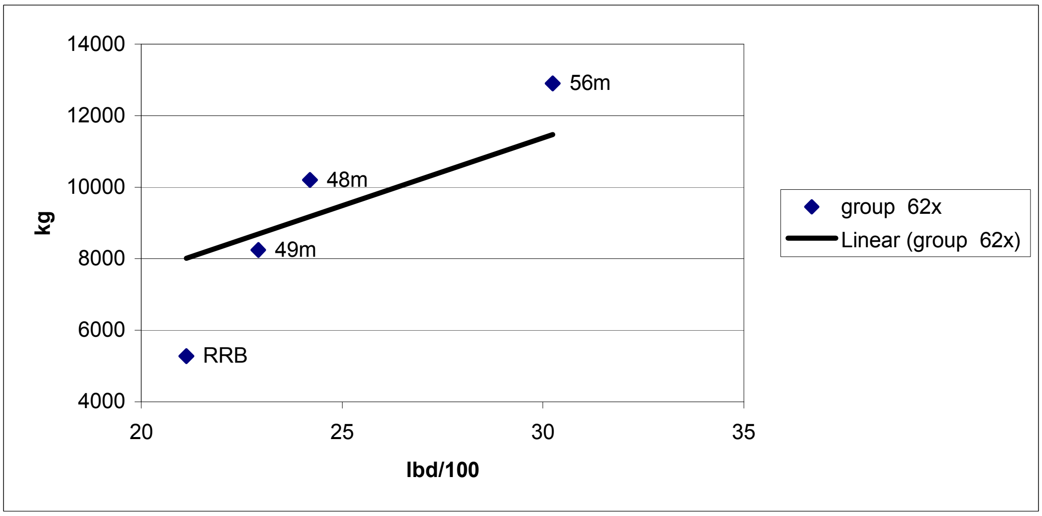

Figure 129 –SG 62 weight check

The 48m weights appear pretty accurate.

17.7.2 Group 63x

The baseline applied is L*B.

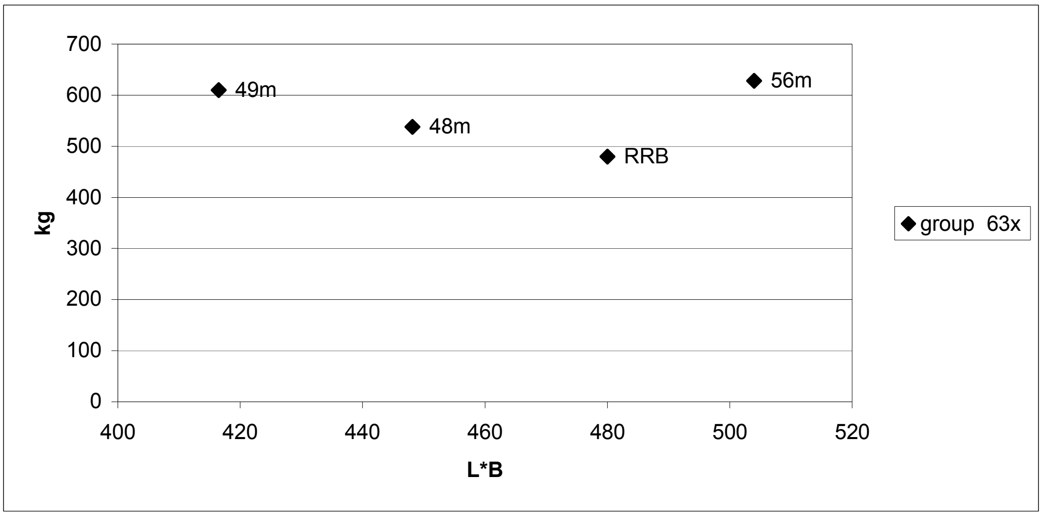

Figure 130 –SG 63 weight check

It appears that the 48m weights estimate is too small by about 100kg.

17.7.3 Group 67x

An attempt was made to match the weights to a baseline of superstructure volume. However, due to the lack of design information with regards to the 48m design it is not possible to judge whether the 48m prediction is accurate.
Also, the superstructure design of the 56m and the RRB differ greatly and hence it could be difficult to establish the accuracy of the 48m design weights for this sub group.

17.8 CONCLUSION

Overall it seems that the 48m design weights are fairly accurate but tend to be underestimated. However, this may be due to the fact that the weights are derived from the 56m vessel, which is a fairly heavy design, whilst the design is more closely related to the RRB.

18 APPENDIX I

Item Name	Quantity	Weight tonne	Long. Arm m	Vert. Arm m	Trans. Arm m	FS Mom. tonne.m
Lightship	1	257.7	20.340	4.221	0.000	0.000
provision	1	1.000	24.000	4.300	0.000	0.000
800	1	3.750	29.000	5.400	0.000	0.000
810	1	1.600	38.500	3.600	0.000	0.000
811	1	2.780	31.610	4.090	0.000	0.000
811 LS	0	0.675	14.700	5.280	0.000	0.000
872	1	3.000	13.500	3.400	0.000	0.000
872 water	1	11.04	1.500	0.900	0.000	0.000
875	1	1.500	21.000	3.400	0.000	0.000
fwd diesel	95%	74.3	24.772	1.639	0.000	73.819
aft diesel p	95%	8.99	9.782	1.889	-1.397	0.692
fw	95%	4.672	30.751	1.465	0.000	0.216
lube oil	95%	1.938	20.253	1.607	0.000	0.025
aft diesel s	95%	8.99	9.782	1.889	1.397	0.692
	Total Weight=	**381.2**	**LCG=20.489**	**VCG=3.463**	**TCG=0.000**	**75.444**
				FS corr.=0.198		
				VCG fluid=3.661		

Table 20 –Group 8 weights FPC

	Weight	Weight	VCG	VMOM	possible LCG	LMOM
Description	rule	kg	m	kgm	m	kgm
HULL						
100 HULL PLATING	L(B + 2D)	19398.68	2.56	49583.04	22.69	440156.1
101 HULL LONGL. & TRANSVERSE FRAMING	L(B + 2D)	16093.96	2.18	35052.65	22.69	365172
102 INNER BOTTOM PLATING	LB	1859.63	1.19	2209.24	22.69	42195.08
110 SUPERSTRUCTURE PLATING	B	4393.69	6.98	30685.55	22.69	99692.9
111 SUPERSTRUCTURE LONG & TRANS FRAMING	B	1255.80	7.21	9053.04	22.69	28494.03
112 SUPERSTRUCTURE DECKS & FLATS	B	5245.42	7.63	40033.07	22.69	119018.7
113 SUPERSTRUCTURE BULKHEADS	B	2365.92	6.97	16480.98	22.69	53682.65
114 SUPERSTRUCTURE HANGAR	INPUT	0.00	0.00	0.00	22.69	0
116 SUPERSTRUCTURE ARMOUR & PROTECTION		0.00	0.00	0.00	22.69	0
120 MAIN TRANSVERSE BULKHEADS	LBD2	5371.15	3.16	16967.47	22.69	121871.5
121 LONGITUDINAL BKHDS	LD2	230.61	2.14	493.96	22.69	5232.473
122 OTHER STRUCTURAL BULKHEADS	(LBD2+LD2)/2	783.57	3.92	3074.71	22.69	17779.09
123 FUNNEL	Vol. Ratio	1300.00	6.90	8970.00	12.80	16640
130 MAIN DECKS	LB	21912.16	4.47	98013.07	22.69	497186.8
140 BRIDGE WINDOWS SIDELIGHTS & SCUTTLES	LB	394.95	8.97	3543.91	22.69	8961.47
141 WATERTIGHT & GASTIGHT DOORS & HATCHES	L	1710.43	5.46	9344.07	22.69	38809.62
142 ESCAPE HATCHES & SCUTTLES	L	222.86	4.28	952.71	22.69	5056.629
143 MANHOLES	L	265.20	1.43	379.50	22.69	6017.388
151 SEATS & SUPPORTS FOR GROUP 1 ITEMS	LB	0.00	0.00	0.00	22.69	0
152 SEATS & SUPPORTS FOR GROUP 2 ITEMS	LB	1174.98	2.06	2421.64	22.69	26660.37
153 SEATS & SUPPORTS FOR GROUP 3 ITEMS	LB	1315.19	2.85	3752.24	22.69	29841.69
154 SEATS & SUPPORTS FOR GROUP 4 ITEMS	LB	5698.18	7.79	44411.58	22.69	129291.6
155 SEATS & SUPPORTS FOR GROUP 5 ITEMS	LB	1204.60	2.65	3187.38	22.69	27332.48
156 SEATS & SUPPORTS FOR GROUP 6 ITEMS	LB	1004.17	4.37	4392.22	22.69	22784.54
157 SEATS & SUPPORTS FOR GROUP 7 ITEMS	LB	2460.55	5.43	13353.42	22.69	55829.96
160 RUDDERS & SKEG	L	4910.29	1.79	8794.32	22.69	111414.4
164 BILGE KEEL	L	0.00	0.00	0.00	22.69	0
165 STABILISING TANKS (INCD. IN 102,120 & 121))	L	0.00	0.00	0.00	22.69	0
170 SHAFT BRACKETS	INPUT	3166.00	0.79	2507.47	22.69	71836.54
172 SEA CHESTS	INPUT	0.00	0.88	0.00	22.69	0
173 ANCHOR HAWSE PIPES & NAVEL PIPES	INPUT	303.00	4.53	1371.68	22.69	6875.07
174 STERN TUBES	INPUT	1008.00	1.04	1052.35	22.69	22871.52
175 SEA TUBES	INPUT	694.40	0.00	0.00	22.69	15755.94
190 WELDING	L(B + 2D)	0.00	3.66	0.00	22.69	0
191 WEIGHING ADJUSTMENT	LB	0.00	2.94	0.00	22.69	0
192 BOLTING	LB	659.57	3.38	2226.05	22.69	14965.65
ROLLING MARGIN	LB	-6833.66	0.00	0.00	22.69	-155055.8
		99569.30		412307.35	22.56	2246370
PROPULSION						
221 GAS TURBINES	Shp	4374.00	3.40	14871.60	13.50	59049
222 PROPULSION DIESEL ENGINES	Shp	0.00	0.00	0.00		0
224 PROPN UNITS CONTROL EQUIPMENT (INTEGRAL)	INPUT	740.00	0.00	0.00		0
225 CLUTCHES GEARING FLEX COUPL & TURN GEAR	INPUT	23400.00	2.60	60840.00	13.00	304200
226 MACHINERY SPACE LIFTING GEAR	INPUT	0.00	0.00	0.00		0
240 SHAFTING	Shp1/2 x L	2700.00	2.40	6480.00	12.50	33750
241 PROPULSORS INC ACT RUDDERS	INPUT	15890.00	2.40	38136.00	0.20	3178
242 SHAFT BEARINGS & STERN TUBES	INPUT	0.00	0.00	0.00		0
243 TORSIONMETRES & BRAKES	INPUT	0.00	0.00	0.00		0
251 SUPPLY SYSTEM	kgp x (Shp)1/2	2640.00	6.50	17160.00	12.80	33792
252 EXHAUST SYSTEM	kgp x (Shp)1/2	1000.00	3.40	3400.00	8.70	8700
271 COOLING WTR SYSTEM FOR PROPN UNITS	kgp x (Shp)1/2	180.00	2.16	388.80	0.20	36
280 COMBST FUEL OIL SERV SYST TO PROPN UNITS	kgp x (Shp)1/2	720.00	2.21	1587.60	1.50	1080
290 LUB OIL SYSTEM TO PROPN UNITS	kgp x (Shp)1/2	440.00	2.00	879.12	1.50	660
		52084.00		143743.12	8.53	444445
ELECTRICAL						
302 DIESEL GENERATOR SETS	kgp x kW	3321.00	3.30	10959.30	10.45	34704.45
310 MAIN SUPPLY EQUIPMENT	kW x Loa	1750.00	3.30	5775.00	11.98	20965
311 DISTRIBUTION EQUIPMENT	kW x Loa	845.89	4.05	3425.85	13.00	10996.55
312 GENERAL SERVICE CONVERSION EQUIPMENT	kW x Loa	1314.86	5.40	7100.23	13.00	17093.14
313 PORTABLE APPARATUS SYSTEM (EQUIPMENT)	kW x Loa	0.00	0.00	0.00		0
320 CABLING	kW x Loa	8132.00	4.65	37813.80	19.30	156947.6
321 GLANDS & CABLE SUPPORT EQUIPMENT	kW x Loa	2281.00	4.65	10606.65	19.30	44023.3
330 GENERAL LIGHTING SYSTEM INC EMERGENCY & CEREMONIAL	BD/100 x Compleme	459.13	5.15	2363.58	19.30	8861.122
331 EMERGENCY LIGHTING SYSTEM	BD/100 x Compleme	0.00	0.00	0.00		0
332 CEREMONIAL LIGHTING	INPUT	175.00	8.37	1464.75	25.00	4375
334 EARTHING	INPUT	190.00	0.00	0.00	25.00	4750
		18468.87		79509.15	16.39	302716.2

Table 21 –FPC Weights 1/3

CONTROL & COMMUNICATIONS						
400 GYRO & OTHER COMPASSES	LBD/100	270.00	4.87	1314.63	25.00	6750
402 NAV AIDS & DIRECTION FINDING EQUIP.	LBD/100	35.00	6.62	231.84	25.00	875
403 LOGS	LBD/100	46.00	3.83	176.36	25.00	1150
404 WIND SPEED & DIRECTION INDICATING SYSTEM	LBD/100	10.00	8.09	80.91	25.00	250
405 NAVIGATION RADAR	LBD/100	283.00	8.69	2457.86	25.00	7075
406 VIEWING DEVICES	LBD/100	220.00	8.82	1940.40	25.00	5500
407 CHRONOMETERS	LBD/100	0.00	0.00	0.00	25.00	0
408 PLOTTING & CHART TABLES	LBD/100	70.00	8.10	567.00	25.00	1750
409 NAVIGATION LIGHTS ETC	LBD/100	132.00	12.29	1622.81	25.00	3300
410 BROADCASTS	LBD/100	50.00	5.40	270.00	25.00	1250
411 RICE EQUIPMENT	LBD/100	0.00	0.00	0.00		0
412 SOUND REPRODUCTION EQUIPMENT	LBD/100	0.00	0.00	0.00		0
414 TELEVISION RADIO & CINEMA EQUIPMENT	LBD/100	94.00	5.76	541.44	25.67	2412.98
415 ALARMS AND WARNINGS	LBD/100	24.00	5.40	129.60	25.00	600
416 NBCD WARNING SYSTEM	LBD/100		8.74	0.00	25.00	0
418 RUDDER ANGLE INDICATORS	LBD/100	0.00	0.00	0.00		0
420 SHIP CONTROL CONSOLE	LBD/100	575.00	8.30	4772.50	31.50	18112.5
421 SYSTEMS CONSOLES	LBD/100	0.00	0.00	0.00		0
423 RUDDER CONTROL SYSTEM	LBD/100	730.00	3.00	2190.00	1.00	730
425 MOVEABLE STABILISER & CONTROL SYSTEM	INPUT		1.17	0.00	22.00	0
427 TANK STABILISATION SYSTEM	LBD/100	0.00	0.00	0.00		0
428 MACHINERY CONTROL SYSTEM	LBD/100	610.41	5.92	3614.82	10.00	6104.057
430 SURFACE/AIR WEAPON CONTROL SYSTEM	INPUT	1180.00	7.20	8496.00	20.00	23600
431 SURFACE/SURFACE WEAPON CONTROL SYSTEM	INPUT	361.00	8.50	3068.50	31.50	11371.5
432 SURFACE/ANTI-SUBMARINE WEAPON CONTROL SYSTEM	INPUT		0.00	0.00		0
435 WEAPON AND SURVEILLANCE RADARS	INPUT		9.23	0.00	20.00	0
436 SONARS	INPUT		0.00	0.00		0
437 CENTRALISED WEAPON SYSTEM	INPUT		2.07	0.00	24.00	0
438 ELECTRONIC WARFARE SYSTEM (EW)	INPUT	2142.00	10.53	22555.26	24.00	51408
440 DEGAUSSING SYSTEM	INPUT		0.00	0.00		0
441 CATHODIC PROTECTION SYSTEM	LBD/100	20.00	2.40	48.00	0.50	10
442 ZINC PROTECTORS	LBD/100	0.00	0.00	0.00		0
444 EARTHING	LBD/100	0.00	0.00	0.00		0
450 RADIO COMMUNICATION SYSTEMS	LBD/100	263.00	11.00	2893.00	30.00	7890
451 UNDERWATER TELEPHONES & ECHO SOUNDERS	LBD/100	94.03	1.83	171.79	24.00	2256.651
452 VISUAL SIGNALLING EQUIPMENT	LBD/100	97.11	8.45	820.68	24.00	2330.64
453 SIRENS AND WHISTLES	LBD/100	20.00	8.92	178.38	24.00	480
454 SATELLITE COMMUNICATIONS	LBD/100	0.00	0.00	0.00		0
		7326.54		58141.77	21.18	155206.3
AUXILIARY SYSTEMS						
500 AIR CONDITIONING PLANTS	Accom+LBD/100	2595.99	3.90	10124.35	39.00	101243.5
501 CHILLED AND TEPID WATER SYSTEM	INPUT		0.00	0.00		0
502 A/C & MECH. VENT SYSTEM (EX MMS-508)	Accom+LBD/100	3623.72	3.90	14132.51	39.00	141325.1
503 FREE STANDING AIR CONDITIONING UNITS	Accom+LBD/100	0.00	0.00	0.00		0
504 NATURAL VENTILATION SYSTEM	Accom+LBD/100	0.00	0.00	0.00		0
505 REFRIGERATION PLANT & EQUIPMENT	Accom	675.00	3.90	2632.50	39.00	26325
508 AIR CONDITIONING & VENT SYSTEM IN MMS	Accom+LBD/100	1446.08	3.90	5639.72	39.00	56397.2
510 MAIN FUEL FILLING HEATING & TRANS SYSTEM	LBD/100	715.22	2.81	2008.35	25.00	17880.57
511 AUXILIARY FUEL SYSTEMS	INPUT	0.00	0.00	0.00		0
520 SEA WATER SYSTEM	LBD/100	1053.57	3.46	3641.13	39.00	41089.09
521 SEA WATER FIRE FIGHTING SYSTEM	LBD/100	1597.00	2.31	3693.86	39.00	62283
522 FLOODING AND SPRAYING SYSTEMS	LBD/100	0.00	0.00	0.00		0
523 PRE-WETTING SYSTEM	INPUT	348.00	6.35	2211.19	39.00	13572
524 BALLASTING TRIMMING AND DRAINAGE SYSTEM	LBD/100	0.00	0.00	0.00		0
525 SEA WATER/FRESH WATER COOLING SYSTEM	LBD/100	900.00	1.79	1611.90	39.00	35100
526 DISTILLING PLANT SYSTEM	LBD/100	336.03	2.60	874.02	39.00	13105.23
527 FRESH WATER SYSTEM	LBD/100	608.86	3.82	2323.43	39.00	23745.71
528 ROD GEARING	LBD/100	0.00	0.00	0.00		0
530 HP AIR SYSTEM	LBD/100	1460.00	2.90	4231.08	39.00	56940
531 LP AIR SYSTEM	LBD/100	0.00	0.00	0.00		0
532 AIR BREATHING SYSTEMS	LBD/100	0.00	2.79	0.00		0
533 CONTROL AIR SYSTEMS	INPUT	0.00	3.08	0.00		0
537 GAS FIRE EXTINGUISHING SYSTEMS	INPUT	688.00	3.38	2322.00	39.00	26832
556 AIRCRAFT LIQUID SYSTEMS	INPUT		0.00	0.00		0
558 AIRCRAFT ELECTRICAL SYSTEMS	INPUT		0.00	0.00		0
560 SEWAGE DISPOSAL SYSTEMS	Accom+LBD/100	1303.18	3.90	5082.39	39.00	50823.9
561 WASTE WATER DISPOSAL SYSTEM	Accom+LBD/100	417.61	3.90	1628.68	39.00	16286.75
562 GARBAGE DISPOSAL SYSTEM	Accom+LBD/100	0.00	0.00	0.00	39.00	0
580 MAIN LUB OIL FILLING & TRANSFER SYSTEM	LBD/100	443.93	2.22	986.86	39.00	17313.33
		18212.19		63143.96	38.45	700262.4

Table 22 –FPC Weights 2/3

OUTFIT & FURNISHINGS						
600 ANCHORS CABLES WINCHES FAIRLEADS ETC	(LBD/100 + kg)	3072.45	4.30	13211.55	40.00	122898.1
601 GRDRAILS STANCHIONS RIGGING AWNINGS ETC	L	1611.07	5.40	8699.79	20.00	32221.43
602 LADDERS AND FITTINGS	LD	406.99	4.90	1992.64	23.00	9360.836
603 NON STRUCTURAL WALKWAYS	LB	2889.32	2.79	8061.21	20.00	57786.44
604 MISCELLANEOUS FITTINGS	LB	82.21	6.75	554.91	23.00	1890.819
610 POWERED & NON POWERED BOATS	INPUT	2500.00	6.15	15375.00	6.97	17425
611 DAVITS & HANDLING EQUIP FOR BOATS	INPUT	2350.00	6.20	14570.00	6.97	16379.5
612 LIFERAFTS LIFEJACKETS STWGES FLOATS ETC	complement	394.29	7.00	2760.00	18.60	7333.714
620 MINOR BULKHEADS & DOORS (MAIN HULL)	LBD/100	1004.24	4.31	4329.28	24.00	24101.78
621 PARTITIONS AND LININGS (MAIN HULL)	LBD/100	1736.42	5.93	10298.70	24.00	41674.06
622 EXTERNAL & INTERNAL PAINT	LBD/100	3179.20	3.29	10472.27	22.69	72135.97
623 DECK COVERINGS (MAIN HULL)	LB	1615.07	4.97	8023.69	24.00	38761.79
625 ACOUSTIC INSULATION (MAIN HULL)	LBD/100	2567.25	3.33	8548.94	24.00	61613.98
626 THERMAL / ACOUSTIC INSULATION (MAIN HULL)	LBD/100	0.00	0.00	0.00	24.00	0
630 FURNISHINGS & FITTINGS IN NAVAL STORES	LB	537.79	3.74	2008.64	25.00	13444.68
631 FURNISHINGS & FITTINGS IN VICTUALLING STORES	LB	0.00	0.00	0.00		0
632 SPARE GEAR STOWAGES	LB	0.00	0.00	0.00		0
633 FURNISHINGS & FITTINGS IN ALL OTHER STORES	LB	0.00	0.00	0.00		0
640 FURNISHINGS FOR OFFICERS ACCOMODATION	complement	1648.57	6.03	9940.89	26.00	42862.86
641 FURNISHINGS FOR CREWS ACCOMMODATION	complement	2400.00	3.47	8316.00	27.00	64800
642 FURNISHINGS FOR HEADS & BATHROOMS	complement	727.14	4.48	3259.05	25.00	18178.57
650 FURNISHINGS FOR OFFICES	Accom+LBD/100	42.95	8.64	371.05	25.00	1073.64
651 FURNISHINGS FOR SICK BAY & DENTAL SURGERIES	complement	0.00	0.00	0.00		0
653 FIRST AID EQUIPMENT THROUGHOUT SHIP	complement	14.29	4.50	64.29	25.00	357.1429
655 FURNISHINGS FOR OPERATIONAL SPACES	Accom+LBD/100	300.62	2.00	600.64	25.00	7515.481
658 FURNISHINGS FOR LOBBIES & PASSAGEWAYS	LB	17.13	3.60	61.66	24.00	411.0476
660 EQUIPMENT FOR GALLEYS PANTRIES ETC.	complement	720.71	4.88	3515.64	25.00	18017.86
661 WATER COOLERS DARS ICE CREAM MCHINES ETC	complement	215.71	4.95	1067.79	25.00	5392.857
662 FURNISHINGS FOR LAUNDRY	complement	132.14	3.96	523.29	25.00	3303.571
663 EQUIPMENT FOR WORKSHOPS & REPAIR SPACES	LBD/100	63.97	3.92	251.02	25.00	1599.232
670 MINOR BKHDS & DOORS (SUPERSTRUCTURE)	Vol. Ratio	415.92	7.90	3285.79	25.00	10398.06
671 PARTITIONS AND LININGS (SUPERSTRUCTURE)	Vol. Ratio	0.00	0.00	0.00	25.00	0
672 EXTERNAL & INTERNAL PAINT (SUPERSTRUCTURE)	Vol. Ratio	0.00	0.00	0.00	25.00	0
673 DECK COVERINGS (SUPERSTRUCTURE)	LB	0.00	0.00	0.00	25.00	0
675 ACOUSTIC INSULATION (SUPERSTRUCTURE)	Vol. Ratio	1339.99	7.90	10585.91	25.00	33499.72
676 THERMAL / ACOUSTIC INSULATION (SUPERSTRUCTURE)	Vol. Ratio	0.00	0.00	0.00	25.00	0
680 PORTABLE FIRE FIGHTING EQUIP (EXC 521)	LBD/100	732.18	4.62	3380.47	24.00	17572.29
681 DAMAGE CONTROL EQUIPMENT	LBD/100	272.83	5.57	1519.95	24.00	6547.989
682 NBC EQUIPMENT	LBD/100	0.00	0.00	0.00		0
690 RAS HIGH POINTS & TRIPODS	INPUT	0.00	0.00	0.00		0
692 CRANES & OTHER NON PORTABLE LIFTING APPLIANCES	INPUT	0.00	0.00	0.00		0
		32990.46		155650.03	22.69	748558.4
ARMAMENT						0
700 MOUNTINGS & LAUNCHERS	INPUT	5490.00	6.47	35520.30	34.02	186769.8
701 AMMUNITION AND MISSILE HANDLING SYSTEM	INPUT	0.00	2.23	0.00		0
702 AMMUNITION AND MISSILE STOWAGES	INPUT	0.00	4.54	0.00		0
710 MOUNTINGS & LAUNCHERS	INPUT	2200.00	6.70	14740.00	-0.70	-1540
711 MISSILE HANDLING SYSTEMS	INPUT	0.00	0.00	0.00		0
720 ANTI SUBMARINE LAUNCHERS	INPUT	0.00	0.00	0.00		0
721 AMMUNITION AND MISSILE HANDLING SYSTEMS	INPUT	0.00	0.00	0.00		0
722 AMMUNITION AND MISSILE STOWAGES	INPUT	260.00	8.50	2210.00	20.25	5265
770 ROCKET FLARE & DECOY LAUNCHERS	INPUT		7.74	0.00	24.00	0
771 SMALL ARMS STORE	INPUT	120.00	8.33	999.60	22.41	2689.2
772 PYROTECHNICS	INPUT	0.00	0.00	0.00		0
		8070.00	6.63	53469.90	23.94	193184

Table 23 –FPC Weights 3/3

19 APPENDIX J

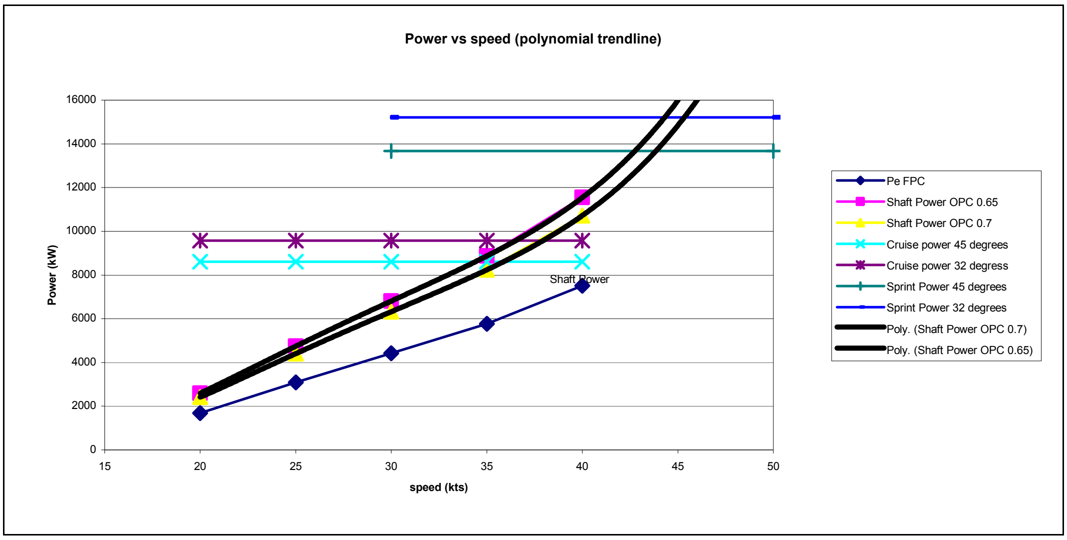

Figure 131 –FPC Power check (polynomial trendline)

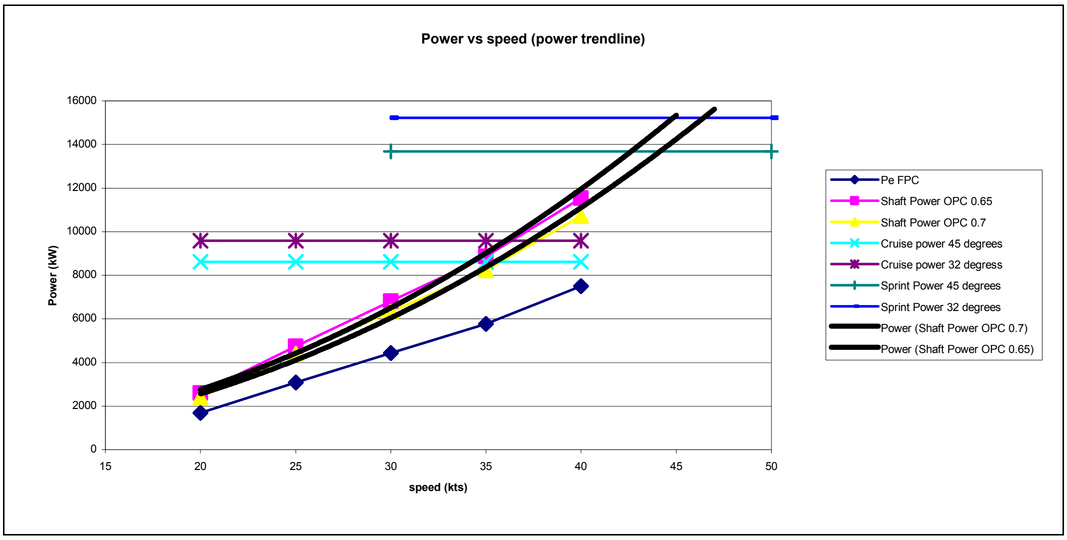

Figure 132 –FPC Power check (power trendline)

20 APPENDIX K

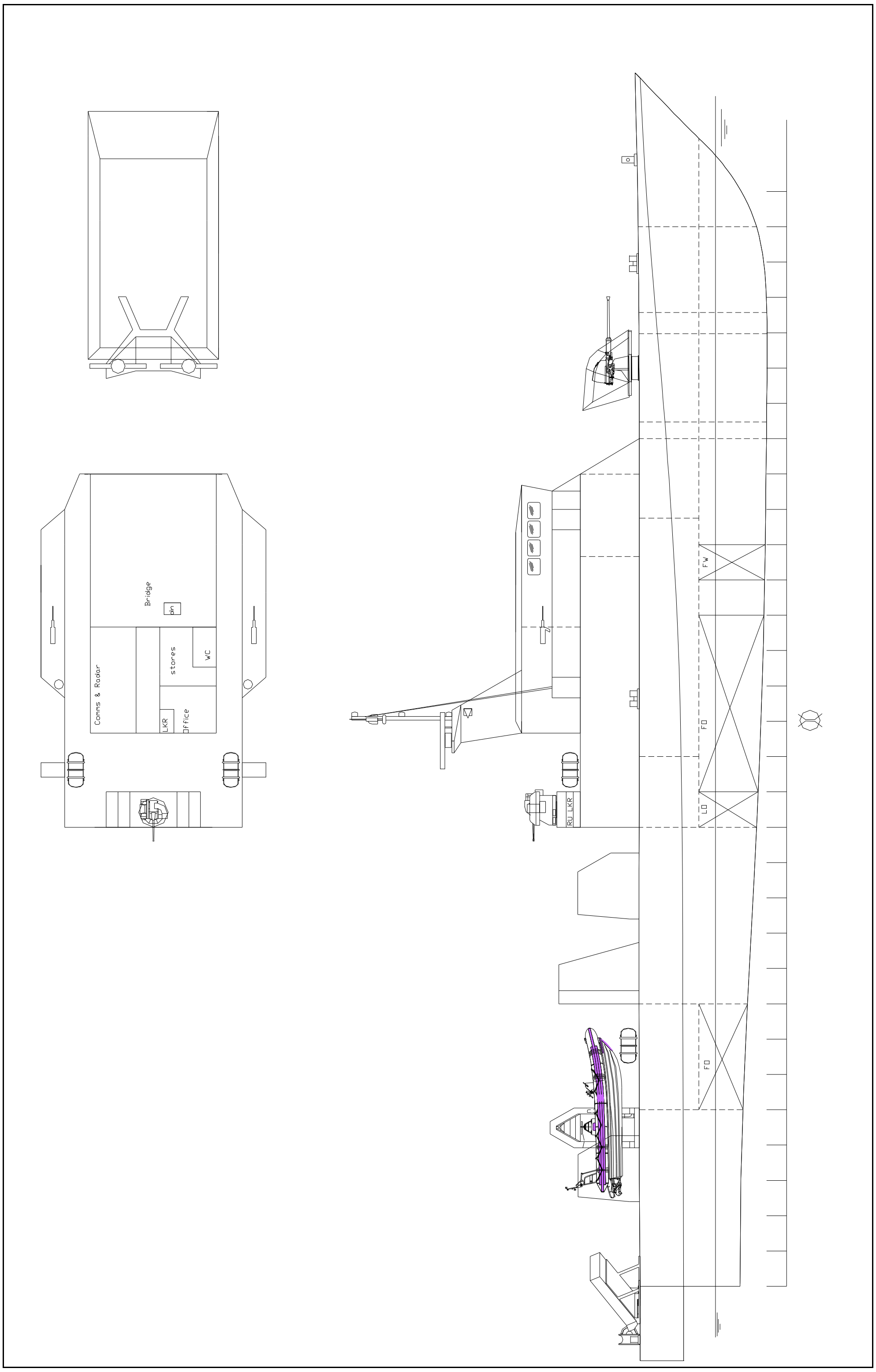

Figure 133 –FPC GA 1/2 not to scale

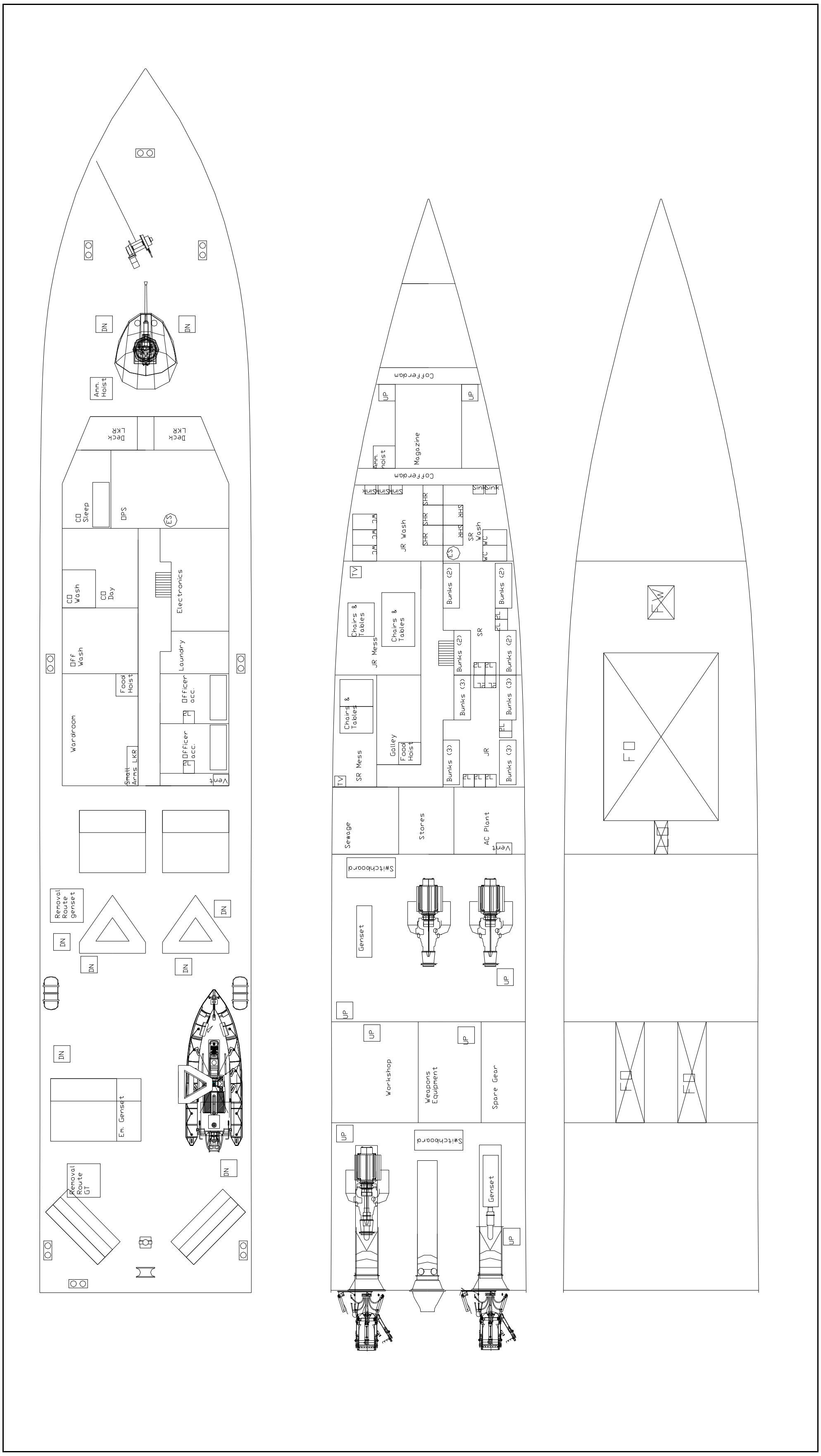

Figure 134 –FPC GA 2/2 not to scale

21 APPENDIX L

- Started of as 145m
- Use as much COTS as possible
- Twin waterjets
- CODLAG
- Azipods
- 100 crew
- Long range and endurance
- Modular weapons fit to allow optional outfit
- Weights revealed design too heavy for length
- Performance check failed
- Stability uncertain
- Length changed to 170m
- 170m changed to 160m, deemed too long and unfavourable customer perception
- Dropped waterjets and pods and went for twin screw propulsion
- Necessary as hull was becoming to fat, flat and wide and hence reduced range at cruise speed
- CODAG
- 150 crew
- Aux weights kept on increasing (because of errors in initial calcs)
- 2deck and 3deck heights increased to allow for shifting of crossdeck structure – needed to reduce likelihood of slamming
- Layout remained largely the same
- Several studies conducted using same baseline ship
- Weights were main design drivers
- Impact on layout investigated for each variation in design
- High speed electric motors behind gearboxes for optional ASW drive (shaft driven too heavy and roomy)
- Throughout design continuous weight checks carried out
- Only two stability checks carried out
- Changing from electric drive to CODAG had no impact on layout issues as even more space became available but weights constant issue
- Main design drivers
    - Weight
    - Range
    - Endurance
    - Cruise speed
- Weights based on catalogue weights or “similar” vessels (T45 and T23)
- Baseline 2
    - Extended helideck
    - Enclosed quarter deck
    - AUV hangar
    - Revised mast and funnel
    - Revised bridge (false floor)
    - Crossdeck moved aft

Figure 135 –FSC background notes

22 APPENDIX M

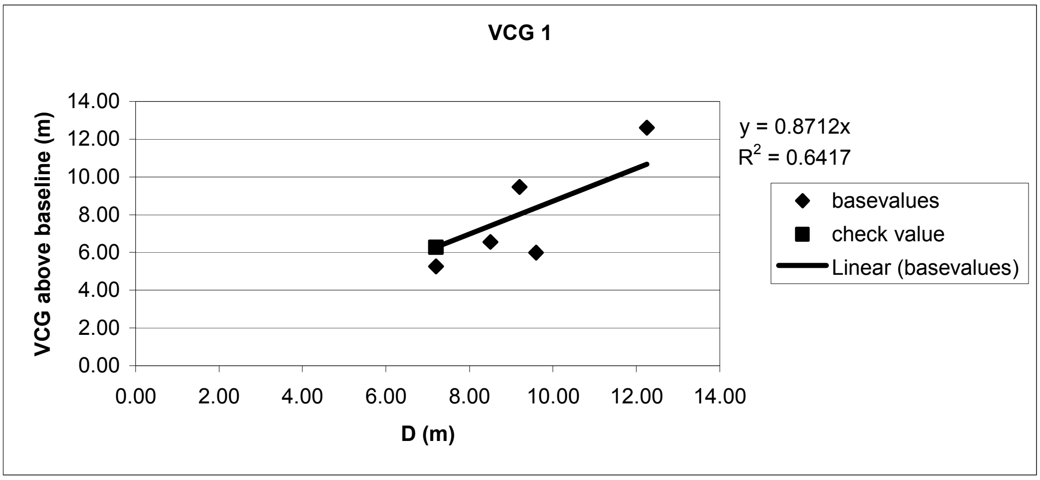

Figure 136 –Group1 VCG equation

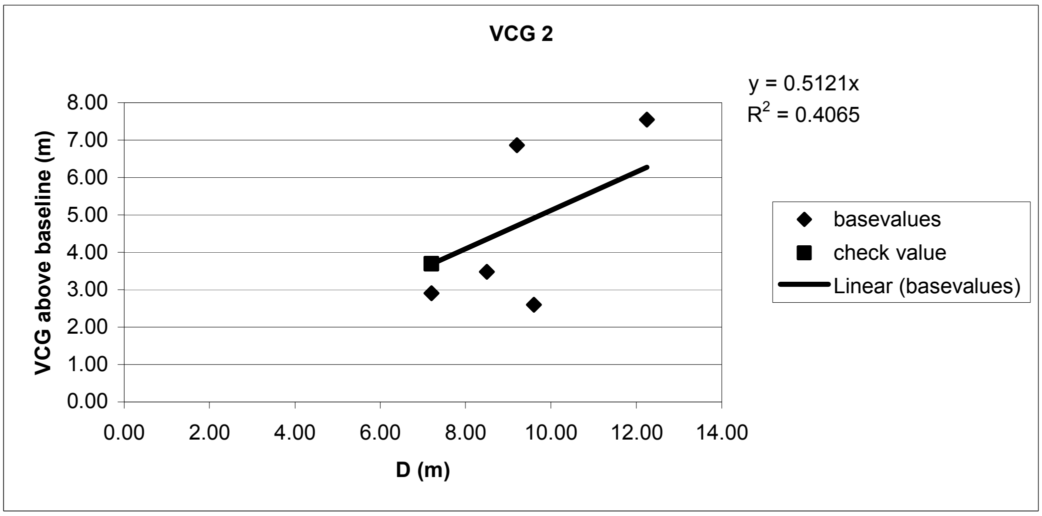

Figure 137 –Group2 VCG equation

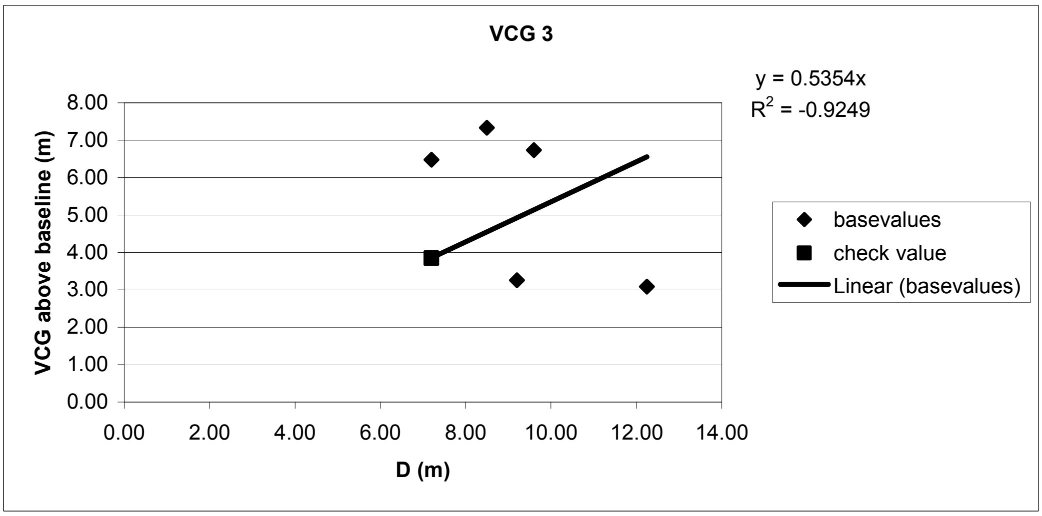

Figure 138 –Group 3 VCG equation

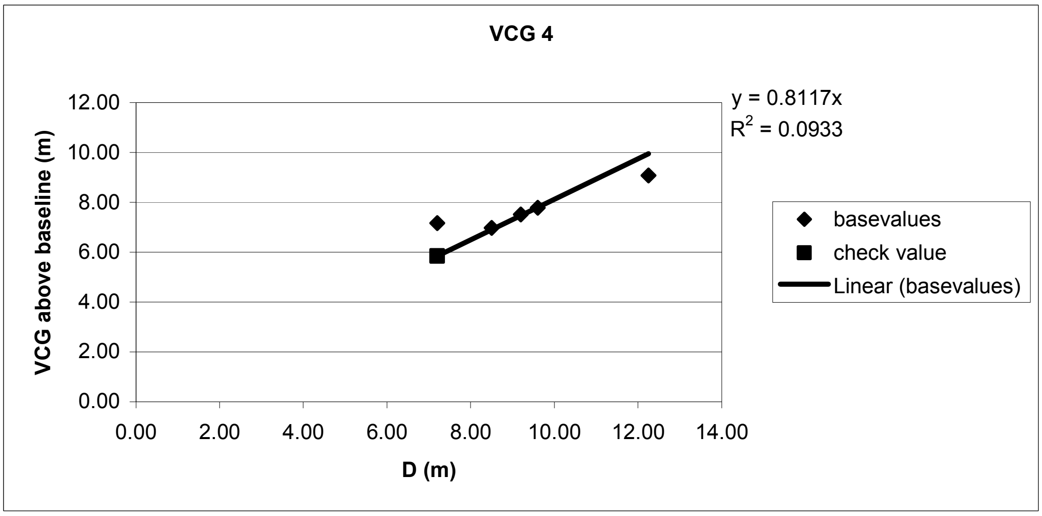

Figure 139 –Group4 VCG equation

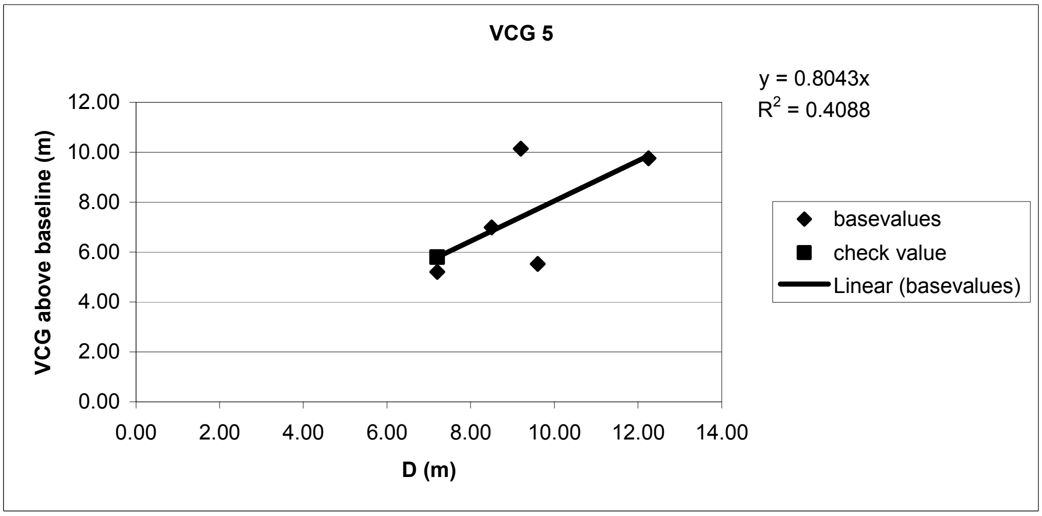

Figure 140 –Group5 VCG equation

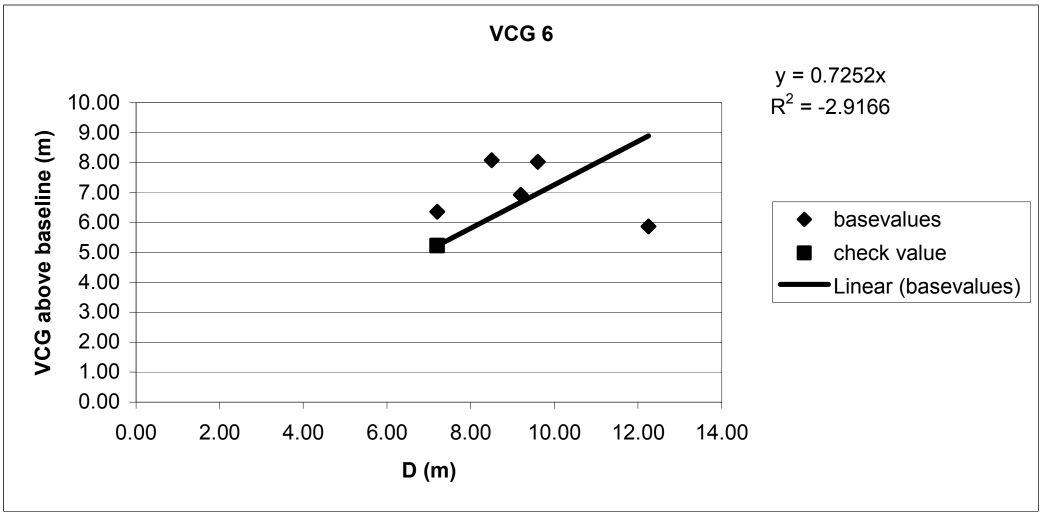

Figure 141 –Group6 VCG equation

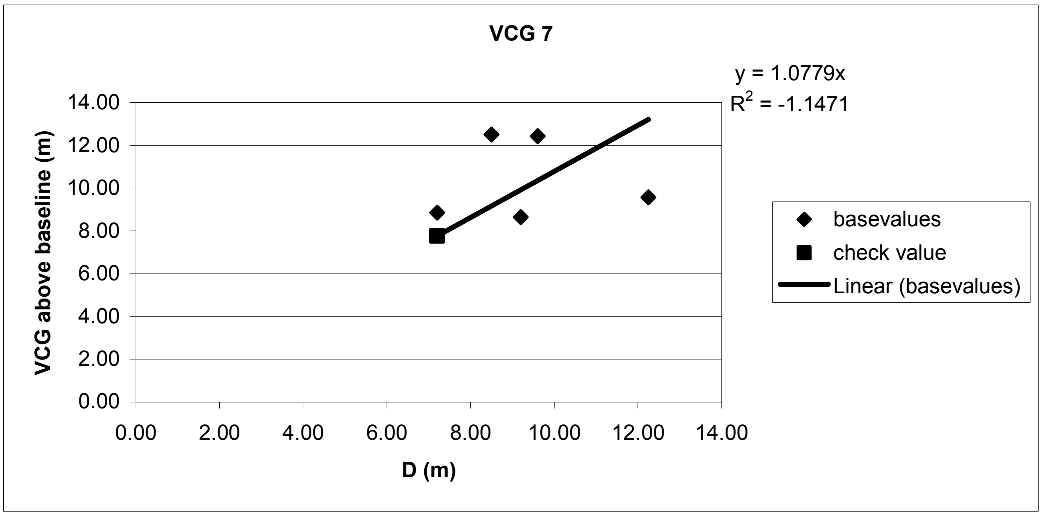

Figure 142 –Group7 VCG equation

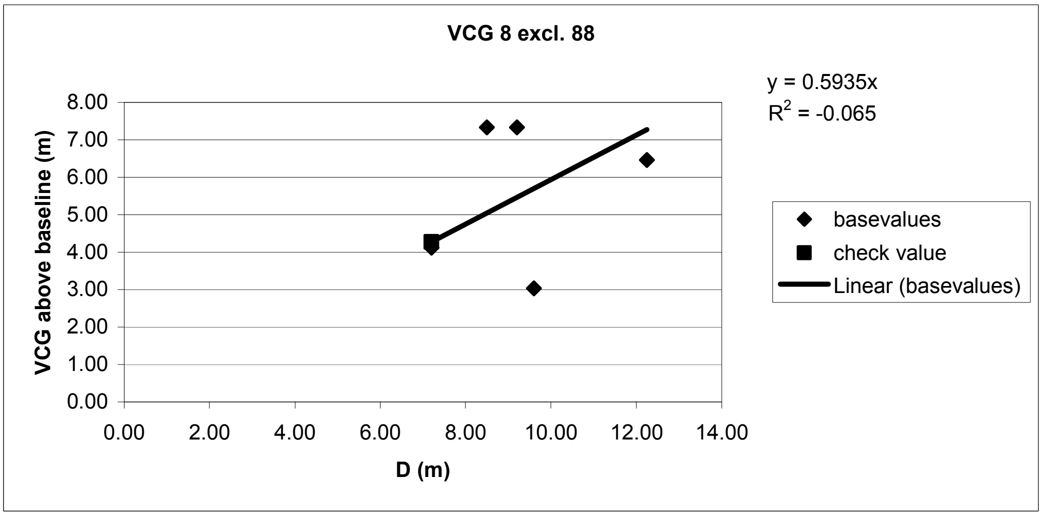

Figure 143 –Group8 excl.88 VCG equation

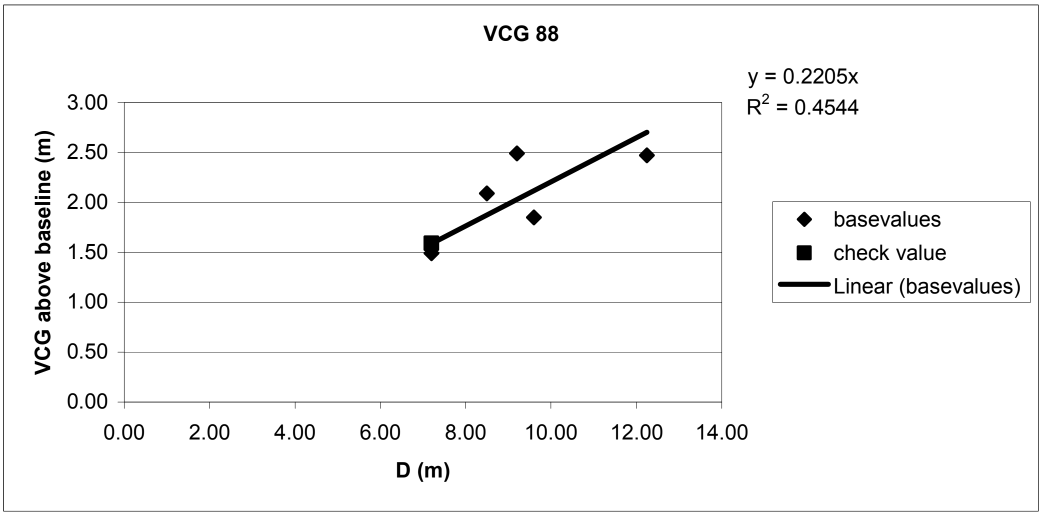

Figure 144 –Subgroup88 VCG equation

23 APPENDIX N

	Coefficient	Factors	Power	Constant
Areas				
Accommodation				
No River/FSC				
JR	2.7116	JR	1	0
SR	2.6035	SR	1	0
Officer	7.9382	Officer	1	0
River/FSC				
JR	4.1778	JR	1	0
SR	6.1133	SR	1	0
Officer	11.398	Officer	1	0
Both				
General	0.0433	LBD/crew (no embarked forces)	1	0
Other	2.4507	Other crew	1	0
Access	0.4695	L*w	1.4049	0
Aviation	0/31/84	No hangar/Flightdeck/hangar		
CS				
General	0.0148	Crew*L (incl. embarked forces)	1	35.856
Officer	0.0415	Off*L	1	0
SR	0.0273	SR*L	1	0
JR	0.2018	JR*√L	1	0
Other	0.7717	Other crew	1	0
Operational				
Warships	0.3207	LB	1	0
OPVs	0.1749	LB	1	0
Platform	0.0865	LBD	1	0
Vertical Access	0.000675	L^2D	1	0
Weights				
10/12/13/14	75.747	LBD*mat factor	1	0
15/16	0.0621	L*power	1	0
17	311.32	L	1	0
11 no hangar	9.3603	LBD*mat factor	1	0
11 hangar	14.766	LBD*mat factor	1	18000
2	11.794	Power	1	0
3	0.1227	L^2BD	1	0
40/41/42/45	2.8307	LBD	1	0
43/44	153.39	L	1	0
50/52/53	10.382	LBD	1	0
51/58	0.0082	L*power	1	0
55	0/6.2/12.8	No hangar/Flightdeck/hangar	1	0
56	87.182	Crew (no embarked forces)	1	0
60/62/67	18.007	LBD	1	0
61/63/64/65/66/68	11.838	LBD	1	0
69	0.0382	LBD*endurance	1	0
80	141.78	Crew (no embarked forces)	1	0
84/85	7.1961	Crew*endurance (no embarked forces)		
87	2.24E-4	LBD*power	1	0
LO	9.84E-4	power	1.5914	0
Water	15.021	Crew*endurance (incl. embarked forces)	1	0
FO		1st principles		
Volumes				
LO		0.89		
FO		0.84		
Avcat		0.788		
VCGs				
1	0.8712	D		
2	0.5121	D		
3	0.5354	D		
4	0.8117	D		
5	0.8043	D		
6	0.7252	D		
7	1.0779	D		
8	0.5935	D		
88	0.2205	D		

Table 24 –Corvette Equation Summary

24 APPENDIX O

	Coefficient	Factors	Power	Constant
Areas				
Accom JR	1.3786	JR Crew	1	16.719
Accom SR	2.2778	SR Crew	1	2.472
Accom Off	4.3229	Officer Crew	1	10.695
Platform	0.0086	Lbp*Bwl*D	1.2187	0
CS JR	0.304	JR Crew	1	10.578
CS SR	0.5117	SR Crew	1	10.041
CS Off	0.9064	Officer Crew	1	6.0734
CS General	-0.0164	Total Crew	1	26.679
Vert access	0.0621	Decks*Lbp	0.9327	0
Operational	0.0056	Displacement	1.6247	0
Access	2.297	Passage width * $\sqrt{A_T}$	1	-1.9645
Weights				
10/12/13/14	0.2222	LBD*material hull factor	0.8028	0
11	0.0298	LBD*SS material factor	0.8168	0
15/16	4.77E-06	L*power	1.1165	0
17	0.1501	L	1	-3.6202
2	0.0201	Power	0.8576	0
3	2.55E-04	L^2BD	1	2.4078
40/42	4.06E-04	Power	1	1.1143
41/45	1.43E-03	LBD	1	-0.1668
43/44	0.3962	L	1	-11.281
50/53	0.0076	LBD	1	-3.0505
51/58	4.31E-06	L*Power	1	-0.5358
52	3.92E-09	LBD*Power*Crew	1	2.0509
56	3.67E-06	LBD*Crew	1.1284	0
60/62/67	8.56E-01	L	1	-18.113
61/63/64/65/66/68	1.70E-01	L*Crew	0.5919	0
7		Direct Input		
80	7.42E-02	Crew	1.0647	0
81/86		Direct Input		
84/85	5.64E-02	Crew* Endurance	0.6923	0
87	7.16E-06	L*Power	1.0602	0
lo	1.76E-06	Power	1.4465	0
fw/bw/gw	7.14E-02	Crew*Endurance	0.8122	0
fo		First Principles		
Volumes				
fw/bw/gw	0.088	Crew*Endurance	0.8122	0
lo	2.37E-06	Power	1.4465	0
fo		First Principles		
VCGs				
1	0.873	D	0.858	0
2	1.081	D	0.4633	0
3	0.6151	D	1.1487	0
4	1.1611	D	1	0
5	0.7567	D	1	0
6	2.5354	D	0.3794	0
7	1.7585	D	0.7798	0
8	0.3779	D	1.0943	0

Table 25 –FAC Equation Summary

25 APPENDIX P

	Dconcept	Original
L	76.11	76
B	10.90	10.2
D	7.04	7.2
T	3.70	3.4
requ. Max power	23443.40	22280
displacement	1502.90	1340.06
area	1616.80	1544.3
vcg	4.88	4.82
L/B	6.98	
L/D	10.81	
B/T	2.95	
Freeboard (amidships)	3.35	
upper limit L/B		
lower limit L/B		
upper limit L/D		
lower limit L/D		
upper limit B/T		
lower limit B/T		
actual speed	29.27	
excess area		
L/F	22.73	
upper limit L/F	21.93	
adjusted upper L/F	22.79	

Table 26 –Basevessel comparison to Dconcept

26 APPENDIX Q

	L	L/D	L/B	B/T	L/F
60m	55.2		6.71	3.60	
castle	75		6.52	3.47	
mk9	64		6.96	3.16	
mk9 alt	64		6.92	3.19	
mk5	88.4		8.46	3.30	
mk7	94.5		8.62	3.51	
t21	109.7		8.93	3.40	
mk10					
Oman OPV	89	10.47	6.50		20.22727
Oman Corvette	76	10.56	7.45		20
Greece Corvette	102.4	11.13	7.09		24.38095
FSC Corvette	118	9.63	7.48		16.73759
River Class	73.6	7.67	5.87		12.68966
56m Qatar					14.85714
Super Vita					17.14706

Table 27 –Limiting Criteria Basevessels

27 APPENDIX R

crew number/standard	76	86	96	76 gen	86 gen	96 gen
	base	17JR/34SR/35off	19JR/38SR/39off			
L	76.11	80.25	83.87	86.53	91.42	96.52
B	10.90	10.85	10.89	10.90	10.95	10.99
D	7.04	7.00	7.01	7.02	7.05	7.08
T	3.70	3.63	3.58	3.51	3.47	3.43
requ. Max power	23443.40	21679.10	20599.00	19496.40	18507.30	17647.30
displacement	1502.90	1550.50	1604.20	1622.60	1700.80	1784.30
Area	1616.80	1754.50	1896.90	2006.30	2205.10	2411.50
Vcg	4.88	4.87	4.92	4.96	5.02	5.07
L/B	6.98	7.40	7.70	7.94	8.35	8.78
L/D	10.81	11.47	11.96	12.34	12.97	13.63
B/T	2.95	2.99	3.04	3.11	3.16	3.21
upper limit L/B						
lower limit L/B						
upper limit L/D				0.78	5.92	11.36
lower limit L/D						
upper limit B/T						
lower limit B/T						
actual speed	29.27					
L/F	22.73	23.86	24.46	24.67	25.49	26.43
upper limit L/F	21.93	23.13	24.17	24.94	26.34	27.82
adjusted upper L/F	22.79	24.03	25.11	25.91	27.37	28.90
Freeboard	3.35	3.36	3.43	3.51	3.59	3.65

Table 28 –Crew Study

aft deck length	18.5	20	21.5	23	24.5	26	27.5
L	73.62	75.39	77.15	78.81	80.21	81.53	82.85
B	10.97	10.92	10.87	10.84	10.84	10.85	10.87
D	7.11	7.06	7.02	6.99	6.99	6.99	6.99
T	3.75	3.71	3.68	3.64	3.61	3.59	3.56
requ. Max power	24914.00	23851.00	22900.00	22073.00	21483.00	21005.00	20556.00
displacement	1484.00	1497.00	1511.60	1525.50	1540.90	1556.20	1572.50
area	1582.70	1606.90	1631.90	1655.60	1681.30	1706.10	1731.10
vcg	4.91	4.88	4.87	4.86	4.87	4.89	4.91
L/B	6.71	6.91	7.10	7.27	7.40	7.51	7.62
L/D	10.36	10.68	10.99	11.28	11.48	11.66	11.84
B/T	2.93	2.94	2.96	2.98	3.00	3.03	3.05
Freeboard (amidships)	3.36	3.35	3.35	3.35	3.37	3.40	3.43
upper limit L/B							
lower limit L/B							
upper limit L/D							
lower limit L/D							
upper limit B/T							
lower limit B/T							
actual speed	28.4	29	29.6				
L/F	21.89	22.49	23.05	23.55	23.77	23.95	24.14
upper limit L/F	21.22	21.73	22.23	22.71	23.11	23.50	23.88
adjusted upper L/F	22.04	22.57	23.10	23.60	24.01	24.41	24.81

Table 29 –Aft Deck Length Study

SSmf	1.00	0.55
L	76.11	76.11
B	10.90	10.83
D	7.04	7.04
T	3.70	3.64
requ. Max power	23443.40	22688.34
displacement	1502.90	1472.51
area	1616.80	1613.58
vcg	4.88	4.85
L/B	6.98	7.03
L/D	10.81	10.81
B/T	2.95	2.97
Freeboard (amidships)	3.35	3.40
upper limit L/B		
lower limit L/B		
upper limit L/D		
lower limit L/D		
upper limit B/T		
lower limit B/T		
actual speed	29.27	29.72
excess area		1.68
L/F	22.73	22.38
upper limit L/F	21.93	21.93
adjusted upper L/F	22.79	22.79

Table 30 –Superstructure Material Study

	no hangar	15 non organic	15 organic	18 non organic	18 organic
Hangar length	0.00	15.00	15.00	18.00	18.00
L	76.11	85.00	88.66	86.07	89.70
B	10.90	11.02	11.05	11.02	11.05
D	7.04	7.04	7.05	7.04	7.06
T	3.70	3.73	3.68	3.71	3.67
requ. Max power	23443.40	22043.80	20998.00	21663.00	20687.70
displacement	1502.90	1710.40	1768.10	1724.60	1782.80
area	1616.80	1840.30	1984.70	1860.70	2004.90
vcg	4.88	4.94	4.98	4.95	4.99
L/B	6.98	7.72	8.03	7.81	8.12
L/D	10.81	12.08	12.57	12.22	12.71
B/T	2.95	2.96	3.00	2.97	3.01
Freeboard (amidships)	3.35	3.31	3.37	3.33	3.39
upper limit L/B					
lower limit L/B					
upper limit L/D			2.70		3.88
lower limit L/D					
upper limit B/T					
lower limit B/T					
actual speed	29.27				
L/F	22.73	25.65	26.30	25.81	26.48
upper limit L/F	21.93	24.50	25.55	24.80	25.85
adjusted upper L/F	22.79	25.45	26.54	25.77	26.86

Table 31 –Hangar Study

area margin	0.00	2.5	5.00	7.5	10	12.5	15	20	25
L	76.11	78.698	80.84	82.994	85.25	87.623	90.08	95.43	101.63
B	10.90	10.837	10.85	10.867	10.89	10.912	10.94	10.981	11.01
D	7.04	6.99	6.99	6.9954	7.01	7.0238	7.04	7.0694	7.09
T	3.70	3.6464	3.60	3.5609	3.53	3.4938	3.46	3.4083	3.36
requ. Max power	23443.40	22121	21264.00	20518	19846.00	19226	18654.00	17619	16638.00
displacement	1502.90	1524.9	1548.30	1574.9	1605.20	1638.1	1673.00	1751.3	1843.50
area	1616.80	1695	1777.90	1863.2	1954.30	2051	2152.00	2370.5	2620.40
vcg	4.88	4.8546	4.88	4.9117	4.94	4.9775	5.01	5.0714	5.12
L/B	6.98	7.26	7.45	7.64	7.83	8.03	8.24	8.69	9.23
L/D	10.81	11.26	11.56	11.86	12.17	12.48	12.80	13.50	14.33
B/T	2.95	2.97	3.01	3.05	3.09	3.12	3.16	3.22	3.28
Freeboard (amidships)	3.35	3.34	3.39	3.43	3.48	3.53	3.57	3.66	3.73
upper limit L/B									
lower limit L/B									
upper limit L/D						1.92	4.57	10.29	17.05
lower limit L/D									
upper limit B/T									
lower limit B/T									
actual speed									
L/F	22.73	23.54	23.85	24.16	24.48	24.82	25.20	26.07	27.22
upper limit L/F	21.93	22.68	23.30	23.92	24.57	25.25	25.96	27.50	29.29
adjusted upper L/F	22.79	23.56	24.20	24.85	25.52	26.23	26.97	28.57	30.43

Table 32 –Area Margin Study

		base						
deckheight	2.30	2.35	2.40	2.50	2.60	2.70	2.80	2.90
L	76.12	76.11	76.11	76.11	76.11	76.19	76.32	76.52
B	10.79	10.90	11.01	11.24	11.47	11.69	11.92	12.14
D	6.96	7.04	7.14	7.32	7.51	7.69	7.87	8.05
T	3.69	3.70	3.71	3.73	3.76	3.78	3.81	3.83
requ. Max power	22945.00	23443.40	23987.45	25072.91	26217.39	27334.00	28526.00	29704.00
displacement	1483.80	1502.90	1524.16	1565.57	1608.01	1651.20	1697.60	1745.80
area	1602.00	1616.80	1632.28	1662.88	1694.08	1726.30	1761.40	1798.90
vcg	4.81	4.88	4.95	5.09	5.24	5.38	5.53	5.68
L/B	7.06	6.98	6.91	6.77	6.64	6.52	6.40	6.30
L/D	10.94	10.80	10.66	10.39	10.14	9.91	9.70	9.50
B/T	2.93	2.95	2.97	3.01	3.05	3.09	3.13	3.17
Freeboard (amidships)	3.27	3.35	3.43	3.59	3.75	3.90	4.06	4.22
upper limit L/B								
lower limit L/B								
upper limit L/D								
lower limit L/D								
upper limit B/T								
lower limit B/T								
excess area	0	0	0.28	0.19	-0.05	0	0	0
actual speed	29.6	29.27	28.96	28.38	27.84	27.38	26.94	26.57
L/F	23.28	22.73	22.19	21.20	20.29	19.51	18.78	18.13
upper limit L/F	21.94	21.93	21.93	21.93	21.93	21.96	21.99	22.05
adjusted upper L/F	22.79	22.79	22.79	22.79	22.79	22.81	22.85	22.91

Table 33 –Deckheight Study

power margin	0.00	2.5	5	7.5	10	12.5	15	17.5	20
L	76.11	77.451	77.876	78.302	78.705	79.164	79.627	80.061	80.542
B	10.90	10.84	10.831	10.822	10.812	10.811	10.803	10.801	10.794
D	7.04	6.986	6.974	6.962	6.95	6.946	6.936	6.931	6.924
T	3.70	3.801	3.844	3.885	3.934	3.985	4.031	4.085	4.134
requ. Max power	23443.40	24577.9	25489.4	26411.2	27409.6	28481.9	29486.5	30652.8	31734.7
displacement	1502.90	1564.8	1590	1614.6	1641.5	1672.5	1700.4	1732.1	1762.4
area	1616.80	1631.7	1637.6	1644.1	1648.8	1656.7	1663.8	1670.5	1678.5
vcg	4.88	4.799	4.779	4.76	4.739	4.724	4.707	4.694	4.678
L/B	6.98	7.14	7.19	7.24	7.28	7.32	7.37	7.41	7.46
L/D	10.80	11.09	11.17	11.25	11.32	11.40	11.48	11.55	11.63
B/T	2.95	2.85	2.82	2.79	2.75	2.71	2.68	2.64	2.61
Freeboard (amidships)	3.35	3.19	3.13	3.08	3.02	2.96	2.91	2.85	2.79
upper limit L/B									
lower limit L/B									
upper limit L/D									
lower limit L/D									
upper limit B/T									
lower limit B/T			-0.79	-1.92	-3.23	-4.47	-5.63	-6.90	-8.06
actual speed	29.27								
L/F	22.73	24.32	24.88	25.45	26.10	26.74	27.41	28.13	28.87
upper limit L/F	21.93	22.32	22.44	22.57	22.68	22.81	22.95	23.07	23.21
adjusted upper L/F	22.79	23.19	23.32	23.44	23.56	23.70	23.84	23.97	24.11

Table 34 –Power Margin Study

passagewidth	base	1.00	1.1	1.2	1.3	1.4	1.5
L	76.11	75.515	77.487	79.346	81.173	83.07	85.179
B	10.90	10.91	10.86	10.842	10.849	10.866	10.887
D	7.04	7.057	7.0144	6.9904	6.9902	6.9953	7.0074
T	3.70	3.7071	3.6698	3.631	3.5955	3.5605	3.5269
requ. Max power	23443.40	23768	22726	21859	21130	20485	19860
displacement	1502.90	1497.7	1514.8	1531.8	1552.7	1576	1603.8
area	1616.80	1598.7	1657.8	1720.5	1790.2	1866.3	1950.7
vcg	4.88	4.8812	4.8632	4.8649	4.8852	4.9112	4.9429
L/B	6.98	6.92	7.14	7.32	7.48	7.64	7.82
L/D	10.80	10.70	11.05	11.35	11.61	11.88	12.16
B/T	2.95	2.94	2.96	2.99	3.02	3.05	3.09
Freeboard (amidships)	3.35	3.35	3.34	3.36	3.39	3.43	3.48
upper limit L/B							
lower limit L/B							
upper limit L/D							
lower limit L/D							
upper limit B/T							
lower limit B/T							
actual speed achieved	29.27	29.075	29.72				
L/F	22.73	22.54	23.17	23.62	23.91	24.18	24.47
upper limit L/F	21.93	21.76	22.33	22.87	23.39	23.94	24.55
adjusted upper L/F	22.79	22.61	23.20	23.76	24.30	24.87	25.50

Table 35 –Passagewidth Study

17						
weight margin	0	2.5	5	7.5	10	12.5
L	76.11	76.426	76.809	77.212	77.603	78.055
B	10.90	10.932	10.956	10.983	11.005	11.023
D	7.04	7.0509	7.0509	7.0557	7.0549	7.0529
T	3.70	3.7663	3.8356	3.9065	3.975	4.0414
requ. Max power	23443.40	24230	24948	25684	26410	27096
displacement	1502.90	1543.1	1582.8	1624.5	1664.8	1705.1
area	1616.80	1625.3	1633.5	1642.9	1651.4	1661.6
vcg	4.88	4.8713	4.8623	4.8565	4.8484	4.8416
L/B	6.98	6.99	7.01	7.03	7.05	7.08
L/D	10.80	10.84	10.89	10.94	11.00	11.07
B/T	2.95	2.90	2.86	2.81	2.77	2.73
Freeboard (amidships)	3.35	3.28	3.22	3.15	3.08	3.01
upper limit L/B						
lower limit L/B						
upper limit L/D						
lower limit L/D						
upper limit B/T						
lower limit B/T				-1.00	-2.52	-3.96
actual speed achieved	29.27	28.829	28.459	28.114	27.804	27.54
L/F	22.73	23.27	23.89	24.52	25.20	25.92
upper limit L/F	21.93	22.03	22.14	22.25	22.36	22.49
adjusted upper L/F	22.79	22.88	23.00	23.12	23.23	23.37

Table 36 –Combined Group1-7 Weight Margin Study

17						
vcg margin	0.00	2.50	5.00	7.50	10.00	12.50
L	76.11	76.11	76.11	76.11	76.11	76.11
B	10.90	11.01	11.12	11.22	11.32	11.42
D	7.04	7.03	7.01	6.99	6.98	6.96
T	3.70	3.68	3.66	3.64	3.62	3.60
requ. Max power	23443.40	23638.38	23807.05	23965.22	24132.94	24287.22
displacement	1502.90	1510.71	1516.76	1522.70	1528.73	1534.28
area	1616.80	1633.15	1648.38	1662.95	1678.16	1692.69
vcg	4.88	4.96	5.04	5.12	5.20	5.28
L/B	6.98	6.91	6.85	6.78	6.72	6.66
L/D	10.80	10.82	10.85	10.88	10.90	10.93
B/T	2.95	2.99	3.04	3.09	3.13	3.17
Freeboard (amidships)	3.35	3.35	3.36	3.36	3.36	3.36
upper limit L/B						
lower limit L/B						
upper limit L/D						
lower limit L/D						
upper limit B/T						
lower limit B/T						
actual speed achieved	29.27	29.16	29.06	28.98	28.88	28.80
Excess Area	0.00	9.67	18.70	27.40	36.48	45.36
L/F	22.73	22.69	22.67	22.66	22.64	22.63
upper limit L/F	21.93	21.93	21.93	21.93	21.93	21.93
adjusted upper L/F	22.79	22.79	22.79	22.79	22.79	22.79

Table 37 –Combined Group 1-7 VCG Margin Study

28 APPENDIX S

Notes for margin interviews

Trying to come up with a sensible margin management approach.

- What margins are in existence?
- How are they derived and calculated?
- How do you deal with uncertainties and assumptions in the required input data?
- Why is the margin there and what does it do?
- What happens if it is exceeded?
- Who is interested in it?
- What margins should there be?
- Do you use any methods, other than margins to account for uncertainties and unknowns?

Figure 145 –Margin Interview Notes

29 APPENDIX T

	extra deck	extra deck	extra deck
crew number/standard	76 gen	86 gen	96 gen
L	68.43	71.80	75.28
B	11.16	11.05	10.96
D	7.27	7.18	7.10
T	3.87	3.81	3.76
requ. Max power	28623.20	26471.60	24517.20
displacement	1447.30	1482.50	1519.50
area	1718.00	1860.60	2008.20
vcg	4.99	4.94	4.90
L/B	6.13411	6.495115	6.868078
L/D	9.409516	9.994014	10.59997
B/T	2.88	2.90	2.92
upper limit L/B			
lower limit L/B			
upper limit L/D			
lower limit L/D			
upper limit B/T			
lower limit B/T			
actual speed	26.45	27.55	28.65
L/F	20.10	21.27	22.49
upper limit L/F	19.72	20.69	21.70
adjusted upper L/F	20.49	21.50	22.54
Freeboard	3.41	3.38	3.35

Table 38 –Crew Mitigation Study

	15 organic extra deck	18 organic extra deck
L	72.51	74.00
B	11.30	11.24
D	7.30	7.25
T	4.00	3.97
requ. Max power	29590.50	28432.00
displacement	1608.20	1618.40
area	1721.80	1742.20
vcg	5.03	5.00
L/B	6.42	6.58
L/D	9.93	10.20
B/T	2.82	2.83
Freeboard (amidships)	3.30	3.28
upper limit L/B		
lower limit L/B		
upper limit L/D		
lower limit L/D		
upper limit B/T		
lower limit B/T	-0.65	-0.25
actual speed	26.37	26.85
L/F	21.99	22.53
upper limit L/F	20.90	21.33
adjusted upper L/F	21.71	22.15

Table 39 –Organic-hangar Mitigation Study (extra deck)

non-organic						
changing deckheight	2.3	2.4	2.5	2.6	2.7	2.8
hangar length	15.00	15	15	15	15	15
L	84.96	85.091	85.311	85.548	85.613	85.613
B	10.92	11.11	11.306	11.502	11.718	11.951
D	6.96	7.1148	7.2755	7.4357	7.6095	7.7963
T	3.71	3.7382	3.764	3.7915	3.8211	3.8521
requ. Max power	21638.00	22429	23263	24122	25148	26299
displacement	1688.90	1733	1780	1829.4	1879.7	1932.7
area	1826.10	1855.8	1889.8	1925.4	1960.4	1998
vcg	4.88	5	5.1252	5.2489	5.3855	5.5342
L/B	7.78	7.66	7.55	7.44	7.31	7.16
L/D	12.20	11.96	11.73	11.51	11.25	10.98
B/T	2.94	2.97	3.00	3.03	3.07	3.10
Freeboard (amidships)	3.25	3.38	3.51	3.64	3.79	3.94
upper limit L/B						
lower limit L/B						
upper limit L/D						
lower limit L/D						
upper limit B/T						
lower limit B/T						
actual speed	30	29.914	29.46	29.034	28.571	28.107
L/F	26.13	25.20	24.29	23.48	22.60	21.71
upper limit L/F	24.48	24.52	24.59	24.65	24.67	24.67
adjusted upper L/F	25.44	25.48	25.54	25.61	25.63	25.63
changing deckheight	2.3	2.4	2.5	2.6	2.7	2.8
hangar length	18.00	18	18	18	18	18
L	85.95	86.186	86.364	86.549	86.806	86.868
B	10.93	11.117	11.311	11.503	11.704	11.919
D	6.96	7.1176	7.2739	7.4327	7.5958	7.7702
T	3.70	3.7192	3.7451	3.7741	3.8022	3.8322
requ. Max power	21286.00	22040	22859	23705	24591	25628
displacement	1701.70	1747.5	1794	1842.6	1894.3	1945.8
area	1844.20	1877.6	1910.4	1943.9	1981.2	2017
vcg	4.89	5.0141	5.1354	5.2568	5.3839	5.5224
L/B	7.87	7.75	7.64	7.52	7.42	7.29
L/D	12.34	12.11	11.87	11.64	11.43	11.18
B/T	2.96	2.99	3.02	3.05	3.08	3.11
Freeboard (amidships)	3.27	3.40	3.53	3.66	3.79	3.94
upper limit L/B						
lower limit L/B						
upper limit L/D	0.86					
lower limit L/D						
upper limit B/T						
lower limit B/T						
actual speed	30	30	29.68	29.248	28.837	28.4
L/F	26.30	25.36	24.47	23.66	22.88	22.06
upper limit L/F	24.77	24.84	24.89	24.94	25.02	25.03
adjusted upper L/F	25.73	25.80	25.86	25.91	25.99	26.01

Table 40 –Non-Organic Hangar Mitigation Study (deckheight)

Organic						
increasing deckheight	2.3	2.4	2.5	2.6	2.7	2.8
hangar length	15.00	15	15	15	15	15
L	88.54	88.793	88.962	89.273	89.486	89.745
B	10.95	11.135	11.33	11.519	11.719	11.91
D	6.98	7.1263	7.2832	7.4386	7.597	7.7582
T	3.67	3.6946	3.7207	3.7475	3.776	3.7582
requ. Max power	20650.00	21333	22123	22868	23696	24556
displacement	1745.60	1791.3	1839	1889.8	1940.8	1994.5
area	1967.50	2001.5	2035	2072.2	2108.2	2147
vcg	4.92	5.0369	5.1594	5.2797	5.4029	5.5287
L/B	8.08	7.97	7.85	7.75	7.64	7.54
L/D	12.69	12.46	12.21	12.00	11.78	11.57
B/T	2.98	3.01	3.05	3.07	3.10	3.17
Freeboard (amidships)	3.31	3.43	3.56	3.69	3.82	4.00
upper limit L/B						
lower limit L/B						
upper limit L/D	3.67	1.80				
lower limit L/D						
upper limit B/T						
lower limit B/T						
actual speed	30	30	30	29.689	29.282	28.899
L/F	26.77	25.87	24.97	24.19	23.42	22.44
upper limit L/F	25.52	25.59	25.64	25.73	25.79	25.86
adjusted upper L/F	26.51	26.58	26.64	26.73	26.79	26.87
Deckheight	2.3	2.4	2.5	2.6	2.7	2.8
hangar	18.00	18	18	18	18	18
L	89.56	89.801	90.033	90.283	90.543	90.796
B	10.96	11.143	11.336	11.522	11.716	11.911
D	6.98	7.1294	7.2857	7.439	7.5968	7.7563
T	3.66	3.6798	3.7055	3.7328	3.7608	3.7896
requ. Max power	20363.00	21033	21781	22522	23318	24158
displacement	1759.80	1805.6	1854.5	1904.1	1956.3	2009.8
area	1987.80	2021.4	2056.4	2091.8	2129.6	2168.2
vcg	4.93	5.0483	5.1707	5.2893	5.4125	5.5378
L/B	8.17	8.06	7.94	7.84	7.73	7.62
L/D	12.83	12.60	12.36	12.14	11.92	11.71
B/T	3.00	3.03	3.06	3.09	3.12	3.14
Freeboard (amidships)	3.33	3.45	3.58	3.71	3.84	3.97
upper limit L/B						
lower limit L/B						
upper limit L/D	4.80	2.91	0.96			
lower limit L/D						
upper limit B/T						
lower limit B/T						
actual speed	30	30	30	29.871	29.472	29.087
L/F	26.92	26.03	25.15	24.36	23.60	22.89
upper limit L/F	25.81	25.88	25.95	26.02	26.09	26.17
adjusted upper L/F	26.81	26.89	26.96	27.03	27.11	27.18

Table 41 –Organic-Hangar Mitigation Study (deckheight)

extra deck	x	x	x	x	x	x	x
area margin	10	12.5	15	17.5	20	22.5	25
L	66.436	67.22	69.259	70.73	72.303	73.87	75.508
B	11.233	11.18	11.124	11.07	11.016	10.97	10.921
D	7.3424	7.29	7.2431	7.20	7.1489	7.11	7.0653
T	3.9172	3.88	3.8466	3.81	3.7765	3.74	3.7111
requ. Max power	30233	29091.00	27974	26890.00	25804	24829.00	23849
displacement	1433.6	1442.80	1453.3	1463.40	1475	1488.20	1500.6
area	1635.1	1692.80	1752.1	1812.90	1878	1943.60	2011.6
vcg	50.201	4.99	4.9697	4.95	4.9246	4.91	4.8851
L/B	5.91	6.01	6.23	6.39	6.56	6.73	6.91
L/D	9.05	9.22	9.56	9.83	10.11	10.39	10.69
B/T	2.87	2.88	2.89	2.90	2.92	2.93	2.94
Freeboard (amidships)	3.43	3.41	3.40	3.38	3.37	3.37	3.35
upper limit L/B							
lower limit L/B							
upper limit L/D							
lower limit L/D							
upper limit B/T							
lower limit B/T							
actual speed	25.723	26.227	26.758	27.308	27.894	28.449	29.029
L/F	19.40	19.71	20.39	20.90	21.44	21.95	22.51
upper limit L/F	19.15	19.37	19.96	20.38	20.84	21.29	21.76
adjusted upper L/F	19.89	20.13	20.74	21.18	21.65	22.12	22.61

Table 42 –Area Margin Mitigation Study

area margin	0	2.5	5	7.5	10
power margin	5.00	5	5	5	5
L	77.88	79.464	81.166	83.027	84.916
B	10.83	10.805	10.794	10.795	10.799
D	6.97	6.9573	6.9536	6.9642	6.976
T	3.84	3.6991	3.5866	3.4964	3.4211
requ. Max power	25470.00	23470	21938	20724	19731
displacement	1589.20	1557.5	1540.9	1536.8	1538.4
area	1637.60	1704.1	1776.1	1855.6	1936.9
vcg	4.78	4.8127	4.8497	4.8931	4.9343
L/B	7.19	7.35	7.52	7.69	7.86
L/D	11.17	11.42	11.67	11.92	12.17
B/T	2.82	2.92	3.01	3.09	3.16
Freeboard (amidships)	3.13	3.26	3.37	3.47	3.55
upper limit L/B					
lower limit L/B					
upper limit L/D					
lower limit L/D					
upper limit B/T					
lower limit B/T	-0.75				
actual speed					
L/F	24.87	24.39	24.11	23.94	23.89
upper limit L/F	22.44	22.90	23.39	23.93	24.47
adjusted upper L/F	23.32	23.79	24.30	24.86	25.42

Table 43 –Power Margin(5%) Mitigation Study (area margin)

Area margin	0	2.5	5	7.5	10
power margin	10.00	10	10	10	10
L	78.73	80.286	82.039	83.888	85.836
B	10.81	10.782	10.759	10.756	10.759
D	6.95	6.9278	6.9172	6.9221	6.9324
T	3.93	3.7688	3.637	3.5379	3.4545
requ. Max power	27378.00	25029	23169	21802	20685
displacement	1641.30	1599.8	1574.3	1565.5	1564.4
area	1650.30	1715	1787.1	1865.2	1947.2
vcg	4.74	4.7711	4.8066	4.8462	4.8883
L/B	7.28	7.45	7.63	7.80	7.98
L/D	11.33	11.59	11.86	12.12	12.38
B/T	2.75	2.86	2.96	3.04	3.11
Freeboard (amidships)	3.02	3.16	3.28	3.38	3.48
upper limit L/B					
lower limit L/B					
upper limit L/D					1.16
lower limit L/D					
upper limit B/T					
lower limit B/T	-3.15				
actual speed					
L/F	26.08	25.42	25.01	24.79	24.68
upper limit L/F	22.69	23.14	23.64	24.18	24.74
adjusted upper L/F	23.57	24.04	24.56	25.12	25.70

Table 44 –Power Margin(10%) Mitigation Study (area margin)

deckheight	2.3	2.4	2.5	2.6	2.7	2.8	2.9
power margin	5.00	5	5	5	5	5	5
L	77.57	78.178	78.748	79.339	79.979	80.681	81.403
B	10.72	10.941	11.171	11.417	11.666	11.934	12.202
D	6.89	7.0558	7.2278	7.4094	7.5946	7.7914	7.9879
T	3.79	3.8947	4.0135	4.149	4.293	4.4571	4.6319
requ. Max power	24575.00	26390	28520	31054	33853	37177	40881
displacement	1545.20	1633.6	1731.4	1843	1964.3	2104.5	2256
area	1618.40	1657.5	1698.6	1742.9	1790.2	1842.4	1896.1
vcg	4.72	4.8335	4.9458	5.063	5.1822	5.307	5.4313
L/B	7.24	7.15	7.05	6.95	6.86	6.76	6.67
L/D	11.26	11.08	10.90	10.71	10.53	10.36	10.19
B/T	2.83	2.81	2.78	2.75	2.72	2.68	2.63
Freeboard (amidships)	3.10	3.16	3.21	3.26	3.30	3.33	3.36
upper limit L/B							
lower limit L/B							
upper limit L/D							
lower limit L/D							
upper limit B/T							
lower limit B/T	-0.40	-1.08	-1.99	-3.11	-4.32	-5.72	-7.24
actual speed							
L/F	25.03	24.73	24.50	24.33	24.22	24.20	24.26
upper limit L/F	22.36	22.53	22.69	22.86	23.05	23.25	23.46
adjusted upper L/F	23.23	23.41	23.58	23.75	23.95	24.16	24.37

Table 45 –Power Margin (5%) Mitigation Study (deckheight)

deckheight	2.3	2.4	2.5	2.6	2.7	2.8	2.9
power margin	10.00	10	10	10	10	10	10
L	78.44	79.016	79.652	80.259	80.988	81.719	82.578
B	10.70	10.932	11.171	11.422	11.679	11.946	12.222
D	6.87	7.0413	7.2178	7.4041	7.5975	7.7948	8.0013
T	3.88	3.9984	4.1277	4.2823	4.4432	4.627	4.8204
requ. Max power	26378.00	28567	30983	33972	37218	41078	45336
displacement	1595.30	1693.7	1801	1925.1	2061	2215	2385.8
area	1630.10	1670.3	1714.5	1761.1	1811.1	1864	1923.2
vcg	4.69	4.7979	4.9123	5.0304	5.154	5.2772	5.4076
L/B	7.33	7.23	7.13	7.03	6.93	6.84	6.76
L/D	11.42	11.22	11.04	10.84	10.66	10.48	10.32
B/T	2.76	2.73	2.71	2.67	2.63	2.58	2.54
Freeboard (amidships)	2.99	3.04	3.09	3.12	3.15	3.17	3.18
upper limit L/B							
lower limit L/B							
upper limit L/D							
lower limit L/D							
upper limit B/T							
lower limit B/T	-2.77	-3.73	-4.71	-6.08	-7.45	-9.09	-10.72
actual speed							
L/F	26.21	25.97	25.78	25.71	25.68	25.80	25.96
upper limit L/F	22.61	22.77	22.95	23.13	23.34	23.55	23.80
adjusted upper L/F	23.48	23.66	23.85	24.03	24.25	24.47	24.72

Table 46 –Power Margin (10%) Mitigation Study (deckheight)

deckheight	2.3	2.4	2.5	2.6	2.7	2.8	2.9
weight margin	5	5	5	5	5	5	5
L	76.899	76.756	76.756	76.756	76.774	76.861	77.013
B	10.841	11.073	11.305	11.537	11.772	12.002	12.232
D	6.9595	7.1434	7.3296	7.5122	7.6987	7.8817	8.0644
T	3.8218	3.8485	3.8749	3.9011	3.9287	3.9564	3.9841
requ. Max power	24356	25548	26740	27978	29286	30592	31913
displacement	1562.3	1604	1648.9	1694.1	1741.2	1789.7	1840.4
area	1620.6	1648.6	1679.9	1712.3	1745	1779.4	1816.2
vcg	4.7919	4.9351	5.0817	5.2266	5.3753	5.5217	5.6688
L/B	7.09	6.93	6.79	6.65	6.52	6.40	6.30
L/D	11.05	10.75	10.47	10.22	9.97	9.75	9.55
B/T	2.84	2.88	2.92	2.96	3.00	3.03	3.07
Freeboard (amidships)	3.14	3.29	3.45	3.61	3.77	3.93	4.08
upper limit L/B							
lower limit L/B							
upper limit L/D							
lower limit L/D							
upper limit B/T							
lower limit B/T	-0.12						
actual speed achieved	28.769	28.165	27.637	27.156	26.714	26.334	26.003
L/F	24.51	23.30	22.22	21.26	20.36	19.58	18.87
upper limit L/F	22.16	22.12	22.12	22.12	22.13	22.15	22.19
adjusted upper L/F	23.02	22.98	22.98	22.98	22.99	23.01	23.06

Table 47 –Groups 1-7 Weight Margin (5%) Mitigation Study (deckheight)

deckheight	2.3	2.4	2.5	2.6	2.7	2.8	2.9
weight margin	10	10	10	10	10	10	10
L	77.7	77.539	77.444	77.444	77.433	77.48	77.591
B	10.883	11.123	11.362	11.599	11.836	12.075	12.31
D	6.9597	7.1465	7.3319	7.5171	7.6994	7.8869	8.0696
T	3.9594	3.9877	4.0157	4.0449	4.0732	4.1039	4.1338
requ. Max power	25745	27059	28392	29745	31159	32626	34096
displacement	1641.8	1686.6	1732.7	1781.7	1830.7	1882.7	1936.3
area	1637.7	1666.7	1697.2	1730.3	1763.5	1798	1834.5
vcg	4.7754	4.9216	5.068	5.214	5.3597	5.5094	5.6561
L/B	7.14	6.97	6.82	6.68	6.54	6.42	6.30
L/D	11.16	10.85	10.56	10.30	10.06	9.82	9.62
B/T	2.75	2.79	2.83	2.87	2.91	2.94	2.98
Freeboard (amidships)	3.00	3.16	3.32	3.47	3.63	3.78	3.94
upper limit L/B							
lower limit L/B							
upper limit L/D							
lower limit L/D							
upper limit B/T							
lower limit B/T	-3.22	-1.78	-0.37				
actual speed achieved	28.099	27.535	27.039	26.608	26.216	25.867	25.566
L/F	25.90	24.55	23.35	22.30	21.35	20.48	19.71
upper limit L/F	22.39	22.35	22.32	22.32	22.32	22.33	22.36
adjusted upper L/F	23.26	23.22	23.19	23.19	23.18	23.20	23.23

Table 48 –Groups 1-7 Weight Margin (10%) Mitigation Study (deckheight)

area margin	0	2.5	5	7.5	10
weight margin	5.00	5	5	5	5
L	76.80	79.573	81.954	84.176	86.519
B	10.96	10.885	10.876	10.892	10.914
D	7.05	6.989	6.969	6.9715	6.9804
T	3.84	3.7844	3.7361	3.6944	3.6564
requ. Max power	24964.00	23429	22374	21555	20807
displacement	1583.30	1607.4	1633	1661.1	1693
area	1633.70	1715	1799	1886	1979
vcg	4.86	1.8338	4.8442	4.8711	4.9018
L/B	7.01	7.31	7.54	7.73	7.93
L/D	10.89	11.39	11.76	12.07	12.39
B/T	2.86	2.88	2.91	2.95	2.98
Freeboard (amidships)	3.22	3.20	3.23	3.28	3.32
upper limit L/B					
lower limit L/B					
upper limit L/D					1.26
lower limit L/D					
upper limit B/T					
lower limit B/T					
actual speed	28.451	29.318	29.943	30	30
L/F	23.87	24.83	25.35	25.69	26.03
upper limit L/F	22.13	22.93	23.62	24.26	24.93
adjusted upper L/F	22.99	23.82	24.54	25.20	25.90

Table 49 – Groups1-7 Weights Margin (5%) Mitigation Study (area margin)

area margin	0	2.5	5	7.5	10
weight margin	10.00	10	10	10	10
L	77.60	80.352	83.088	85.459	87.811
B	11.00	10.934	10.887	10.909	10.934
D	7.06	6.9902	6.9441	6.9484	6.9559
T	3.98	3.9212	3.8705	3.8265	3.7873
requ. Max power	26415.00	24789	23426	22529	21760
displacement	1664.60	1689.4	1717	1749.3	1783.1
area	1651.90	1732.6	1818.9	1910.7	2004.3
vcg	4.85	4.819	4.8051	4.8341	4.8638
L/B	7.05	7.35	7.63	7.83	8.03
L/D	11.00	11.49	11.97	12.30	12.62
B/T	2.77	2.79	2.81	2.85	2.89
Freeboard (amidships)	3.08	3.07	3.07	3.12	3.17
upper limit L/B					
lower limit L/B					
upper limit L/D				0.48	3.14
lower limit L/D					
upper limit B/T					
lower limit B/T	-2.53	-1.82	-0.96		
actual speed	27.802	28.615	29.353	29.858	30
L/F	25.19	26.18	27.03	27.37	27.71
upper limit L/F	22.36	23.16	23.95	24.63	25.31
adjusted upper L/F	23.23	24.06	24.88	25.59	26.29

Table 50 –Groups1-7 Weights Margin (10%) Mitigation Study (area margin)

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	L	B	D	Displacement	Speed (Max. = 30kts)	Power	Freeboard	Constraints	Notes
Crew - standard outfit (76/86/96, base 76)	4m/10 crew	Constant	Constant	50t/10 crew	Increasing to 30	Decreasing In excess of 1.1MW/10 crew	Marginal increase	Ok	
Crew - generous outfit (76/86/96, base 76)	+10m from baseship & 5m/10crew	0.05m/10crew	0.03m/10 crew	+120t from baseship & 80t/10crew	30kts	-3950kW from baseship & approx. -900kw/10crew	+0.15m from baseship & 0.08m/10crew	All above L/D (0.78% @76, +5.1%/10crew)	For possible mitigation see next row
Extra deck SS	-7.7m from baseship & +3.4m/10crew	+0.25m from baseship & -0.1m/10crew	+0.23m from baseship & -0.09m/10crew	-55t from baseship & +35t/10crew	-2.8kts from baseship & +1.1kts/10crew	+5190kW from baseship & approx. – 2000kW/10crew	+0.06m from baseship & -0.03m/10crew	Ok	
Aft deck length (18.5m – 27.5m, baseship 20.6m)	-2.5m from baseship & +1m/1m aft deck increase	Constant	Decreases marginally	-19t from baseship & +15t/1.5m aft deck increase	-0.9kts from baseship & +0.5kts/1.5m aft deck increase	+1470kW from baseship & approx. –4%/1.5m aft deck increase	Constant	Ok	
Materials (SSmf 0.55, baseship SSmf 1)	Fixed at 76.11m	-0.07m	Constant	-30t	+0.5kts	-755kW	+0.05m	Ok	
Hangar (Baseship no hangar non-organic)									
15m Non-Organic	+9m from baseship	+0.1m from baseship	Constant	+210t from baseship	30kts	-1400kW from baseship	-0.04m from baseship	Above L/F (+0.2)	For possible mitigation see next row
15m Non-Organic Increased Deckheight (2.3m-2.8m)	+8.8m from baseship & 0.16m/0.1m deckheight increase	0.2m/0.1m deckheight increase	-.08m from baseship & 0.16m/0.1m deckheight increase	+186t from baseship & +50t/0.1m deckheight increase	30kts @2.3m & -0.45kts/0.1m deckheight increase	-1800kW from baseship & 2.6%/0.1m deckheight increase	-0.1 from baseship & +0.13m/0.1m deckheight increase	Ok from 2.4m deckheight upwards	Only marginal increase in deckheight required
15m Organic	+12.5m from baseship	+0.15m from baseship	Constant	+265t from baseship	30kts	-2445kW from baseship	Marginal increase	2.7% above L/D	For possible mitigation see next row
15m Organic Increased Deckheight (2.3m-2.8m)	+12.4m from baseship & 0.25m/0.1m deckheight increase	+0.05m from baseship & 0.2m/0.1m deckheight increase	-.06m from baseship & 0.15m/0.1m deckheight increase	+242t from baseship & 50t/0.1m deckheight increase	30kts for dkh>=2.5m; -0.35kts/0.1m deckheight increase for dkh<2.5	-2800kW from baseship & 3.5%/0.1m deckheight increase	-0.04m from baseship & 0.13m/0.1m deckheight increase	Outside L/D for dkh<2.5m; outside L/F for dkh<2.4m	
18m Non-Organic	+10m from baseship	+0.1m from baseship	Constant	+222t from baseship	30kts	-1780kW from baseship	Marginal decrease	Above L/F (+0.04)	For possible mitigation see next row
18m Non-Organic Increased Deckheight (2.3m-2.8m)	+9.84m from baseship & 0.2m/0.1m deckheight increase	+0.03m from baseship & 0.2m/0.1m deckheight increase	-0.08m from baseship & 0.16m/0.1m deckheight increase	+200t from baseship & 50t/0.1m deckheight increase	30kts for dkh<=2.4; -0.4kts/0.1m deckheight increase for dkh>=2.5	-2157kW from baseship & 3.7%/0.1m deckheight increase	-0.08m from baseship & 0.13m/0.1m deckheight increase	Above L/D for dkh=2.3m (0.86%); outside L/F for dkh=2.3m (0.6)	Only marginal increase in deckheight required

	L	B	D	Displacement	Speed (Max. = 30kts)	Power	Freeboard	Constraints	Notes
18m Organic	+13.6m from baseship	+0.15m from baseship	Constant	+280t from baseship	30kts	-2756kW from baseship	+0.04m from baseship	3.9% above L/D	For possible mitigation see next row
18m Organic Increased Deckheight (2.3m-2.8m)	+13.45m from baseship & 0.25m/0.1m increased deckheight	+0.06m from baseship & 0.19m/0.1m increased deckheight	-0.06m from baseship & 0.16m/0.1m increased deckheight	+258t from baseship & 50t/0.1m deckheight increase	30kts for dkh<=2.5; -0.3kts/0.1m increased deckheight for dkh>2.5	-3080kW from baseship & 3.5%/0.1m deckheight increase	Marginal decrease from baseship & 0.13m/0.1m increased deckheight	Outside L/D for dkh<=2.5; outside L/F for dkh=2.3	
Area (0% - 15%, 2.5% steps; 15%-25%, 5% steps)	2.3m/2.5% area margin applied	Marginal decrease for area<12.5%; 0.04m/5% for area>12.5%	Marginal changes	+2%/2.5% area margin increase	30kt	-3%/2.5% area margin increase	0.04m/2.5% area margin increase	Outside L/D for area>=12.5%;	2.5% area margin correspond to 4.8% actual area added; for possible mitigation see next row
Extra deck SS (10% - 25%, 2.5% steps)	-9.7m from baseship & 1.55m/2.5% area margin increase	+0.33m from baseship & -0.05m/2.5% area margin applied	+0.3m from baseship & -0.05m/2.5% area margin applied	-70t from baseship & 0.8%/2.5% area margin applied	-3.5kts from baseship & 0.56kts/2.5% area margin applied	6790kW from baseship & -4%/2.5% area margin applied	+0.08m from baseship & -0.01m/2.5% area margin applied	Ok	
Deckheight (2.3m – 2.9m, 0.1m steps; base 2.35m)	Constant for dkh<=2.6m, marginal increase for dkh>2.6m	-0.11m from baseship & 0.23m/0.1m deckheight increase	-0.08m from baseship & 0.18m/0.1m deckheight increase	-19t from baseship & 2.7%/0.1m deckheight increase	+0.3kts from baseship & -2%/0.1m deckheight increase	-500kW from baseship & 4.3%/0.1m deckheight increase	-0.08m from baseship & 0.16m/0.1m deckheight increase	Above L/F for dkh=2.3m; Ok for all others	
Power (0% - 20%, 2.5% steps; uncapped)	0.44m/2.5% margin applied	Marginal decrease	Marginal decrease	1.7%/2.5% margin applied	30kts	3.7%/2.5% margin applied	-0.06m/2.5% margin applied	Below B/T for margin >=5%; above L/F for margin>=2.5%	2.5% power margin corresponds to 3.7% actual power increase; for possible mitigation see next rows
Extra area 5% margin (values @min required area margin)	+5m	-0.11m	-0.09m	+38t	30kts	-1505kW	+0.02m	Ok	Values @5% applied area margin
Extra area 10% margin (values @min required area margin)	+7.8m	-0.14m	-0.12m	+63t	30kts	-1641kW	+0.03m	Ok, but if increased >=10% then L/D exceeded	Values @7.5% applied area margin

	L	**B**	**D**	**Displacement**	**Speed** (Max. = 30kts)	**Power**	**Freeboard**	**Constraints**	**Notes**
Extra deckheight 5% margin (values @min required deckheight)	NA	NA	NA	NA	NA	NA	NA	NA	Not possible to bring design within constraints using deckheight only
Extra deckheight 10% margin (values @min required area deckheight)	NA	NA	NA	NA	NA	NA	NA	NA	Not possible to bring design within constraints using deckheight only
Passagewidth (1m – 1.5m, 0.1m steps; baseship 1.03m)	-0.6m from baseship & 1.9m/0.1m passagewidth increase	Marginal changes	Marginal changes	-5t from baseship & 1.5%/0.1m passagewidth increase	-0.2kts from baseship & 0.7/0.1m passagewidth until 30kts	+300kW from baseship & -3.5%/0.1m passagewidth increase	Initial marginal increase, overall 0.1m/0.5m passagewidth increase	Ok	
Weights (0% - 12.5%, 2.5% steps; only 1-7 combined listed)	0.39m/2.5% weights margin applied	+0.03m/2.5% weights margin applied	Marginal increase	2.5%/2.5% weights margin applied	Average is – 0.35kts/2.5% weights margin applied but rate decreases with increasing margin	+730kW/2.5% weights margin applied	-0.07m/2.5% weights margin applied	Below B/T for weights margin>=7.5%; above L/F for weights margin >=2.5%	For possible mitigation see next rows
Extra area 5% margin (values @min required area margin)	NA	NA	NA	NA	NA	NA	NA	NA	Not possible to bring design within constraints using area margin only
Extra area 10% margin (values @min required area margin)	NA	NA	NA	NA	NA	NA	NA	NA	Not possible to bring design within constraints using area margin only
Extra deckheight 5% margin (values @min required deckheight)	+0.7m	+0.4m	+0.29m	+146t	-1.7kts	+3300kW	+0.1m	Ok	Values @2.5m deckheight
Extra deckheight 10% margin (values @min required deckheight)	+1.3m	+0.7m	+0.47m	+280t	-2.7kts	+6900kW	+0.12m	Ok	Values @2.6m deckheight
VCG (0% - 12.5%, 2.5% steps; only 1-7 combined listed)	Constant	+0.1m/2.5% applied VCG rise	-0.02m/2.5% applied VCG rise	Average 6t/2.5% VCG rise but rate decreases with increasing margin	-0.1kts/2.5% applied VCG rise	0.7%/2.5% applied VCG rise	Marginal increase	Ok	2.5% applied VCG margin corresponds to 1.6% actual rise in VCG

Table 51 –Parametric Study Summary Table

31 APPENDIX V

The data is sorted by ascending task numbers. The task numbers are based on the task numbers assigned in the Project schedule.

31.1 DEFINITIONS

31.1.1 Timings

These descriptions are used to illustrate at what stage data needs to be transferred. They are fixed to the domains and do not refer to the overall project timings, i.e. each domain has a “start” and “end”. For overall project timings see the MS Project chart.

- Start
    - This denotes items that ideally need to be received/transferred at an early stage so that the receiving domains can commence/continue work.
- End
    - This denotes items that need to be received/transferred at the final stages.
- ASAP
    - This denotes items that need to be received/transferred as soon as possible. Usually these are items that are iterative.
- Iterative
    - This denotes data that is iterative and relies on input from the receiving domain. This implies that a first estimate needs to be output to the receiving domain and the data is then refined using feedback from the receiving domain.

31.1.2 Criticality

These values are used to describe the urgency with which the data needs to be received/transferred. They are provided to give the project manager a quick and easy overview of critical issues that need close observation during a feasibility study. The criticality values are assigned based on the findings from interviews, case studies and domain investigations. The values are assigned to both the input and output domain to ensure that both sets of domain managers are aware of any potential issues.

- 1
    - No delay allowed. The information is critical to the functioning of the receiving domain. The receiving domain cannot continue/start unless the data is received.
- 2
    - Some delay allowed. The information is important to the functioning of the receiving domain. However, a minor delay will have no significant effect on the domain.
- 3
    - Delays are allowed. This item is not critical for the operation of the domain. However, it needs to be received before the domain can finalise its output.

The above timings and criticality values are combined to provide a more detailed description of the data transfer process. For example an item that has “start / 1” assigned to it needs to be received at the very start of the domain so that work can commence.

31.2 DOMAIN DESCRIPTIONS LOOP0

31.2.1 Task 3 Customer

This is the starting point for all projects. It is linked to all domains. On this loop the main reason for its inclusion is the provision of the URD and other customer requirements. Clarifications can be sought from the customer via informal meetings however a record must be kept of the outcome to be discussed at the next formal meeting. If any of the requirements are changed the configuration and document change procedure must be followed.

31.2.2 Task 4 Production

The production domain is included at this early stage as it is responsible for some of the main constraints on the design, such as maximum size. Most of the production study can be carried out before the customer requirements are known.

Inputs

Data	From	Timing/Criticality	Notes
Customer Requirements	Customer	Start – Iterative / 3	Most work carried out up-front and customer requirements are only required to prepare final recommendation

Table 52 –Task 4 Inputs

Outputs

Data	To	Timing	Notes
Preferred Hullform	Parametric Study	End	Includes limits on hullform
Dimension Constraints	Parametric Study	End	Only minor changes between projects; includes items such as berth capacity

Table 53 –Task 4 Outputs

The main purpose of the study at this high-level is to provide an input with respect to constraints and build duration, as well as preferred hullform features. No margins can be applied to the production domain, as it is not possible to exceed the maximum parameter constraints.

31.2.3 Task 5 Aviation

The purpose of including this domain at such an early stage is to make a few but crucial decisions: Does the vessel need to support rotary aircrafts or UAVs, and is the required support organic or inorganic.

Inputs

Data	From	Timing/Criticality	Notes
Customer Requirements	Customer	Start / 1	

Table 54 –Task 5 Inputs

Outputs

Data	To	Timing	Notes
Equipment Data	• Parametric Survey	End	• Rotary Aircraft: Yes/No • Aircraft Type
	• Crewing Study	End	
Support Data	• Parametric Survey	End	• Organic/Inorganic: Yes/No • Hangar: Yes/No • Fuel • Manpower
	• Crewing Study	End	
Equipment Cost	Costing	End	

Table 55 –Task 5 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Equipment and/or support change	Both of these have severe impact on the design and thus need to be fixed at a very early stage.	

Table 56 –Task 5 Controls

No margins can be applied to this domain at this stage. The only way of allowing for future changes would be to design for a larger helicopter than originally anticipated.

31.2.4 Task 6 Weapon Study

The purpose of the domain at this stage is to determine the likely weapon and communication systems. This study needs to be concluded before the parametric survey can be completed.

Inputs

Data	From	Timing/Criticality	Notes
Customer Requirements	Customer	Start / 1	

Table 57 –Task 6 Inputs

Outputs

Data	To	Timing	Notes
Equipment Weight	Parametric Study	End	
Equipment Location	Parametric Study	End	
Equipment Manpower	Crewing Study	End	
General Equipment Requirements	Parametric Study	End	Items such as clearances, power, heat
Estimated electrical load	Electrical loop1	End	

Table 58 –Task 6 Outputs

At this stage of the design it is only necessary to establish a high-level decision about the combat systems, e.g. deciding whether or not the vessel will have air-search radar.
It is very difficult to include margins to control this domain as combat systems can only be treated as stepped functions.
The results from the weapon study form the baseline for the weapon domain on loops 1 – 3.

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Equipment could be For But Not With	Treat as if fitted	Items such as space, power, heat

Table 59 –Task 6 Controls

31.2.5 Task 7 Parametric Study

This study is used to derive a first set of parameters for the design. It is the first integration of the data from the initial studies and the customer requirements. The main aim of the parametric study is to determine a set of parameters that meets all the initial requirements, such as speed, endurance and complement. It also provides a first GA.

Inputs

Data	From	Timing/Criticality	Notes
Propulsion Configuration	Propulsion Study	Start – Iterative / 2	
Fuel Prediction	Propulsion Study	Start – Iterative / 2	
Customer Requirements • Endurance • Range • Speed • Preferred ship type • Desired Stability Standards	Customer	Start / 1	
Weapon Configuration	Weapon Study	Start / 2	
Complement	Crewing Study	Start – Iterative / 2	But first estimate required right at the start
Habitability Standards	Crewing Study	Start / 1	
Preferred Hullform	• Production	Start / 1	
	• Propulsion Study	Start – Iterative / 2	
	• Customer	Start – Iterative / 1	
Aviation Equipment & Support Data	Aviation	Start / 1-2	Aviation decision needs to be known at the very start
Dimension Constraints	Production	Start / 1	Maximum Berth length etc.

Table 60 –Task 7 Inputs

Outputs

Data	To	Timing	Notes
Hullform	• Results from parametric study	End	
	• Propulsion Study	End – Iterative	
Weights	Results from parametric study	End	
Margin Policy	• Results from parametric study	End	• See section on margin policy derivation
GA	• Results from parametric study	End	
	• Propulsion Study	End - Iterative	
	• Crewing Study	End – Iterative	
Actual Required Power	Propulsion Study	End – Iterative	
Overall Dimensions	Crewing Study	End – Iterative	

Table 61 –Task 7 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Delay in receiving data	Informal meetings with domains whilst they are still developing their solutions	
Derived hullform provides inadequate space envelope	Reiterate solution with different propulsion configuration	
Derived hull form does not meet customer requirements	• Reiterate solution with different parent hullform • Discuss requirements with customer	

Table 62 –Task 7 Controls

Other issues

For designs with little empirical data it is necessary to consult structures to obtain a reliable first weights estimate. This is to allow for any novel structural design techniques. Although no electrical data is known at this stage sufficient space should be reserved for generator rooms and associated equipment.

31.2.6Task 8 Propulsion Study

This is an initial propulsion study investigating possible propulsion configurations for the type of vessels under investigation. It runs in parallel with the parametric study. The main aim of the propulsion study is to identify different propulsion means, such as all electric propulsion, and decide on the method most suitable for the design.

Inputs

Data	From	Timing/Criticality	Notes
Customer Requirements • Range	Customer	Start / 1	
• Speed		Start / 1	
Available Space	Parametric Study	Start – Iterative / 2	
Actual Required Power	Parametric Study	Start – Iterative / 2	

Table 63 –Task 8 Inputs

Outputs

Data	To	Timing	Notes
Equipment Weight	Parametric Study	End – Iterative	
Equipment Location	Parametric Study	End – Iterative	
Equipment Manpower	HF	End	
General Equipment Data	Costing	End	ILS also needs to be consulted
Fuel Prediction	Parametric Study	End – Iterative	
Preferred Hullform	Parametric Study	End – Iterative	

Table 64 –Task 8 Outputs

The development of the actual equipment is very iterative as it relies on input from the parametric study.

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Initial equipment choice might not satisfy power requirements derived in parametric study	• Suggest alternative propulsion configuration • Power Margins	Propulsion equipment must be treated as a stepped function, as it comes in distinct sizes

Table 65 –Task 8 Controls

The outcome from the propulsion study is also used as the baseline system for loops 1 – 3.

31.2.7 Task 9 Crewing (HF)

The crewing domain is part of the HF domain. At this stage the purpose of the domain is to derive a first estimate of the required complement. A baseline study can be carried out once the approximate type of vessel is known, derived from the initial customer requirements.

Inputs

Data	From	Timing/Criticality	Notes
Customer Requirements	Customer	Start – Iterative / 1	Includes items such as manning

			policies and accommodation standards, see also customer output
Propulsion Machinery Manpower	Propulsion Study	Start / 3	
Aviation Capabilities	Aviation	Start / 2	
Combat System Configuration	Weapon Study	Start / 3	
Dimensions	Parametric Study	ASAP – Iterative / 1	First complement needs rough dimensions (i.e. type of ship)

Table 66 –Task 9 Inputs

Outputs

Data	To	Timing	Notes
Complement	Parametric Study	End – Iterative	Complement will be amended as parametric study defines dimensions
Complement	Customer	End – Iterative	Agree staffing levels
Habitability Standards	Parametric Study	End	

Table 67 –Task 9 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Data does not arrive in time	Calculate complement based on assumptions and clearly record these	Domain does not use margins but instead uses assumptions to deal with uncertainties (training margins)
Change in required habitability standards	Communicate to Parametric Study as dimensions will need recalculating	

Table 68 –Task 9 Controls

Once data from the Propulsion Study, Aviation domain and Weapon study is collected then the complement can be refined. The refined complement is then used as an iterative input into the parametric study. This close link is required as complement has a major impact on the overall dimensions of the vessel, as highlighted by the parametric survey. However, if the dimensions of the vessel change then it is very likely that the required complement changes correspondingly.
The output from the crewing study will be used as the baseline for all subsequent design changes.

31.3 DOMAIN DESCRIPTIONS LOOP1

31.3.1 Task 12 ILS

ILS runs in parallel to the “actual” design process and acts as a constant advisor to the individual domains. It is the domains’ responsibility to ensure that ILS has been informed of any changes and it is ILS’s responsibility to ensure that all domains are aware of any ILS requirements. At this stage it is also necessary to “tailor” the ILS tasks relevant to the project.

Inputs

Data	From	Timing	Notes
Maintenance Philosophy	Customer	Start / 1	
Operator Feedback	Customer	Start / 2	
Support Philosophy	Customer	Start / 1	
Equipment Data (Location, Weight, Manpower, General Requirements)	General Vehicle Capability	Start – Iterative / 2	
	Weapons	Start – Iterative / 2	
	Electrical (High level)	Start – Iterative / 2	
	Auxiliary (High level)	Start – Iterative / 2	
GA	• Results from parametric study	Start / 2	
	• Naval Architecture	Start – Iterative / 3	
Production Requirements	Production	Start – Iterative / 3	
Human Factors Feedback	HF	Start – Iterative / 2	Ergonomics, Access Routes, etc
Structural Design	Structures	Start – Iterative / 3	Access, Removal etc.

Table 69 –Task 12 Inputs

Output

Data	To	Timing	Notes
ILS Recommendations	• General Vehicle Capabilities	End – Iterative	Provide feedback with regards to equipment location, removal and access routes, stores size etc.
	• Weapons	End – Iterative	
	• Production	End – Iterative	
	• HF	End – Iterative	
	• Naval Architecture	End – Iterative	
	• Structures	End – Iterative	
	• Auxiliary	End – Iterative	
	• Electrical	End – Iterative	
Preliminary TLC estimates	Costing	End	

Table 70 –Task 12 Outputs

31.3.2 Task 15 Customer

This domain is included as it is necessary to continually ensure that no requirements have changed. If any requirements are changed this needs to be transferred to all domains. The customer also needs to communicate the required zoning policy and desired electrical distribution network.

31.3.3 Task 16 Results from parametric study

This domain is an intermediary between the concept level and loop 1. Its main purpose is to move the data gathered during the parametric study onto loop 1.

Inputs

Data	From	Timing/Criticality	Notes
Hullform	Parametric Study	Start / 1	
Weights	Parametric Study	Start / 1	
Margin Policy	Parametric Study	Start / 1	
GA	Parametric Study	Start / 1	

Table 71 –Task 16 Inputs

Outputs

Data	To	Timing	Notes
Hullform	• Naval Architecture	End	
	• General Vehicle Capability	End	
	• Production	End	
	• Costing	End	
	• Structures	End	
Weights	• Naval Architecture	End	
	• Structures	End	
GA	• General Vehicle Capability	End	
	• Weapons	End	
	• Production	End	
	• Costing	End	
	• Naval Architecture	End	
	• Structures	End	
	• ILS	End	
	• Auxiliary (high level)	End	
	• Electrical (high level)	End	
Margin Policy	• General Vehicle Capability	End	• See section on margin policy derivation
	• Weapons	End	
	• Production	End	
	• Costing	End	
	• HF	End	
	• Structures	End	
	• Naval Architecture	End	
	• Auxiliary (high level)	End	
	• Electrical (high level)	End	

Table 72 –Task 16 Outputs

Possible Issues and Control Methods
There are no issues identified with this domain, as it is primarily a "transfer" domain.

31.3.4 Task 17 Auxiliary (High Level)

The inclusion of this domain is necessary to identify the required zoning policy. This has a large impact on the overall layout of the vessel.

Inputs

Data	From	Timing	Notes
Customer Requirements	Customer	Start / 1	Desired zoning policy; requirements for black/grey water
GA	Results from Parametric Study	Start / 1	
Margin Policy	Results from Parametric Study	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 73 –Task 17 Inputs

Output

Data	To	Timing	Notes
Zoning Policy	Naval Architecture	End	
Aircon compartment requirements	Naval Architecture	End	Provide information regarding desired locations for aircon plants
	ILS	End - Iterative	

Table 74 –Task 17 Outputs

31.3.5 Task 18 Electrical (High Level)

The main issue to be decided at this stage is the placement of the generator room and the associated compartments, such as the switchboard room. Also to be decided is the space allowance on each deck for electrical distribution compartments.

Inputs

Data	From	Timing	Notes
Customer Requirements	Customer	Start / 1	Desired electrical distribution network
GA	Results from Parametric Study	Start / 1	
Margin Policy	Results from Parametric Study	Start / 3	
User Loads	Weapons	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 75 –Task 18 Inputs

Output

Data	To	Timing	Notes
Equipment Choice	Naval Architecture	End	High level decision on required generator size
	ILS	End – Iterative	
Equipment Location	Naval Architecture	End	Provide information regarding desired locations for generator room and switchboard location
	ILS	End - Iterative	

Table 76 –Task 18 Outputs

31.3.6 Task 19 General Vehicle Capability

The purpose of this domain is to determine whether the vessel is required to carry and support any general vehicles, such as ROVs, towed arrays, sweeping gear, boats and also items such as cargo cranes. If there is a need for any of this then the domain needs to identify the preferred kit, its preferred location, likely weights and any other requirements.

Inputs

Data	From	Timing/Criticality	Notes
Customer Requirements	Customer	Start / 1	
GA	Results from Parametric Study	Start / 2	
Hullform	Results from Parametric Study	Start / 2	
Margin Policy	Results from Parametric Study	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 77 –Task 19 Inputs

Outputs

Data	To	Timing	Notes
Equipment Weight	Naval Architecture	End	
	ILS	End – Iterative	
Equipment Location	Naval Architecture	End	
	ILS	End – Iterative	
Equipment Manpower	HF	End	
	ILS	End – Iterative	
General Equipment Requirements	Naval Architecture	End	
	ILS	End – Iterative	
General Equipment Data	Costing	End	

Table 78 –Task 19 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Technology to be used might not be fully developed	• Apply sound engineering judgement and record decision • Allow for by applying adequate margins in design	

Table 79 –Task 19 Controls

31.3.7 Task 20 Weapons

At this stage of the design process the purpose of the weapon domain is to refine the combat system choices made in 0.4.

Inputs

Data	From	Timing/Criticality	Notes
Customer Requirements	Customer	Start / 1	
GA	Results from parametric study	Start / 2	
High-Level Combat Systems	Weapon Study	Start / 1	
Margin Policy	Results from Parametric Study	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 80 –Task 20 Inputs

Outputs

Data	To	Timing	Notes
Equipment Weight	Naval Architecture	End	
	ILS	End – Iterative	
Equipment Location	Naval Architecture	End	
	ILS	End – Iterative	
Equipment Manpower	HF	End	
	ILS	End – Iterative	
General Equipment Requirements	Naval Architecture	End	
	ILS	End – Iterative	
General Equipment Data	Costing	End	

Table 81 –Task 20 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Equipment does not fit	Needs to be communicated to Naval Architecture along with preferred solution	

Table 82 –Task 20 Controls

31.3.8 Task 21 Costing

This domain is included to provide a first cost estimate and also provide constraints with regards to maximum costs. This implies that the estimating and the sales department are involved.

Inputs

Data	From	Timing	Notes
Hullform	Results from Parametric Study	Start / 2	
Customer Requirements	• Customer	Start / 1	Determine likely target price
	• Market research	Start / 1	
GA	Results from Parametric Study	Start / 1	
Aviation Equipment Data	Aviation (top loop)	Start / 2	
Combat System Data	Weapons	Start / 2	
Propulsion Equipment Data	Propulsion Study (top loop)	Start / 2	
General Vehicle Capability Data	General Vehicle Capability	Start / 2	
Preliminary Production Costs	Production	Start – Iterative / 2	
Margin Policy	Results from Parametric Study	Start / 3	
Preliminary TLC Estimates	ILS	Start / 3	

Table 83 –Task 21 Inputs

Outputs

Data	To	Timing	Notes
Costing Information	• Naval Architecture • Project Management	End	Only if design is below target price to advise as how much more can be spent
Budget Targets	• All domains	End	
	• Production	End – Iterative	

Table 84 –Task 21 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Not all equipment data known	Make guesstimates based on similar vessels and record assumption	Needs continuous updating once data becomes available
Design exceeds target price	Arrange review with all departments to decide on possible cost cutting opportunities	

Table 85 –Task 21 Controls

31.3.9 Task 22 Production

This domain is included to provide a revised estimate of the production costs based on the hullform and layout chosen during the parametric study. It also outputs comments with regards to producability and build specific structures issues.

Inputs

Data	From	Timing	Notes
Hullform	Results from parametric study	Start / 1	
GA	Results from parametric study	Start / 1	
Customer Requirements	Customer	Start / 2	Specific requirements such as blocks etc.
Margin Policy	Results from Parametric Study	Start / 3	
Budget Targets	Costing	Start – Iterative / 2	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 86 –Task 22 Inputs

Outputs

Data	To	Timing	Notes
Production Costs	Costing	End – Iterative	
Producability Feedback	• Naval Architecture	End	This includes concerns regarding launching, unit size, etc.
	• Structures	End	
Production Requirements	ILS	End – Iterative	Access Panels etc.

Table 87 –Task 22 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Producability Issues	Consult relevant domain and ask for possible design changes	
Launching Issues	If vessel can not be launched this needs to be flagged immediately	STOP EVENT
Build program clashes with other projects	This needs to be flagged immediately	STOP EVENT

Table 88 –Task 22 Controls

31.3.10 Task 23 HF

This domain is included on this to loop to provide a revised crewing estimate based on the equipments chosen.

Inputs

Data	From	Timing	Notes
General Vehicle Capability Manpower	General Vehicle Capability	Start / 1	
Combat System Manpower	Weapons	Start / 1	
Margin Policy	Results from Parametric Study	Start / 3	
Budget Targets	Costing	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 89 –Task 23 Inputs

These inputs are in addition to the complement calculation already carried out.

Outputs

Data	To	Timing	Notes
Revised Complement	Naval Architecture	End	
HF Feedback	ILS	End – Iterative	

Table 90 –Task 23 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Complement exceeds initial assumptions	Inform Naval Architecture and discuss possible solutions	This is not a huge problem unless the complement exceeds the initial assumptions by more than 10 (for a corvette type ship)

Table 91 –Task 23 Controls

31.3.11 Task 24 Structures

The main purpose of the structures domain at this stage is to develop a first set of scantlings and provide a more detailed structural weight than that from the parametric study.

Inputs

<table>
<tr><th>Data</th><th>From</th><th>Timing/Criticality</th><th>Notes</th></tr>
<tr><td>Producability Feedback</td><td>Production</td><td>Start / 3</td><td>Issues regarding launch supports etc</td></tr>
<tr><td rowspan="2">Hullform</td><td>• Results from parametric study</td><td>• Start / 1</td><td rowspan="2">Initial data from parametric study and then refined information from naval architecture domain</td></tr>
<tr><td>• Naval Architecture</td><td>• Start – Iterative / 2</td></tr>
<tr><td rowspan="2">Weights</td><td>• Results from parametric study</td><td>• Start / 1</td><td rowspan="2">See above</td></tr>
<tr><td>• Naval Architecture</td><td>• Start – Iterative / 2</td></tr>
</table>

GA	• Results from Parametric study	• Start / 1	See above
	• Naval Architecture	• Start – Iterative / 2	
Margin Policy	Results from Parametric Study	Start / 3	
Budget Targets	Costing	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 92 –Task 24 Inputs

Output

Data	To	Timing	Notes
Structural Weights	Naval Architecture	End – Iterative	
Structural Design	ILS	End – Iterative	
	Naval Architecture	End – Iterative	

Table 93 –Task 24 Outputs

The first structural weights estimate is based on the results from the parametric study and then revised using the data available from the naval architecture domain.

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Structural Weights exceed original assumptions	• Weight Margin • Explore alternative material solutions	See margin policy section
Design is structurally unfeasible	Inform all domains	STOP EVENT

Table 94 –Task 24 Controls

31.3.12 Task 25 Naval Architecture

This domain provides a first integration including all the revised equipment data and feedback, as well as a first stability check.

Inputs

Data	From	Timing	Notes
Hullform	Results from Parametric Study	Start / 2	
Weights	Results from Parametric Study	Start / 2	
GA	Results from Parametric Study	Start / 1	
General Vehicle Capability • Equipment Weight	General Vehicle Capability	Start / 2	
• Equipment Location		Start / 1	

• General Equipment Requirements		Start / 3	
Combat Systems • Equipment Weight	Weapons	Start / 2	
• Equipment Location		Start / 1	
• General Equipment Requirements		Start /3	
Revised Complement	HF	Start / 3	
Costing Information	Costing	Start / 2	Advisory as to how close design is to target price
Producability Feedback	Production	Start / 3	
Structural Weights	Structures	Start – Iterative / 2	See structures output table
Margin Policy	Results from Parametric Study	Start / 3	
Budget Targets	Costing	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	
Structural Design	Structures	Start – Iterative / 2	Frame spacing and required bulkheads
Zoning Policy	Customer	Start / 2	
	Auxiliary (High Level)	Start / 2	
Aircon Compartment Requirements	Auxiliary (High Level)	Start / 3	Desired areas and locations for aircon plants based on zoning policy
Generator & Switchboard Data	Electrical (High Level)	Start / 2	Basic information about location and requirements – possibly coupled with propulsion

Table 95 –Task 25 Inputs

Output

Data	To	Timing	Notes
GA	Structures	End – Iterative	
	ILS	End – Iterative	
Hullform	Structures	End – Iterative	
Weights	Structures	End –	

		Iterative	
All data (including Margin Policy)	Naval Architecture Loop 2	End	

Table 96 –Task 25 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Failed Stability Check	• Margins • Review of design parameters	See section on margin policy
Conflicting design issues	• Consult with relevant domains	See section on parametric survey results

Table 97 –Task 25 Controls

Other issues
For high-speed vessels it is important to have a first tank estimate ready so that bottom raking damage can be assessed.
The GA should be kept at quite a high-level at this stage to avoid unnecessary rework.
For trimarans it is important to bear in mind that visibility fore and aft and along the sides can be problematic.

31.4 DOMAIN DESCRIPTIONS LOOP2

31.4.1 Task 28 Naval Architecture

The domain is included to provide a link between loop 1 and loop 2. No actual computations are carried out at this stage.

Inputs

Data	From	Timing	Notes
All Naval Architecture Data	Naval Architecture Loop 1	Start / 1	

Table 98 –Task 28 Inputs

Output

Data	To	Timing	Notes
GA	• HF	End	
	• Propulsion	End	
	• General Vehicle Capability	End	
	• Aviation	End	
	• Weapons	End	
	• ILS	End	
Hullform	• Propulsion	End	
	• General Vehicle Capability	End	
	• Aviation	End	
	• Weapons	End	
Revised Performance Figures	Propulsion	End	
Margin Policy	Propulsion	End	
	Aviation	End	

Table 99 –Task 28 Outputs

Possible Issues and Control Methods
There are no issues identified with this domain, as it is primarily a transfer domain.

31.4.2 Task 29 Customer

This domain is included as it is necessary to continually ensure that no requirements have changed. If any requirements are changed this needs to be transferred to all domains.

31.4.3 Task 30 ILS

ILS runs in parallel to the "actual" design process and acts as a constant advisor to the individual domains. It is the domains' responsibility to ensure that ILS has been informed of any changes and it is ILS's responsibility to ensure that all domains are aware of any ILS requirements.

Inputs

Data	From	Timing	Notes
All ILS Data	ILS	Start	
GA	Naval Architecture (2.2)	Start / 2	
	Naval Architecture	Start – Iterative / 3	
Equipment Data (Location, Weight, Manpower, General Requirements)	• General Vehicle Capability	Start – Iterative / 2	
	• Weapons	Start – Iterative / 2	
	• Propulsion	Start – Iterative / 2	
	• Aviation	Start – Iterative / 2	
Human Factors Feedback	HF	Start – Iterative / 2	

Table 100 –Task 30 Inputs

Output

Data	To	Timing	Notes
ILS Recommendations	• General Vehicle Capabilities	End – Iterative	Provide feedback with regards to equipment location, removal and access routes, stores size etc.
	• Weapons	End – Iterative	
	• Propulsion	End – Iterative	
	• HF	End – Iterative	
	• Naval Architecture	End – Iterative	
	• Aviation	End – Iterative	

Table 101 –Task 30 Outputs

31.4.4 Task 33 Propulsion

At this stage of the project it is necessary to carry out a more in-depth investigation into the propulsion system. This involves creating a more detailed propulsion system layout and identifying any associated issues. The inputs received from tasks 34, 35 & 36 in incorporated during the "propulsion impact feedback" task in the project schedule.

Inputs

Data	From	Timing/Criticality	Notes
GA	Naval Architecture	Start / 1	
Hullform	Naval Architecture	Start / 2	
Revised Performance Figures	Naval Architecture	Start / 1	
Possible Changes in Requirements	Customer	Start / 1	Only if applicable
Equipment Location Feedback	• General Vehicle Capability	Start – Iterative / 2	
	• Aviation	Start – Iterative / 2	
	• Weapons	Start – Iterative / 2	
Margin Policy	Naval Architecture	Start / 3	
Budget Targets	Costing	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 102 –Task 33 Inputs

Output

Data	To	Timing	Notes
Equipment Weight	Naval Architecture	End	
	ILS	End – Iterative	
Equipment Location Feedback	• General Vehicle Capabilities	End – Iterative	
	• Aviation	End – Iterative	
	• Weapons	End – Iterative	
	• ILS	End – Iterative	
Equipment Location	Naval Architecture	End	
Equipment Manpower	HF	End	
	ILS	End – Iterative	
General Equipment Data	Naval Architecture	End	
	ILS	End – Iterative	

Table 103 –Task 33 Outputs

The equipment location is a highly iterative output. This is due to possible interference with other equipment, especially on the weatherdeck. It is unlikely that the overall position of the ER will change much, however items such as exhausts can have a major impact on weapon systems etc.

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Equipment interferes with other items	• Consult relevant domain and derive solution • Arrange formal review if no informal solution is found	In both cases it is important to inform other domains of agreed solution
No equipment can be found to match updated performance criteria	• Consult naval architecture	This should only occur if there is a requirement change

Table 104 –Task 33 Controls

31.4.5 Task 34 General Vehicle Capability

This domain is included to evaluate the implications of the propulsion system on the general vehicle capability layout. This is necessary to ensure various equipments do not interfere with each other.

Inputs

Data	From	Timing/Criticality	Notes
Equipment Location Feedback	• Propulsion	Start – Iterative / 1	
	• Aviation	Start – Iterative / 2	
	• Weapons	Start – Iterative / 2	
GA	Naval Architecture	Start / 1	
Hullform	Naval Architecture	Start / 2	
Budget Targets	Costing	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 105 –Task 34 Inputs

Output

Data	To	Timing	Notes
Equipment Location Feedback	• Propulsion	End – Iterative	
	• Aviation	End – Iterative	
	• Weapons	End – Iterative	
	• ILS	End – Iterative	
Equipment Weight	Naval Architecture	End	
	ILS	End – Iterative	
Equipment Location	Naval Architecture	End	
Equipment Manpower	HF	End	

	ILS	End – Iterative	
General Equipment Data	Naval Architecture	End	
	ILS	End – Iterative	

Table 106 –Task 34 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Interference between equipment can not be resolved	Inform Naval Architecture and seek alternative solution	

Table 107 –Task 34 Controls

31.4.6Task 35 Aviation

Similar to the general vehicle capability this domain is included to evaluate the implications of the propulsion layout on the aviation equipment.

Inputs

Data	From	Timing	Notes
Equipment Location Feedback	• Propulsion	Start – Iterative / 1	
	• General Vehicle Capability	Start – Iterative / 2	
	• Weapons	Start – Iterative / 2	
GA	Naval Architecture	Start / 1	
Hullform	Naval Architecture	Start / 2	
Margin Policy	Naval Architecture	Start / 3	
Budget Targets	Costing	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 108 –Task 35 Inputs

Output

Data	To	Timing	Notes
Equipment Location Feedback	• Propulsion	End – Iterative	
	• General Vehicle Capability	End – Iterative	
	• Weapons	End – Iterative	
	• ILS	End – Iterative	
Equipment Weight	Naval Architecture	End	
	ILS	End – Iterative	
Equipment Location	Naval Architecture	End	
Equipment Manpower	HF	End	

	ILS	End – Iterative	
General Equipment Data	Naval Architecture	End	
	ILS	End – Iterative	

Table 109 –Task 35 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Interference between equipment can not be resolved	Inform Naval Architecture and seek alternative solution	

Table 110 –Task 35 Controls

31.4.7 Task 36 Weapons

This domain is included to resolve any potential design interferences with domains 33, 34, 35.

Inputs

Data	From	Timing	Notes
Equipment Location Feedback	• Propulsion	Start – Iterative / 1	
	• General Vehicle Capability	Start – Iterative / 2	
	• Aviation	Start – Iterative / 2	
GA	Naval Architecture	Start / 1	
Hullform	Naval Architecture	Start / 2	
Budget Targets	Costing	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 111 –Task 36 Inputs

Output

Data	To	Timing	Notes
Equipment Location Feedback	• Propulsion	End – Iterative	
	• General Vehicle Capability	End – Iterative	
	• Aviation	End – Iterative	
	• ILS	End – Iterative	
Equipment Weight	Naval Architecture	End	
	ILS	End – Iterative	
Equipment Location	Naval Architecture	End	
Equipment Manpower	HF	End	
	ILS	End – Iterative	
General Equipment Data	Naval Architecture	End	

	ILS	End – Iterative	

Table 112 –Task 36 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Interference between equipment can not be resolved	Inform Naval Architecture and seek alternative solution	

Table 113 –Task 36 Controls

31.4.8 Task 38 HF

At this stage of the design a revised crew estimate has to be carried out to allow for changes in equipment and layout. Feedback with respect to habitability issues is also output. These issues include items such as ergonomics, access routes, escape routes and noise/vibration concerns.

Inputs

Data	From	Timing/Criticality	Notes
Equipment Manpower Data	• Propulsion	• Start / 1	
	• Aviation	• Start / 3	
	• General Vehicle Capability	• Start / 3	
	• Weapons	• Start / 3	
Initial GA	Naval Architecture (2.2)	Start / 1	
Revised GA	Naval Architecture	Start – Iterative / 2	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 114 –Task 38 Inputs

The input from the Naval Architecture domain is highly iterative. However, at this stage of the design it is not anticipated that the complement is likely to change by a significant amount.

Output

Data	To	Timing	Notes
Revised Complement	Naval Architecture	End – Iterative	
Habitability Issues	Naval Architecture	End – Iterative	Includes items such as ergonomics and access routes
	ILS	End – Iterative	

Table 115 –Task 38 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Complement exceeds initial assumptions	Inform Naval Architecture and discuss possible solutions	This is not a huge problem unless the complement exceeds the initial assumptions by more than 10 (for a corvette type ship)

Table 116 –Task 38 Controls

31.4.9 Task 39 Naval Architecture

This domain provides the integration of all the revised equipment data, and also a further stability and performance check.

Inputs

Data	From	Timing/Criticality	Notes
Propulsion • Equipment Weight	Propulsion	Start / 2	
• Equipment Location		Start / 1	
• General Equipment Data		Start / 3	
General Vehicle Capability • Equipment Weight	General Vehicle Capability	Start / 2	
• Equipment Location		Start / 1	
• General Equipment Data		Start / 3	
Aviation • Equipment Weight	Aviation	Start / 2	
• Equipment Location		Start / 1	
• General Equipment Data		Start / 3	
Weapons • Equipment Weight	Weapons	Start / 2	
• Equipment Location		Start / 1	
• General Equipment Data		Start / 3	
Revised Complement	HF	Start – Iterative / 3	Not likely to change much
Habitability Issues	HF	Start – Iterative / 2	

ILS Recommendations	ILS	Start – Iterative / 3	

Table 117 –Task 39 Inputs

Output

Data	To	Timing	Notes
Revised GA	HF	End – Iterative	
	ILS	End – Iterative	

Table 118 –Task 39 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Failed Stability Check	• Margins • Review of design parameters	See section on margin policy
Conflicting design issues	• Consult with relevant domains	See section on parametric survey results
Failed Performance check	• Consult with propulsion	Are power margins correct?

Table 119 –Task 39 Controls

Other issues
The GA should be more detailed than at the end of loop1 but should still be kept at a reasonably high-level to avoid major rework during loop3.

31.5 DOMAIN DESCRIPTIONS LOOP3

31.5.1 Task 42 HF

This domain is included as a transfer domain. It relays the latest available complement data stored in the HF domain.

Inputs

Data	From	Timing/Criticality	Notes
All crewing related data	HF	Start / 1	

Table 120 –Task 42 Inputs

Output

Data	To	Timing	Notes
Complement	• Electrical	End	
	• Aux. & Dom. Systems	End	
	• Electrical	End	
	• Aux. & Dom. Systems	End	
	• Propulsion	End	
	• General Vehicle Capability	End	
	• Aviation	End	

	• Weapons	End	
	• ILS	End	

Table 121 –Task 42 Outputs

31.5.2 Task 43 Propulsion

This domain is included as a transfer domain. It relays the data stored in the propulsion domain onto loop 3.

Inputs

Data	From	Timing/Criticality	Notes
All equipment data	Propulsion	Start / 1	
Revised GA	Naval Architecture	Start / 1	
Revised Power Requirements	Naval Architecture	Start / 1	
Habitability Issues	HF	Start / 2	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 122 –Task 43 Inputs

Output

Data	To	Timing	Notes
General Equipment Data	• Electrical	End	Items such as heat, power, etc.
	• Aux. & Dom. Systems	End	
	• Production	End	
	• ILS	End – Iterative	
Equipment Cost	Costing	End	

Table 123 –Task 43 Outputs

No issues are identified, as the domain is included as a transfer function.

31.5.3 Task 44 Naval Architecture

This domain is included as a transfer domain. It relays the latest available GA and powering data stored in the Naval Architecture domain.

Inputs

Data	From	Timing/Criticality	Notes
GA	Naval Architecture	Start / 1	
Hullform	Naval Architecture	Start / 1	
Weights	Naval Architecture	Start / 1	
Power Requirements	Naval Architecture	Start / 1	

Table 124 –Task 44 Inputs

Output

Data	To	Timing	Notes
GA	• Electrical	End	
	• Aux. & Dom. Systems	End	

	• Propulsion	End	
	• General Vehicle Capability	End	
	• Aviation	End	
	• Weapons	End	
	• ILS	End	
Revised Power Requirements	• Electrical	End	
	• Aux. & Dom. Systems	End	
	• Propulsion	End	
Margin Policy	• Electrical	End	
	• Aux. & Dom. Systems	End	

Table 125 –Task 44 Outputs

31.5.4 Task 45 Customer

This domain is included as it is necessary to continually ensure that no requirements have changed. If any requirements are changed this needs to be transferred to all domains.

31.5.5 Task 46 ILS

ILS runs in parallel to the "actual" design process and acts as a constant advisor to the individual domains. It is the domains' responsibility to ensure that ILS has been informed of any changes and it is ILS's responsibility to ensure that all domains are aware of any ILS requirements.

Inputs

Data	From	Timing	Notes
All ILS Data	ILS	Start	
GA	Naval Architecture (3.7)	Start / 1	
	Naval Architecture	Start – Iterative / 3	
Equipment Data (Location, Weight, Manpower, General Requirements)	• General Vehicle Capability	Start – Iterative / 2	
	• Weapons	Start – Iterative / 2	
	• Propulsion	Start – Iterative / 2	
	• Aviation	Start – Iterative / 2	
	• Electrical	Start – Iterative / 2	
	• Aux. & Dom. Systems	Start – Iterative / 2	
Human Factors Feedback	HF (3.6)	Start / 2	
	HF	Start – Iterative / 2	
Production Feedback	Production	Start – Iterative / 3	Removal, Access etc.

Table 126 –Task 46 Inputs

Output

Data	To	Timing	Notes
ILS Recommendations	• General Vehicle Capabilities	End – Iterative	Provide feedback with regards to equipment location, removal and access routes, stores size etc.
	• Weapons	End – Iterative	
	• Propulsion	End – Iterative	
	• HF	End – Iterative	
	• Naval Architecture	End – Iterative	
	• Aviation	End – Iterative	
	• Electrical	End – Iterative	
	• Aux. & Dom. Systems	End – Iterative	
	• Production	End – Iterative	
TLC estimates	Costing	End	

Table 127 –Task 46 Outputs

31.5.6Task 49 Weapons

This domain is included as a transfer domain. It relays the latest available equipment data stored in the weapons domain.

Inputs

Data	From	Timing/Criticality	Notes
All equipment data	Weapons	Start / 1	
Revised GA	Naval Architecture	Start / 1	
Habitability Issues	HF	Start / 2	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 128 –Task 49 Inputs

Output

Data	To	Timing	Notes
General Equipment Data	• Electrical	End	Items such as heat, power, etc.
	• Aux. & Dom. Systems	End	
	• Production	End	
	• ILS	End – Iterative	
Equipment Cost	Costing	End	

Table 129 –Task 49 Outputs

31.5.7Task 50 Aviation

This domain is included as a transfer domain. It relays the latest available equipment data stored in the aviation domain.

Inputs

Data	From	Timing/Criticality	Notes
All equipment data	Aviation	Start / 1	
Revised GA	Naval Architecture	Start / 1	
Habitability Issues	HF	Start / 2	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 130 –Task 50 Inputs

Output

Data	To	Timing	Notes
General Equipment Data	• Electrical	End	Items such as heat, power, fire fighting, etc.
	• Aux. & Dom. Systems	End	
	• Production	End	
	• ILS	End – Iterative	
Equipment Cost	Costing	End	

Table 131 –Task 50 Outputs

31.5.8 Task 51 General Vehicle Capability

This domain is included as a transfer domain. It relays the latest available equipment data stored in the general vehicle capability domain.

Inputs

Data	From	Timing/Criticality	Notes
All equipment data	General vehicle capability	Start / 1	
Revised GA	Naval Architecture	Start / 1	
Habitability Issues	HF	Start / 2	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 132 –Task 51 Inputs

Output

Data	To	Timing	Notes
General Equipment Data	• Electrical	End	Items such as heat, power, fire fighting, etc.
	• Aux. & Dom. Systems	End	
	• Production	End	
	• ILS	End – Iterative	
Equipment Cost	Costing	End	

Table 133 –Task 51 Outputs

31.5.9 Task 52 Electrical

The purpose of this domain is to provide a detailed description of the electrical equipment and provide information with regards to items such as cabling.

Inputs

Data	From	Timing/Criticality	Notes
General Equipment Data	• Propulsion	Start / 2	
	• Weapons	Start / 2	
	• Aviation	Start / 2	
	• General Vehicle Capability	Start / 2	
	• Aux. & Dom. Systems	Start - Iterative / 2	
GA	Naval Architecture	Start / 1	
Complement	HF	Start / 2	
Habitability Issues	HF	Start / 2	
Customer Requirements	Customer	Start / 1	
Revised Power Requirements	Naval Architecture	Start / 3	
Equipment Location	Aux. & Dom. Systems	Start – Iterative / 2	
Margin Policy	Naval Architecture	Start / 3	
Budget Targets	Costing	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 134 –Task 52 Inputs

Outputs

Data	To	Timing	Notes
Equipment Weight	Naval Architecture	End	
	ILS	End – Iterative	
Equipment Location	• Naval Architecture	End	
	• Aux. & Dom. Systems	End – Iterative	
	• ILS	End - Iterative	
Equipment Manpower	HF	End	
	ILS	End – Iterative	
General Equipment Data	• Naval Architecture	End	
	• Aux. & Dom. Systems	End – Iterative	
	• Production	End	
	• ILS	End – Iterative	
Cabling Data	Naval Architecture	End	
Equipment Cost	Costing	End	

Table 135 –Task 52 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
No suitable equipment can be found	Consult all domains	Should not occur if appropriate margins are applied
Equipment can't be fitted	Consult Naval Architecture	Possibly rearrange layout

Table 136 –Task 52 Controls

31.5.10 Task 53 Aux. & Dom. Systems

The purpose of the domain is to provide detailed information about the auxiliary and domestic systems equipment as well as on items such as pipe routes etc.

Inputs

Data	From	Timing/Criticality	Notes
General Equipment Data	• Propulsion	Start / 2	
	• Weapons	Start / 2	
	• Aviation	Start / 2	
	• General Vehicle Capability	Start / 2	
	• Electrical	Start – Iterative / 2	
GA	Naval Architecture	Start / 1	
Complement	HF	Start / 2	
Habitability Issues	HF	Start / 2	
Customer Requirements	Customer	Start / 1	
Revised Power Requirements	Naval Architecture	Start / 3	
Equipment Location	Electrical	Start – Iterative / 2	
Margin Policy	Naval Architecture	Start / 3	
Budget Targets	Costing	Start / 3	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 137 –Task 53 Inputs

Outputs

Data	To	Timing	Notes
Equipment Weight	Naval Architecture	End	
	ILS	End – Iterative	
Equipment Location	• Naval Architecture	End	
	• Electrical	End – Iterative	
	• ILS	End – Iterative	
Equipment Manpower	HF	End	

	ILS	End – Iterative	
General Equipment Data	• Naval Architecture	End	
	• Electrical	End – Iterative	
	• Production	End	
	• ILS	End – Iterative	
System Route Data	Naval Architecture	End	
Equipment Cost	Costing	End	

Table 138 –Task 53 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Equipment does not meet requirements	Consult all domains	Should not occur if appropriate margins are applied
Equipment can't be fitted	Consult Naval Architecture	Possibly rearrange layout

Table 139 –Task 53 Controls

31.5.11 Task 54 HF

At this stage a final revised complement calculation is carried out using the refined information available from the electrical and auxiliary & domestic systems domains.

Inputs

Data	From	Timing/Criticality	Notes
Equipment Manpower	• Electrical	Start / 1	
	• Aux. & Dom. Systems	Start / 1	
ILS Recommendations	ILS	Start – Iterative / 3	

Table 140 –Task 54 Inputs

Output

Data	To	Timing	Notes
Revised Complement	Naval Architecture	End	
Habitability Issues	Naval Architecture	End	Any issues arising due to location of equipment (noise, vibrations etc.)
	ILS	End – Iterative	
Training Costs	Costing	End	Can be carried out after complement and habitability are transferred

Table 141 –Task 54 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Complement exceeds initial assumptions	Inform Naval Architecture and discuss possible solutions	This is not a huge problem unless the complement exceeds the initial assumptions by more than 10 (for a corvette type ship)

Table 142 –Task 54 Controls

31.5.12 Task 55 Naval Architecture

This domain provides the final integration of all the data available. It also provides final performance and stability check.

Inputs

Data	From	Timing/Criticality	Notes
Equipment Location	• Electrical	Start / 1	
	• Aux. & Dom. Systems	Start / 1	
Equipment Weight	• Electrical	Start / 2	
	• Aux. & Dom. Systems	Start / 2	
Complement	HF	Start / 3	
Habitability Issues	HF	Start / 3	
Cabling Data	Electrical	Start / 2	
General Equipment Data	• Electrical	Start / 3	
	• Aux. & Dom. Systems	Start / 3	
System Route Data	Aux. & Dom. Systems	Start / 2	
ILS Recommendations	ILS	Start – Iterative /3	

Table 143 –Task 55 Inputs

Output

Data	To	Timing	Notes
GA	• Costing	End	Production takes priority over costing
	• Production	End	
	• ILS	End – Iterative	
Hullform	• Costing	End	Production takes priority over costing
	• Production	End	
Cost Data	Costing	End	

Table 144 –Task 55 Outputs

Possible Issues and Control Methods

Issues	Applicable Controls	Notes
Failed stability check	• Check whether margins are appropriate	

	• Consult domains to investigate alternative location of equipment	
Failed performance check	• Check whether margins are appropriate • Consult with propulsion domain to investigate whether minor changes can rectify the situation	
Revised equipment does not fit into original dimensions	• Check equipment space envelope • Investigate alternative layout	

Table 145 –Task 55 Controls

Other Issues
The importance of RAS requirements needs to be addressed. Escape routes and arrangements need to be investigated. Though both of these issues are no "stop-events" they do require close attention. Also, during the internal arrangement it is important to always bear system routes in mind. This includes issues such as having aircon plants adjacent to major passageways.

31.5.13 Task 56 Costing

This domain provides a final costing estimate based on the equipment chosen.

Inputs

Data	From	Timing/Criticality	Notes
GA	Naval Architecture	Start / 1	
Hullform	Naval Architecture	Start / 3	
Material Cost	• Production	Start / 1	
	• Naval Architecture	Start / 1	
Equipment Cost	• Propulsion	Start / 2	
	• Weapons	Start / 2	
	• Aviation	Start / 2	
	• General Vehicle Capability	Start / 2	
	• Aux. & Dom. Systems	Start / 2	
	• Electrical	Start / 2	
Training Costs	HF	Start / 2	
Production Cost	Production	Start / 1	
TLC Estimates	ILS	Start / 3	

Table 146 –Task 56 Inputs

31.5.14 Task 57 Production

This domain provides a final integration of the design in a production context. The main output at this stage is an approximate build duration and a build cost.

Input

Data	From	Timing/Criticality	Notes
GA	Naval Architecture	Start / 1	
Hullform	Naval Architecture	Start / 1	
General Equipment Data	• Propulsion	Start / 2	
	• Weapons	Start / 2	
	• Aviation	Start / 2	
	• General Vehicle Capability	Start / 2	
	• Aux. & Dom. Systems	Start / 2	
	• Electrical	Start / 2	
Budget Targets	Costing	Start / 3	Only required as a check as original budget targets are set after production costs are estimated
ILS Recommendations	ILS	Start – Iterative / 3	

Table 147 –Task57 Inputs

Output

Data	To	Timing	Notes
Production Cost	Costing	End	
Material Cost	Costing	End	
Production Feedback	ILS	End – Iterative	

Table 148 –Task 57 Outputs

32 APPENDIX W

TOPV Summary Parameters	
Dimensions:	
Loa	118.3m
Lwl	109.5m
B (main hull)	8.6m
Boa	27.5m
D (at amidships)	11.8m
T (at full load)	4.19m
Displacement (deep-deep)	2175t (includes full service tanks & cargo)
Displacement lightship	1750t
Propulsion:	
V_{max}	25.5knots
V_{cruise}	13.5knots
Engine configuration	CODAD
Engine Type	Caterpillar 3616
Crew	20JR, 14SR, 10Off, 30SF
Endurance	28 days
Aviation Capabilities	1x Merlin, full organic support
Other Capabilities	2xPac22, 2x15t crane (cargo hold for 4 TEUs)
Weapons	1x25mm, 2xGPMG

Aft working platform has sufficient space for towing arrangements, AUV storage or towed arrays.
Stability conforms to DefStan 02-109 and also complies with HSC bottom raking damage.
Sufficient free space available to incorporate items such as increased cargo hold area & possible missile systems.

Figure 146 –Summary Parameters for TOPV

speed range	time spent (%)	Speed (kts)	power/engine (combined)	power/engine (trailing)	SFC	engines used	fuel (t) combined	fuel (t) trailing
boat ops/loiter	10	2.5	400	400	220	1	59.136	59.136
harbour	25	7.5	400	400	220	1	147.84	147.84
cruise	40	14	1200	1380	218	1	703.1808	808.657
max	25	26	6000	6000	206	2	4152.96	4152.96
							5063.12	**5168.59**
						difference	**105.48**	
						oil price (k£/t)	285	
						cost difference/yr	**£30,060.98**	

Table 149 –TOPV fuel cost comparison for gearbox options

	weight	vcg	vmoment
grp1	1011.81	8.74	8840.61
grp2	171.76	3.84	659.54
grp3	68.64	10.39	713.26
grp4	22.32	6.67	148.81
grp5	94.54	9.30	878.99
grp6	264.47	11.64	3077.78
grp7	1.77	15.40	27.32
total lightship	1635.31	8.77	14346.32
total lightship incl. weight margins	1749.79	8.77	15350.56
grp8 (deep-deep)	331.53	2.66	880.69
total deep-deep incl. margins	2081.32	7.80	16231.25
grp8 light seagoing	58.62	2.66	155.92
VCG margin	0.04		
lightship	1749.79	9.12	
deep-deep	2081.32	8.09	
light seagoing	1808.41	8.91	

Table 150 –TOPV Weights and VCG estimates

Lightship weight	1749.79	t	
Lightship LCG (from Triton)	53.13	m	
known items	**Weight**	**LCG**	**moment**
cranes	27.4	70.2	1923.48
avcat modules	2.9	35.1	101.79
engines/gearboxes	89.28	44.1	3937.248
generators	15.5	48	744
hangar	13.5	47.6	642.6
Boats	4.1	46.1	189.01
gun pedestal	1.3	85	110.5
shafting	35	30	1050
			8698.628
new total moment	91624.22736	tm	
new LCG	**52.36**	**m**	

Table 151 –TOPV LCG estimate

GA see attached CD.

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