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MARINE DESIGN & TECHNOLOGY

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PART1

Section A: General Engineering Design

Introduction

Design is the process by which human intellect, creativity, and passion are translated into useful artefacts. Engineering design is a. subset of this broad design process in which performance and quality objectives and the underlying science arc particularly important. Reengineering design is a loosely structured, open-ended activity that includes problem definition, learning processes, representation, and decision-making.

Engineering designers attempt to create solutions to satisfy particular specifications while complying with all constraints. When a satisfactory ablution cannot be discerned, the designer must create new options. The traditional design approach has been one of deterministic problem solving, typically involving efforts to meet functional requirements subject to various technical and economic constraints.

In seeking ft logical and rigorous structure to aid in developing a satisfactory design, or one that is acceptable to the customer or user of the product, a number of approaches have been proposed to organize, guide, and facilitate the design process. Examples include Taguchi's theory of robust design, Deming's principles of quality control. Quality Function Deployment, design for manufacture, and concurrent engineering. In some cases these approaches can lead to different and conflicting answers. It is important, therefore, that they be assessed individually and collectively to determine both their strengths and limitations for particular applications.

Like any industrial engineering design activity, a new ship design process is an organized activity based on a systematic approach to the task. There are various engineering design philosophies that are adopted by different ship designers and construction establishments. Shipbuilding industry was mainly based on traditional techniques that were developed by experiences of local shipbuilders throughout its history. The modern shipbuilding could not deviate from the experiences of the previous generations too far, as most ships are designed and built based on previous models, although there are occasionally some novel ideas for a new design for a ship that would come to forefront of the shipbuilding technology.

A ship is a complex piece of a kit, which is put together by a large number of participants everyone of whom contributes in many different ways to the development of individual pieces of the final product. Most parts of a ship are designed and manufactured by more than on group of engineers and non-engineering teams who are specialized in their own specific areas of technologies; e.g. Naval Architects teams deal with the ship shapes and forms, and dimensions; Mechanical Engineering teams, design and develop ship parts that enable the vessel to have adequate capacity to perform satisfactorily under ultimate working conditions; Propeller Design Team develops appropriate propellers for specific applications; Rudder Design Specialists develop appropriate rudders and associated gears; Electrical and Electronic Engineering teams design and develop the required systems for a ship; Steel manufacturing and fabrication team develops strategy for the production of appropriate steel grades, cutting and welding processes for the construction of a ship; Financial Controllers conduct costing and economical management for a ship building project; Legal team looks after the contracts and management of disputes; Operational teams coordinate various activities within the groups and ensure compliance with all appropriate rules; etc..

In this section of the module a simplified procedure for mainly naval architectural aspects of a new ship design will be explored. As part of the skill development for mechanical and marine engineers in order to develop a better understanding of new ship design procedure, a paper based project is proposed to be carried out the details of which will be given later in this document.

Engineering Organisational Structures

Traditionally an engineering organisation would be structured based on hierarchal relationship between various people and departments within the company (Fig 3.1 (a)). In this type of organisations, departments specialise in a specific area(s) and individuals within each department would also be responsible for specific tasks. Generally there would be no communications between departments at similar levels within the company. Information is gathered by individuals and passed on to their managers via whom it is then passed on to higher levels. Normally, there would be no requirements to appraise the raw information within the departments prior to conveying the same to the higher levels. The information gathered in this manner is then processed and analysed by the higher management team based on which decisions are made and commands are formed. Then the commands would be dispatched to others normally at lower layers of management to carry out orders. Higher management would also retain certain degree of monitoring system in place to control the activities of the company. The monitoring and control mechanisms within such organisations are mainly focused on achieving targets set by the higher management. Other format for a traditional organisation would be the flow of information exists between various departments at similar levels (Fig 3.1 (b)). In this format some limited analysis is carried out on the information at lower tiers of management before the information is passed on to the higher management levels; hence more people participate in the decision-making processes.

In modern organisations, the relationship regarding the flow of information, command and control have changed, and gathering information although still is the main functional requirements of dedicated departments within given areas of expertise, the information is shared through as many departments as possible or required, and some processing and analysis would be carried out by al recipients and decisions are made based on organisational response as a unit. Hence; more people with varied expertise and interests are involved in the decision-making process.

Figure 3.9 indicates a typical organisational structure in an engineering company in which information flow is not only upward direction, but also the information is shared with all other units within the company. Normally the information is saved in a databank to which all departments would have access. Each department (staff) that accesses the information would appraise the information and analyse and makes feedback or takes action (as required) and records are updated accordingly.

Individual departments or staff would have responsibilities based on the remit of their role(s) and expertise.

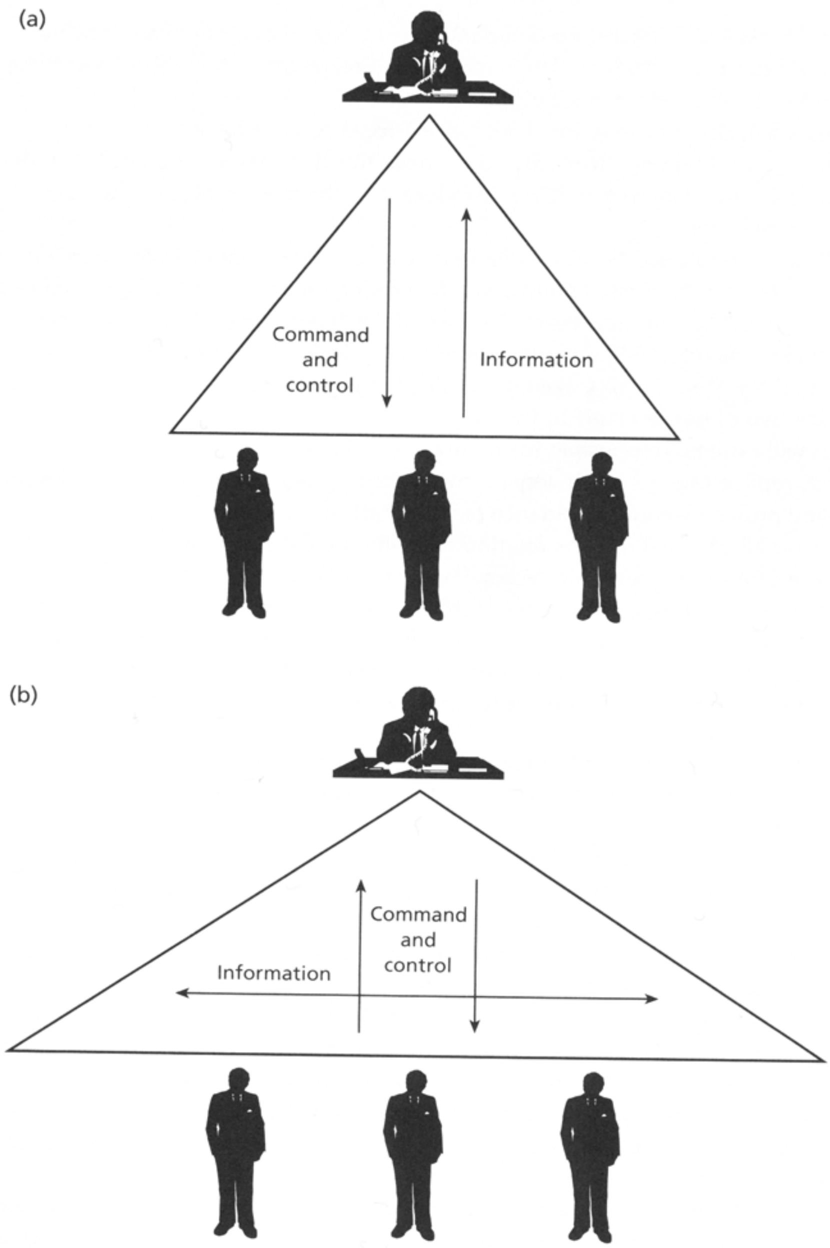


Figure 3.1 Traditional view of an organization: (a) hierarchical; (b) flattened.

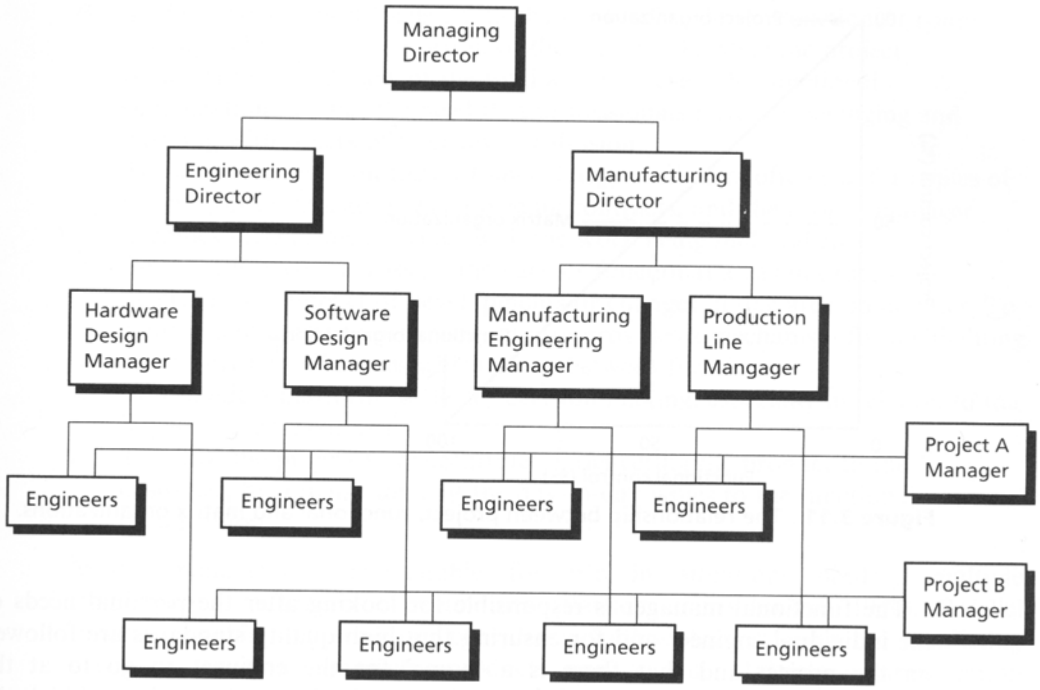


Figure 3.9 A simple matrix management scheme.

Figure 3.10 shows a typical responsibility chart based on project requirements and functional responsibilities.

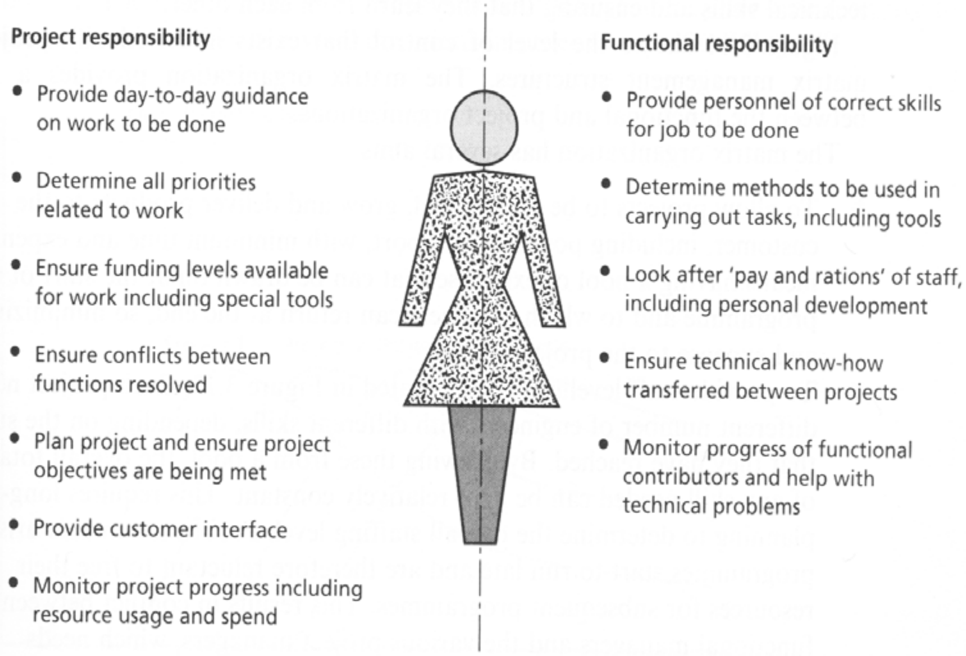


Figure 3.10 Responsibilities within a matrix organization.

Traditional engineering design were carried out in specific order that was based on functional requirements and technical specifications as defined by engineers and then the design work would be divided into specific areas. Each part of the design would be distributed to a specific engineer with a specific expertise. E.g. A new car design would be split into the following sections:

- Car body shape,
- Interior mechanical and electrical fittings
- Interior accessories.
- Mechanical body design
- Mechanical chassis design
- Gearbox design.
- Engine design
- Etc.

This was only based on the engineering aspects of a car. The technical specification for each section would be drawn from industrial standards and regulations for compliance and some previous experience and expectations, and a lot of personal contributions from individuals

In order to produce a successful design much more details must be covered. Details such as identification of customer needs and expectations, market capacity and demand for the product, future trends, competition status, manufacturing capabilities, distribution network, marketing techniques, and many more.

In traditional design practices, individuals involved in the design process would be only concentrating on their own area(s) and normally either no communications or very little communications would be held with other parties involved. This resulted in weaker designs, either over engineering or under engineering of products, multiple extra work carried out in different departments for the same task which caused waste of time, money, and energy; longer time to respond to market demands, markets would be driven by engineering requirements rather than product design be driven by market requirements, etc.

THE CHANGING NATURE OF ENGINEERING DESIGN

In the past it was too often sufficient to design, produce, and market designs based mostly on lore, empiricisms, and extrapolations. Many industrial processes and products remained essentially unchanged as long as the companies were profitable and the industries were unchallenged.

In today's economy the globalisation of business and markets, the changing nature of world trade regulations and business operations, and the impacts of information technology on business have fundamentally changed the economy and are having a profound effect on engineering practice.

To be competitive in today's global marketplace, incremental changes and empirical methods are inadequate. Products must be developed and introduced to markets faster, with unprecedented demands for high performance and low cost.

Strategic changes in existing industries are required to counter the salary differences between the workers in this country who produce exports and those across the globe who produce imports. Furthermore, new and unprecedented demands on the performance and operation of new and emerging technologies and the major innovations required for industries to be competitive on a global scale have surpassed the existing general knowledge from which such designs can be made. There is little or no experience on which to base such technological advances. Thus, there exists a chasm between existing empirically developed systems and possible innovations.

Engineers today do have extraordinary tools and resources including computers, remarkable materials, and advanced engineering environment? at their disposal. Much deeper understanding of the industrial processes is required, however, before those resources can be put to good use. The result, a new and essential tool for engineering practice also known as Research for Design (R4U), can be used to develop knowledge bases that enable innovative, reliable, cost-effective, and efficient designs. Design is a complex process involving aspects ranging from product quality to life-cycle analysis, but first and foremost, the physicochemical phenomena or behaviour of the system elements, must be understood to make the innovations required and to assure functional performance of the design.

The research in R4D is focused and directed to provide the designers the specific information they require in real time. It differs from the R in R&D, which usually means basic scientific research. R4D focuses on the people-made world to expand die knowledge base from which advances in design and production can be made. It is often multi-disciplinary and addresses the functional characteristics of large systems that consist of intricate components. Every company must have an ever increasing, relevant engineering knowledge base and the technologies and the people for translating that base into products rapidly and efficiently.

R4D requires researchers to be in continual e6ntact with designers and systems engineers in order to identify, define, and obtain the precise information required for the development of cutting-edge technologies. Recent technological advances in distributed networking, telecommunications, multi-user computer applications, and interactive virtual reality (called "advanced engineering environments" [NRC, 1999]) not only enable disparate communities to interact in real lime but also allow seamless integration of research, development, and application cycles to bring about efficient interactions and rapid progress.

Major advances in engineering design are based on increased computational power and communication (information technology). High-fidelity models of complex systems and advanced visualization techniques, as reported in Advanced Engineering Environments: Achieving the Vision, Phase 1 (NRC, 1999), provide powerful new tools to today's designers. But stunning graphics and improved models are not sufficient to design increasingly complex systems; methodologies to make sound design decisions are required.

CURRENT STUDY

The National Science Foundation asked the Board on Manufacturing and Engineering Design to examine theories and techniques for decision making under conditions of risk, uncertainty, and conflicting human values. This report reviews existing tools and theories and identifies opportunities to establish a more rigorous fundamental basis for decision making in engineering design. The specific tasks were as follows:

- Identify approaches to decision making in other fields, such as operations research, economics, and management sciences that address issues of risk and value. This will include a review of the state of the art and the extent of validation of these approaches. The committee is also charged to investigate the pertinence and validity of these approaches for building an improved decision-making framework for engineering design that can rigorously deal with probability, preferences, and risk in the manufacturing climate of 2020.

- Identify the strengths and limitation of tools currently used in engineering design as they relate to decision making and issues of risk and values in the increasingly complex manufacturing climate described in Visionary Manufacturing Challenges/or 2020 (NRC,1998) and other recent studies. This will include such methodologies as design for manufacture, Taguchi's theory of robust design. Quality Function Deployment, and concurrent engineering.

- Prepare recommendations for future' development, validation, and application of these tools in order to improve design decision-making capability in a logical and rational manner. Address the implications of adopting these techniques for engineering practices and for die engineering curriculum. Recommend core competencies in mathematics and engineering necessary for improved decision-making by design practitioners.

Concurrent Engineering Design Philosophy

Concurrent Engineering Philosophy relies on the quality and quantity of participants in a design process. A product design in this way will be based on a common forum for dialogue between all parties concerned with the product. This relationship between parties includes a vast spectrum of variables, to name a few: end-user (customer), operators, distributors, marketing, manufacturing, finance, materials and logistics, engineers, lawyers, regulators, and so on. The concurrent nature of the relationship between all parties concerned would demand a continuous and simultaneous dialogue between all parties. Every department would have access to the information databank and would be able to update information and feedback into the forum. Thus decisions are made based on high quality and high resolution data, hence the result would also be improved product, shorter development time, faster response to internal and external demands and pressures, avoiding unnecessary multiple layers and functions, better focus on product quality, lowering costs, etc. Most modern engineering companies adopt the practice of concurrent engineering philosophy. Shipbuilding is no exception and due to its nature it requires to be most open to progressive attitudes in design and construction of large industrial products such as ships, and offshore structures.

Generic Engineering Design Process

In general, designing of mechanical components and parts follow a logical step-by-step process that would include the following steps:

- ***Recognition of a need;*** which would come from various sources such as market research, or a request for tender in terms of a design brief, or a modification to an existing product, or simply from intuition by an inventor, etc.
- ***Definition of the problem or specification;*** no matter what the source of the need may be, from the start a full technical appraisal of the desired product must be determined which would lead to the creation of the technical specification for the desired product. Technical specifications are developed by consultations between the designer, and those who want the product such as users, owners, market research, field studies, etc. The technical specification should contain all relevant information describing the product, covering a variety of design considerations such as function, materials, appearance, environmental effect, product life, reliability, safety, interchange ability, standardization of parts, maintenance and service requirements and costs, together with any constraints that the design must meet.
- ***Design Synthesis;*** In this stage a number of alternative solutions would be generated as rough ideas. Here the geometry of the product is most important and can be determined by the function of the product, but also manufacturing process and material requirements are important considerations.
- ***Evaluation of preliminary designs;*** This would involve modelling of a product and testing the model to compare with alternative designs. The modelling of a product could include physical scaled model, or a computer model. Testing of models would result in selecting a more appropriate design idea and develop it further through optimisation.
- ***Detailed Design;*** Once the winning design concept has been identified and selected, then further details should be determined. This would include detail specifications such as dimensions, materials, tolerances and shapes, surface finish, manufacturing processes, production lists, etc.

The flowchart below indicates a generic design process as described above.

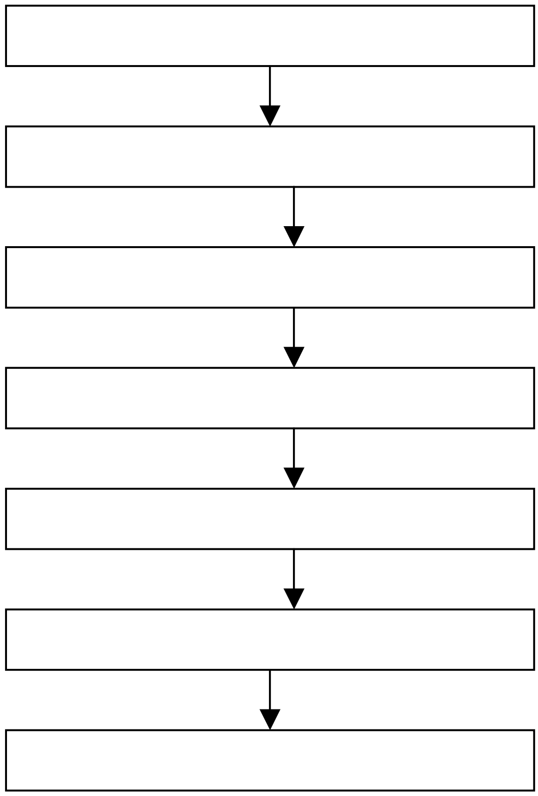


Fig.1 A typical mechanical engineering design process

Using computers for design evaluation

In the evaluation stage of a design process, all designs have to be checked for conformance with the specification. The specification has to be sufficiently detailed for the evaluation process to determine which designs meet the specification criteria and which do not.

The areas covered in a typical technical specification require various techniques to be incorporated into the evaluation stage. In particular to mechanical engineering design, the following areas of design evaluation would include:

- Strength under load.
- Displacement of the structure under load.
- Thermal behaviour.
- Fluid flow properties.
- Electrical/electronic behaviour.

All of the above represent properties of the physical behaviour of the design. In this module, the aim is to demonstrate and apply FEM in mechanical engineering design, mainly the physical structure to carry an applied load or loads, hence the module contents will be concerned with the use of continuum mechanics in determining the following criteria:

- The strength of a structure.
- The displacement of parts of the structure when loaded.
- The optimal thinness of material for a given displacement.

Other criteria that would be covered in a higher-level (L3) module would include:

- The effect of heat on internal stresses and displacement
- The fatigue life of a structure
- The dynamic response of a structure
- Crash worthiness.

When using computers for design evaluation, a design engineer requires the following skills:

- Analysis of results from physical or numerical experiments.
- Reasoning to provide logical and intellectual arguments to follow certain decisions. This may vary depending on the design engineer's experience.
- Storage, handling, and processing of data as input and output to and from a system in an efficient manner.
- Error detection, and handling, where the error can be corrected in the analytical process to improve accuracy of the results.

Computers are tools by which storage, handling of data and numerical aspects of analysis can be carried out at much faster rates with higher accuracy, and humans are better at reasoning and intellectual appraisal of the design, hence combining the two together would provide an effective tool to produce superior designs.

Therefore, the following advantages are claimed for the application of computer aided design tools:

- Increased design efficiency and effectiveness because the computer carries out repetitive tasks.
- Simplification of the design process by using an integrated data storage system, allowing many people access to relevant information when they want it.
- Economy of material and labour through a reduction in the amount of prototype building and testing required.

Better documentation through computer-generated drawings, bills of materials, part lists, work schedules, and so on.

Section B: A New Ship Design Procedure

Step-1: Recognition of the need for a particular ship type

This is the choice for the ship-owner to decide, and normally depending on the function that a ship is to perform, and the market demand, the ship type is decided. For example, it is a well-known fact that natural gas will be the main fuel for industrial and domestic application for the next 30 to 50 years. Presently, gas takes less than 25% of fuel market, and it is to rise to over 50% by the year 2020. Most of the gas presently is transported from Russia and Middle East via pipelines, but more and more of it will be required to be transported by ships' hence; presently the shipbuilding industry is being kept well occupied by orders for gas carrier tankers for the next 10 years. This trend started well before the time when it became obvious that such major development is will be required globally.

Step-2: Produce the basic ship general requirements

This is also mainly dependent on the requirements that the owners/operators would demand from a ship' i.e. accommodation type, fuel type, special features such as cranes, some deck machinery, or even other special features such as ability to sail in ice water, or some unique machinery, etc. Normally such demands would be based on specific needs for the ship to have specialist equipments, like seismic survey gear, satellite communication equipment, particular computing facilities, special product carriage facilities, etc.

Step-3: Generate Technical Specifications for the ship

Technical specification is perhaps the most important document that needs to be prepared with a great care and attention paid to its details and contents. Normally in this document all technical requirements associated with the ship when fully operational will be inserted and this document forms the basis for the legal contract between the ship-owner, ship-designer, and shipbuilder. Each party's responsibilities will be detailed in the contract mostly based on the technical specification document. In practice many ships are built based on one common design from which a number of very similar vessels are built. These similar ships are referred to as Sister-Ships. Sister ships won't necessarily be identical in all their details, but would be very similar in most of their main features such as their dimensions, accommodation layout, general speed and power performance, etc. Some differences in some machinery selection may differ, which might be due to different owner's preferences; e.g. sister ships with different distillation units for fresh water generating, different crane arrangements, or accommodation layouts, etc.

Step-4: Establish basic parameters and dimensions for the ship

Basic parameters for a new ship would be based on general requirements of the ship to fully satisfy the functional needs of the ship. Normally the ship owners would outline their basic needs and draw up the Technical Specifications for the desired ship (refer to step-3). A basic set of information as indicated in the "Vessels Particulars", which is in the attached document "Ship Information Sheet", would be made available. This basic information is to be treated as the very first step for design of a new ship by the Naval Architect. If the proposal for a new ship is completely a novel idea which has no precedence, then the idea will have to be developed more like a new invention; however, most new ship designs, especially for merchant vessels, would be based on existing or previous models, and the new design would incorporate very similar model and modify the same to produce a new ship that can satisfy the new requirements. The dimensions for the new design as the basic parameters will be determined and scaled models are made for testing in towing tanks. Results are analysed, and further modifications might become necessary after which other sets of models will be produced and tested, until optimised design is achieved. Final sets of calculations for the prediction of new ship design will be carried out results of which will be reviewed in the next stage of design. This is referred to as Synthesise of design, which is explained in the next step. With the advent of super computers and advanced software developments, computer based simulations and testing of designs are also available. Traditionally a number of scale models used to be made for testing, but nowadays it is more common to carry out computer simulations and then producing only scale model for the final version. Test models could be made of a number of materials, such as aluminium, wood, PVC, etc.

Determination of the basic parameters for a new ship design is demonstrated in the example that follows after the step-7 in this document.

Step-5: Synthesise design concepts for the ship

Once the basic parameters are established, the design team may suggest a number of possible options. Basic dimensions and requirements are determined, and a number of options are produced. In the synthesis stage of design, all options are considered and compared objectively.

Step-6: Evaluate design alternatives and select final ship design parameters

Many different criteria for comparison of alternatives would be taken into account; such as, Theoretical performance, Manufacturing capabilities and facilities, materials availability, costing and financing arrangements, skills requirements for building and/or operation, decommissioning issues, environmental regulations, classification societies rules and guidelines, and so on. In conclusions to this stage of design, the most suitable option is selected and approved to go to the next stage of design.

Step-7: Initiate detailed design

This is perhaps the most complicated stage of design. The winning design proposal is reviewed in details; alterations are made as necessary in order to optimise the design. The optimisation will be carried out based on mainly mathematical performance for the design. The main decisions are made during this stage; such as accommodation type and size, propulsion system and size, inclusion of many main systems and technologies within the engine-room and deck machinery, navigational systems, etc. Many of this type of decisions could not be made at earlier stages hence the costing of the final design would still include alterations and amendments that might be brought in at this stage.

Finally, for the design of a new ship a large number of teams that each includes a large number of expertises will be working together. Hence; the application of appropriate engineering design philosophy such as Concurrent Engineering would be necessary.

Section C: A New Ship Design Calculations

1- *Ship Owners Requirements*

A ship is required with the following particulars:

- Type: General Cargo
- Deadweight: 20240 tonnes
- Service Speed: 16 knots
- Route: Worldwide

2. *Basic Ship Data*

A ship similar to what the designer and ship owners agree is selected as the basic ship for design purposes. All known data from the basic ship is extracted from relevant documents.

Data extracted from documents for the basic ship:

- Type: General Cargo Class SD-14
- Builders: Cammel Lairds
- Deadweight (DWT): 15265 tonnes
- Service Speed (V_k): 15 knots
- Draught $_{Max}$ (H): 8.84 m
- Breadth $_{Mld}$ (B_{Mld}): 20.42 m
- Length $_{BP}$ (L_{BP}): 137.50 m
- Depth $_{Mld\ Max}$ (D_{Mld}): 11.73 m
- Block Coefficient (C_B): 0.7007
- Propulsion type: Single Screw
- Engine: Sulzer, P_B = 7600 HP = 5670 kW

Data calculated for the basic ship:

Displacement in tonnes: $\Delta_t = L_{BP} * B_{Mld} * H * C_B * \rho_{SW}$ ***(Eq. P1-1)***

$$\Delta_t = 137.5 * 20.42 * 8.84 * 0.7007 * 1025 = 17826 \text{ tonnes}$$

Deadweight Coefficient $C_d = \dfrac{DWT}{\Delta}$ ***(Eq. P1-2)***

Using the actual data from the basic ship the following ratios must be determined:

$$\frac{L_{BP}}{B_{Mld}} \quad \& \quad \frac{B_{Mld}}{H_{Max}} \ \& \quad \frac{H_{Max}}{D_{Mld}} \ \& \quad \frac{C_B}{C_d} \ \& \quad C_{B*C_d}$$ ***(Eq. P1-3)***

Basic Ship Data		
Type	***General Cargo***	**SD-14**
DWT	15265	tonne
L_{bp}	137.5	m
B_{Mld}	20.42	m
D_{Mld}	11.73	m
H_{max}	8.84	m
V_k	15	knots
C_b	0.7007	
P_b	7600	HP
P_b	5669.6	kW
SW Density	1.025	tonne/m cub

Table P1-1

Basic Ship Calculated Data		
Displacement	**17826**	**tonnes**
Basic Ratios	Cd	0.856
	L/B	6.734
	B/H	2.310
	H/D	0.754
	Cb/Cd	0.818
	Cb * Cd	0.600
Ac	**565**	

Table P1-2

3- New Ship Basic Dimensions Calculations:

Starting point is the desired features as per owners requirements:

NEW SHIP			Important dimensional restraints				
Type	General Cargo		Region	L max (m)	B max (m)	H max (m)	Air draught (m)
DWT	20240	tonne	Panama Canal	289.56	32.31	12.04 TFW	57.91
Speed	16	knots	Suez	None	74 & 11 or		None
Route	Worldwide				48 & 17.7		
			St. Laurence	225.5	23.8	8	35.5

Table P1-3

Using the data from the basic ship, important initial assumptions are made to determine some basic parameters for the new design.

New Ship Initial Basic Assumptions	
C_b	0.7
C_d	0.85
L/B	6.734
B/H	2.310
H/D	0.754
Cb/Cd	0.818
Cb * Cd	0.600
SW Density	1.025

Table P1-4

The L_{BP} for new ship can be estimated by:

$$L_{New} = \sqrt[3]{\frac{DWT}{\rho C_b C_d}(\frac{L}{B})^2(\frac{B}{H})}$$ This will result in L_{New} = 151.48 m ***(Eq. P1-4)***

Calculate the Admiralty Coefficient for the basic ship by:

$$A_c = 26(\sqrt{L} + (\frac{150}{V_k})$$ Hence: $A_c = 26(\sqrt{137.5} + (\frac{150}{15}) = 564.88$ ***(Eq. P1-5)***

This is an indication of ship performance in respect of its power consumption, speed and length. The closer the Ac is to 600 mark, the more efficient the design would be.

Calculate the Ac for the new ship.

$A_{cNew} = 26(\sqrt{151.48} + (\frac{150}{16}) = 563.75$ This indicates that the new ship would be very similar to the basic ship in terms of A_C coefficient; however, it is far too early to make that judgement as the power required for the ship is yet to be determined and its final dimensions should be optimised further.

Initial Calculated New Ship Dimensions		
Lbp	151.48	m
BMld	22.50	m
DMld	12.92	m
Hmax	9.74	m
Vk	16.00	knots
Cb	0.696	Low
SW Density	1.025	tonne/m.cub
Displacement	23668.92	Tonne
Cd	0.855	OK
Cb/Cd	0.8137	
Cb * Cd	0.5950	
Ac	563.751	***99.80%***

Table P1-5

To estimate the more realistic Ac for the new ship, length for the new ship could be altered to match.

Manipulating the L_{New} in order to reduce difference between the Ac values for the two ship designs, would result to the length for the new ship to be reduced to 152.55 m.

Thus the L_{New} is now accepted to be 152.55 m, which would give Ac_{New} of 564.88.

Now using the L_{New} and the established dimensional ratios, other parameters such as B, D, H, C_b and Δ can be determined.

For C_b use the following formula:

$$C_b = 1 - 0.23\left(\frac{V}{\sqrt{L_{BP}}}\right) \qquad \textbf{\textit{(Eq. P1-6a)}}$$

this will result in $C_b = 0.701$, but using C_b formula for general cargo:

$$C_b = 1 - 0.234\left(\frac{V}{\sqrt{L_{BP}}}\right) \qquad \textbf{\textit{(Eq. P1-6b)}}$$

would give $C_b = 0.696$. This is too low. The length is manipulated to improve particulars. By iterations, the length for new design is set at 156 m. This produces the desirable results in all areas. Then the breadth, depth, and draught are also manipulated to give reasonable results. All the time, an eye is meticulously kept on any variations in other details such as A_C, C_d, and C_b values.

Iterated Results from Initial Calculations for New Ship Dimensions						
L_{bp}	156.00	m		***Dimensional Ratios***		
B_{Mld}	22.40	m		L/B	6.964	Higher
D_{Mld}	12.80	m		B/H	2.370	Higher
H_{max}	9.45	m		H/D	0.738	Lower
V_k	16.00	knots		Cb/Cd	0.820	Higher
C_b	0.700	OK		Cb*Cd	0.598	Lower
SW Density	1.025	tonne/m.cub				
Displacement	23701.47	Tonnes				
C_d	0.854	OK				
C_b/C_d	0.8200	OK				
$C_b * C_d$	0.5980	OK				
A_c	568.490	***100.64%***	Excellent			

Table P1-6

The results are tabulated and presented as the first proposed dimensions for the new design.

4- Power Estimation

The first estimation of power requirements for the new ship would be based on the calculation of the Admiralty Coefficient using the brake power formula as follows:

$$A_C = \frac{\Delta_t^{\frac{2}{3}} * V^3}{P_b} \qquad \textbf{\textit{(Eq. P1-7)}}$$

Here the previous calculated value for the Ac is used to determine the power required to propel this new vessel if A_C is to remain at 568.49.

Power	5945.03	kW

5- Calculation of Half-Ordinates for New Ship

The table for the half-ordinates for the basic ship is used to determine the half-ordinates for the new ship as follows:

Half-Ordinates New = Half-Ordinates Basic ± [0.5*(B_{New}/B_{Basic})] ***(Eq. P1-8)***

If the dimensions for the new design are greater than the basic ship, then the half-ordinates will increase, and in case of smaller dimensions for the new design than the basic ship, then this will decrease.

Half-Ordinates Table for Upper-Deck		
B_{new}/B_{basic}		**1.10**
Section	**Basic Ship**	**New Ship**
0	6.17	6.72
1/4	7.55	8.10
1/2	8.58	9.13
3/4	9.35	9.90
1	10.00	10.55
1 1/2	10.97	11.52
2	11.42	11.97
2 1/2	11.61	12.16
3	11.70	12.25
4	11.70	12.25
5	11.70	12.25
5	11.70	12.25
6	11.70	12.25
7	11.70	12.25
7 1/2	11.60	12.15
8	11.10	11.65
8 1/2	10.03	10.58
9	8.40	8.95
9 1/4	6.42	6.97
9 1/2	5.38	5.93
9 3/4	4.30	4.85
10	1.70	2.25
10	3.08	3.63

Table P1-7

Comparison Table				
	Basic Ship	**New Ship**	**Diff %**	**Remarks**
Deadweight	15265	20240	132.59%	OK
L_{bp}	137.5	156.00	113.45%	OK
B_{Mld}	20.42	22.40	109.70%	OK
D_{Mld}	11.73	12.80	109.12%	OK
H_{max}	8.84	9.45	106.90%	OK
V_k	15	16.00	106.67%	OK
C_b	0.701	0.700	99.94%	OK
SW Density	1.025	1.025	100.00%	OK
Displacement	17825.665	23701.469	132.96%	OK
C_d	0.856	0.854	99.72%	OK
C_b/C_d	0.818	0.820	100.22%	OK
C_b * C_d	0.600	0.598	99.66%	OK
P_b	5669.600	5945.030	104.86%	OK
A_c	564.877	568.490	100.64%	OK

Table P1-10

6 Define the terms Lightweight, Deadweight and Balance of Weights

Lightweight W_{Light} is the displacement of the ship when she is complete and ready for sea, but no crew, passengers, baggage, stores, fuel, water, cargo are on board.

Deadweight (DWT) is the difference between the displacement at any draught and the lightweight. Thus deadweight includes fuel, water, cargo, stores, crew, passengers and baggage.

Balance of Weights: For every ship, there is a balance of weights table, which includes:

Steel weight, which is in the construction of the ship.

Wood & Outfit weight, which is all the accessories installed on the ship superstructure and accommodation, etc.

Machinery weight, which is the total of all engine-room and deck machinery, including cranes etc.

The total of these items weight is referenced as the "Lightweight". The owners specify the Deadweight, and thus the fully loaded displacement of the ship is the summation of the lightweight and deadweight.

$$W_{Light} = W_S + W_{W\&O} + W_M \qquad \& \qquad \Delta_t = W_{Light} + DWT \qquad \textbf{(Eq. P1-9)}$$

A ship designer always attempts to reduce Lightweight, without endangering the safety of the vessel and the strength of the hull. Balance of the Weights is therefore referenced to the relationship between the Lightweight and the Deadweight of the ship.

The ratios Block Coefficient (C_b) & Deadweight Coefficient (C_d) are reflections of the following relationships:

$$C_b = \frac{\Delta_t}{\nabla \rho} \qquad \& \qquad C_d = \frac{DWT}{\Delta_t} \qquad \textbf{(Eq. P1-10)}$$

In theory the values for C_b & C_d for a new design is close or even the same as the basic ship. But in practice, due to many alterations and modifications made in order to improve and/or satisfy the owners' requirements, these values for the new ship will invariably be different from that of the basic ship

DWT and speed is decided by the owners, thus considering these factors to be fixed, Naval Architect may only modify the dimensions and power required for the new design, bearing in mind all restrictions such as routes, draught, stability, and the cost of power, etc.

In order to increase efficiency of the vessel, Admiralty Coefficient A_C must be improved and with the DWT and V fixed, then only Δ & P may be varied.

$$A_C = \frac{\Delta_t^{\frac{2}{3}} * V^3}{P_b} \qquad \textit{(Eq. P1-7)}$$

Increase displacement with fixed DWT or decrease power. Increasing displacement would entail increasing lightweight, which shall result in increased dimensions, hence higher construction costs, also the vessel would require higher power to maintain the same desired speed. This is contradictory to the economics of ship design and construction.

Reducing power for the same displacement and speed would only be achieved if propulsion machinery design is improved to give higher efficiencies, and that is not within the remits of the Naval Architecture. With advent of technologies, progress has been made steadily in improving mechanical systems.

Table P1-8 below represents typical values for C_b & C_d coefficients for merchant ship types.

Ship Type	**C_b**	**C_d**
General Cargo	0.65 – 0.735	0.62 – 0.72
Ore Carrier	0.65 – 0.735	0.72 – 0.77
Bulk Carrier	0.65 – 0.735	0.78 – 0.84
Oil Tanker	0.75 – 0.82	0.80 – 0.86
Passenger	0.6	0.50 - 0.90
Container	0.575	0.50 - 0.90
Salvage	0.425	0.50 - 0.85

Table P1-8

Table P1-9 below presents the general formulae for the estimation of C_b values for different ship types.

SHIP TYPE	BLOCK-COEFFICEINT
GENERAL FORMULA	$C_b = 1.2 - (0.390 \frac{V}{\sqrt{L}})$
GENERAL CARGO	$C_b = 1.0 - (0.234 \frac{V}{\sqrt{L}})$
TANKERS	$C_b = 1.0 - (0.195 \frac{V}{\sqrt{L}})$
VLCC	$C_b = 1.0 - (0.182 \frac{V}{\sqrt{L}})$
BULK CARRIER	$C_b = 1.0 - (0.170 \frac{V}{\sqrt{L}})$
PASSENGER LINER	$C_b = 1.0 - (0.254 \frac{V}{\sqrt{L}})$
CONTAINER LINERS	$C_b = 1.0 - (0.265 \frac{V}{\sqrt{L}})$
SALVAGE	$C_b = 1.0 - (0.289 \frac{V}{\sqrt{L}})$

Table P1-9

Table P1-10 shows the basic ship and new design data for closer comparison. At this stage of the design process, the new ship data seems reasonable and thus the next stage of the analysis could begin. However, the following sections include some basic guideline values and ratios. Check with the guidelines to see if your new data stand closer scrutiny.

Ship Dimensional Ratios

There are several dimensional ratios that govern the basic ship designs. These ratios would be applicable within certain range of validity for specific ship types. These ratios are used to estimate basic dimensions for a new ship design based on an existing or old ship particulars.

The equation below indicates a general relationship between the B_{Mld} and $L_{B.P.}$

$$Log(B_{Mld}) = 0.9 - (0.025 * \sqrt{L_{BP}}) \qquad \textbf{\textit{(Eq. P1-11)}}$$

Table P1-11 below gives typical dimensional ratios for merchant vessels.

Ship Type	**L/B**	**B/H**	**H/D**
General Cargo	6.3 to 6.8	2.1 to 2.8	0.66 to 0.74
Tankers	7.1 to 7.25	2.4 to 2.6	0.76 to 0.78
VLCC	6.4 to 6.5	2.4 to 2.6	0.75 to 0.78
Salvage	2.30 to 5.75	1.90 to 5.25	0.60 to 0.99

Table P1-11

Table P1-12 below indicates basic relationship between L_{BP} and B_{Mld} for a variety of ship types.

SHIP TYPE	**$L_{.BP}$ & B_{Mld} RATIOS**
TANKERS	B = (L/9) + 6.0 TO 7.5 m
VLCC	B = (L/9) + 4.5 TO 6.5 m
SALVAGE	B = (L/9) + 4.5 TO 7.7 m

Table P1-12

Table P1-13 below contains some typical values for H/D ratio for different ship types.

SHIP TYPE	**TYPICAL H/D RATIO**
OIL TANKERS	0.80
GENERAL CARGO	0.75
LNG/LPG	0.50
SALVAGE	0.87

Table P1-13

Equation below indicates the range of L/D ratio for merchant vessels.

(L/D) = from 6.50 to 11.60 m

Summary

Using various dimensional ratios and relationships for an existing ship can assist in estimating the basic dimensions for a new design. However, the dimensions determined in this way shall only be treated as the first estimate. The designer should then take into considerations all other factors affecting the ship in order to select the final dimensions for the new design. These factors range from particular restrictions, economy, owners requirements, fabrication capabilities, and any other items of concern.

With the advent of computer capabilities nowadays available, normally the Naval Architect would have the use of software to model a new design and alter dimensions in order to improve the design. The use of Admiralty Coefficient is a good indicator of ship performance; hence this is used in order to alter ship dimensions for a new design as a n optimising tool. The A_C value depends on the ship displacement and speed directly and propulsion power inversely. Any improvement in the A_C value to move closer to 600 by the Naval Architect would mainly be possible by altering the ship's basic dimensions only, which could improve ship's hull form and lower her residual resistance too. However, normally the ship's speed is a desired figure set by the owners within certain reasonable expectations. Improvements in the powering of the vessel are in reality limited by the mechanical/electrical propulsion available technologies.

PART 2

Section D: New Ship Design – Determination of Characteristics

1. *Estimation of new ship weights*

The determination of actual light ship weight will have to include the following details:

- Steel weights
- Wood & Outfitting Weights
- Machinery Weights

Steel weight includes all steel used in the construction of the vessel in the forms of plates, beams, girders, scantling frames, bulkheads, hatch covers, tank tops, welding rods consumed in the construction, etc. There are a number of methods used in determination of steel weight used in a new ship construction, which shall be discussed later in this document. Steel weight may amount to over 80% of the lightship weight.

Wood & Outfitting (W&O) weight includes the weight of all items that are fitted to the ship such as doors, interior fittings, furniture, lightings, etc. W&O weight may amount to less than 5% of light ship weight.

For a cargo ship with no unusual features, W&O is approximately estimated by:

$$W\ \&\ O = \alpha * \frac{L * B}{100} \qquad \textbf{(Eq. P2-1)}$$

α is the W&O coefficient that is determined from the basic ship. This ranges form 20 to 25 fr a vessel built around 1990 with a crew compliment of about 20 to 25. The size of the α coefficient depends upon a standard type of accommodation, number of crewmembers, refrigerated stores, etc. Obviously, the selection of a basic ship is extremely important, if acceptable accuracy is to be obtained.

Machinery weights include the weights of all deck and engine-room machinery, piping, instrumentation, electrical distribution boards, etc. This weight could amount to over 15% of the light ship.

A ship's total displacement weight is made up of the light ship weight plus the weight of all the personnel, stores, fuel, and cargo. Normally, a ship proves its commercial success based on the weight or volume of the cargo that she could carry. So, if the total displacement cannot be increased, the designer must endeavour to reduce the light ship weight to its minimum. The ship's lightweight may be optimised in a variety of methods such as selecting most appropriate dimensions for a new ship design, use of lighter materials in the construction, reduction in wood & outfitting, selection of most weight/power or performance efficient machinery, and the arrangements of spaces and layouts to take best advantage of the volumes available to carry cargo.

Steel Weight Approximation Methods

As the largest segment of the lightship weight comprises the steel weight used in a new design, for a new design the steel weight could be estimated by the following methods:

a) Weight per meter method.
b) The cubic number method.

Weight per meter Method: This method is used to give approximation to the dimensions of new ship design for steel weight. In this method comparison is made between the proportionate dimensions for shear, scantling, etc, and all structure that is measured to the upper most continuous deck and longitudinal materials are considered only. Other materials and structure such as doublings, beams, knees, etc are not taken into account directly. Differences between the dimensions of the new design and the basic ship are calculated simply by addition or subtraction.

The following relationship is used in estimation of steel weight:

$$\frac{W_{SteelNew}}{W_{SteelBasic}} = \frac{L_{New} * Weight / m_{New}}{L_{Basic} * Weight / m_{Basic}} \qquad \textbf{\textit{(Eq. P2-2)}}$$

Cubic Number Method: This method is similar to the weight per meter method, but the proportionate dimensions for the new design and steel weight is calculated based on the ratios of the length cubed:

$$\frac{W_{SteelNew}}{W_{SteelBasic}} = (\frac{L_{New}}{L_{Basic)}})^3 \qquad \textbf{\textit{(Eq. P2-3)}}$$

This is originated from:

$$W_{SteelNew} = \frac{L_{New} * B_{New} * D_{New}}{10} * C \qquad \textbf{\textit{(Eq. P2-4)}}$$

Where:

$$C = \frac{W_{SteelBasic}}{L_{Basic} * B_{Basic} * D_{Basic}} \qquad \textbf{\textit{(Eq. P2-5)}}$$

The two methods shown above are only used for estimation of steel weight for a new ship, however, where the basic ship and the new ship design do not necessarily match very closely due to particular major differences between the two, the steel weight are calculated through the following methods for the actual steel weight in a new ship:

a) Slog-Slog Method: This is used where the basic ship data is either unreliable or available. In this method all dimensions of steel plates, stiffeners, thickness and densities are collected in a database and a set of preliminary plans are drawn. The volume of total steel required for the new ship is calculated and thus the weight of steel for the new design is estimated.

b) Differences Method: In this method, the information for the basic ship is used and the following ratios are applied to determine the difference between the steel weights in the basic ship and the new design. Length 85%, Breadth 55%, and Depth 30%. The use of this method will be demonstrated in an example later in this document.

Steel Weight Estimation by Empirical Formulae

There have been a number of research findings in the area of steel weight approximation for new design. The following empirical formulae are presented as the results of years of research:

J. M. Murray (1965): This is a formula for the calculation of net steel weight of a ***bulk carrier L_{bp} between 72 & 225 m***; not designed for the ORE trade:

$$W_{Steel} = \frac{[26.6*10^{-3}*L^{1.65}*(B+D+\frac{H}{2)})*(0.5C_b+.4)]}{0.8} \qquad \textbf{\textit{(Eq. P2-6)}}$$

S. Sato (1967): This is a formula presented for the calculation of ***large ships mainly tankers***.

$$10^5*W_{Steel} = [\frac{C_b}{0.8}]^{\frac{1}{3}}*[5.11*L^{3.3}*\frac{B}{D}+((2.56*L^2)*(B+D)^2)] \qquad \textbf{\textit{(Eq. P2-7)}}$$

I Buxton (1964): This was presented a generic formula for the calculation of steel weight that incorporates a coefficient “a” known as the “Buxton’s Coefficient”. This coefficient depends on the type of the ship concerned:

$$W_{Steel} = a*[(L^{1.8}B^{0.6}D^{0.4})*((0.5*C_b)+0.4)] \qquad \textbf{\textit{(Eq. P2-8)}}$$

Then the above equation is differentiated with respect to L, B, and D separately. This would result in tonnes/m run for each dimension. For example a = 0.001119 for a bulk carrier vessel.

$$\frac{W_{Steel}}{\partial L} = a*[(L^{0.8}B^{0.6}D^{0.4})*((0.9*C_b)+0.72)] \qquad \text{t/m run length}$$

$$\frac{W_{Steel}}{\partial B} = a*[(L^{1.8}B^{-0.4}D^{0.4})*((0.3*C_b)+0.24)] \qquad \text{t/m run breadth}$$

$$\frac{W_{Steel}}{\partial D} = a*[(L^{1.8}B^{0.6}D^{-0.6})*((0.2*C_b)+0.16)] \qquad \text{t/m run depth}$$

<u>Steel Weight Summary</u>

The main factors affecting steel weight in a ship are:

- Dimensions (L, B, D, H)
- Dimensional ratios (L/B, B/H, L/H, H/D, etc)
- Length of superstructure
- Number of decks
- Number of bulkheads,
- Block coefficient
- Deck house, and Mast house
- Deck shear
- Engine scantling

Net Scantling Weight is the steel weight that is actually ordered by the shipyard. It is subjected to a rolling margin ±2.5% on the thickness of plating.

Invoice Weight is the weight of steel actually purchased by the shipyard usually in the form of large rectangular plates about the size of a Double-Decker bus.

Net Steel Weight is the actual steel weight that ends up in the new ship; in another word, it takes into account the wastage. Normally this constitutes 8% to 10% of the area of Nest of Plates area.

There are a number of methods for obtaining the steel weight of a ship, such as the following methods:

- Weight per meter method,
- Cubic number method
- Slog-Slog method
- Method of Differences
- Computational technique (Modern ship building practice)

Example-1: Steel weight calculation

A general cargo ship is 122 m L_{bp}, by 16.45 m B_{Mld}, by 9.2 m D_{Mld} with a catalogued steel weight of 2700 tonnes. A new similar design is being considered having preliminary dimensions of 131 m length, 17.08 m breadth, and 10.1 m depth. Estimate steel weight for the new design after correcting for the main dimensions only.

Solution by Differences Method:

Establish the weight ratios per meter L, B, and D for the basic ship:

For L_{bp} $\quad \frac{2700}{122} * 0.85 = 18.81$ t/m Length

For B_{Mld} $\quad \frac{2700}{16.45} * 0.55 = 90.27$ t/m Breadth

For D_{Mld} $\quad \frac{2700}{9.2} * 0.30 = 88.04$ t/m Depth

Adjustments for L, B, and D in new design:

For Length: (131-122)*18.81=169.29 tonnes added

For Breadth: (17.08-16.45)*90.27=56.87 tonnes added

For Depth: (10.1-9.2)*88.04=79.24 tonnes added

Total added steel weight = 305.4 tonnes

New ship steel weight shall be about 2700+305.4 = 3005.4 tonnes

It should be noted that the change in dimensions are not always positive, in some cases changes in one or more dimensions may be negative or even zero.

Tutorial:

A basic vessel has 135 m length, 18.3 m breadth, and 10 m depth with steel weight of 3470 tonnes. A new design for general cargo is being considered having length of 136.8m, B=19.1 m, and D = 9.8m. Estimate the steel weight for new design after correcting for the main dimensions.

Other corrections for Steel Weight calculation

After modifying for the main dimensions only, further modifications will be required for slight differences in the steel structures between the basic ship and the new design. Generally, the modification for the main dimensions only gives the biggest changes in steel weights. Other modifications shall include the changes between the hull forms (C_b values at full draught), scantling changes, and the fwd and aft shears of the main deck

C_b Correction

This is carried out as follows:

±0.5% for each 0.001 change in the C_b at fully loaded draught.

Example-1a:

Reconsider example-1 where the steel weight for the new design after correcting for dimensions only was 3005.4 tonnes. Supposing that the C_b values are 0.725 and 0.74 for the basic and new ship respectively, when fully loaded. Calculate the "Form" or "C_b" correction.

$$Correction\_C_b = \frac{C_{bNew} - C_{bBasic}}{0.001} * 0.5\% * W_{SteelNew}$$

$$Correction\_C_b = \frac{0.740 - 0.725}{0.001} * \frac{0.5}{100} * 3005.4 \approx 23 \text{ tonnes}$$

Scantling Correction

This can be taken as a fraction of the dimensional corrections. It is really a correction for the difference in proportions of the main dimensions. Feedback from ships already built indicates that the scantling corrections should be:

$$\left\{\begin{array}{l} \frac{1}{3} * LenghtCorrection \\ \frac{1}{4} * BreadthCorrection \\ \frac{1}{2} * DepthCorrection \end{array}\right\} \text{Scantling Correction ratios}$$

Example-1b:

Reconsider example-1 where the length, breadth, and depth corrections were 169.29, 56.87, and 79.24 tonnes respectively. The scantling corrections will be determined as:

$$ScantlingCorrection = (\frac{1}{3} * L_{correction}) + (\frac{1}{4} * B_{correction}) + (\frac{1}{2} * D_{correction})$$

$$ScantlingCorrection = (\frac{1}{3} * 169.29) + (\frac{1}{4} * 56.87) + (\frac{1}{2} * 79.24) = 110 \text{ tonnes (approx.)}$$

Shear Correction

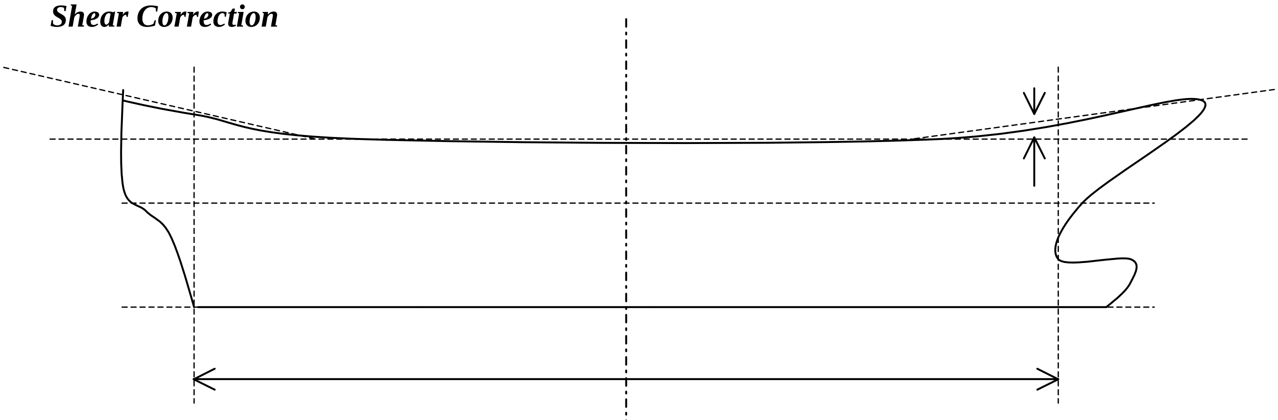


Figure P2-1 Shear definition

This is obtained by calculating the average shear for both the basic and the new design, the difference between the two answers is then multiplied by the depth correction in tonnes per meter run. Standard formulae for forward and aft shears are:

$$ShearAFT = [\frac{L}{3} + 10] * 25mm \qquad \&$$

$$ShearFWD = 2 * ShearAFT = [\frac{L}{3} + 10] * 50mm$$

and the height of average shear fore & aft is determined by:

$$\delta D = \frac{ShearAFT + ShearFWD}{6} \text{ in meters}$$

Hence the shear correction for the new design is calculated by:

$$ShearCorrection = (\delta D_{New} - \delta D_{Basic}) * D_{Correction}$$

Example-1c:

Reconsidering Example-1, $D_{Correction}$ was 88.04 tonne/meter run.

Supposing for the basic ship the Shear Aft, and FWD are: 1.27 m and 2.75 m respectively.

Calculate the shear corrections for the new design if she has shears 1.38 m and 3.5 m for aft and fore respectively.

Solution:

Determine the δD value for both ships:

$$\delta D_{Basic} = \frac{1.27 + 2.75}{6} = 0.67 \quad \& \qquad \delta D_{New} = \frac{1.38 + 3.5}{6} = 0.81$$

Calculate the shear correction by:

$$ShearCorrection = (0.81 - 0.67) * 88.04 = 12.3 \text{ tonnes}$$

There are many other similar items that cause positive or negative modifications due to structural differences between the basic ship and the new design. This is why this method is known as the Method of Differences. When everything has been considered for the steel weight calculations, the items may be tabulated as shown below:

Item	**Correction size (tonne)**
Main dimensions correction	305.4
C_b Correction	23
Scantling Correction	110
Shear Correction	12.3
Total Correction	**450.7 say 451 tonnes**
Steel weight for basic ship	2700 tonnes
Steel weight for new design	2700+451 = **3151 tonnes**

Once all the corrections are determined, then the total will be added to or subtracted from the basic ship steel weight in order to estimate the steel weight for the new ship.

However, the full list of correction items to be considered for a real design in practice is indicated in the table below:

Correction Item	**+ve**	**-ve**
Dimensions		
C_b		
Scantling		
Shear		
Bulwards		
Poop deck		
Bridge deck		
Boat deck		
Wheel-House top		
Watertight bulkheads		
Non-watertight bulkheads		
Deep tanks		
Oil & fuel bunkers		
Machinery casings		
Shaft tunnel		
Double bottoms		
Miscellaneous		
Total		

<u>Computational Methods for Steel Weight Calculation</u>

In 1964 at the Institute of Engineers & Shipbuilders in Scotland (IESS), J. M. Murray of Lloyd's Register of Shipping suggested a formula for estimating the final steel weight for a bulk-carrier ranging in length from 75 m to 225 m (Eq. P2-6)

$$W_{Steel} = 26 * 10^{-3} * L^{1.65} (B + D + \frac{H}{2}) * (\frac{0.5C_b + 0.4}{0.8}) \text{ tonnes}$$

Example-2:

Use Murray's formula to give a first approximation to the steel weight for a vessel having the following preliminary information:

L = 253 m, B = 39.63 m, D = 16 m, H = 12.81 m, C_b = 0.815

Solution

$$W_{Steel} = 26*10^{-3}*253^{1.65}(39.63+16+\frac{12.81}{2})*(\frac{0.5*0.815+0.4}{0.8}) = 15025 \text{ tonnes}$$

The same example could be solved using other similar empirical formulae such as Sato (1967), or Buxton (1964). These type of formulae have been developed using actual steel weight in a large number of ships built to date prior to the publications, and determined empirical relationships for specific ship types. These are known as computational methods and should only be used as the first approximation to estimate steel weight only.

W&O Weight Approximation Methods

The basic formula given earlier (Eq. P2-1) is a good approximation method, however, using the data from the basic ship could also result in an acceptable estimated W&O weight as follows:

$$\frac{W\&O_{New}}{W\&O_{Basic}} = \frac{L_{New}*B_{New}}{L_{Basic}*B_{Basic}} \qquad \textbf{(Eq. P2-9a)}$$

Munro Smith suggests that the dimensions of L & B affect W&O in part. The extent of this factor depends upon the ship type. The following formula has been suggested for General Cargo ship type.

For General Cargo $W_{W\&ONew} = [\frac{W_{W\&OBasic}}{2}]+[\frac{W_{W\&OBasic}}{2}*\frac{L_{New}*B_{New}}{L_{Basic}*_{Basic}}]$ ***(Eq. P2-9b)***

For Oil Tankers $W_{W\&ONew} = [\frac{2*W_{W\&OBasic}}{3}]+[\frac{W_{W\&OBasic}}{3}*\frac{L_{New}*B_{New}}{L_{Basic}*_{Basic}}]$ ***(Eq. P2-9c)***

Example: W&O weight calculation

A basic general cargo ship is 134 m length, B=18.12 m, with W&O weight of 700 tonnes. A new similar design is being considered, having L = 138.5 m, and B = 18.7 m. Estimate the W&O weight for new design.

Solution:

Method-1 Using Eq. P2-1 $W\&O = \alpha*\frac{L*B}{100}$

Determine the size of α coefficient from the basic ship data:

$$\alpha = \frac{W\&O_{Basic}*100}{L_{Basic}*B_{Basic}} = \frac{700*100}{134*18.12} = 28.829$$

Use this value to estimate the new ship W&O weight:

$$W\&O_{New} = 28.829*\frac{138.5*18.7}{100} = 746.67 \quad \text{tonnes}$$

Method-2 Using Munro Smith formula (Eq. P2-9b):

$$W\ \&\ O_{New} = [\frac{700}{2}] + [\frac{700}{2} * \frac{138.5*18.7}{134*18.12}] = 723.33 \text{ tonnes}$$

There is a discrepancy between the two solutions. Method-1 relies more directly on the information derived from a very similar ship; hence it would be more reliable compared to method-2 in which the formula has been derived empirically based on studies of a large number of ships. Another option for the designer would be to accept the average between the two results, e.g. in this case $W\&O_{New}$ would be in the region of 735 tonnes. Note that this is only an estimate at this stage.

Tutorial:

A basic general cargo ship is 137 m length, by B = 19.7 m, and has W&O weight of 657 tonnes. A new similar ship is being considered with a length of 132 m, B = 20.53 m. Estimate the W&O weight for the new design.

Summary

The important factor in the W&O weight considerations would be the number of crew on board a ship. This factor is under constant review and the pressure is brought to bear to reduce the manning level as much as practically feasible. Ships built in the era prior to 1970's would have accommodated crew compliments of 43 to 45 persons. However, ships built post 1070's have managed to half that number or lower still. This would naturally reduce the W&O requirements for similar ships; consequently the α coefficient is reduced as the direct result of manning levels in new ship designs.

It is therefore recommended that both methods are used to estimate the W&O weight for a new design, and further modifications will have to be made based on any differences in the W&O arrangements between the basic ship and the new design, etc.

A tabulated statement bringing in all these differences together in conjunction with the first estimate will give the final W&O weight for the new design.

Machinery Weight Approximation Methods

This aspect of weight prediction for the new design machinery may not be as straight forward, because the weight of machinery would largely depend on the type of the systems employed in a new ship, which is not necessarily the same as the basic ship. However, the basic ship data are used quite successfully in order to determine the major dimensions and some particulars for a new design.

The choice of propulsion machinery is perhaps the most crucial decision that the ship designer in collaboration with the ship owners and builders would have to make. This choice would influence the space required and the weight of the machinery for the new design. The equations presented here are used to estimate the machinery weight, which includes the main engine weight.

The power of the propulsion system employed also influences the machinery weight. This power is inversely proportional to the Admiralty Coefficient (A_C). A_C has already been discussed in previous part of this document (See section-c, subsections 3 & 4).

a) $A_c = 26(\sqrt{L} + (\frac{150}{V_k})$ & b) $A_C = \frac{\Delta_t^{\frac{2}{3}} * V^3}{P_b}$ ***(Eq. P2-10)***

Where, Displacement is in tonnes, ship speed is in knots, and power is in kW. A_c ranges from 200 to 600, the higher the Ac value closer to 600, the more efficient the design is considered to be. The above formula in b is valid for ship speeds up to 20-knots. For faster vessels, the index for the ship speed is raised to 4, and then the A_C range would exceed 600.

The equation shown above in "a" is used to determine the A_C for a new design and the same value is then used to estimate the power requirement for the new design based on a particular displacement and ship speed. The power estimated in this way will indicate the brake power for diesel plant or the shaft power for a steam plant. These powers are then used in the following formula to determine the corresponding machinery weights:

$W_{machinery} = \frac{P_b}{10} + 200$ Gives weight in tonnes for Diesel Machinery ***(Eq. P2-11)***

$W_{machinery} = \frac{Ps}{17} + 280$ Gives weight in tonnes for Steam Turb. Mach. ***(Eq. P2-12)***

The machinery weight calculated in this manner includes the weight of the main engine. Silver & Dawson provide the following formula as an alternative:

$W_{machinery} = \frac{Pb}{30} + 1000$ Gives weight in tonnes for Diesel Machinery ***(Eq. P2-13)***

$W_{machinery} = \frac{Ps}{55} + 950$ Gives weight in tonnes for Steam Turb. Mach. ***(Eq. P2-14)***

C B Barrass (1997) provides the following formula for the machinery weight estimation:

$W_{machinery} = 0.075P_b + 300$ Gives weight in tonnes for Diesel Machinery ***(Eq. P2-15)***

$W_{machinery} = 0.045P_S + 500$ Gives weight in tonnes for Steam Turb. Mach.***(Eq. P2-16)***

All above methods estimate the machinery weight that includes the main engine weight as well. The following equations provide formulae for the estimation of main engine weight.

$W_{ME} = \frac{3}{7} * W_{machinery}$ Gives Main Engine Weight for Diesel Engine ***(Eq. P2-17)***

$W_{ME} = \frac{1}{7} * W_{machinery}$ Gives Main Engine Weight for Steam Plant ***(Eq. P2-18)***

$W_{ME} = \frac{1}{4} * W_{machinery}$ Gives Main Engine Weight for Pilstick Engine ***(Eq. P2-19)***

Example: Machinery Weight Calculation

Data for a basic ship is as follows:

P_{bBasic} = 5250 kW Δ_{Basic} = 13500 tonnes, V_{Basic} = 16 knots, $W_{MachBasic}$ = 680 tonnes. A new design for a similar ship is being considered with Δ_{New} = 14100 tonnes, V_{New} = 16.25 knots. **Estimate** the total machinery weight for the new design.

Solution

Establish the A_C value for the basic ship.

$$A_{CBasic} = \frac{13500^{\frac{2}{3}} * 16^3}{5250} = 442.34$$

$A_{Cbasic} = A_{Cnew}$ Thus the same value is used to estimate the brake power for the new ship;

$$P_{bNew} = \frac{14100^{\frac{2}{3}} * 16.25^3}{A_C} = 5666 \text{ kW}$$

Determine the power to machinery weight ratio for the basic ship:

$\frac{P_{bBasic}}{W_{MachBasic}} = \frac{5250}{680} = 7.72$ Using the same ratio for the new ship the machinery weight is estimated:

$$\frac{P_{bNew}}{Powr / WeightRatio} = \frac{5666}{7.72} = 734 \text{ tonnes}$$

Note: This only gives the first prediction for the new design machinery weight. Modification will have to be made later for any differences between the basic ship and the new design, for changes in the arrangements of the machinery installation.

Having obtained the total machinery weight, it is possible to estimate the weight of the main engine. If single screw ships are being considered, the equations Eq. P2-17 to 19 can be utilised.

Reconsidering the earlier example, using the Eq. P2-17 shall give:

Main engine weight = $734 * \frac{3}{4} = 315$ tonnes for diesel engine.

Now continue with the design procedure Part 3 in the next document.

PART 3

Section E: New Ship Design – Approximate Hydrostatic Particulars

1. *Calculation of New Block Coefficient*

The block coefficient is a good indication of hull form. Previously, some aspects of C_b have been discussed in Ship Design Procedure Part-1. It was established that C_b values for various ship types follows predictable patterns for the type.

Generally C_b varies with displacement, L, B, and H.

$$C_b = \frac{\Delta}{L * B_{Mld} * H * \rho_{SW}} \qquad \textbf{\textit{(Eq. P3-1)}}$$

This relationship indicates that the C_b varies with all elements in the formula that may change. For example, at maximum displacement, the maximum draught, length at water line, and breadth moulded are used and hence the C_b at maximum limits is determined. Therefore, as displacement changes from minimum to maximum, draught also changes correspondingly.

There is also a relationship between C_b and Water-plane Area Coefficient (C_w), which is generally defined by:

$$C_W = \frac{2}{3}C_b + \frac{1}{3} \qquad \textbf{\textit{(Eq. P3-2)}}$$

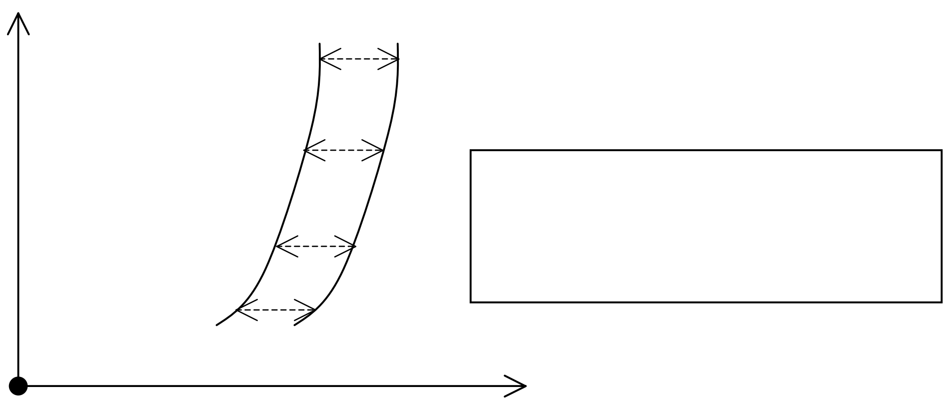
Equation P3-2 is applicable only for Summer Load Water Line (SLWL).

For general cargo ships this is approximately: $C_W = C_b + 0.1$ ***(Eq. P3-3)***

The relationship between C_b and C_w produces a consistent value k.

$$C_w - C_b = k \qquad \textbf{\textit{(Eq. P3-4)}}$$

R. Munro Smith suggested that once the C_b values were known, at each draught then a similar set of values could be obtained for C_w. Feedback from existing ships suggested that C_b & C_w curves drawn against draught were parallel, separated by a value 'k' as shown in figure P3.1.



It is necessary to produce a table of displacement at SLWL and corresponding draughts from lightship to fully loaded condition. Then expressing the change in draught in percentage terms. The C_b value changes with changes in draught by the following relationship:

$$\frac{C_b}{C_{bo}} = (\frac{H}{H_o})^{(\frac{C_w}{C_b}-1)} \qquad \textbf{\textit{(Eq. P3-5)}}$$

Also $$\frac{\Delta}{\Delta_o} = (\frac{H}{H_o})^{\frac{C_w}{C_b}} \qquad \textbf{\textit{(Eq. P3-6)}}$$

Where: H, Δ, and C_b are new draught, displacement and block coefficient; H_o, Δ_o, and C_{bo} are original (maximum) draught.

E.g. if the draught at maximum SLWL displacement is 10 m, then any new draught at new displacement in terms of percentage of the maximum would be calculated from Eq. P3-5 as shown in table below (Table P3-1):

Draught m	**Draught Ratio**	**Δ**	**C_b**	**C_w**	**k**
From design	***H/H_o***	***Calculate***	***Eq. P3-1***	***Eq. P3-2***	***Eq. P3-4***
10 Maximum	100% or 1				
9	90% or 0.9				
8	0.8				
7	0.7				
6	0.6				
5	0.5				
4	0.4				
3 Minimum	0.3				

Table P3-1

Water Plane Area (WPA) Variation

Water plane area varies with draught. Let maximum draught be H_o and the WPA at this draught be A_o, where L & B are considered constant; thus

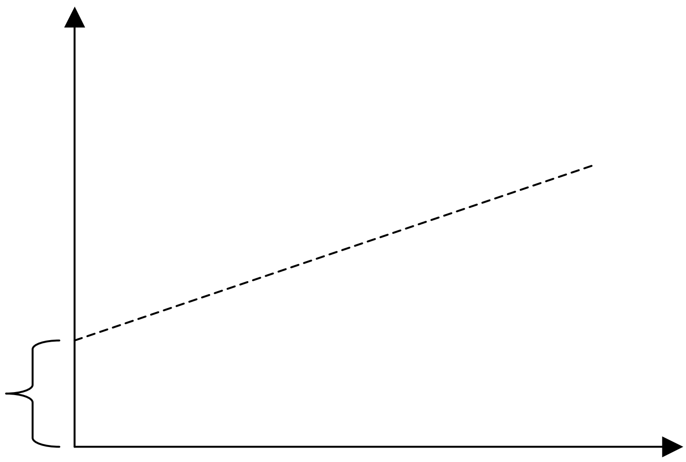
$$A_o = L * B * C_w \qquad \textbf{\textit{(Eq. P3-7)}}$$

A graph of Log_{10}^{WPA} against Log_{10}^{H} shall produce a straight line (graph P3-2) for which the governing equation is Y = mX + C; and in this case it will be:

$$Log_{10}^{WPA} = mLog_{10}^{H} + Log_{10}^{K} \qquad \textbf{\textit{(Eq. P3-8)}}$$

Where C = Log_{10}^{K} is a constant from which K is a constant, and m is the slope of the graph; therefore:

$$WPA = K * H^m \qquad \textbf{\textit{(Eq. P3-9)}}$$



Volume of displacement (∇) when fully loaded can be determined by integration of WPA equation (Eq.P3-9).

$$\nabla = \int_0^{H_o} K H_o^m \partial H_o = \frac{K H_o^{m+1}}{m+1} \qquad \textit{\textbf{(Eq. P3-10)}}$$

Also when fully loaded $\nabla = L * B * H_o * C_b$ ***(Eq. P3-11)***

Thus the Eq.P3-10 is equal to Eq. P3-11, which can be written as:

$$\nabla = \frac{K H_o^{m+1}}{m+1} = L B H_o C_b \qquad \textit{\textbf{(Eq. P3-12)}}$$

Re-arranging further will give:

$$(m+1) L B C_b = K H_o^{(m+1)} \qquad \textit{\textbf{(Eq. P3-13)}}$$

Now by equating Eq. P3-7 and Eq. P3-13, it will be shown that:

$$L B C_w = L B C_b (m+1) \qquad \textit{\textbf{(Eq. P3-14)}}$$

Hence; $\frac{C_w}{C_b} = m+1$ ***(Eq. P3-15)***

As in Eq. P3-10, when fully loaded the volume of displacement is $\nabla_o = \frac{K H_o^{m+1}}{m+1}$, and for any other draught 'H', the volume of displacement is:

$$\nabla = \int_0^{H_o} K H^m \partial H = \frac{K H^{m+1}}{m+1}$$

Thus $\frac{\nabla}{\nabla_o} = \frac{\frac{K H^{m+1}}{m+1}}{\frac{K H_o^{m+1}}{m+1}} = (\frac{H}{H_o})^{\frac{C_w}{C_b}}$ ***(Eq. P3-16)***

Alternatively: ***(Eq. P3-17)***

Note that where the volume of displacement is known, the weight of displacement can be calculated by multiplying the volume by water density; hence:

$$\left(\frac{H}{H_o}\right) = \left(\frac{\Delta}{\Delta_o}\right)^{\frac{C_b}{C_w}} \qquad \textbf{\textit{(Eq. P3-18)}}$$

Ship Stability Data

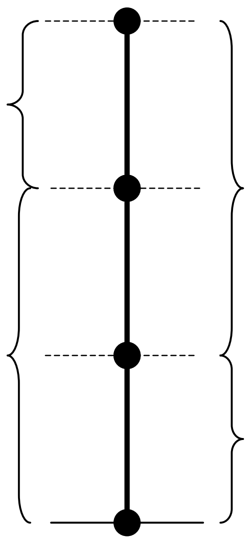


Figure P3-3 shows the normal arrangement between various significant points along the vertical stability fulcrum that describe specific properties associated with the physical design of a ship's hull and the balance of distributed weights within the vessel. These significant points are:

K Keel of the ship that is the point on the lowest physical part of the ship hull bottom.

B Centre of buoyancy is the point at which all up-thrust force due to buoyancy is assumed to act against the gravity force.

G Centre of gravity is the point at which all the gravitational force acting on the ship is assumed to act downward.

M Metacentre is the point about which the ship is assumed to rotate about like a pendulum.

Normally in a steady ship condition without any rolling or pitching etc., the stability fulcrum is totally vertical and all significant points fall on the same vertical line. Any deviation from this condition causes the vessel to heel to one side or the other. The position of K and M remains unchanged for small angles of heel, but the other two significant points G and B move along the straight line that goes through all four points according to the new conditions, with the M remaining in the same position, and all the others changing positions. The new straight line going through all four points will make an angle with the original vertical line. This angle is known as the angle of heel.

These changes may occur due to adding, removing or shifting masses in the vessel. At any given loading condition, the position of the significant points (mainly G & B) must be known in order to determine the stability of the ship.

In stability calculations, the size of the distances between these significant points is used in a variety of mathematical relationships. When designing a new ship, these values are estimated as follows:

KB Values

KB values can be approximated using one of the following formulae:

1- General formula: $$KB = 0.535 * H$$ ***(Eq. P3-19)***

2- Morrish's formula: $$KB = H - \frac{1}{3}[\frac{\nabla}{WPA} + \frac{H}{2}]$$ ***(Eq. P3-20)***

Or $$KB = H - \frac{1}{3}[\frac{LBHC_b}{LBC_W} + \frac{H}{2}]$$ ***(Eq. P3-21)***

Or $$KB = H - [H\frac{C_b}{C_W} + \frac{H}{2}]$$ ***(Eq. P3-22)***

Or $$KB = H(\frac{5}{6} - \frac{C_b}{3C_W})$$ ***(Eq. P3-23)***

3- Common formula: $$KB = \frac{H}{1 + \frac{C_b}{C_W}}$$ ***(Eq. P3-24)***

BM_T Values

The main formula for the BM_T is $\frac{I}{\nabla}$ for any ship's water plane area. The transverse second moment of inertia for any ship is: $I = \frac{LB^3}{k}$. The "k" value depends on the shape of the area; e.g. k=12 for rectangular shape. Let $\eta_o = \frac{1}{k}$; then for rectangular area shape: $I = \eta_o LB^3$ thus $BM_T = \frac{I}{\nabla} = \frac{\eta_o LB^3}{LBHC_b}$ this can be written as:

$$BM_T = \frac{\eta_o B^2}{HC_b}$$ ***(Eq. P3-25)***

Note: the values for the η_o is worked out based on the water plane area coefficient C_w, as these are interdependent.

E.g. for rectangular shape $\eta_o = \frac{1}{12} = 0.08333$ and C_w = 1; however ship shape is somewhere in between a rectangular and rhombus shape (fig. P3-4).

Normally the lowest C_w value is about 0.6. A graph of η_o vs. C_w^2 is drawn, which gives a straight line. Then the corresponding values for the η_o transverse is read from the graph.

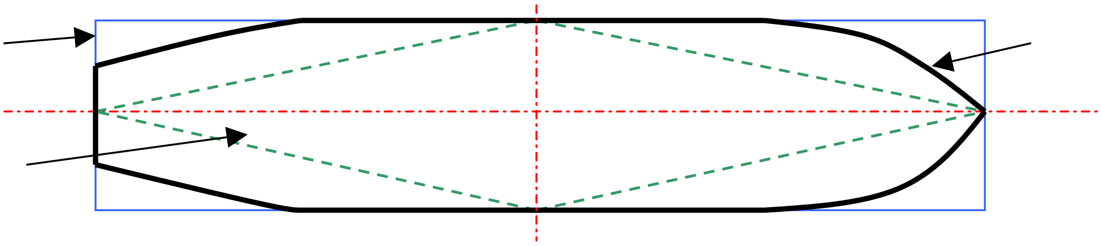


Table P3-2 gives the values for $\eta_{oT} = 0.08333 * C_w^2$:

C_w	C_w^2	η_{oT}
0.50	0.25	0.0208
0.55	0.3025	0.0255
0.60	0.36	0.0306
0.65	0.4225	0.0361
0.70	0.49	0.0481
0.75	0.5625	0.0491
0.80	0.64	0.0546
0.85	0.7225	0.0614
0.90	0.81	0.0685
0.95	0.9025	0.0758
1.00	1.00	0.0833

Table P3-2

Finally, the BM_T values for any given draught and corresponding C_b & C_w can be determined form:

(Eq. P3-26a)

Special notes on BM_L (longitudinal): BM values for longitudinal considerations are calculated much in the same manner as shown for the BM transverse; it can be shown that:

$$BM_L = \frac{\eta_{oL} L^2}{HC_b} \qquad \textbf{(Eq. P3-26b)}$$

Here L^2 replaced the B^2, because longitudinal stability is considered.

The relationship for $\boldsymbol{\eta_{oL} = 0.075 * C_w^2}$ ***(Eq. P3-26d)***; based on which a graph of η_o longitudinal vs. C_w values can be produced; thus:

(Eq. P3-26c)

KM_T Values

This is the height of Metacentre above the keel, which can be calculated from:

$KM_T = KB + BM_T = KG + GM_T$ ***(Eq. P3-27)***

As shown above, BM_T value depends on the ship hull form, but GM_T depends on the loading condition of the vessel. In order to calculate the KM_T values, the other required values must be determine.

KG Values

The value of the KG for the lightship condition is estimated from the results of an inclining experiment, carried out on the ship, just before completion.

It is usual to express KG as a percentage of depth moulded to the upper most continuous deck. The KG in the light ship condition is affected by the following factors:

a) Ship type.
b) Propelling machinery type.
c) The arrangement and structures such as accommodation, extent of isolated cargo spaces, cargo handing equipment, etc.

It is advisable to determine the KG for the lightship in the following manner:

i. From basic ship data determine:

ii. From basic ship machinery data determine:

iii. Then calculate for basic ship:

iv. Calculate KG for lightship Basic:

$$KG_{lightshipBasic} = \frac{\sum Moments}{\sum Weights} = \frac{\alpha_{Hull} + \alpha_{mach}}{W_{Hull} + W_{mach}} \qquad \textbf{\textit{(Eq. P3-28)}}$$

- This ratio can be used for the new ship.

For general cargo ships the KG of the Hull (without the machinery weight), is 60% to 70% of the depth to the upper most continuous deck.

For sheltered deck vessels, the KG would be in order of 68% to 73% of the depth moulded, when fully loaded upto the pencil marks.

GM_T Values

This is the most important of the stability values. In all conditions to have equilibrium, G MUST be below M. When a ship is fully loaded, the following are typical values:

Ship type	**Typical GM_T when fully loaded**
General cargo and medium size tankers	0.3 m to 0.5 m
Ro-RO and Container ships	1.5 m
Ore Carriers	2 m to 3 m
MCA Minimum value	0.15 m

Table P3-3

MCTC Values

MCTC stands for Moment to Change Trim by 1 Centimetre.

General formula is: ***(Eq. P3-29)***

For merchant ships the GM_L can be replaced with BM_L as follows:

(Eq. P3-30)

Also: $C_w = \frac{WPA}{L * B}$ hence: ***(Eq. P3-31)***

And: $TPC_{SW} = \frac{WPA}{100} * \rho_{SW}$ ***(Eq. P3-32)***

Simplifying the Eq. P3-30 and substituting equations (P3-31 & 32) will give:

$$MCTC_{SW} = \frac{7.32 * (TPC)^2_{SW}}{B}$$ ***(Eq. P3-33)***

This is comparable with the formula suggested by Munro-Smith:

(Eq. P3-34)

TPC Values

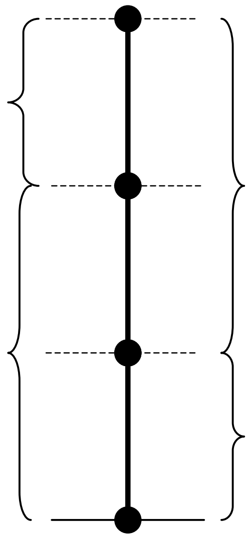
The Tonnes per Centimetre Immersion value represents the mass in tonnes required to change the draught of a ship for 1 cm. Generally it is determined by:

(Eq.P3-35)

Water Plane Area (WPA) can be determined by:

(Eq.P3-36)

Summary



It has been shown how to determine various components relating to the hydrostatics of a ship. A table can be arranged in which the basic information from the model ship is used to determine basic dimensions for the new design. Once some basic parameters for the new design are established, then all hydrostatic particulars can be determined at various draughts or displacements, etc. The new design table should include the following items:

L	B	D	C_d	H	H%	Δ	∇	C_b	C_w	Cw/Cb	m	$C_{w\,Sqr}$	k	η_{oT}	η_{oL}
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

KB	BM_T	BM_L	KM_T	KM_L	WPA	TPC	MCTC	KG	GM_T	GM_L
17	18	19	20	21	22	23	24	25	26	27

Table P3-4

All items in table P3-4 are numbered sequentially, in order to make references to appropriate equations given in the preceding notes.

Summary of Calculation Procedure: Table P3-5

Item	Ref. No.	Equation	Eq. No.
L, B, D, C_d, H_{max}	1,2,3,4,5	Derived form basic ship comparisons	Eq. P1-1 to 5
C_b	9	$\frac{\Delta}{\Delta_o} = (\frac{H}{H_o})^{\frac{C_w}{C_b}}$	Eq. P3-6
C_w	10	$C_W = \frac{2}{3} C_b + \frac{1}{3}$	Eq. P3-2
m	12	$\frac{C_w}{C_b} = m + 1$	Eq. P3-15
k	14	$C_w - C_b = k$	Eq. P3-4
h_{oT}	15	$\eta_{oT} = 0.08333 * C_w^2$	Table P3-2
h_{oL}	16	$\eta_{oL} = 0.075 * C_w^2$	Eq. P3-26d
KB	17	$KB = \frac{H}{1 + \frac{C_b}{C_W}}$	Eq. P3-24 or 23
BM_T	18	$BM_T = \frac{\eta_o B^2}{HC_b}$	Eq. P3-25
BM_L	19	$BM_L = \frac{\eta_{oL} L^2}{HC_b}$	Eq. P3-26b or 26c
KM_T	20	$KM_T = KB + BM_T = KG + GM_T$	Eq. P3-27
KM_L	21	$KM_L = KB + BM_L = KG + GM_L$	Similar to Eq. P3-27
WPA	22	$C_w = \frac{WPA}{L * B}$	Eq. P3-31
TPC	23	$TPC_{SW} = \frac{WPA}{100} * \rho_{SW}$	Eq. P3-32
MCTC	24	$MCTC_{SW} = \frac{7.32 * (TPC)_{SW}^2}{B}$	Eq. P3-33
KG	25	$KG_{lightshipBasic} = \frac{\sum Moments}{\sum Weights} = \frac{\alpha_{Hull} + \alpha_{mach}}{W_{Hull} + W_{mach}}$ This requires further work	Eq. P3-28
GM_T	26	$GM_T = KM_T - KG$ Requires further work	Eq. P3-27
GM_L	27	$GM_L = KM_L - KG$	Eq. P3-27

Table P3-5 Summary

Part 4

Section F: New Ship Structural Design

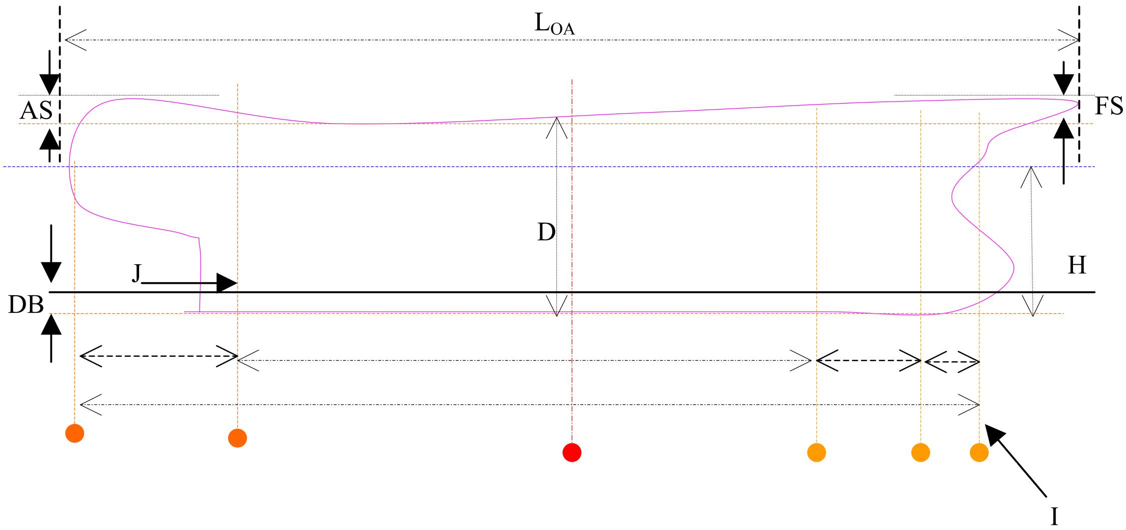
Structural design process when considering a new ship will include the most important forces that shall act on the ship in service during her lifetime. These forces are from external sources such as ocean waves and wind, and also forces due to loading of the ship. The effect of the forces either from the environment or the loading arrangement would mainly be causing bending and shearing in the ship's structure.

Theoretical assessment methods regarding bending and shearing of a structure can be found in appropriate textbooks. In these document practical methods of analysis of ship's structure for a new design is explored further.

Classification Societies provide detailed design procedures for ships structure, but access to them is expensive and also these documents are very complex to follow. However, in some parts reference to classification rules would be made.

Frame Spacing

When designing a new ship, it is important that the strength of the ship's hull is calculated accurately. The ship's hull strength will mainly depend on the arrangement of the frame spacing and sizes and material properties of the frames, and plating that form the ship. In order to calculate the frame spacing for a new ship, the following procedure can be applied.



General Guidelines

Frame Section	Spacing in mm
X_1 about 7% of L_{BP}	600
X_2 about 80% of L_{BP}	750
X_3 about 6% of L_{BP}	700
X_4 about 7% of L_{BP}	600

Number of frames for each section Calculations:

$$X_1 = \frac{7\% * L}{0.6} \quad \& \quad X_2 = \frac{80\% * L}{0.75}$$

$$X_3 = \frac{6\% * L}{0.70} \quad \& \quad X_4 = \frac{L - X_1 - X_2 - X_3}{0.60}$$

To determine the exact positions of the fore and aft collision bulkheads, the length between perpendiculars will be divided into a factor of 10 equal lengths. Each major division is referred to as a ***station***, and station-5 falls on the amidships centre-line. The start and finishing points of the length between perpendiculars is correspondent to the start and finishing of waterline when the vessel is fully loaded on an even keel.

Station-1 normally divides the engine-room from the rest of the ship's hull. Most merchant vessels would have their accommodation superstructure abaft of this station above the engine-room, but not all design would do the same. There may also be a void space separating the engine-room from the ship's hull forward of the aft bulkhead. In some ship types the void space is used to accommodate special equipments such as cargo pumps, hydraulic machinery etc.

Normally the space between station-1 to station-8 would be customised to carry cargo.

At station-8 and station-9 collision bulkheads are fitted. The space provided in these areas may be used to fit deck machinery, stores, etc.

Double Bottom depth is determined by: $D_{DB} = \frac{1000 * B}{36} + (205 * \sqrt{D_{Mld}})$

<u>SUMMARY</u>

A TABLE OF RESULTS CAN BE PROVIDED USING THE APPROPRIATE GENERAL GUIDELINES.

Section	**Length**	**Frame spacing**	**No. Frames**	**Remarks**
X_1				
X_2				
X_3				
X_4				
DB	L_{BP}		Continuous	DB Height

Section G: New Ship Rudder Design

History

The invention of the rudder evolved from oars, which were mounted on the side of ships for manoeuvring watercraft in Ancient Egypt. It was the quarter rudder, which was first used until the end of the Middle Ages in Europe. With the increasing size of ships and freeboards, quarter-rudders became less suitable for the task and were replaced in Europe by more sturdy stern-mounted rudders with gudgeon and Pintle attachments from the 12-century.

The world's oldest known representation of a stern-mounted rudder can be found on a pottery model of a Chinese junk (Sailing vessel) dating from the 1st century CE, predating their introduction in the West by a thousand years. It is thought that the introduction of the stern-mounted rudder in the West may have been unrelated to that of the invention in the East as technical specifications differ, although inspiration may have been gained through trade exchanges with the East.

Methodology

Application

The rudder is the most common form of manoeuvring device fitted on Ships. A rudder in its simplest form is a flat sheet of material attached to a ships stern by use of a hinge mechanism. Most rudders consist of a Rudder Stock which attached to it is a lever, in order to provide leverage for turning the Rudder.

Types

There are a variety of types of rudder with the most common being:

Conventional rudder – These rudders have a streamlined section in order to give a good lift to drag ratio and are of double plate construction

Special Rudders – The aim of special rudders is usually to improve the lift to drag ratio. For example, a flap rudder uses a flap at the trailing edge to improve the lift by changing aerofoil shape.

Active Rudders – Active rudders are usually spade type rudders incorporating a faired housing with a small electric motor driving a small propeller.

Kitchen Rudder – This rudder is a two-part tube shrouding the propeller and turning about a vertical axis.

Sizes and Construction

The size and shape of a rudder plays an important part in its efficiency. The area of a rudder may be the order of 2% of the product of the ship's length. The majority of rudders are semi-balanced but balanced rudders and unbalanced rudders all area aft of the turning axis is also fitted. The vertical dimensions of rudders are restricted so the fore and aft dimensions must be increased to obtain the desired area.

On small ships a single plate rudder may be used but larger ships use faired double plate rudders. The construction of a faired double plate rudder may consist of a cast frame but more often consists of a fabricated frame of vertical and horizontal plate webs with a solid or tubular main piece, which coincides with the turning axis. The faired side plates are welded to the frame while top and bottom plates are fitted to provide a watertight and buoyant structure. The rudderstock usually comprises of a solid round or tubular section ending in a flanged coupling, which can be bolted to a matching flange at the top of the rudder.

Simple unbalanced rudders turn on ‘Pintle’, which are fitted to ‘gudgeon’ attached to the rudderpost. The top Pintle is a locking Pintle, which helps prevent vertical movement of the rudder, with the bottom Pintle being a bearing Pintle, carrying the weight of the rudder.

Rudder Theory

When a rudder is turned from the centreline plane to any angle, the water flows round the rudder and creates an additional resistance on that side of the centreline. The force F which acts on the rudder parallel to the centreline has two components:

(a) The force created by the formation of streamlines round the rudder, i.e. due to change in the direction of the water.

(b) The suction on the after side of the rudder caused by eddying (a current of water moving in a direction contrary to the main current)

The force F follows the laws of fluid friction and may be determined from the expression.

$$\boldsymbol{F = k A v^2} \ \mathbf{N}$$

Where k = a coefficient which depends upon the shape of the rudder, the rudder angle and the density of the water. When the ship speed is expressed in m/s, average values of k for sea water vary between about 570 and 610.

A = rudder area

v = ship speed

The area of rudder is not specified by Classification Societies, but experience has shown that the area should be related to the area of the middle-line plane (i.e. length of ship x draught), and values of one sixtieth for fast ships and one-seventieth for slow ships have been found successful,

i.e. area of rudder = $\frac{L \times d}{60}$ for fast ships

= $\frac{L \times d}{70}$ for slow ships

If the rudder is turned to an angle α, then the component of force acting normal to the plane of the rudder Fn is given by:

$$Fn = F \sin \alpha = k A v^2 \sin \alpha$$

This force Fn acts at the centre of effort of the rudder. The position of the centre of effort varies with the shape of the rudder and the rudder angle. For rectangular rudders the centre of effort is between 20% and 38% of the width of the rudder from the leading edge. The effect of normal force is to tend to push the rudder back to its centreline position. Such movement is resisted by the rudderstock and steering gear. It is therefore possible to calculate the turning moment or torque on the rudderstock.

If the centre of effort is b m from the centre of the rudder stock, then at any angle α

Torque on stock: $\boldsymbol{T = Fn \times b = k A v^2 b \sin \alpha} \ \mathbf{N\,m}$

From the basic torsion equation the diameter of the stock may be found for any given allowable stress.

$$\frac{T}{J} = \frac{\tau}{r}$$

where τ = allowable stress in N/m^2

r = radius of stock in m

J = second moment of area about a polar axis in m^4

$$J = \frac{\pi D^4}{32} = \frac{\pi r^4}{2}$$

For any rudder, at constant ship speed, values of torque may be plotted on a base of rudder angle. The area under this curve up to any angle is the work done in turning the rudder to this angle, and may be found by the use of Simpson's Rule. Care must be taken to express the common interval in radians, not degrees.

If the centre of the rudderstock is between 20% and 38% of width of the rudder from the leading edge, then at a given angle the centre of stock will coincide with the centre of effort and thus there will be no torque. The rudder is then said to be balanced. At any other rudder angle the centres pf stock and effort will not coincide and there will be a torque of reduced magnitude. Thus it may be seen that the diameter of stock and power of the steering gear may be reduced if a balanced rudder is fitted.

It is usual to limit the rudder angle to 35 degrees on each side of the centreline, since, of this angle is exceeded; the diameter of the turning circle is increased.

Rudders Design

Rudders are used for directional control of ships. A rudder is usually located at the after end of the ship.

The radial force acting on a ship during a steady turn is given by :

$$F = \frac{\Delta * V^2}{R * g}$$

where:

F is force in tonnes

Δ is ship's displacement in tonnes

R is radius of turning circle in meters

g is gravitational acceleration 9.81 m/s^2

and V is ship speed in m/s.

Example

Determine the radial force required for a ship of 10,000 tonnes displacement turning in a circle of 1000m diameter at a steady speed of 16 knots.

Solution:

V = 16 x 1852/3600 = 8.23 m/s

$F = \dfrac{\Delta * V^2}{R * g}$ = 138.2 tonnes = 696.682 MN

Rudder Force Q

The force on the rudder depends upon:

- The area of the rudder
- The form of the rudder
- The speed of the water passing the rudder
- The angle of attack (helm limited to 35^o in port or starboard direction).

For middle line rudders behind single screw, the formula proposed by Baker and Bottomley is:

$$Q = 18AV^2\theta \text{ in Newtons.}$$

Where A is the rudder area in m^2

V is the water velocity passing the rudder in m/s

θ is the angle of attack in degrees.

For twin rudders behind wing propellers, the formula proposed by Gawn are:

$Q = 21.1AV^2\theta$ in Newton for Ahead motion

$Q = 19.1AV^2\theta$ in Newton for Astern motion

For middle line rudders behind twin screws, the formula is $Q = 15.5AV^2\theta$

Example:

Calculate the force for a rudder on the middle-line behind twin screws with an area of 13.9-m2 and ship speed of 15 knots at angle of attack of 35^o.

V = 15.5 knots = 15.5 x 1852 / 3600 = 7.716 m/s

$$Q = 18AV^2\theta = 15.5 \times 13.9 \times 7.716^2 \times 35 = 448.9 \text{ kN}$$

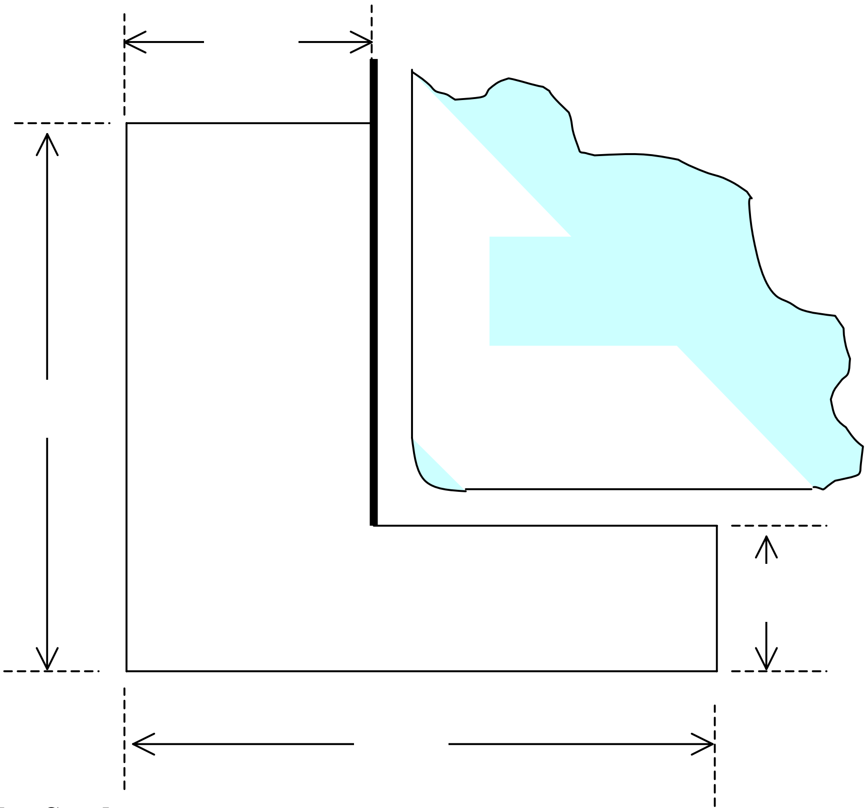
Centre of Pressure

The centre of pressure of a rudder is the point at which the resultant force on it may be considered to act.

Gawn suggested that for a rectangular rudder, the centre of pressure is 0.35 times the breadth of the rudder abaft the leading edge if behind deadwood, and the centre of pressure is 0.31 times the breadth of the rudder abaft the leading edge if in the open figure.

Example

The centre line rudder on a twin-screw ship is as shown in the following figure. Determine for 35^o and a ship speed of 19.5 knots the force and torque on the rudder.



Diameter of Rudder Stock

If bending moment is small, then the rudder stock diameter can be calculated by:

$d^3 = \frac{16xT}{\pi x \sigma}$ where:

d = diameter of rudder stock in meters

σ = allowable stress in N/m^2.

T = Torque in Nm

If the bending moment is considered then torque can be replaced by $M + \sqrt{M^2 + T^2}$

Where M is bending moment.

Example

The centre of pressure of a rudder is 0.21m abaft the axis of rotation and 1.22m below the bearing. The normal force on the rudder is 600 kN. Determine the diameter of the rudderstock if the maximum stress allowed is 77.22 MN/m^2.

Solution:

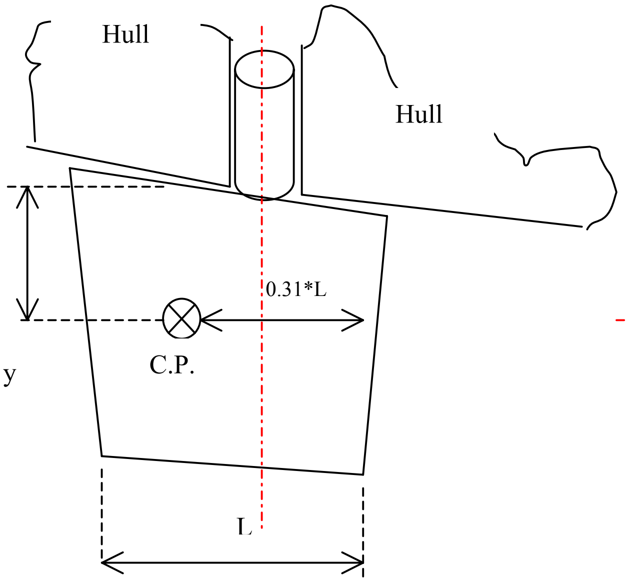
Bending Moment M = 600x1000x1.22 = 732 kNm

Twisting Moment (Torque) T = 600 x 1000 x 0.21 = 126 kNm

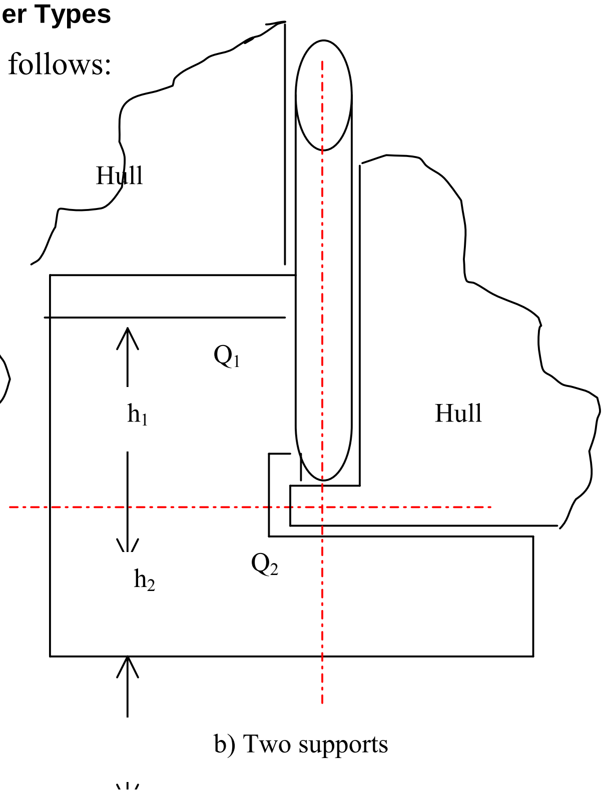
Then $d^3 = \frac{16x(M + \sqrt{M^2 + T^2})}{\pi x \sigma}$ Hence; d = 0.46m

Rudder Types

Four typical types of rudder are shown as follows:



a) One support



b) Two supports

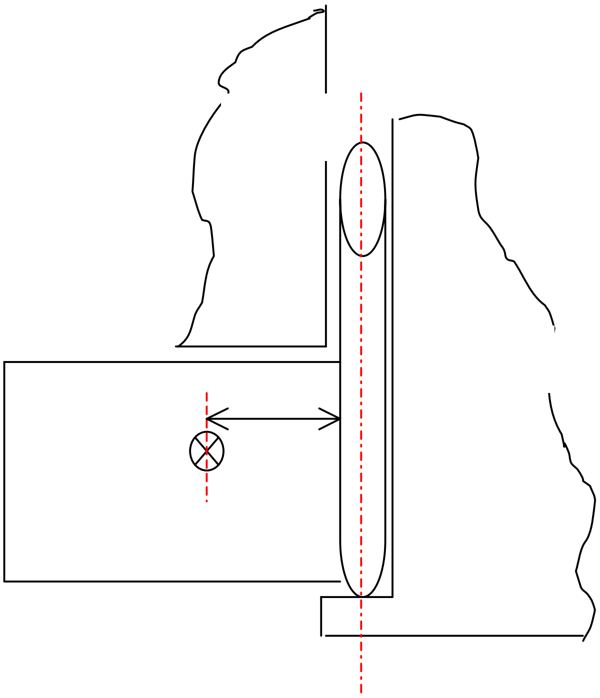
Designs

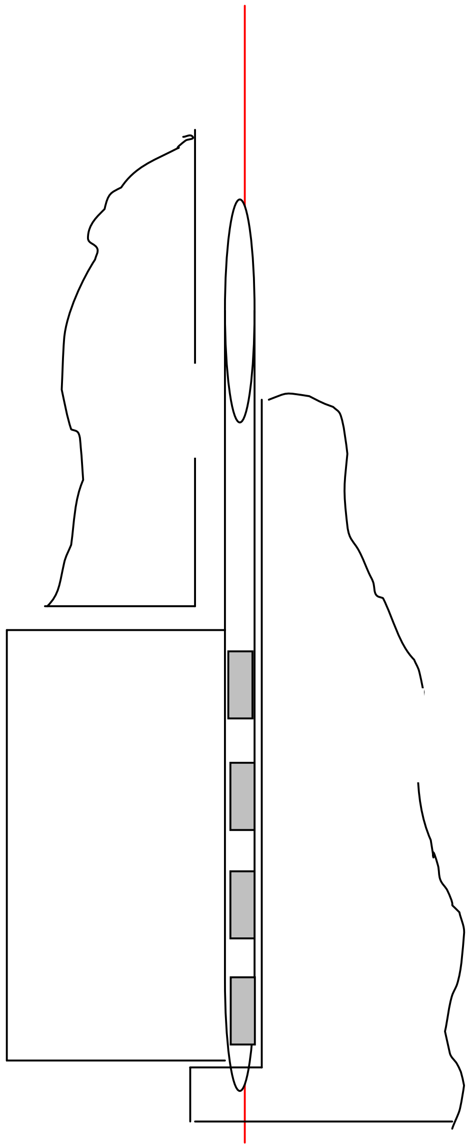
$$RudderArea = \frac{LxH}{60to70}$$

Where:

L = Length Between Perpendiculars in meters.

H = mean load draught in meters





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[2] Eric Tupper, 1996, Introduction to Naval Architecture, Reed educational and professional publishing Ltd 1996, 0-7506-2529-5

[3] http://en.wikipedia.org/wiki/Rudder, 10/09/2005, 19:34

[4] http://blackboard.livjm.ac.uk/webapps/portal/frameset.jsp?tab=courses&url=/bin/common/course.pl?course_id=_14699_1, 10/16/2005, 21:26

Classification Societies see:

http://www.iacs.org.uk/_pdf/Rec61.pdf

http://www.iacs.org.uk/ureqs/URS.PDF

Section I: New Ship Propeller Design

Propeller Design Procedure for 4-bladed propellers aerofoil

1. Calculate B_P using $B_P = \frac{0.0367 * N * P_D^{0.5}}{V_a^{2.5}}$
2. Trace B_P value on the diagram to intersect the optimum pitch ratio line.
3. Lift off the values for the pitch ratio, propeller efficiency and slip constant from the corresponding points on the diagram.
4. Use slip constant to calculate propeller diameter $\delta = 3.28 \frac{N_d}{V_a}$.
5. Use pitch ratio value to calculate propeller pitch.
6. Finally; using propeller efficiency, diameter, and pitch design the propeller.

The same procedure applies for various types of propellers, but each type would have specific diagram for the type.

Example

A new ship design rpm is 100, delivered power is P_D = 4600 kW at propeller tail shaft.

Ship's apparent velocity is V_a = 10.85 knots. Calculate; pitch and efficiency of propeller using B_P diagram.

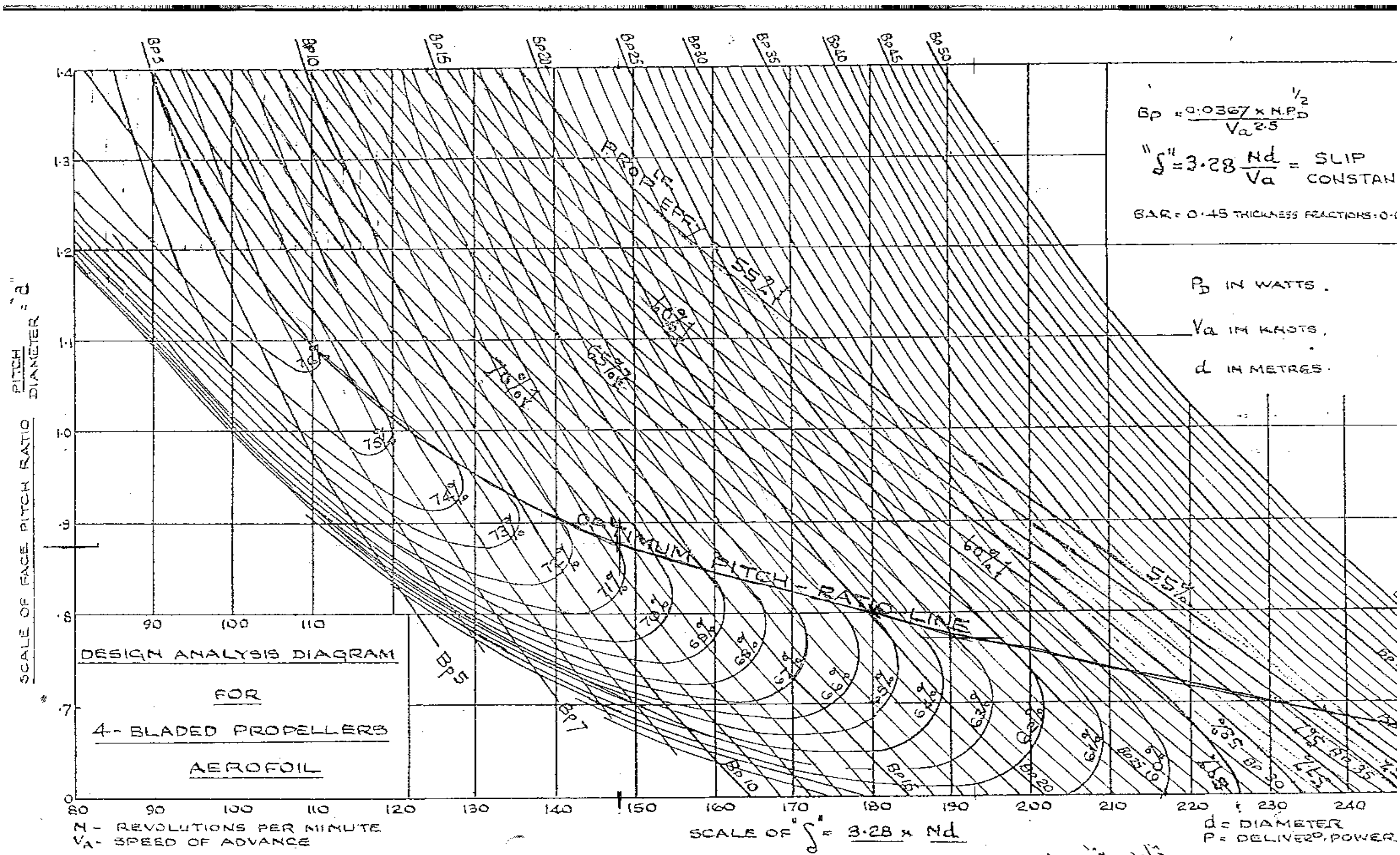
Solution

Using

$$B_P = \frac{0.0367 * N * P_D^{0.5}}{V_a^{2.5}} = 20.29$$

From diagram $a = \frac{Pitch}{Diameter}$ = 0.8 and $\delta = 181$ and efficiency = 64.9% then d for propeller diameter is 5.99m. Take it to be 6.0 m.

Apply this to $a = \frac{Pitch}{Diameter}$, and then propeller pitch is 4.80m.



DESIGN ANALYSIS DIAGRAM
FOR
4-BLADED PROPELLERS
AEROFOIL
$Bp = \frac{0.0367 \times N.P_D^{1/2}}{V_a^{2.5}}$
$"\delta" = 3.28 \frac{Nd}{V_a}$ = SLIP CONSTAN
BAR = 0.45 THICKNESS FRACTIONS: 0.
P_D IN WATTS.
Va IN KNOTS.
d IN METRES.
SCALE OF FACE PITCH RATIO $\frac{PITCH}{DIAMETER}$ "a"
OPTIMUM PITCH-RATIO LINE
PROP EFF.
N - REVOLUTIONS PER MINUTE
V_A - SPEED OF ADVANCE
SCALE OF "δ" = 3.28 × Nd
d = DIAMETER
P = DELIVERED POWER
Bp3 Bp5 Bp7 Bp10 Bp15 Bp20 Bp25 Bp30 Bp35 Bp40 Bp45 Bp50
76% 75% 74% 73% 72% 71% 70% 69% 68% 67% 66% 65% 64% 63% 62% 61% 60% 59% 58% 57% 55%
80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240
0 ·7 ·8 ·9 1·0 1·1 1·2 1·3 1·4

The Optimum Pitch Ratio Line is the most important line on the B_P-δ diagram, because: Once B_P value of a propeller is calculated; it is then traced to intersection with the optimum pitch ratio line. From this point all other relevant information regarding the propeller efficiency, diameter, and pitch can be determined.

Where B_P is proportional to RPM, $\sqrt{P_D}$, and $\frac{1}{V_a^{2.5}}$, all of which are set by the vessel design, but when designing the appropriate propeller, it is the Optimum Pitch Ratio Line that reveals all other necessary information in order to enable the Naval Architect to design the best suited propeller.

Thrust on the Propeller Blade

After obtaining the propeller efficiency, diameter, and pitch from the diagram, the following steps are taken in order to obtain the thrust on individual propeller blades:

$$\eta_{Prop} = \frac{P_T}{P_D} \quad \& \quad \eta_{Shaft} = \frac{P_D}{P_B}$$

But $P_T = Thrust * V_a$ OR $T = \frac{P_T}{V_a}$

$$\text{Also } OneBladeArea = BAR * \frac{\pi D^2}{No.Blades}$$

BAR is a value dependent on the thickness fraction of the propeller blades, and is determined for individual propellers as part of the analysis. In the case for the graph supplied here, BAR = 0.45, and number of blades is 4; thus:

$$ThrustonBlade = \frac{Thrust}{AreaofBlade} = \frac{T}{0.45 * (\frac{\pi D^2}{4})} = \frac{8.89 * T}{\pi D^2}$$

Stopping Distance “S”

As part of ship design, there are a number of concerns that the designer must be able to predict as the behaviour of the vessel in operation. Stopping distance is predicted from:

$$S = 0.38\left[(\frac{DWT}{10000})^2 - (\frac{DWT}{10000})\right] + 1.6 \text{ (in knots)}$$

Stopping Time “t”

Stopping time associated with the stopping distance will also have to be predicted and it can be determined by:

$$t = \left[2.67 * (\frac{DWT}{10000})^2\right] - \left[0.67 * (\frac{DWT}{10000})\right] + 10 \text{ (in minutes)}$$

Stopping Distance to Length Ratio

The stopping distance to ship’s length between perpendicular ratio is given by:

$$\frac{S}{L_{BP}} = \left[2 * (\frac{DWT}{10000})\right] + 10.5$$

This ratio can be used to estimate the stopping distance for a ship at any given deadweight based on its length between perpendiculars.

Bulbous-Bow Shapes

The interactions between the bow of a ship and water flow around the bow while the ship is in motion has been the subject of many intensive research programme over the past 150 years. The first decision to be taken in relation to the bow shape is whether to fit a "normal" or a "bulbous" bow. A normal bow shape is cheaper to build and a bulbous bow is only fitted on ships with high kinetic energy ($KE = \frac{1}{2}mv^2$). Consequently, ships with high mass such as super-tankers and OBO's, and with high speeds are fitted with bulbous bow.

If a vessel is relatively small mass and slow speed, e.g. less than 3000 tonnes DWT, and less than 12 knots speed, the bulbous bow will in fact cause drag effect and so should NOT be fitted with bulbous bow.

Froude Number (Fr) in combination with block coefficient C_b can be used to produce a graph shown below:

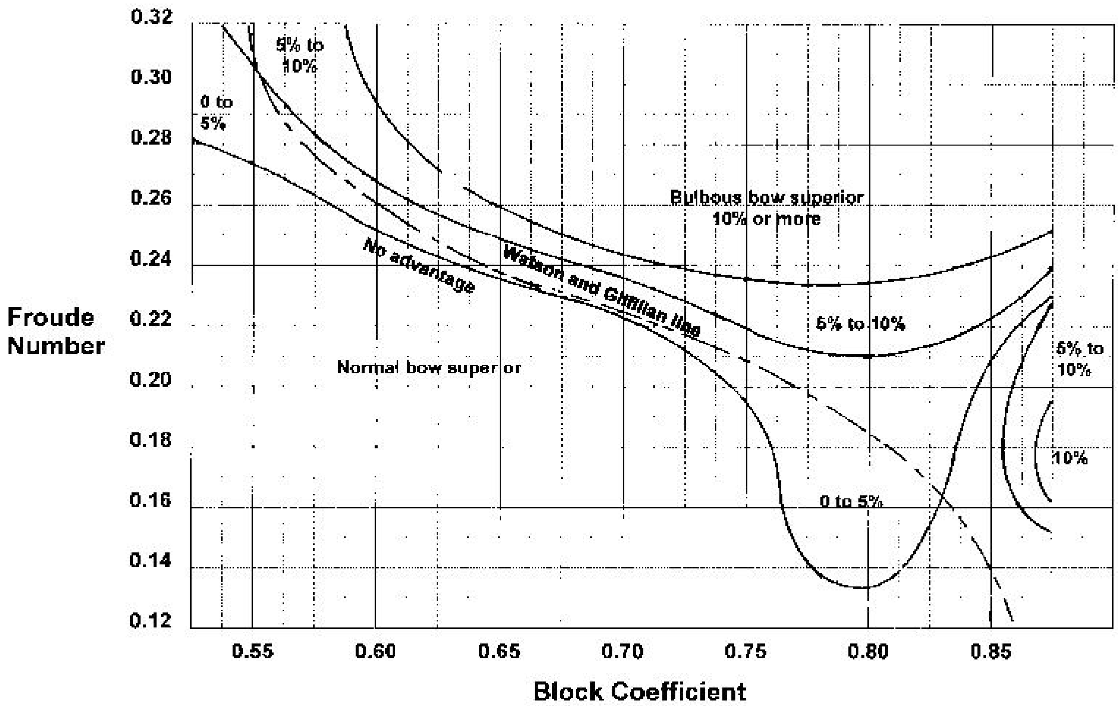


Figure P4-1 Bow Lines Selection Guide

Froude number is calculated by: $Fr = \frac{InertiaForce}{GravityForce} = \frac{v^2}{gL_{BP}}$

The designer would determine the Fr and C_b for the new ship and using guidelines such as the graph shown above would make decisions regarding the bowlines.

The superimposition of the Watson/Gilfillan C_b line on the diagram in figure P4-1 indicates the area which is of practical concern and it can be seen that bulbous bows:

- are advantageous for fast ships with C_b values less than 0.625 and Fr greater than about 0.26;

- present no advantage for ships with C_b values between 0.625 and 0.725 unless there are “over driven” according to Watson/Gilfillan criterion;
- are again advantageous for C_b values between 0.725 and 0.825, but probably not for C_b values over 0.825.

It is worth emphasising that overall economy may require a balance between designing for optimum performance fully loaded and in the ballast condition.

A bulbous bow will generally help to reducing pitching, ot on the other hand it is more likely to cause slamming.

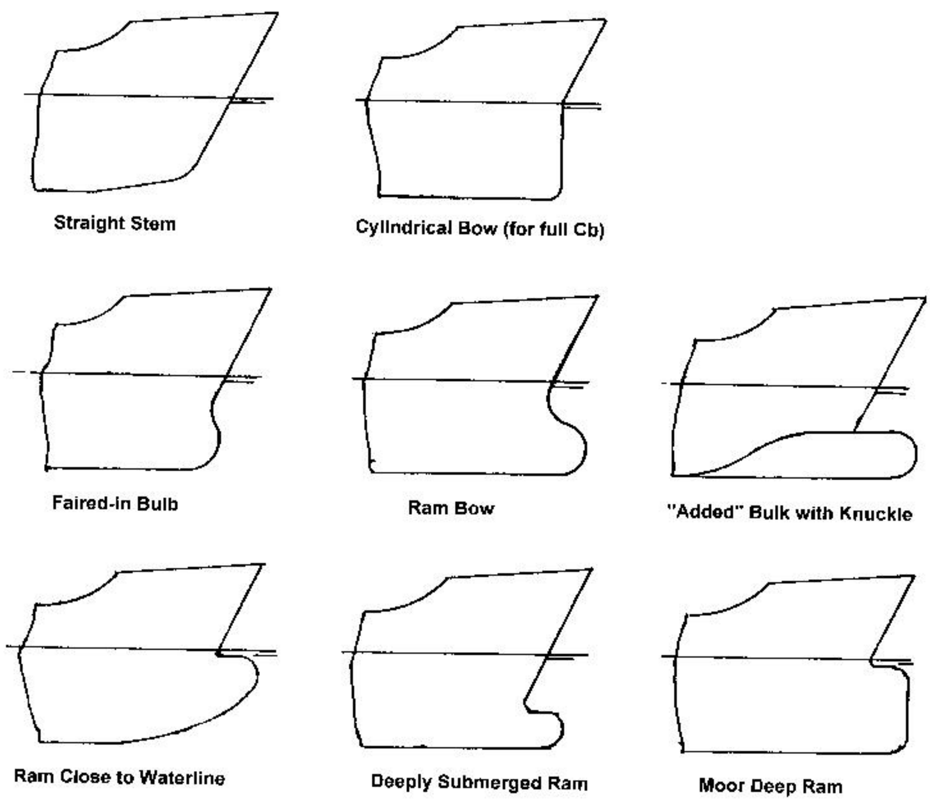


Figure P4-2 Various Bow Line Configurations

There are a number of configurations as shown in figure P4-2. It should be noted that in most cases the cutting edge of the bow would be cylindrically curved, and in some cases, it would be shaped sharpened.

Bulbous bows are fitted on ships for the following reasons:

1. To increase the speed for the same power if the ship speed at loaded draught.
2. To reduce vibrations at the fore end of the ship, due to the existence of extra steel in the structure.
3. Extra steel in the structure shall produce extra strength in the forepeak tank.
4. To reduce pitching due to bow shape effect on the water flow around the bow.
5. The bulbous bow shape can cause the thin ice to be broken ahead of the ship.

Stern Section Shape

The stern lines have to be considered in relation to the following roles:

- The accommodation of the propeller(s) with good clearances that will avoid propeller excited vibration problems;
- The provision of good flow to the rudder(s) to ensure both good steering and good course stability;
- The termination of the ships waterlines in a way that minimises separation and therefore resistance;
- The termination of the ships structure in a way that provides the required support for the propeller(s) and rudder(s) plus necessary space for steering gear, stern mooring and towage equipment etc. and is economical to construct.

Flow to the Propeller

Where the propeller diameter (D) on a single-screw ship is of normal size in relation to the draught (H), i.e. D/H is approximately 0.75, the main consideration is ensuring good flow to the propeller, with a figure of 28 to 30^o being about the maximum acceptable slope of a waterline within the propeller disc area. Keeping to such a figure tends to force the longitudinal centre of buoyancy (LCB) forward on a full-bodied ship. Lloyd's recommends minimum clearances as a fraction of the propeller diameter for a four-bladed propeller are:

Tip to stern-frame arch	=1.00 * K
Stern-frame to leading edge at 0.7R	=1.5 * K
Trailing edge to rudder at 0.7R	= 0.12
Tip to top of sole piece	= 0.03

Where $K = \left(0.1 + \frac{L}{3050}\right)\left(\frac{2.56C_b * P}{L^2}\right) + 0.3$ & P = power in kW

The recommended clearance for four-bladed propeller on a twin-screw ship, is 1.00*K. Other values are given in the rules for three, five, and six-bladed propellers.