Automatic Hull Form Generation

using

Neural Nets and Genetic Algorithms

By

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This is to certify that the work presented in this thesis paper is the outcome of the investigation carried out by the candidate under the supervision of Dr. Chowdhury Mofizur Rahman(Supervisor) in the Department of computer Science and Engineering, Bangladesh University of Engineering and Technology, Dhaka and Dr. Reaz Hasan Khondoker(Co-Supervisor) in the Department of Naval Architecture and Marine Engineering, Bangladesh University of Engineering and Technology, Dhaka. It is also declared that neither of this thesis nor any part thereof has been submitted or is being concurrently submitted anywhere else for the award of any degree or diploma.

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Abstract

The rapid generation of faired hull surface is very important. Especially, early fairing and modeling of ship hull in preliminary design stage has more effective advantages in many sides like performance analysis, production design, and process management etc. Hull form fairing process, however, still has been a very iterative and time-consuming job. For automatic fairing, hull form must be modeled using computer. In the field of surface modeling of hull form, geometric complexity of hull form gives many difficulties in adopting surface modeling technique that can describe the irregular topological characteristics precisely.

Generation of faired hull surface is also very important in ship production procedure. Ship drawings are prepared in scales of 40:1 to 100:1. During the construction phase, full-scale drawings are prepared at the so-called "loft-floor". In this process, the minute discontinuity in the shape of the vessel that is not apparent in the scaled drawings becomes apparent. This requires a modification of the drawings that is both tedious and time consuming. Computer based techniques are being evolved to measure the continuity of the shape and thus to ensure that the scaled drawings are truly continuous avoiding the necessity of the corrections from the lofting process.

For designing ship's hull, four parameters are supplied by the owner-length, displacement, speed and type of the ship. Neural Networks is a robust technique to find the breadth and draft from the

given values. A linear relation between the parameters can generate a design from length, breadth and draft. This design provides a guideline for generating similar and initial populations with small variations to be fed in a GA-based learner. Cross over and mutation operator along with add alternate operator of GAs can be used to generate new populations (hull form data) from the existing populations to evolve into new generations and the fitness of the generations can be computed including the new ones. After that weak population can be discarded, as they can not survive. Only strong population with good fitness can compete and be able to improve their fitness and evolve themselves to generate new populations until an acceptable solution is found.

This computer-based design makes the vessels hull form design fully automated. The proposed system learns about the design from some previously designed ships and generates weight matrices. These weight matrices along with Neural Nets and Genetic Algorithms create a design, which satisfy all the hydrostatic properties within reasonable error (less than 2%). Moreover, the process has been able to design a ship by examining 60 generations with a population size of 50, i.e., all together 3000 populations are manipulated to get almost accurate design. The proposed system, for the first time, design a method for modeling and fairing of hull form in fully automated manner.

Chapter 1

Introduction and Literature Review

1.1. Introduction

A ship or vessel is one of the most complex engineering structures, and in common with the majority of engineering projects its design represents a compromise between many conflicting requirements. The design and construction of a vessel, which fulfils all the requirements that, have been stipulated, is no ordinary achievement. In the effort to efficiently fulfil the demands for a ship on any service the united skill and ingenuity of Naval architects, shipbuilders and marine engineers are required. Besides different engineering measures, the design of hull form is important one and achieved by Naval architects.

In naval architecture the start of the iterative process of design is a preliminary definition of the external hull geometry. The influence of the hull geometry of the vessel is such that the major changes made during subsequent iterations can cause severe disruptions to the convergence towards a final solution. It is therefore important that the initial hull form definition is well conceived.

The first stage of hull form synthesis involves the development of a symbolic model. This is a set of values for key parameters that correlate with various aspects of operational and economic performance and largely based on empirical data. Some of these parameters are of numeric nature, and may be dimensional (linear dimensions, areas, volume and centroid) or non-dimensional (form coefficients such as block coefficient, water plane coefficient and various other ratios of lengths, areas and volumes). Others are of a more abstract nature, referring to the presence and extent of more subtle form features (terms such as 'tumble home', 'flare' and 'hard bilge'). An important further requirement of any form is that it is fair, meaning the absence of any unwanted form features.

The task of the naval architect is to derive a geometrical definition (an iconic model) which corresponds to this parametric description. There are two alternative approaches that are usually considered. One is to apply some geometrical transformation to an existing form such that the resulting form satisfies some or all of the new parametric requirements. The other is to synthesize in an intuitive and informal way.

The advent of interactive graphical CAD has enhanced the original approach by allowing rapid reevaluation of the design parameters when changes are made. However, the process is essentially still manual and time consuming. Unfortunately CAD has not significantly aided the form transformation approach to design. Firstly there is the problem transferring existing hull forms recorded as offsets to the B-Spline surface representation used by most modern ship CAD systems, and secondly B-Spline surfaces can not be manipulated by the conventional transformation algorithms [3,4].

However, in the era of computer, this design can be automated by using computer tools like Neural Networks and Genetic algorithms that are the important for such types of purposes. Both of them are iterative techniques to design some tools or methods as well as intelligent learning techniques.

1.2. Literature Review

In the field of surface modeling of hull form, geometric complexity of hull form gives many difficulties in adopting surface modeling technique, which can describe the irregular topological characteristics precisely. Many methods have been developed to generate curves and surfaces from a set of data points or one group of parameter curves [16,25,28]. The earlier ones, such as cubic Spline, Coons patches, Gordon's patches and Spline in tension, interpolated all the defining points. In general, their main drawbacks are their global behavior that implies that any local changes affect the complete shape. Also a problem is dealing with some quantities, such as cross-derivatives and others, whose influence in the shape is not obvious for the designer. The use of Bezier curves and surfaces introduced the concept of control polygons and meshes that provide a more intuitive geometric control of the shape. To smooth existing surface, a lot of methods have been applied; for example, mesh fairing method [19], reflection line method [23], FANGA curves method [24], minimizing a sum of the squares of principal curvatures [5] etc.

B-Spline [26] curves and surfaces have been widely used for the representation of ship hull geometry. The properties of B-Spline, namely the local control, stronger convex hull and the possibility of introducing discontinuities by increasing multiplicity in control points have proved to be more suitable for the task than the Bezier formulation. B-Spline can contain Beziers as a particular case and also are not able of representing exactly conic shapes. Fog [9] represented the entire hull by a single fourth order non-uniform tensor product B-Spline surface. Beyer [2] used B-Spline curves on the design tool DCM, developed for the interactive modeling of hulls, which allowed to select the type of continuity between curve segments (C^0, C^1 or C^2). The system HULLSURF [6] represents the hull form by bi-cubic B-Spline patches defined over boundaries approximated by B-Spline curves, both using uniform knot vectors.

Jensen [17] developed an automatic procedure for generating a single B-Spline surface to represent a ship hull surface. First the longitudinal and any knuckle lines are interpolated by cubic Spline. Then, for each section, a user-defined number of control points is obtained by least-square approximation. The grid composed by the section control points is then used to generate a tensor product B-Spline surface. Standersky [30] combines the interactive capabilities of the B-Spline tensor product surface with the variation approach to the shape generation of ship hulls.

More recently, Bardis and Vafiadou presented a model [1] that tries to combine the B-Spline formulation with the local control of the patch boundaries obtained by concepts borrowed from the Beta-Spline formulation. First, longitudinal boundary lines are approximated by B-Spline curves interpolating selected points. Then, transverse sections and the longitudinal parametric first derivatives are approximated by B-Spline curves fitted to section-offset points and longitudinal tangent values, respectively. Finally B-Spline surface patches are generated between each pair of consecutive curves, using first derivative values from the tangent values on the boundaries multiplied by bias functions β1, similar to those used in Beta-Spline formulations. Beta-Spline are a generalization of B-Spline which added two new variables, the shape parameters β1 and β2 called bias and tension, respectively, allowing the capability of controlling the degree of continuity at the joints between curve segments without interfering with the order or the number of control vertices. However, this extra control is obtained at the cost of replacing the requirement of second degree parametric continuity, C2, between curve segments used in B-Spline, by the requirements of the so called geometric continuity, G2, of the unit tangent and curvature vectors.

As it is seen that most of the formulations in the recent past are based on B-Spline, which have the limitation of not being able to deal in an exact way with conic and quadric shapes, which are essential in the hull geometry. This limitation is solved by NURBS, (Non-Uniform Rational B-Spline) as proposed by Ventura et. al. [33] which are a generalization of B-Spline, in the rational form, that use an extra degree of freedom, the control point weight. As a superset of B-Spline, they retain all their properties, with a stronger convex hull and the additional capability of representing conic and quadric shapes exactly, which previously was only possible using the analytical expressions. This set of properties makes NURBS particularly attractive as a mathematical formulation for hull form modeling systems.

Yoon et al [36] provides a CAD system for generating the faired hull surface rapidly. It consists of two major parts, surface modeling and surface fairing. Surface model is constructed by geometric continuous (GC) composite surface modeling technique. For surface modeling of non-rectangular patch the new interpolation method is used. In order to get the good global fairness various fairing methods are examined. Modified direct curvature manipulation in curve fairing, energy minimization of normal vector line curve-net and solving the inverse problem by constrained reflection line using optimization technique gives quite good results. Interactive graphic system with user friendly GUI is implemented using the Phig+ library in UNIX environment.

As a basis ship form transformation method, the LACKENBY's method [21] is usually applied in ship lines design to vary block coefficient C_b and longitudinal position of center of buoyancy LCB, etc. However, in LACKENBY's method, while shifting the transverse sections along longitudinal direction, the designed waterline is also changed. In other words the LACKENBY's method cannot be used to vary the designed waterline independently. The method, which tries to vary directly each transverse section line in some form of mathematical function, is only applicable in a very small range. The mathematical method based on the draft functions may be used, but it should first represent the parent ship form at high accuracy, so it is too complicated and not convenient. To overcome the disadvantage of conventional basis ship form transformation method, Zhang et al [37] develops a new method to vary the designed waterline independently. The variation in their method is defined as:

(1) It must keep the area curve of transverse section unchanged;

(2) Provided the required designed waterline is practicable, the method is suitable;

(3) The demands for varying the contours of stern and stem are also considered.

Birmingham et. al [5] tried to introduce an element using GAs to automate the hull form generation of vessels. From the commercial viewpoint the advantages are improved productivity and improved quality of designs, as a wider range of alternatives can be considered in a methodical manner with greater conformity to specified requirements. Additionally, the designer's understanding of the design limitations is enhanced, so bolstering expertise. From an academic perspective, there are various benefits of their method. Methodical control of form parameters is central to a number of areas of research, a current example being the parametric study of vessels' hydrodynamic performance [12,13]. The system also poses questions relating to the nature and philosophy of design, and suggests different ways of specifying a design and the routes taken to reach a particular definition. However, this procedure is not an efficient one, though it automates the system. Since they took a sample of 100 individuals and proceed using cross over and mutation operator of GAs up to 300 generations to get the results.

In view of the above the objective of the study is concentrated to;

- Analysis of Neural nets and Genetic Algorithms for the generations of automatic hull form of vessels as these two are the important tools for automation of anything. Automatic hull form generation is a time consuming iterative process that can easily be speeded up by using Neural Nets and genetic Algorithms.
- Development of an efficient algorithm for generating the hull forms of vessels automatically based on given parameters
- Analyzing the efficiency of the devised algorithms.

The main application of this study is in designing different types of ships with varying functional requirements. This concept can also be used in other architectures like designing of house, roads, super-markets, bus stops, floor planning, etc. To meet the demand arisen from the application area of computer theorems, the concept may be used in different automatic designing and increasing the efficiency of the design process.

1. 3. Outline of the thesis

The remaining of the thesis is organized as follows. In Chapter 2, a brief explanation on ship geometry is given. Different types of geometric co-efficient and the design principles of hull geometry of a vessel are mentioned there. Standard values for different dimensional and non-dimensional parameters and/or co-efficient are also pointed out. This will serve as the base of our study in latter chapters.

In Chapter 3, the concepts and theorems of neural network such as weight matrices for learning or designing something, network concepts with hidden layer, back-propagation algorithm, etc, are described and discussed. The application mechanism of back-propagation principle for deciding the values for some dimensional and non-dimensional parameters for a particular ship is explained.

In Chapter 4, We focus on the concepts of Genetic Algorithms (GAs) and their applications for generating the hull form surface. The technique includes generating new population using different operations and discarding week population to get smart designed hull form. For every population fitness is calculated.

Chapter 5 discusses the techniques for efficient implementation of concepts achieved in previous chapters. Essential algorithms for designing hull form using neural nets and GAs that will be generated automatically and fulfils all necessary parameters are mentioned. Techniques for generating training set population and methods changing weight matrices for neural nets and new population for GAs are discussed. Fitness measurement technique for individual population is also included in this chapter.

Chapter 6 analyses the result found in our experiments and compares them for different sizes of population, for different values and time duration. Impacts of taking more generation and more population are examined and the result is presented here. This chapter also provides the values of required parameters (both inputted and non-inputted) for the designed ship comparing with given or standard ones.

Finally, we summarize the thesis in Chapter 7, in which some interesting problems and proposals are addressed for future study.

Chapter 2

Ship Geometry

The exterior form of a ship's hull is a curved surface defined by various lines. Precise and unambiguous means are needed to describe this surface, inasmuch as the ship's form must be configured to accommodate all internals, must meet constraints of buoyancy, stability, speed and power, and seakeeping, and must be 'buildable'. Hence, the lines consist of orthographic projections of the intersections of the hull form with three mutually perpendicular sets of planes, drawn to a suitable scale.

The *Profile* or *sheer plan* shows the hull form intersected by the centerplane-a vertical plane on the ship's centerline-and by buttock planes which are parallel to it, spaced for convenient definition of the vessel's shape and identified by their distance off the centerplane [Figure 2,2]. The centerplane intersection shows the profile of the bow and stern.

In the sheer plan, the base line representing the bottom of the vessel is parallel to the design water line, DWL, showing that the vessel is designed for an "even keel" condition [31]. Some vessels-especially tugs and fishing vessels- are often designed with the molded keel line raked downward aft, giving more draft at the stern than the bow when floating at the DWL; such vessels are said to have designed *drag to the keel.*

The *half-breadth* or *waterline plan* the intersection of the hull form with planes parallel to the horizontal base plane, which is called the base line. All such parallel planes are called waterline planes, or waterplanes [Figure 2.3]. It is convenient to space most waterplane equally, but a closer spacing is often used near the base line where the shape of the hull form changes rapidly. DWL represents the design waterline, near which the fully loaded ship is intended to float. All waterlines are identified by their height above the baseline.

The *body plan* shows the shapes of sections determined by the intersection of the hull form with planes perpendicular to the buttock and waterline planes [Figure 2.1]. Planes defining the body plan are known as body plan stations. They are usually spaced equally apart, such that there are 10 spaces-or multiples thereof in the length of the ship, but with a few extra stations at the ends of the ship at one half or one quarter this spacing.

Most ships are symmetrical about the centerplane, and the lines drawing shows waterlines in the half-breadth plan on only one side of the centerline. Asymmetrical features on some ships, such as overhanging flight decks on aircraft carriers, must be depicted separately. Correspondingly, the body plan shows sections on one side of the centerline only those in the forebody on the left hand side and those in the afterbody on the right.

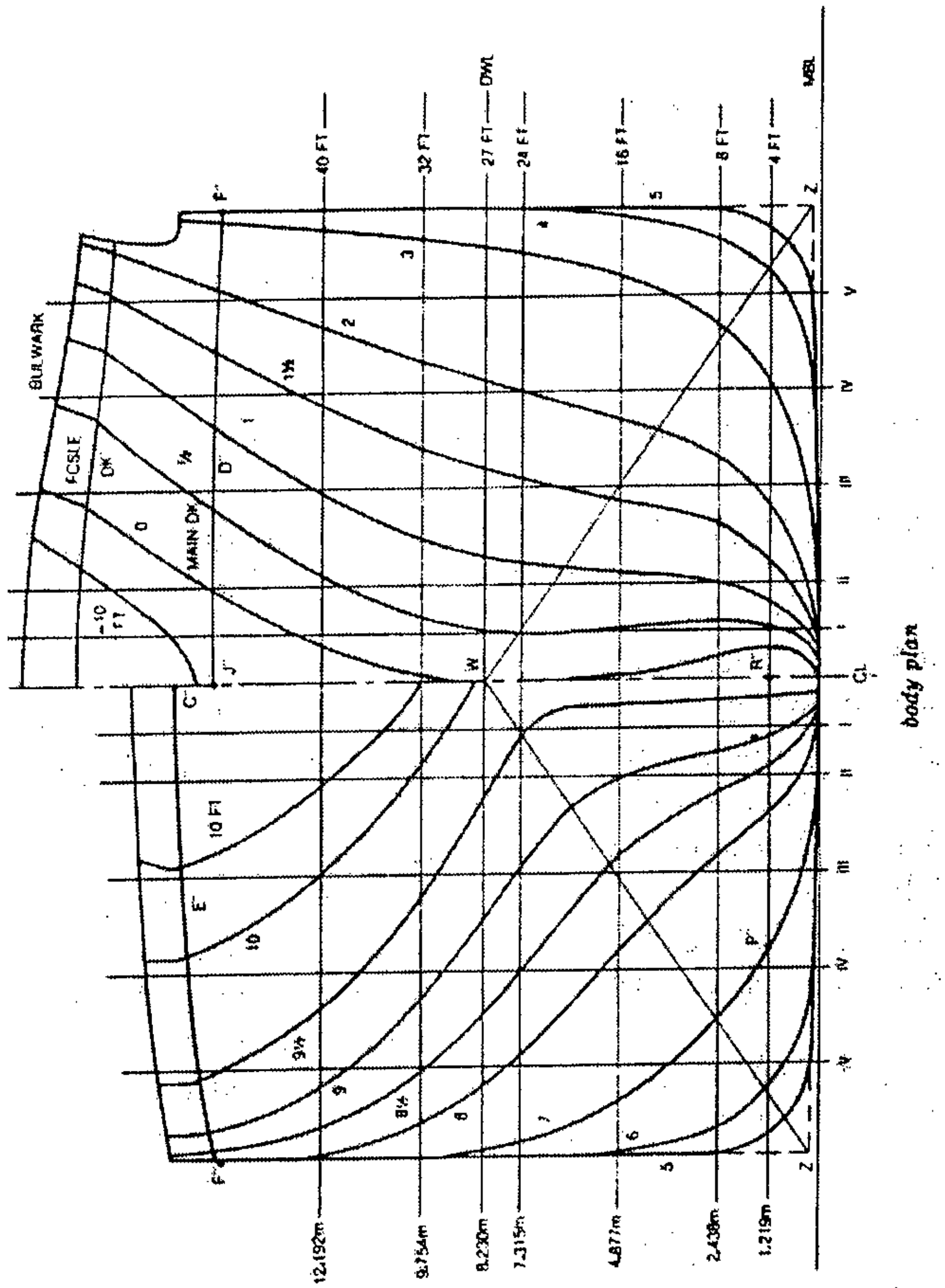

Figure 2.1: Body plan

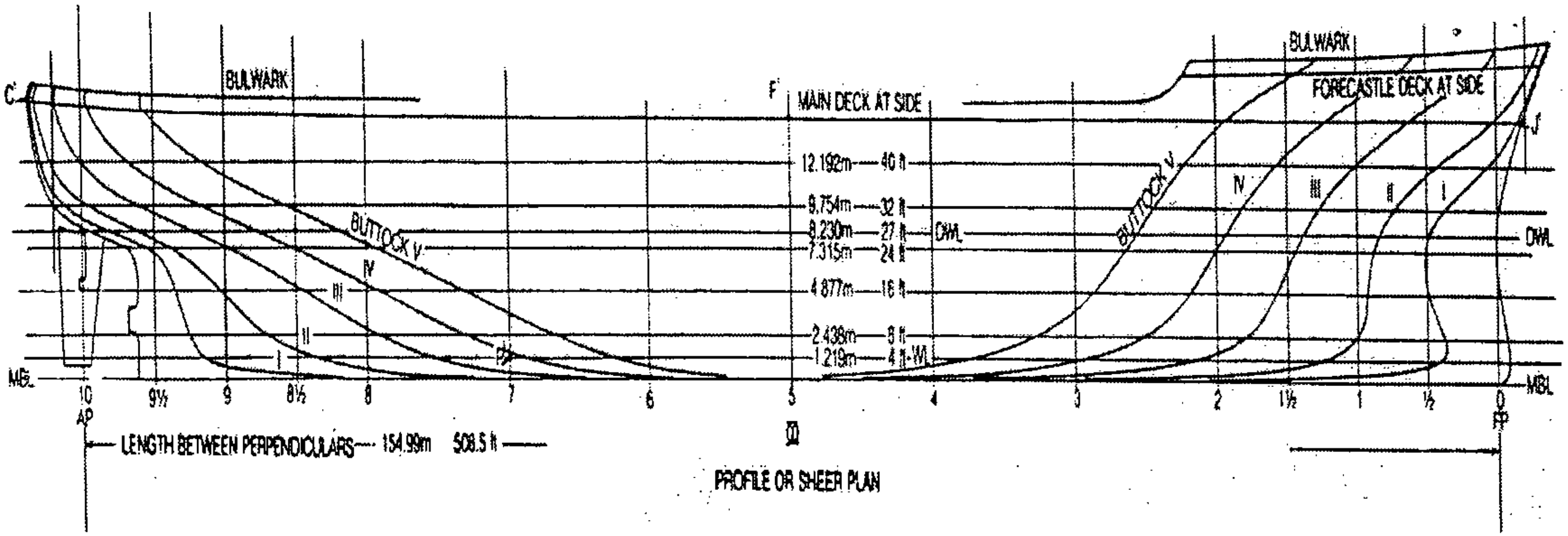

Figure 2.2: Profile or Sheer Plan

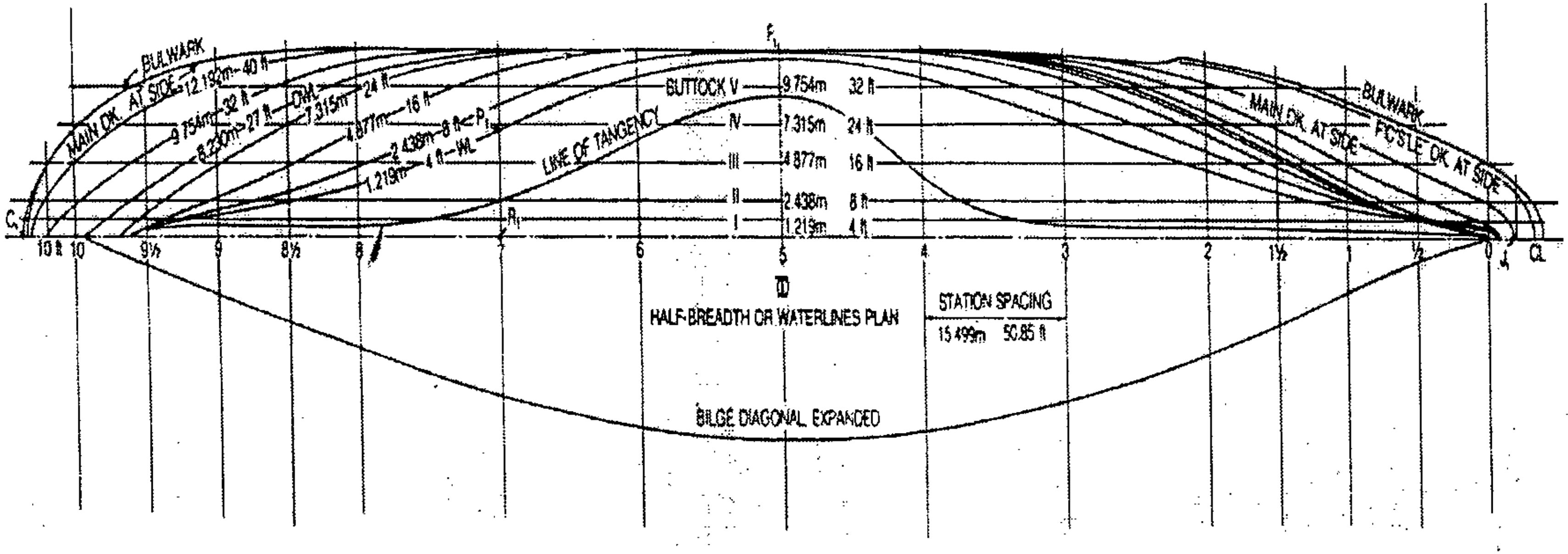

Figure 2.3: Half Breadth or Waterplane

The first stage of hull form synthesis involves the development of symbolic model. This is a set of values for key parameters that correlate with various aspects of operational and economic performance, and largely based on empirical data. These parameters are divided into two groups:

- Dimensional parameters.
- Non-dimensional parameters.

Linear dimensions such as Length, Breadth, Depth, Draft, *Lpp* and DWL; Areas such as Waterplane area, Midship area and sectional area as well as volume or displacement are also considered as dimensional parameters, whereas various co-efficient required to design below water shape like Block Co-efficient (C_b), Midship Co-efficient (C_M), Prismatic Co-efficient (C_P), Waterplane Co-efficient (C_{WP}), Volumetric Co-efficient (C_V), Vertical Prismatic Co-efficient (C_{VP}), Ratio of Dimensions, etc, are non-dimensional parameters [5].

2.1. Dimensional Parameters

Dimensional parameters have the property that it can be changed directly by the Naval architects to fulfil other parameters. Here is a short description of dimensional parameters:

a) Length

Length of the ship means maximum length of the ship that is observed in the above water shape. Though the above water shape of the hull form is not important in design process, some other parameters related to the below water shape depends on length, such as DWL, breadth, depth, waterplane area, sectional area, draught, etc.

b) Breadth

The maximum width of the ship both in below water shape and above water shape is same and is considered as breadth. Breadth is used to calculate other parameters like midship area, waterplane area, depth, draught, etc.

c) Draft

In general, the amount of water a vessel draws, or draft, is the distance measured vertically from the waterline at which the vessel is floating to its bottom. Drafts may be measured at different locations along the length. They are known as molded draft if measured to the molded base line; keel drafts if measured to the bottom of the keel. Mean draft is defined as the average of drafts forward and aft.

Ships are customarily provided with draft marks at the ends and amidships, arranged in a plane parallel to the station planes and placed as close to the perpendiculars as practical. These draft marks are for the guidance of operating personnel, and therefore the drafts indicated should be keel drafts.

The difference between drafts forward and aft is called *trim*. If the draft aft exceeds that forward, the vessel is said to have trim by stern. An excess of draft forward causes trim by the bow-or trim by the head. When trim is determined by reading the draft marks and the angle of inclination or the displacement of the vessel is to be determined, it is important to account for the specific fore and aft location of the marks.

d) Length between Perpendiculars (*Lpp*)

A vertical line in the sheer plan is drawn at the intersection of DWL, which is often the estimated summer load line and the forward side of the stem. This is known as the *forward perpendicular*, abbreviated as *FP*. A corresponding vertical line is drawn at the stern, designated the *after perpendicular* or *AP*. When there is a rudderpost the *AP* is located where the after side of the rudderpost intersects the DWL.

An important characteristic of a ship is its length between perpendiculars, sometimes abbreviated LBP or *Lpp*. This represents the fore-and-aft distance between the *FP* and *AP* and is generally the same as the length L defined in the American Bureau of Shipping Rules for building and classing Steel Vessels (Annual). However, according to the rules, it is not to be less than 96 percent and need not be greater than 97 percent of the length on the summer load line [22].

When comparing different designs, a consistent method of measuring ship lengths should be used. Overall length is invariably available from the vessel's plans and LBP is usually also recorded. However, for hydrodynamic purposes, length on the prevailing waterline may be significant; alternatively, an "effective length" of the underwater body for resistance considerations is sometimes required.

e) DWL

DWL represents the design waterline, near which the fully loaded ship is intended to float. This line indicates the region up to which the ship is submerged in full loaded condition. This is also known as summer load line as it is the deepest waterline to which a merchant vessel may legally be loaded during the summer months in certain specified geographical zones.

f) Deck line

The deck surface is represented by a line in sheer plan, called deck line. The deck surface is crowned or cambered, i.e., curved in an athwartship direction with convex surface upwards, or sloped by straight lines to a low point at the deck edge. A ship's deck is also usually given longitudinal sheer; i.e., it is curved upwards towards the ends, usually more at the bow than at the stern. In case the sheer line of the deck at side curves downward at the ends, the ship is said to have reverse sheer.

g) Sectional Area Curve

A fundamental drawing in the design of a ship– particularly relative to resistance-is the sectional area curve for a ship with some parallel middle body. The sectional area curve represents the longitudinal distribution of cross sectional area below the DWL. The ordinates of a sectional area curve are plotted in distance-squared units. Inasmuch as the horizontal scale, or abscissa, represents longitudinal distance along the ship, it is clear that the area under the curve represents the volume of water displaced by the vessel up to the DWL, or volume of displacement.

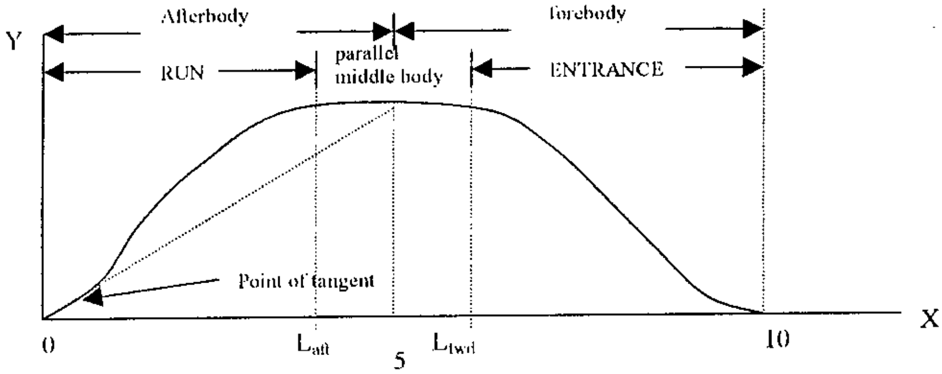

Figure 2.4: Geometry of Sectional Area Curve

The sectional area curve will have a starting value at the stern, some slope at that point and a gentle swing into a possible parallel middle portion, followed by a similar shape in the forebody [18]. The maximum value will be at L_{max}, where there may be a parallel length L_{par} so that the aft position of the parallel length will be at $L_{aft}=L_{max}-0.5L_{par}$ and the forward position will be at $L_{fwd}=L_{max}-0.5L_{par}$.

Using y as the value of the sectional area as a function of the distance from $AP(x)$ the curve for the afterbody may be expressed as:

$$y_a=A+Bx+Cx^2+Dx^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

which has to satisfy the following requirements

$y_a=y_s=0$	$at\ x=0$
$dy_a/dx=\underline{AS}$ (aft slope)	$at\ x=0$
further, $dy_a/dx=0$	$at\ x=L_{aft}$
and $y_a=y_{max}$	$at\ x=L_{aft}$

For the forebody the expression will be

$$y_f=E+Fx+Gx^2+Hx^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.2)$$

which has to comply with the requirements below

$dy_f/dx=0$ at $x=L_{fwd}$

$y_f=y_{max}$ at $x=L_{fwd}$

and $y_f=0$ at $x=L_{pp}$

also $dy_f/dx=-\underline{FS}$(forward slope) at $x=L_{pp}$

The equations may be solved to give

$A=y_s=0$

$B=\underline{AS}$

$D=2(2y_s-2y_{max}+\underline{AS}L_{aft})/L_{aft}$

$C=\underline{AS}/(2L_{aft})-1.5DL_{aft}$

$H=(2y_{max}-\underline{SF}(L_{pp}-L_{fwd}))/(L_{pp}-L_{fwd})^3$

$G=(-y_{max}-H(L_{pp}^3+2L_{fwd}^3-3L_{fwd}^2L_{pp}))/(L_{pp}-L_{fwd})^2$

$F=-2G\,L_{fwd}-3HL_{fwd}^2$

$E=-FL_{pp}-GL_{pp}^2-HL_{pp}^3$

h) MidShip Section

An important matter for any ship is the location and shape of the midship cross section, which was originally used to indicate the fullest cross section of the vessel [Figure 2.5]. In some of the early sailing ships this fullest section was forward of the midlength and in some high-speed ships and sailing yachts, the fullest section under water is somewhat abaft the midlength. In any case, the usual practice in modern commercial vessels of most types is to locate midship section halfway between the perpendiculars, while in naval ships it is usually midway between the ends of the DWL.

In many modern vessels, particularly cargo vessels, the form of cross section below the DWL amidships extends without change for some distance forward and aft, usually including the midship location. Such vessels are said to have parallel middle body.

i) Body Plan Stations

In order to simplify the calculation of underwater form characteristics, it is customary to divide the LBP into 10 or 20 or 40 intervals by the body plan planes. The locations of these planes are known as body plan stations, or simply stations, and are indicated by straight lines drawn in the profile and half-breadth plans at right angles to the vessel's baseline and centerline, respectively.

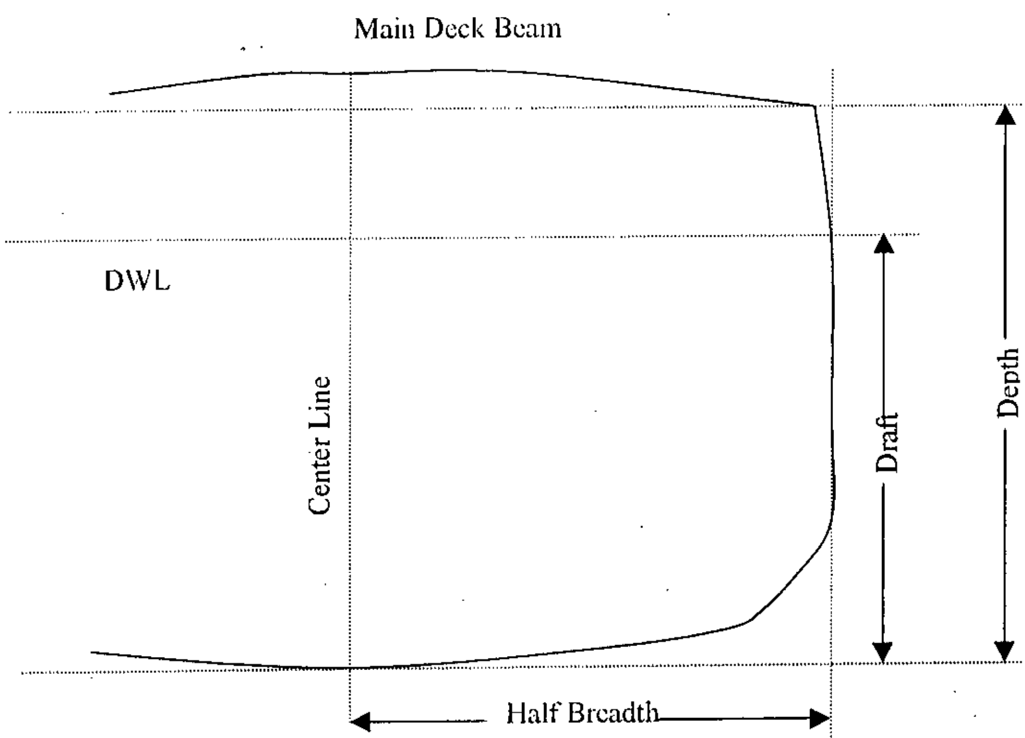

Figure 2.5: Geometry of MidShip Section

Body plan stations are customarily numbered from the aft forward, with the *FP* designated as station 0. It will be noted that additional stations are drawn midway between stations 0 and 1, and 9 and 10, and sometimes between 1 and 2, 2 and 3, 7 and 8, and 8 and 9, as well. This is done to better define the vessel's form near the ends where it may change rapidly for small longitudinal distances.

Additional stations are often also shown forward of the *FP* and abaft the *AP*. These may receive letter or distance designations from the perpendiculars, or a continuation of the numbering system equivalent to that used in the remainder of the ship, as negative numbers forward of the *FP* and numbers in excess of 10 abaft the *AP*.

j) Waterplane Area

The area at the waterline coincidental with the DWL is called waterplane area. This area is important for calculating the different co-efficient and other parameters of the ship.

k) Displacement of Volume

The volume of the underwater portion of a vessel may be calculated by integrating the cross sectional area curve, i.e., the area under the cross sectional area curve represents the underwater volume. This result is known as the volume of displacement, ∇, up to the waterline at which the vessel is floating.

If we know the mass density of the water, ρ, in which a ship is floating, we can calculate the weight of the displaced fluid, or the displacement weight, W,

$$W = \rho g \nabla \qquad (2.3)$$

By Archimedes' priciple this weight is equal to the weight of the ship and its contents. If the volume is measured in cubic meter (m^3) and weight in tons, then the relation becomes

$$\Delta = \rho\nabla \qquad (2.4)$$

where mass displacement, Δ, is in metric tons; volume displacement, ∇, is in m^3; and ρ= 1.00tons/m^3 in Fresh Water(*FW*) and ρ=1.026tons/m^3 in Salted Water(*SW*). The mass displacement is also known as draught.

Effect of Density on Displacement

A decrease in the density of the fluid in which a vessel floats requires an increase in the volume of displacement ∇ in order to satisfy static equilibrium requirements. Therefore, a ship moving from salt water to fresh water, for example, experiences an increase in draft, δT. This increase can be calculated by equating the increase in displacement volume to the volume of a layer of buoyancy of uniform thickness, δT, distributed over the original load waterplane. This increase in displacement volume

$$\nabla_F - \nabla_S = \nabla_S \frac{\rho_S}{\rho_F} - \nabla_S = \nabla_S\left(\frac{\rho_S}{\rho_F} - 1\right)$$

where subscript S refers to salt water, subscript F to fresh water. But, on the assumption that the ship is "wall sided", the equal layer of buoyancy is,

$$\nabla_F - \nabla_S = A_{WP}.\delta T$$

Hence,

$$A_{WP}.\delta T = \nabla_S\left(\frac{\rho_S}{\rho_F} - 1\right)$$

and the increase in draft is,

$$\delta T = \frac{\nabla_S}{A_{WP}}\left(\frac{\rho_S}{\rho_F} - 1\right) = \frac{\nabla_S(\gamma_S - 1)}{A_{WP}} \qquad (2.5)$$

Where ∇ is displacement volume, ρ is mass density, A_{WP} is waterplane area, and $\rho_S/\rho_F = \gamma_S$ is specific gravity [22].

The centroid of the underwater body may shift, both vertically and longitudinally, with such a change in medium. In particular, an increase in draft as a result of a decrease in fluid density causes the vertical location of the center of buoyancy to rise with respect to the keel as a result of an increase in displacement volume, ∇.

2.2.Non-dimensional Parameters or Co-efficient of Form

In comparing ships' hull forms, displacements and dimensions, a number of co-efficient are used in naval architecture. These coefficients are useful in power estimation and in expressing the fullness of a ship's overall form and those of the body plan sections and waterlines.

a) Block Co-efficient, C_B

This is defined as the ratio of the volume of displacement ∇ of the molded form up to any waterline to the volume of a rectangular prism with length, breadth and depth equal to the length, breadth and mean draft of the ship, at that waterline. Thus

$$C_B = \frac{\nabla}{L.B.T} \qquad (2.6)$$

Where L is length, B is breadth and T is mean molded draft to the prevailing waterline. Some authorities take L as LBP and some as an effective length. B may be taken as the molded breadth at the design waterline and at amidships, the maximum molded breadth at a selected waterline.

Values of C_b at design displacement may vary from about 0.36 for a fine high-speed vessel to about 0.92 for a slow and full Great Lakes bulk carrier.

b) Midship Co-efficient, C_M

The midship section co-efficient, C_M, sometimes called simply midship coefficient, at any draft is the ratio of the immersed area of the midship station to that of a rectangle of breadth equal to molded breadth and depth equal to the molded draft amidships.

$$C_M = \frac{Immersed\ area\ of\ midship\ section}{B.T} \qquad (2.7)$$

Thus, values of C_M may range from about 0.75 to 0.995 for normal ships.

c) Prismatic Co-efficient, C_P

The prismatic co-efficient, sometimes called longitudinal prismatic co-efficient, or simply longitudinal co-efficient, gives the ratio between the volume of displacement ∇ and a prism whose length equals the length of the ship and whose cross section equals the midship section area.

$$C_P = \frac{\nabla}{L \times immersed\ area\ of\ midship\ section} = \frac{\nabla}{L.B.T.C_M} = \frac{C_B}{C_M} \qquad (2.8)$$

Thus, the term longitudinal co-efficient was originated and used by Adm. D. W. Taylor (1943) for the reason that this co-efficient is a measure of the longitudinal distribution of a ship's buoyancy. If two ships with equal length and displacement have different prismatic co-efficient, the one with the smaller value of C_P will have the larger midship sectional area ($B.\ T.\ C_M$) and hence a larger concentration of the volume of displacement amidships. This is clearly shown by figure 2.6, which compares the sectional area curves for two different vessels. The ship with the smaller C_P is also characterized by a protruding bulbous bow, which causes the swelling in the sectional area curve right at the bow, and its extension forward of station 0.

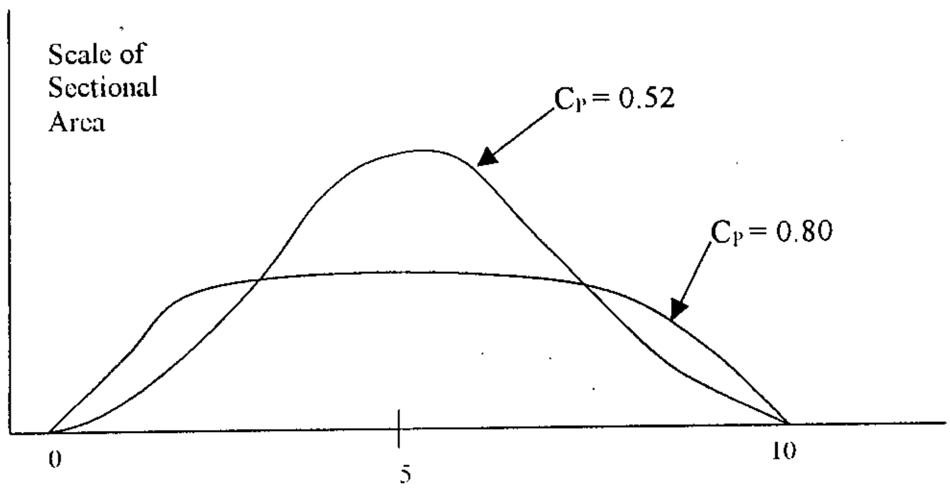

Figure 2.6: Sectional Area for different Prismatic Coefficients

Prismatic co-efficient is a frequently used parameter in studies of speed and power. Usual range of values is from about 0.50 to about 0.90. A vessel with a low value of C_P (or C_b) is said to have a fine hull form, while one with a high value of C_P has a full hull form.

d) Waterplane Co-efficient, C_{WP}

The waterplane co-efficient is defined as the ratio between the area of the waterplane A_{WP} and the area-circumscribing rectangle. Thus,

$$C_{WP} = \frac{A_{WP}}{L.B} \qquad (2.9)$$

As with the other co-efficient, the length and breadth are not always taken in a standard way. The co-efficient may be evaluated at any draft. The values of C_{WP} at the DWL range from about 0.65 to 0.95, depending upon type of ship, speed, and other factors.

e) Vertical Prismatic Co-efficient, C_{VP}

This co-efficient is the ratio of the volume of a vessel's displacement to the volume of a cylindrical solid with a depth equal to the vessel's molded mean draft and with a uniform horizontal cross section equal to the area of the vessel's waterplane at that draft. This ratio is analogous to the prismatic or longitudinal co-efficient, except that the draft and area of waterplane have been substituted for the vessel's length and area of midship section. The vertical prismatic co-efficient of fitness is designed as C_{VP} and written as follows:

$$C_{VP} = \frac{\nabla}{C_{WP} \times L \times B \times T} = \frac{C_B}{C_{WP}} \qquad (2.10)$$

f) Volumetric Co-efficient, C_V

This co-efficient (or fatness ratio) is defined as the volume of displacement divided by the cube of one tenth of the vessel's length, or

$$C_V = \frac{\nabla}{\left(\frac{L}{10}\right)^3} \qquad (2.11)$$

In essence, it is the dimensionless equivalent of displacement-length ratio. These co-efficient express the displacement of a vessel in terms of its length. Ships with low volumetric co-efficient might be said to be "thin", while those with a high co-efficient are "fat". Values of the volumetric co-efficient ranges from about 1.0 for light, long ships like destroyers, to 15.0 for short heavy ships like trawlers.

g) Ratios of Dimensions

The three principal dimensions of the underwater body are sometimes referred to in ratio form. These are noted below, with approximate ranges for each:

Ratio of length to breadth (L/B) = Approx. range 3.5 to 10

Ratio of Length to Draft (L/T) = Approx. range 10 to 30

Ratio of Breadth to Draft (B/T) = Approx. range 1.8 to 5.

2.3. Some other terms about Ship Geometry

In designing a ship we must be familiar with some other terms especially different types of centers. These terms are explained below:

2.3.1. Longitudinal Center of Flotation (LCF)

The *center of floatation*, which is the point in the waterplane at which a weight added to a vessel would produce parallel sinkage, with no change of trim or heel, is at the centroid of waterplane area. The longitudinal location, LCF, is found by calculating the longitudinal moment of waterplane area in conjunction with the calculation of area. Any axis of reference may be used to find the moment, such as the *FP* or *AP*. A midship axis is often preferred, in order to reduce the magnitude of numbers which result. Positive distance is customarily taken forward of amidships; negative is abaft amidships. *LCF* is then moment divided by area.

2.3.2. Longitudinal Center of Buoyancy (*LCB*)

The calculation of a molded displacement curve requires that all portions of the vessel's below the waterline of interest be included. This requires integration of volumes upward from the baseline. Should the vessel extend below the baseline, as from *drag to the keel*, a finite volume of displacement would exist at zero mean molded draft. The usual method is to calculate sectional areas directly and then to integrate them longitudinally. The longitudinal center of buoyancy for the waterline of interest is also conveniently found in this calculation.

In order to find the longitudinal moment of volume, the sectional areas are multiplied by their non-dimensional distances from amidships. The longitudinal center of buoyancy is then found as the quotient of moment divided by volume.

2.3.3. Vertical Center of Buoyancy (*VCB*)

A basic feature of any vessel from the point of view of stability is the height of the center of buoyancy above the baseline, called <u>*KB*</u>. It may be calculated by first finding the vertical moment of the volume of displacement above the baseline at any waterline.

In integral form, the moment up to draft T_P is,

$$\int_0^{T_P} T\, A_{WP}\, dT$$

$$Then, \quad \underline{KB} = \frac{\int_0^{T_P} T\, A_{WP} dT}{\int_0^{T_P} A_{WP} dT} = \frac{\int_0^{T_P} T\, A_{WP} dT}{\nabla} \quad \text{.........................(2.12)}$$

2.4. Calculating Speed of the Ship

A relation between length, displacement and speed has been established by the Posdunine formula and later modified by Van Lammeren,

$$L = C\left(\frac{V}{2+V}\right)^2 \Delta^{\frac{1}{3}} \quad \text{.........................(2.13)}$$

Where $C = 23.5$ for single-screw cargo and passenger ships when V=11 to 16.5 knots.

$C = 24$ for twin-screw cargo and passenger ships when V=15.5 to 18.5 knots

$C = 26$ for very fast passenger ships when V=20 knots and upwards.

2.5. Geometrical Characteristics of Typical Ships

The typical values of different parameters for different ships are listed in the following table [22]

Parameters	Pass. Liner	Cargo Pass Ship	Container Ship	Gen.Cargo Ship	Barge Carrier	Roll Off Ship	Bulk Carrier	Gt. Lakes Carrier
Length, L	301.75	166.60	262.13	171.80	272.29	208.48	272.03	304.80
Displacement, Δ, S.W., t	46720	18250	50370	18970	38400	34430	100500	71440
Block Co-efficient, C_b	0.532	0.582	0.579	0.612	0.582	0.568	0.836	0.924
Midship Co-efficient, C_M	0.953	0.967	0.965	0.981	0.922	0.972	0.996	0.999
Prismatic Co-efficient, C_P	0.558	0.603	0.600	0.624	0.631	0.584	0.839	0.924
Waterplane Co-eff, C_W	0.687	0.725	0.748	0.724	0.765	0.671	0.898	0.975
Vert. Prismatic Coeff, C_{PV}	0.774	0.807	0.774	0.845	0.662	0.846	0.931	0.948
Volmetric Co-eff., C_V	1.93	4.87	3.26	4.65	2.46	5.18	5.54	2.55
Length to breadth ratio	9.28	6.40	7.94	6.84	8.13	6.27	8.09	9.45
Breadth to draft ratio	3.21	2.93	2.91	2.81	3.57	3.19	2.31	4.06
Speed(knots)	33	20	25	20	22	23	16.5	13.9

Table 2.1(a): Geometrical Characteristics of Typical Ships

Parameters	Crude Oil Carrier	Petroleum Tanker	LNG Tanker	Double ended Ferry	Fishing Trawler	Arctic Ice Breaker	Naval Frigate	Naval Dock Ship
Length, L	335.28	201.47	285.29	94.49	25.65	221.62	135.64	170.99
Displacement, Δ, S.W., t	308700	43400	97200	2760	222	10900	3390	12850
Block Co-efficient, C_b	0.842	0.772	0.722	0.392	0.538	0.488	0.449	0.563
Midship Co-efficient, C_M	0.966	0.986	0.995	0.732	0.833	0.853	0.741	0.933
Prismatic Co-efficient, C_P	0.845	0.784	0.726	0.534	0.646	0.853	0.741	0.933
Waterplane Co-eff, C_W	0.916	0.854	0.797	0.702	0.872	0.740	0.727	0.720
Vert. Prismatic Coeff, C_{PV}	0.919	0.904	0.906	0.558	0.617	0.660	0.618	0.782
Volmetric Co-eff., C_V	8.9	5.98	4.64	3.51	16.2	8.97	1.7	2.8
Length to breadth ratio	5.96	7.00	6.25	4.62	3.54	4.51	9.05	6.59
Breadth to draft ratio	2.66	2.64	3.99	5.20	2.65	2.79	3.14	4.62
Speed(knots)	15.2	16.5	20.4	16.1	10.7	18	30	21.5

Table 2.1(b): Geometrical Characteristics of Typical Ships

2.6. Calculation of Different Areas and Volumes

Though it is necessary to draw three types of figure (profile, waterplane and body plan) to design and explain a vessel's shape, body plan is the most important one. In design phase three types of lines are drawn-stations, waterlines and buttock lines. 10 or multiple of 10 numbers of lines are drawn at equal distances to divide the L_{PP}, each of, which is called stations. Several substations are also drawn at both ends of the ship to represent the curve as its changes rapidly there. Draft-from DWL to base line is divided by using waterlines, which are normally taken, at equal distance for the benefits of calculating the different parameters. Breadth is divided by using buttock lines. Since, the breadth is symmetric with respect to centerline, one side of it is shown on the figure.

Now, for calculating the parameters, only body plan is sufficient and other two-figure profile and waterplane can also be generated from body plan [Figure 2.1].

This body plan is represented by an offset table where each row represent the half-breadth distance from the center line at a particular station and each column represents the half-breadth distance from the center line along with a particular waterlines [Table 2.3].

Sometimes buttock heights from the base line also are shown on the table.

Stn#	Baseline	WL-1	WL-2	WL-3	WL-4	WL-5	WL-6
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.000	0.000	0.000	0.000	0.191	1.887	2.599
1.0	0.000	0.000	1.577	2.216	2.398	2.836	2.954
1.5	0.000	1.614	2.416	2.708	2.954	3.109	3.310
2.0	1.322	2.380	2.754	2.836	3.073	3.237	3.492
2.5	1.933	2.699	3.319	3.620	3.747	3.820	3.966
3.0	3.529	3.766	4.003	4.076	4.130	4.185	4.404
4.0	3.620	4.003	4.185	4.267	4.404	4.440	4.559
5.0	3.839	4.231	4.422	4.459	4.559	4.559	4.559
6.0	3.620	4.003	4.185	4.267	4.404	4.440	4.559
7.0	3.383	3.747	3.875	3.912	3.975	4,021	4.194
7.5	2.489	2.845	3.137	3.228	3.292	3.456	3.565
8.0	1.878	2,252	2.562	2.763	2.909	3.009	3.118
8.5	0.675	1.422	1.696	1.851	2.070	2.152	2.435
9.0	0.000	0.310	0.839	1.058	1.249	1.413	1.614
9.5	0.000	0.000	0.000	0.210	0.246	0.264	0.529
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

*WL represents for Water line

Table 2.2: Half Breadth table for the Body Plan of a 59.2m Cargo Passenger Ship.

Therefore the half cross section at a particular station will look like the following curve:

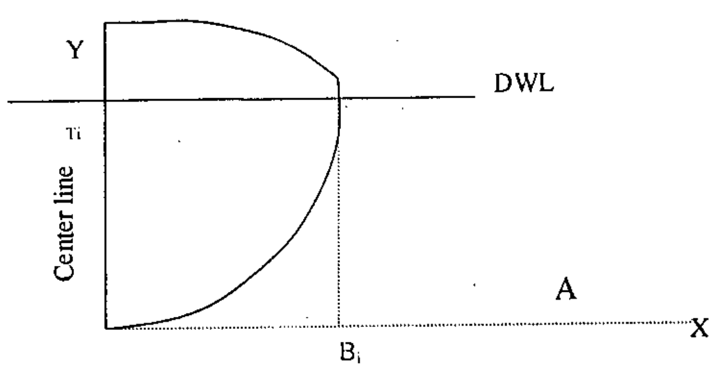

Figure 2.7: Half Cross Section at a particular station

So, Area under the curve,

$$A = \int_{0}^{B_i} y dx$$

So Cross sectional area at station i = $2(T_iB_i-A)$

$$= 2\left(T_i B_i - \int_{0}^{B_i} y dx \right)$$

Midship section area is the cross section area at the station, which is used to represent midship.

For calculating the volume displacement, we need to draw a curve whose abscissa is represented by the station number and ordinates are represented by the cross section area at that station. This curve is called sectional area curve [Figure 2.4].

So, Volume displacement,

$$\nabla = \int_{0}^{L_{aft}} y_a dx + \int_{L_{fwd}}^{L_{PP}} y_f + L_{par} T \text{..........................(2.14)}$$

Where y_a is the equation for aftbody, y_f is the equation for forebody, L_{aft} is the aftbody before parallel middle body, L_{fwd} is the forebody beyond parallel middle body and L_{par} is the length of parallel middle body.

Moreover, the waterplane area may be calculated from curve of DWL by integrating the forebody curve, aftbody curve and parallel middle body curve in similar way given in equation 2.14.

2. 7. Fairness

With the exception of deliberate discontinuities at the stem, knuckles, chines, transom corners, etc, the shape of a vessel's exterior form below the deck is virtually always designated as a fair surface. A fair surface is defined as one that is smooth and continuous, and which has no local bumps or hollows, no hard spots and a minimum of points of inflection. Localized flat spots between areas of the surface with curvatures of equal sign are generally considered unfair, unless they occur as part of the bottom or sides, especially with parallel middle body. Mathematically, the property of fairness of surface might be thought of as that of continuity in a plot of curvature, or radius of curvature, of the intersection of any plane with the surface. Inasmuch as waterlines, buttocks and station lines all represent the intersection of planes with the molded surface, it may be seen that a fair hull form will be characterized by fairness in these curves; correspondingly, it is usually assumed that if these curves are fair, then so will the hull form. In general, discontinuities in the first derivative, indicating abrupt changes in slope, occur at knuckle lines. Other sudden changes in curvature, indicated by discontinuities in the second derivative, are considered to show unfairness. A common situation on ships with parallel middle body in a bilge of constant radius r, connecting to flat bottom and /or side, with a change in curvature of the transverse section from $1/r$ to 0 at the point of tangency. Although such a section is not fair, its shape is not necessarily disadvantageous. It can be made fair if desired by easing the transition in curvature.. On the other hand, continuity in both first and second derivative does not guarantee fairness, inasmuch as the achievement of fairness has always been and probably will continue to be a matter of opinion or judgement.

The process of fairing a set of line invariably an iterative, or cut and try one, requiring patience and perseverance. It consists essentially of investigating the fairness or suitability of each line of the vessel in succession. It often happens that, after testing and accepting a number of lines, the next line to be considered will require changes to be made to it that will be so far-reaching as to affect some of the lines previously accepted. It then becomes necessary to make whatever changes seems best, all things considered, and to proceed a new through the same fairing steps as before. Usually several such difficulties have to be overcome successively before the whole fairing process in completed. Thus, the process may be laborious.

Fairing lines for a new ship design is normally accomplished at least twice- first in the design phase, and second in the construction phase.

In the design phase, there is greater freedom to make changes and to achieve hull form features which the designer favors. Curves are usually drawn using a combination of free hand sketching, ship curves and flexible battens held by batten weights.

In the construction phase, the lines are reasonably well defined at the start. The process of fairing is more localized and directed at achieving consistency among the various views. However, the larger scale used in this case is intended to assure that local derivations, which may not have been evident in the earlier small-scale design phase, will be eliminated.

Chapter 3

Neural Networks and its application in Hull Form Generation

For some kind of problem, such as hull form generation, pattern recognition, etc. Our conventional computer algorithms are obviously not suitable. We, therefore, borrow features of the massive parallelism and inter-connectivity from the physiology of the brain as the basis for our new processing models. Hence, the technology has come to be known as artificial neural system (ANS) technology, or simply Neural Networks. Neural Networks technology may be studied from two points of views-installation of new hardware fulfilling the Neural Concepts and software implementation using Neural technology concepts. In first one the machine will be such that it contains thousands (or millions) of processors inside a single machine, like billions of neurons in human brain, each of them having limited power, but when working in parallel they will be able to simulate human intelligence. Designing software using ANS technology simulates human thinking capabilities.

An ANS is robust in the sense that it will respond with an output even when presented with inputs that it has never seen before, such as inconsistent parameters in hull form generation. The inherent ability to deal with inconsistent parameters is a significant advantage of an ANS approach over a traditional algorithmic solution. The power of an ANS approach lies not necessarily in the elegance of the particular solution, but rather in the generality of the network to find its own solution to particular problems. But the problem with this technique is its inability to start from the point among solution space with higher probability to converge. It starts the process from a random point [15].

3.1. Learning Techniques of Biological Neuron

Biological neural systems are not born pre-programmed with all the knowledge and abilities that they will eventually have, like conventional programming techniques. A learning process that takes place over a period of time somehow modifies the network to incorporate new information .

The basic theory comes from a 1949 book of Hebb, *Organization of Behavior*, "When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic changes takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased" [30].

Hebb theorised that the area of the synoptic junction increases during learning process. More recent theories assert that an increase in the rate of neurotransmitter release by the pre-synoptic cell is responsible. In any event, changes certainly occur at the synapse.

3.2. Learning Techniques of Artificial Neural Systems (ANS)

The individual computational elements that make up most artificial neural system models is called 'Neuron'. Neurons in a Neural Network are in a one to one relationship with actual biological Neurons.

There are two mode of neural network operation: training mode and production mode. In training mode, the network is trained, simply by a means of encoding information about the particular problem to find its solution, given only examples of the desired behavior. Once the network is trained adequately, it switches to production mode, where both learning and problem solving take place simultaneously. The information propagation through the network will result in a single element at the output.

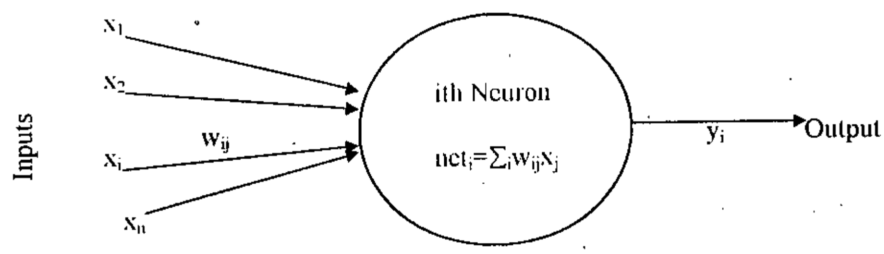

Figure 3.1: Structure of a single Neuron

Figure 3.1 depicts the basic structure of a single neuron. Like biological behavior, each neuron has many inputs. The inputs the *ith* neuron receives from the *jth* neuron is indicated as x_j. Each connection to the *ith* neuron has associated with it a quantity called weight. The weight on the connection from *jth* node to the *ith* node is denoted by w_{ij}.

Each neuron determines a net input value based on all its input connections,

$$net_i = \sum_j x_j w_{ij} \text{...} (3.1)$$

Once the net input is calculated, it is converted to an action value,

$$a_i = F_i(a_i(t-1), net_i(t)) \text{...} (3.2)$$

and the output is calculated from this activation value as,

$$y_i = f_i(a_i) \text{..} (3.3)$$

Usually, $a_i = net_i$. So, $y_i = f_i(net_i)$ or in vector notation,

$$y = w^t x \text{...} (3.4)$$

3.2.1. The LMS Learning Rule

Given an input vector x_i, it is straightforward to determine a set of weights w, which will result in a particular output value y. Suppose we have a set of input vectors $\{x_1, x_2, \ldots, x_L\}$, each having its own desired output value d_k, $k=1,L$ (where L is the number of input vector in the training set.). Least mean square (LMS) learning rule finds a single weight vector that associate each input vector with its desired output value. If the actual output value is y_k for the kth input vector, then the corresponding error term is $\varepsilon_k = d_k - y_k$. So expected error

$$\langle \varepsilon_k^2 \rangle = \frac{1}{L}\sum_{k=1}^{L} \varepsilon_k^2 \quad = \langle (d_k - w^t x_k)^2 \rangle \quad = \langle d_k^2 \rangle + w^t \langle x_k x_k^t \rangle w - 2\langle d_k x_k^t \rangle w$$

Defining a matrix $R = \langle x_k x_k^t \rangle$ called the correlation matrix and a vector $p = \langle d_k x_k \rangle$,

$$\langle \xi_k^2 \rangle = \langle d_k^2 \rangle + w^t R w - 2p^t w \text{ ....} (3.5)$$

for minimum weight w^*,

$$(\partial \xi(w) / \partial w) = 2Rw - 2p \qquad or \qquad 2Rw^* - 2p = 0 \qquad or$$

$$w^* = R^{-1} p \text{ ....} (3.6)$$

Small adjustments are made to the weight values as each input-output combination is processed until a correct output is found. Because the weight vector is variable in this procedure, an explicit function of timestep t is written. The initial weight vector is denoted $w(0)$ and the weight vector at timestep t is $w(t)$. At each step, the next weight vector is calculated according to $w(t+1) = w(t) + \Delta w(t)$, where $\Delta w(t)$ is the change in w at the tth timestep. To get the magnitude of the change, multiply the gradient by a suitable constant, μ. So, this procedure results in the following expression,

$$w(t+1) = w(t) - \mu \nabla \xi(w(t)) \quad \ldots(3.7)$$

The negative of the gradient is in the direction of steepest descent. The value of $\nabla \xi(w(t))$ is determined analytically as $\nabla \xi(w(t)) = -2\varepsilon_k(t)x_k$, where $\varepsilon_k(t)$ is the error function for input k and at timestep t [15]. So,

$$w(t+1) = w(t) + 2\mu\varepsilon_k(t)x_k \quad \ldots(3.8)$$

This equation is called LMS algorithm.

For each step in the iteration process, we perform the following:

1) Apply an input vector x_k.

2) Determine the value of the error squared, $\varepsilon_k^2(t)$, using the current value of the weight vector,

$$\varepsilon_k^2(t) = (d_k - w^t(t)x_k)^2$$

3) Calculate an approximation to $\nabla \xi(w(t)) = -2\varepsilon_k(t)x_k$.

4) Update the weight vector using the expression $w(t+1) = w(t) + 2\mu\varepsilon_k(t)x_k$.

5) Repeat steps 1 through 4 with the next input vector, until the error has been reduced to an acceptable value.

Algorithm 3.1: LMS Learning Algorithm

3.2.2. Two Layer Networks

Using ANS technology, we produce one or more output(s) from some given inputs. These output may be calculated directly from the inputs or may be found through several intermediate steps. If the output found directly from the inputs then the network is known as one layer network. The intermediate layers that are placed between the inputs and outputs are called hidden layer. Number of layers in a network varies from problem to problem, but solution of most problems requires one hidden layer. This type of network is called two layers network. An example of two layers network as follows:

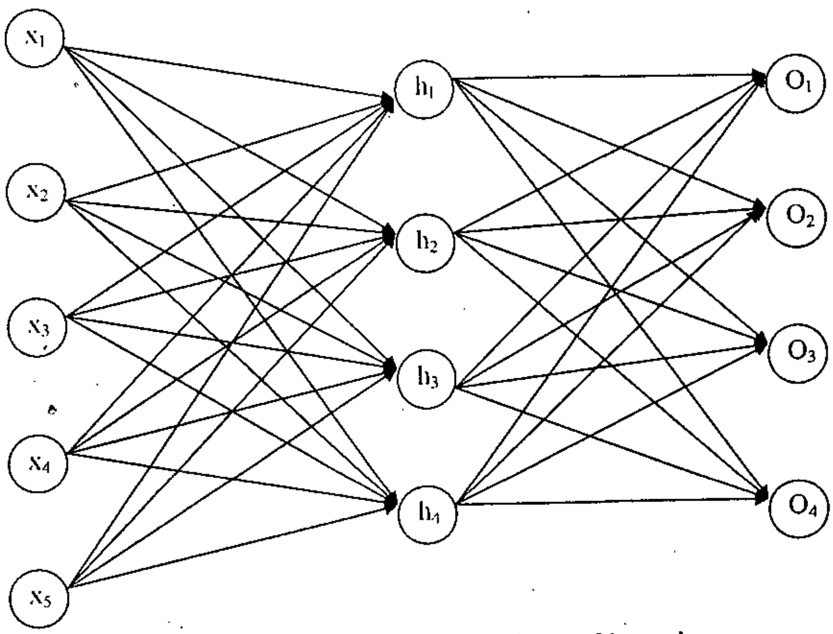

Figure 3.2: Structure of Two Layers Network

In figure 3.2, $\{x_1, x_2, x_3, x_4, x_5\}$ are inputs whereas $\{O_1, O_2, O_3, O_4\}$ are outputs. $\{h_1, h_2, h_3, h_4\}$ are intermediate hidden values. The hidden values are calculated from the inputs and outputs are calculated from hidden values. Two weight matrices are maintained-one for calculating hidden values from inputs and other for calculating output from hidden values.

3.2.3. Backpropagation Learning Approach

Backpropagation network (BPN) would not have to be programmed explicitly; it would adapt itself to 'learn' the relationship between input and output from a set of example patterns, and would be able to apply the same relationship to new input patterns. To begin with, the network learns a predefined set of input - output example pairs by using a two-phase propagate-adapt cycle. After an input pattern has been applied as a stimulus to the first layer of network units, it is propagated through each upper layer until an output is generated. This output is then compared to the desired output, and an error signal is computed for each output unit.

The error signals are then transmitted backward from the output layer to each node in the intermediate layer (also called hidden layer) that contributes directly to the output. However, each unit in the intermediate layer receives only a portion of the total error signal, based roughly on the relative contribution the unit made to the original output. This process repeats, layer by layer, until each node in the network has received an error signal that describes its relative contribution to the total error. Based on the error signal received, connection weights are then updated for each unit to cause the network to converge toward a state that allows all the training patterns to be encoded.

Suppose an input vector, $x_p = (x_{p1}, x_{p2}, \ldots\ldots, x_{pN})^t$, is applied to the input layer of the network. The input units distribute the values to the hidden-layer units. The net input to the jth hidden unit is $net^h_{pj} = \sum^N_{i=1} w^h_{ji} x_{pi} + \theta^h_j$, where w^h_{ji} is the weight on the connection from the ith input unit, and θ^h_j is the bias term. The "*h*" superscript refers to quantities of the hidden layer. Assume that the activation of this node is equal to the net input; then, the output of this node is $i_{pj} = f^h_j(net^h_{pj})$. The equations for the output nodes are

$$net^o_{pk} = \sum^L_{j=1} w^o_{kj} i_{pj} + \theta^o_j \quad \ldots\ldots (3.9)$$

$$O_{pk} = f^{o}_{k}(net^{o}_{pk}) \quad \ldots (3.10)$$

Where the "o" superscript refers to quantities on the output layer [34].

The Backpropagation algorithm for two layer network is as follows

1) *Apply the input vector,* $x_p = (x_{p1}, x_{p2}, \ldots\ldots, x_{pN})^t$ *to the input units.*
2) *Calculate the net input values to the hidden layer units:* $net_{pj}^{h} = \sum^{N}_{i=1} w_{ji}^{h} x_{pi} + O_j^h$.
3) *Calculate the outputs from the hidden layer:* $i_{pj} = f_j^h(net_{pj}^h)$
4) *Move to the output layer. Calculate the net input values to each unit:* $net_{pk}^{o} = \sum^{L}_{j=1} w_{kj}^{o} i_{pj} + O_k^o$.
5) *Calculate the outputs:* $O_{pk} = f_k^o(net_{pk}^o)$.
6) *Calculate the error terms for the output units:* $\delta_{pk}^{o} = (y_{pk} - O_{pk}) f_k^{o1}(net_{pk}^o)$.
7) *Calculate the error term for the hidden units :* $\delta_{pj}^{h} = f_j^{o1}(net_{pj}^h) \sum_k \delta_{pk}^o w_{kj}^o$. *Notice that the error terms on the hidden units are calcualted before the connection weights to the output layer units have been updated.*
8) *Update weights on the output layer:* $w_{kj}^{o}(t+1) = w_{kj}^{o}(t) + n\, \delta_{pk}^{o} i_{pj}$.
9) *Update weights on the hidden layer:* $w_{ji}^{h}(t+1) = w_{ji}^{h}(t) + n\, \delta_{pj}^{h} x_i$.

Algorithm 3.2: Backpropagation Algorithm

The order of the weight updates on an individual layer is not important.

3.3. Use ANS Concepts for fixing Breadth and Draft of the ship

The parameters that are required to design ships' hull form can be divided into different categories-some parameters are taken as inputs such as length, displacement, speed, type of the ship, etc. The clients supply these parameters. Some inputs are not supplied by the customers. These parameters are calculated from the given ones applying previously designed ships' characteristics and the experiences as well as intelligence of naval architects. Among these breadth and draft are the most important ones. Others are calculated from the design of the vessel.

Unfortunately, most of these parameters conflict with each other. For example, there is a linear relation for breadth and draft with length. So, applying historical information breadth and draft can be calculated from the given length. However, displacement depends on length, breadth and draft. This calculated displacement might rise a conflict with the given one. Again, the given speed might also create difficulties as it depends on length, displacement and a predefined constant. Hence, an intelligence technique is needed to resolve these problems.

We can make a compromise between draft, breadth, displacement and speed using the neural net concepts. For the start of analysis, breadth and draft are calculated from the given dimension ratio for a given type of ships. However, length, breadth draft, and type of ship are used as inputs of the network, wherever displacement, speed, draft and breadth are used as outputs. Waterplane area, Sectional area and midship area are placed in the hidden layer.

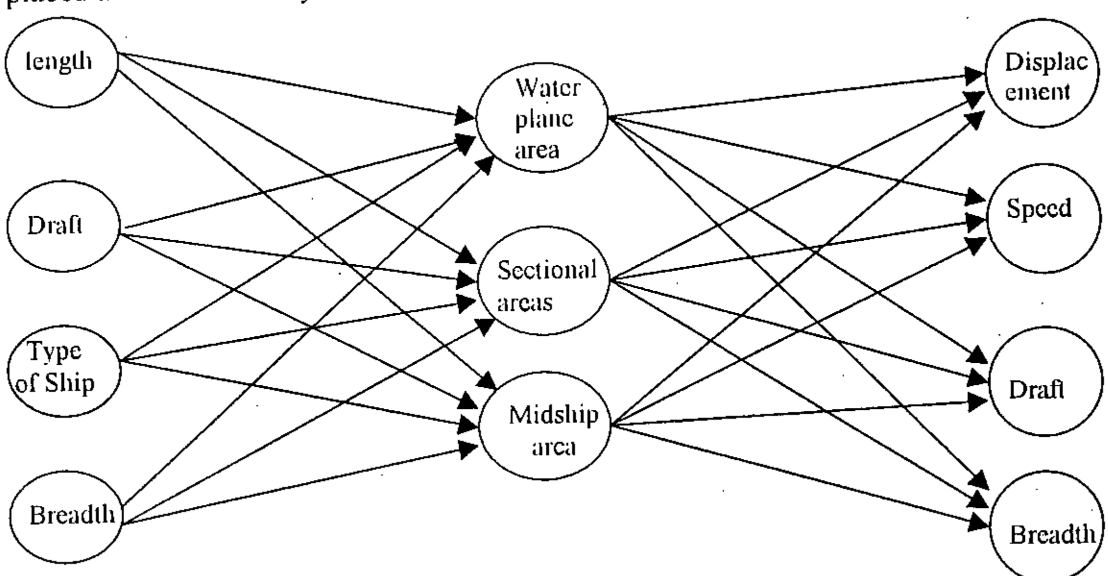

Figure 3.3: Adjustment of Breadth and Draft using Neural Nets.

There are two matrices in this example, matrix A which is used to calculate values at hidden layer from the input layer and matrix B for calculating output from the values at hidden layer. Moreover,

$$X=[length, Draft, Breadth]^t$$

$$H=[waterplane\ area, Sectional\ areas, midship\ area]^t$$

$$O=[Displacement, Speed, Draft, Breadth]^t$$

Weight matrix A and B will be different for different type of ships. So, the input, type of ship, is not included in the weight matrix; it will be used only for selecting the weight matrices for a particular ship.

The procedure works as follows:

1. *Calculate hidden output matrix using the formula* $H(t)=A(t)*X$.
2. *Move to the output layer and calculate output matrix* $O=H(t)*B(t)$.
3. *Calculate the error for particular output i using the formula* $\varepsilon_i^2(t) =((d_i-O_i)/O_i)^2$. *where* d_i *is the desired output and* O_i *is the calculated output.*
4. *Adjust the weight matrix* $B(t)$ *to calculate new weight matrix* $B(t+1)$ *using the formula,*

   $$B(t+1)_{ij} = B(t)_{ij}+B(t)_{ij}*\varepsilon_i(t).$$
5. *Calculate New hidden matrix* $H(t+1) = B(t+1)^{-1}*O$
6. *Calculate the error for particular value i at hidden layer using the formula* $\xi_i^2(t)= ((H_i(t)-H_i(t+1))/H_i(t))^2$.
7. *Adjust the weight matrix* $A(t)$ *to calculate new weight matrix* $A(t+1)$ *using the formula,*

   $$A(t+1)_{ij}=A(t)_{ij}+A(t)_{ij}*\xi_i(t).$$
8. *Replace t by t+1 and go to step 1 until acceptable output is found.*

Algorithm 3.3: Algorithm for Adjustment Breadth and Draft Using Backpropagation.

Started with $t = 0$, the system proceeds up to the errors reach at a point of acceptable condition.

The algorithm depicts that by multiplying the matrix *A* with input matrix the values at hidden layer are calculated and this calculated hidden matrix is multiplied by matrix *B* which produces the output matrix *O*. This output matrix normally doesn't match with the desired output values. So, error matrix for the output is computed and used to adjust weight matrix *B*. Again, using the inverse of *B* we can recalculate the hidden matrix *H* again and can find the error matrix that is used to adjust the weight matrix *A*. This process is repeated until a reasonable output is found so that the error in Breadth, Draft, displacement and speed are acceptable. In our experiment, The system reached almost in steady-state-condition after 110 iterations.

For the first time, the weight matrices are taken randomly and the algorithm is applied upon the matrices. This is the learning mode. After learning mode, different weight matrices are found for different type of ships. In production mode, the algorithm multiplies inputs by weight matrix *A* to generate the value of hidden layer, and then the generated matrix would be multiplied by matrix *B* to generate the output matrix. In training mode, for each value of output matrix, the difference is calculated which is known as output error matrix. The weight matrix *B* is modified based on this output error matrix using the equation presented in step 3 of the algorithm. Again, weight matrix B is inverted and this inverted matrix is used to generate hidden matrix *H* again from the output matrix. Similarly, weight matrix *A* is modified. However, the process proceeds from input matrix to output matrix and then from output to input. This process is known as back-propagation.

Chapter 4

Genetic Algorithms and its application in Hull Form Generation

Genetic algorithms (GAs) is on of the key elements in the design and implementation of robust concepts learning systems. The use of GAs is motivated by recent studies showing the effects of various forms of bias built into different concepts learning systems. By incorporating GAs as the underlying adaptive search mechanism, we are able to construct a concept learning system that has a simple, uniform architecture with several important features. Firstly, the system is surprisingly robust even with minimal bias. Second, the system can be easily extended to incorporate traditional forms of bias found in other concept learning systems. Finally, the architecture of the system encourages explicit representation of such biases and, as a result, provides for an important additional feature: the ability to dynamically adjust system bias [8].

Design of hull form is an iterative process in which the system is updated itself every time by using learning concepts. In the process of designing hull form geometry, at first a hull form is designed based on previous experiences and some techniques. Unfortunately, this design does not satisfy the parameters. This unwanted design motivate the naval architects to move a particular direction so that he/she can change the design to adjust the parameters; continuing the process several times. This task requires intelligent learning concepts whenever GAs can robustly fulfil it.

4.1. Basic Principle of GAs

GAs involve inductive hypothesizes for the concepts to be learned from a set of positive and negative examples of the target concepts. Examples (instances) are represented as points in an n-dimensional feature space that is defined a priori and for which all the legal values of the features are known. The internal representation of GAs involves using fixed length (generally binary) string to represent points in the space to be searched. Each point is represented in a Disjunctive Normal Form (DNF). This is achieved by restricting each element of a conjunction to be a test of the form: If the value of feature *i* of the examples is in the given value set, then return true, else return false. The algorithms always generate single output (called class).

For example, if there are two features, *F1 = { small, medium, large }*, *F2 = { sphere, cube, brick, tube }* and *class = { widget, gadgets }*, then there may be a rule, if *{ F1 = medium or large } and { F2 = sphere or cube }*, then it is a *widget*. This rule is expressed in fixed length string,

F1	*F2*	*Class*
011	1100	0

Since the left-hand sides are conjunctive forms with internal disjunction, there is no loss of generality by requiring that there be at most one test for each feature. A concept consists of one or more rules. There are two basic strategies to represent these rules: the Michigan approach and the Pittsburgh approach. Systems using the Michigan approach maintain a population of individual rules that compete with each other for space and priority in the population. In contrast, systems using the Pittsburgh approach maintain a population of variable length rule sets that compete with each other with respect to performance on the domain task. That is, each individual in the population is a variable length string representing an unordered set of fixed length rules. To illustrate this representation more concretely, consider the following example of a rule set with two rules:

F1	*F2*	*Class*	*F1*	*F2*	*Class*
100	1111	0	011	0010	0

This rule set is equivalent to, if *(F1 = small)* then it is a *widget* or if *((F1 = medium or large) and (F2 = brick))* then it is *widget*. Notice that a feature test involving all 1's matches any value of a feature and is equivalent to "dropping" that conjunctive term.

4.1.1. Cross Over and Mutation

There are two Genetic Operators to produce new generation: Cross Over and Mutation. Cross-Over takes two individuals and produces two new individuals by swapping portions of genetic materials (e.g., bits). As an example, consider the following two rule sets:

F1	*F2*	*Class*	*F1*	*F2*	*Class*
100	0100	0	011	0010	0
010	0001	0	110	0011	0

Note that the left cut point is offset two bits from the rule boundary, while the right cut point is offset one bit from the rule boundary. The bits within the cut points are swapped, resulting in a rule set of three rules and a rule set of one rule:

F1	*F2*	*Class*	*F1*	*F2*	*Class*	*F1*	*F2*	*Class*
100	0001	0	110	0010	0	011	0010	0
010	0101	0						

Mutation simply flips random bits within the population, with a small probability (e.g., 1 bit per 1000).

4.1.2. The Adding Alternative Operator and the Dropping Condition Operator

To increase generality of Genetic algorithms Michalski(1983) added another operators in Genetic Algorithms (GAs) hypothesis [7]. These are – the adding alternate operator and the dropping condition operator. The adding alternate operator, unlike normal mutation operator, has an asymmetric mutation rate. In particular, in the studies reported that this operator incorporates a 75% probability of mutating a bit to a 1, but a 25% probability of mutating it to a 0. To illustrate, the adding alternative operator might change the disjunct

F1	*F2*
100	100

to

F1	*F2*
100	110

Note that feature *F2* has been generalized in this disjunct.

As with the other genetic operators, the adding alternative operator is applied probabilistically to a subset of the population each generation. In the studies reported it was applied at a rate of 0.01(1%).

A second, and complementary, generalization mechanism leading to simpler hypotheses involves removing what appear to be nearly irrelevant conditions from a disjunct. This operator, called *dropping condition operator(DC)*, is based on the generalization operator of the same name described in Michalski(1983). For example, if the disjunct is *(F1 = small or medium) and (F2 = Sphere)*, then the *DC* operator might create the new disjunct *(F2=Shpere)*.

When this operator is applied to a particular member of the population (i.e., a particular rule set), each disjunct is deterministically checked for possible condition dropping. The decision to drop a condition is based on a criterion from Gordon (1990) and involves examining the bits of each feature in each disjunct [11]. If more than half of the bits of a feature in a disjunct are 1's, then the remaining 0 bits are changed to 1's. By changing the feature to have all 1 values, this operator forces the feature to become irrelevant within that disjunct and thereby simulates the effect of a shortest disjunct. To illustrate, suppose this operator is applied to the following disjunct:

F1	*F2*
110	100

Then the dropping condition operator will result in a new disjunct as follows:

F1	*F2*
111	100

Note that feature *F1* is now irrelevant within this disjunct.

As with the other genetic operators, this new operator is applied probabilistically to a subset of the population each generation. In the experiments reported here, a rate of 0.60 (60%) was used.

4.2. Fitness Function for GAs

The fitness of each individual rule set is computed by testing the rule set on the current set of training examples and letting

$$Fitness(individual\ i) = (Percent\ correct)^2 \qquad (4.1)$$

This provides a bias toward correctly classifying all the examples while providing a non-linear differential reward for imperfect rule sets. This bias is equivalent to one that encourages *consistency* and *completeness* of the rule sets with respect to the training examples. A rule set is consistent when it covers no negative examples and is complete when it covers all positive examples [8].

4.3. Use of Genetic Algorithms for Hull Form Generation

The multi-model nature of the search landscape requires the utilization of an adaptive search. Various Strategies that have emerged include Simulated Annealing, Tabu Search and Evolutionary Computing, related to Genetic Algorithms (GAs) which have been chosen in this case. The effectiveness of GAs in a variety of settings, including engineering design, has been extensively documented [10,29,32].

The mechanism of a simple GA is the evolution of a population of individuals, each member of the population being a set of numbers which are an encoding of the design variables (in this case the control points) representing a hull form or a specific point in the design space. Each design's attributes can be evaluated and a measure of merit or "fitness" can be established. In the simplest case, a single aggregate value for fitness is used. More sophisticated approaches consider the values of individual attributes. The starting point of the process is the creation of a pseudo-randomized initial population. Each individual is then evaluated, and a selection process carried out on a probabilistic basis, whereby the fitter hulls have a greater chance of surviving. This selected population is then split into pairs of hull on a random basis. Parts of the encoded variable groups are then swapped or "crossed over" within each pair, according to a specified probability. The final stage involves making changes or "mutations" as well as the adding alternate operator to randomly chosen elements of the encoded variable groups. The population fitness are then re-evaluated, and the process is repeated until some stopping criterion is reached, usually an indicator of convergence or an upper limit on the number of "generations".

4.3.1. Crossover

Control points have a localized influence on the surface they define, that is a control point has the most influence on the part of the surface it is closest to. It is therefore reasonable to expect that within a whole B-Spline surface, there will be localized regions of varying merit, each region being principally influenced by a "subnet" of control points. Intuitively, a crossover type operation could combine high-rating subnets in a single net, producing a superior surface.

In most GAs, the encoded design variable are arranged in a one-dimensional array. For a pair of arrays, crossover is achieved by randomly defining one or more "crossover points" which divide both arrays into sub-arrays segments with equal length. Alternate segments are then swapped between the two arrays.

The search variables in this case are the attributes of the vertices of the control net. The control net is topologically two-dimensional, thus must be "unwound" in some way to form a one-dimensional array. However, this process is likely to adversely affect the preservation of high-rating sub-nets. This is because a sub-net consists of points that are topologically neighboring in two dimensional sense, a property which is unable to be preserved in one dimensional when the control net is unwound. The approach taken to this problem is to avoid unwinding the control net altogether. The notion of a crossover point (that divides a variable array) is extended to a line that divides up a variable matrix into two-dimensional sub-matrices, which are swapped in a similar fashion to the sub-arrays in the one dimensional case.

4.3.2. Mutation

In GA design, the type of mutation operator used depends principally on the type of variable encoding used. When real coding (simply representing the variables as real numbers) is used, a proven mutation method is Gaussian mutation. A variable has a deviation added to it, with the deviation sizes having a Gaussian distribution (with a mean of zero, and a controllable variance). This is the mutation operator being used in this application.

The deviation value distribution consists of two half distributions. These are approximately Gaussian, one between zero and a specified negative limit, the other between zero and a specified positive limit. Both half-distributions have the same variance, specified independently of the negative and positive limits. The truncation of the half-distributions by the limits is achieved by replacing deviation values outside the limits with a value chosen randomly from between the limits. In this way, as the specified variance is increased, the deviation values tend towards a uniform distribution.

Individuals that are mutated with a higher variance are more likely to receive larger deviations, and so travel farther through the search space, a process that could be viewed as exploration of new regions. Lower variances are more likely to produce more localized moves. If this occurs in a high-rating region of the search space, this could be viewed as exploitation of that region. The variance used is thus made a function of an individual's fitness. Weak individuals are best used to explore entirely new regions, whereas fit individuals are encouraged to exploit the regions for their high fitness.

4.3.3. The Adding Alternative Operator

Similar to the mutation operator, the adding alternative operator depends on the type of code used. For the real coding that is used here, we calculate the tendency to move in a particular direction by measuring whether the offset will be added or deleted for getting better fitness. This tendency is measured by taking the average deviation of other individuals from the taken individual with respect to the taken control point. However, the direction of movement is considered as positive direction while the opposite direction is the negative direction. The limit in the positive direction is three times as that of the negative direction (comparing 75% tendency to mutate a bit to a 1 and 25% tendency to mutate a bit 0). Hence, the operator is almost like mutation one except the limits of positive offset and negative offset.

4.4. The Algorithm for Generating Hull Form using GAs

To use GAs for designing body plan, we use some initial populations who are the members of first generation. In GAs concepts, first generation is taken randomly, but some prior knowledge of the design can enhance and speed up the process. Based on previous knowledge, a single population or design is taken, and then some random populations are generated by making a slight change in this population. Here, the table of body itself is an individual. Then using the operators of GAs, new populations are generated. The algorithm for generating original hull form is as follows:

```
Procedure HullFormGA
Begin
    t=0
    Initialize population P(t) using weight matrix, given parameters
    and random functions.
    fair P(t)
    fitness P(t)
    Until (done)
        t=t+1
        Select P(t) from P(t-1)
        Crossover P(t)
        Mutate P(t)
        Add_alternate_operator P(t)
        fair P(t)
        fitness P(t)
    end of loop
End of Procedure
```

Algorithm 4.1: Hull Form Generation using GAs

According to the algorithm, fairing operation is performed on the initial population and their fitness is measured. Best-fit individuals are selected for the next generation for survival. Crossover, Mutation and add alternate operator is applied upon these selected individuals and some new population are generated. Without loss of generality, we can assume that the newly generated populations don't have fair surface. Hence, fairing operator is performed upon these newly generated populations and then their fitness is calculated. However, the newly generated populations are merged with current populations; among this mixture best-fit populations are transferred to the next generation.

4.5. Choosing a Fairing Method

The rapid generation of faired hull surface is very important. In the field of surface modeling of hull form, geometric complexity of hull form gives many difficulties in adopting surface modeling technique, which can describe the irregular topological characteristics precisely. However, B-Spline is applied in this experiment, as fairing method to avoid unwanted move of a point. Many researchers suggest that B-Spline is the most suitable method for fairing hull forms of vessels [25,27,28].

4.6. Fitness Measurement for the Hull Form

The designed hull form has many parameters that might be used for measuring fitness compared with one parameter used in the concepts of GA algorithms. These parameters are different co-efficient, draught, speed, etc. All of these are not equally sensitive. Again, quality of design is determined by the correctness of co-efficient, not by the correctness of draught or speed. So, the co-efficient can be used as the fitness measurement parameters, which can be determined by taking the average fitness of individual criterion. The fitness function can be chosen as follows:

$$fitness(individual \quad i) = \frac{1}{n} \sum_{for\ all\ parameters} (percent\ correct)^2 \qquad (4.2)$$

Chapter 5

Implementation of Automatic Hull Form Generation Technique

In this chapter, we explain the implementation of the concepts explained in earlier chapters. Hull form is the external geometry of the vessels that requires iterative process when designed using conventional methods. In this iterative process, there are several difficulties. First, the process is manual and time consuming. Second, the process does not support conventional algorithms [4,35]. The hull surface has the most complex geometric structure that is not supposed to be given by a particular shape. The design of this complex geometry must satisfy several co-efficient, parameters and requirements that are explained in earlier chapters. But it is not easy task to design a hull form that satisfies all the parameters. Again, the designers don't have any straightforward technique for this. However, these things need to be taken into consideration in designing automatic hull form.

In automatic hull form generation, two robust techniques of artificial intelligence have been used. Both of these two techniques can design any surface that are under many severe constraints and can make a compromise between these constraints. Neural network has the capability to find the solution through adaptive searching technique that leads to the final solution. On the other hand Genetic Algorithms can work in any situation and finds survival population. The method moves from generation to generation for a best-fit population, which can compromise with all constraints.

In general, Neural Network and Genetic Algorithms start from a random point. However, pre-fit population or samples are more suitable for the processes and find solutions more quickly. Pre-fit population could be found by examining hull form characteristics, their equations, relation between parameters, etc.

The whole implementation process is divided into three main components. First of all half-breadth weight matrices are generated that would provide population with pre-fitness. Secondly, breadth and draft are adjusted using Neural Network Concepts. Breadth, draft, length, displacement and speed of the ship are very related terms and relations among them create some constraints. Neural Networks solve these constraints and adjust the parameters. Finally, GAs is used for searching the exact solution by examining several generations. For this, the algorithms need to measure fitness for every population in every generation. Unfortunately, GA doesn't guarantee fairness of the surface of the hull form, which can't be ignored. So, for every population especially for newborn population fairing techniques would be used. However, being complex geometric form, hull form surface can't be faired using least-square or other single equation fitting techniques. Fairness is done taking pair-wise points. The method is known as B-Spline [24].

5.1. Generation of Half-breadth Weight Matrices

In the design of a ship, three types of figures are drawn-profile, body plan and water plane [Figure 2.1,2.2 and 2.3]. These three figures are essential for understanding the design clearly. But only body plan is sufficient to explain the ship's hull form. All the essential co-efficients of the ship are found from body plan only. So, in analysis of hull form design the design of profile and water plane may be ignored. Moreover, the body plan is represented by a table, which contains two parts-half breadths and buttock heights. In body plan the curve represents the station lines [Figure 2.1]. Buttock heights are the height of the curve from the base line whereas half breadth is the distance of the station lines from the centerlines. Hence, for simplicity of the design, we can ignore the buttock height portion of the table, as the body plan can be generated only from the half breadth table [Table 5.11].

Now, though it is possible to start the design of hull form using Genetic Algorithms from a random point, the process converges quickly if we start from a pre-fit designed hull form which is drawn using previously designed ships. This idea has been borrowed from the conventional design methods where the Designers make a sketch at first based on his/her experiences. Then, the co-efficient is calculated and the design is modified several times before reaching at the final solution.

By examining 104 ships, it was found that half breadth and co-efficient depend on the type of the ships. However, for a particular type of the ship, there is a linear relation between half-breadth and one of the following parameters.

1. Length
2. Breadth
3. Draft

4. (Displacement)$^{1/3}$

The relation can be represented by the equation

$$Y = bX \quad \text{......} (5.1)$$

Where Y is the half-breadth table, b the weight matrix and X is the one of the above four values.

Therefore, if once the weight matrix for one of the above parameters (length, breadth, draft or (Displacement)$^{1/3}$) is produced then the half-breadth table can be calculated easily by multiplying the weight matrix with corresponding parameter. However, we don't use the parameter (displacement)$^{1/3}$ for calculating half-breadth table as the displacement is supplied by the owner of the ship that may deviate in significant amount.

Note that, the half-breadth table that is found in the process is only an approximate design like initial sketch done by the naval architects in conventional methods. Moreover, if the average of more ships is taken to produce the weight matrices, then it is possible to minimize the deviation. We examine 21 cargo-passenger vessels for calculating the weight matrices. The list of vessels is given in table 5.1.

Serial No.	Length	Breadth	Draft
1	32.00	7.32	2.00
2	20.75	5.33	1.80
3	34.70	7.38	2.16
4	31.50	7.00	2.05
5	11.50	3.70	1.20
6	27.75	6.71	1.88
7	62.60	11.78	3.46
8	22.93	6.86	1.82
9	26.55	6.86	1.85
10	38.00	7.93	2.13
11	51.30	9.28	3.30
12	41.35	7.62	2.86
13	44.50	7.92	2.97
14	38.25	7.93	2.82
15	16.50	4.00	1.40
16	39.00	9.20	3.02
17	37.63	7.32	2.86
18	48.78	9.15	3.56
19	40.10	8.54	3.05
20	44.00	9.14	3.32
21	21.15	6.00	1.60

Table 5.1: List of 21 Cargo-passenger vessels that are used to calculate the weight matrices.

The weight matrices produced for different parameters by examining and taking the average of 21 cargo-passenger ships are given below:

Stn#	Base	WL1	WL2	WL3	WL4	WL5	WL6
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.000	0.000	0.000	0.000	0.021	0.207	0.285
1.0	0.000	0.000	0.173	0.243	0.263	0.311	0.324
1.5	0.000	0.177	0.265	0.297	0.324	0.341	0.363
2.0	0.145	0.261	0.302	0.311	0.337	0.355	0.383
2.5	0.212	0.296	0.364	0.397	0.411	0.419	0.435
3.0	0.387	0.413	0.439	0.447	0.453	0.459	0.483
4.0	0.397	0.439	0.459	0.468	0.483	0.487	0.500
5.0	0.421	0.464	0.485	0.489	0.500	0.500	0.500
6.0	0.397	0.439	0.459	0.468	0.483	0.487	0.500
7.0	0.371	0.411	0.425	0.429	0.436	0.441	0.460
7.5	0.273	0.312	0.344	0.354	0.361	0.379	0.391
8.0	0.206	0.247	0.281	0.303	0.319	0.330	0.342
8.5	0.074	0.156	0.186	0.203	0.227	0.236	0.267
9.0	0.000	0.034	0.092	0.116	0.137	0.155	0.177
9.5	0.000	0.000	0.000	0.023	0.027	0.029	0.058
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 5.2: Weight Matrix for calculating Half Breadth from Breadth.

Stn#	Base	WL-1	WL-2	WL-3	WL-4	WL-5	WL-6
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.000	0.000	0.000	0.000	0.023	0.086	0.100
1.0	0.000	0.000	0.034	0.066	0.076	0.093	0.102
1.5	0.000	0.039	0.068	0.085	0.083	0.098	0.104
2.0	0.026	0.071	0.088	0.095	0.100	0.104	0.107
2.5	0.058	0.083	0.097	0.102	0.107	0.108	0.109
3.0	0.075	0.093	0.104	0.108	0.110	0.110	0.110
4.0	0.090	0.095	0.108	0.108	0.110	0.111	0.111
5.0	0.090	0.095	0.108	0.108	0.110	0.111	0.111
6.0	0.085	0.094	0.103	0.106	0.108	0.110	0.111
7.0	0.055	0.078	0.092	0.097	0.100	0.104	0.108
7.5	0.028	0.059	0.075	0.085	0.092	0.099	0.103
8.0	0.013	0.041	0.057	0.068	0.078	0.089	0.097
8.5	0.002	0.022	0.041	0.053	0.067	0.079	0.088
9.0	0.000	0.010	0.025	0.036	0.047	0.062	0.076
9.5	0.000	0.000	0.000	0.009	0.027	0.040	0.059
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 5.3: Weight Matrix for calculating Half-breadth from Length

Stn#	Base	WL-1	WL-2	WL-3	WL-4	WL-5	WL-6
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.000	0.000	0.000	0.000	0.752	1.615	1.870
1.0	0.000	0.000	0.636	1.235	1.426	1.744	1.899
1.5	0.000	0.730	1.265	1.585	1.551	1.837	1.951
2.0	0.477	1.332	1.647	1.771	1.872	1.946	1.996
2.5	1.075	1.552	1.808	1.901	1.995	2.013	2.030
3.0	1.393	1.744	1.946	2.015	2.046	2.047	2.051
4.0	1.679	1.772	2.016	2.023	2.058	2.066	2.076
5.0	1.679	1.772	2.016	2.023	2.058	2.066	2.076
6.0	1.584	1.760	1.932	1.988	2.023	2.061	2.076
7.0	1.028	1.458	1.709	1.820	1.868	1.946	2.009
7.5	0.522	1.108	1.394	1.587	1.725	1.852	1.915
8.0	0.252	0.760	1.061	1.268	1.456	1.661	1.818
8.5	0.032	0.412	0.762	0.991	1.251	1.472	1.648
9.0	0.000	0.191	0.459	0.666	0.887	1.155	1.416
9.5	0.000	0.000	0.000	0.123	0.508	0.744	1.109
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 5.4: Weight Matrix for calculating Half-breadth from Draft

The performance and accuracy of the design for different weight matrices are as follows:

Parameters	Typical	Length Weight		Breadth Weight		Draft Weight		Combined Weight	
	Values	Values	% Error	Values	% Error	Values	% Error	Values	% Error
C_b	0.582	0.621	6.701	0.616	5.842	0.630	8.247	0.603	3.483
C_M	0.967	0.981	1.448	0.974	0.724	0.983	1.655	0.984	1.728
C_P	0.603	0.633	4.975	0.632	4.809	0.640	6.136	0.613	1.600
C_{WP}	0.725	0.735	1.379	0.729	0.552	0.731	0.828	0.727	0.275
C_{VP}	0.807	0.845	4.709	0.845	4.709	0.862	6.815	0.829	2.654
C_V	4.870	5.370	10.267	5.170	6.160	5.150	5.749	5.040	3.373

Table 5.5: Accuracy comparison of Hull Form designed using different Weight Matrices(generated from 30 examples of cargo-passenger vessels).

Hence, it is clearly noted from Table 5.5 that if we calculate the half-breadth using different weight matrices and then take the average, we get more accurate result. However, first sketch or initial design can be found from the equation,

$$Y = \frac{1}{3}\sum_{i} b_i X_i \quad \text{..} (5.2)$$

where i stands for length, draft and breadth.

5.2. Adjustment of Breadth and Draft using Neural Nets

When the owner ask for designing a ship to a designer, some parameters such as length, displacement, speed, etc. are supplied. Let us assume that all the values supplied by the owner are consistent with each other.

For a particular type of ship the dimensional ratio of length to breadth and breadth to draft are similar. Therefore, we can easily calculate the breadth and draft from the given length using some practical dimensional ratios.

An Example of 28.2 Cargo-Passenger Ship	
Length (L)	28.2 m
L/B Ratio	6.4
Breadth	4.41 m
B/T Ratio	2.93
Draft	1.50 m
Required Displacement	394 tons
Required Speed	20 knots

Table 5.6: An example for calculating Breadth, Draft and Displacement from Length.

Unfortunately, the calculated displacement and speed may not match with the given ones.

The half breadth table for the ship explained in Table 5.6 is given below:

Stn#	Base	WL1	WL2	WL3	WL4	WL5	WL6
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.000	0.000	0.000	0.000	0.623	1.924	2.296
1.0	0.000	0.000	0.893	1.596	1.817	2.208	2.382
1.5	0.000	0.993	1.658	2.027	2.033	2.345	2.491
2.0	0.691	1.720	2.096	2.234	2.373	2.475	2.565
2.5	1.391	1.992	2.350	2.491	2.606	2.636	2.676
3.0	1.967	2.357	2.598	2.679	2.719	2.729	2.768
4.0	2.269	2.424	2.698	2.718	2.775	2.789	2.818
5.0	2.304	2.460	2.736	2.749	2.800	2.809	2.818
6.0	2.173	2.412	2.613	2.683	2.740	2.784	2.818
7.0	1.577	2.067	2.340	2.457	2.516	2.601	2.692
7.5	0.925	1.571	1.905	2.113	2.261	2.415	2.496
8.0	0.556	1.126	1.478	1.718	1.930	2.152	2.327
8.5	0.141	0.643	1.038	1.292	1.589	1.824	2.046
9.0	0.000	0.242	0.596	0.839	1.091	1.387	1.681
9.5	0.000	0.000	0.000	0.180	0.550	0.789	1.198
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 5.7: Half-Breadth Matrix for 28.2m Ship with Breadth 4.41m and Draft 1.50m

From the Table 5.7, the displacement of the ship is found 341 tons which is 13.45% lower than typical displacement whereas the speed is 22.31 knots which is 11.45% higher (better) than the typical value.

The average errors for 21 cargo-passenger ships listed in Table 5.1 are 18.87% in displacement and 12.77% in speed.

So, we need to make a compromise between displacement, speed, breadth and draft.

To provide a reasonable displacement and speed, breadth and draft need to be adjusted. While length of the ship is unchanged as it is one of the desired parameters. Some deviation in displacement and speed in the final design are usually accepted by the owner.

Now, for the adjustment of breadth and draft two-layer Network is considered [Figure 3.3]. For the problem of designing hull form, the network has four inputs-length, breadth, draft and type of ship; three hidden values-water plane area, sectional areas and midship area and four output values such as displacement, breadth, draft and speed. To analyze the network two weight matrices were needed, one say *A* for calculating hidden values from the inputs and another called *B* for calculating output from hidden values [Algorithm 3.3].

The initial values of matrix *A* and matrix *B* are taken randomly. As matrix *A* calculated three outputs from 3 inputs (though there are 4 inputs, one of them, type of the ship is used in selecting weight matrices for particular types of ship), it is normally 3x3 dimensional. However, the matrix *B* is 3x4 dimensional, which is not possible as inversion of matrix is necessary in back-propagation technique. So, we need to make B as a 4x4 dimensional matrix. Note that a 3×4 dimensional matrix can be converted into 4×4 dimensional by adding a row at bottom containing only 1 for each column.

There are two modes in using back-propagation for adjusting breadth and draft-training mode and production mode. In training mode, two weight matrices are produced- A and B. The two matrices that are produced for 21 example ships [Table 5.1] and for 30 iterations in training mode is given in Table 5.8 and Table 5.9.

$$\begin{pmatrix} 0.832 & 0.845 & 0.112 \\ 0.014 & 0.817 & 0.989 \\ 0.864 & 0.833 & 0.984 \end{pmatrix}$$

Table 5.8: Weight Matrix A for calculating hidden layer from input layer.

$$\begin{pmatrix} 0.279 & 0.527 & 0.004 & 0.012 \\ 1.208 & 0.103 & 0.147 & 0.473 \\ 1.120 & -0.215 & 0.489 & 1.572 \\ 1 & 1 & 1 & 1 \end{pmatrix}$$

Table 5.9:Weight matrix B for calculating output layer from hidden layer

In production mode, the hidden layer output is calculated from input layer and weight matrix A. There are three values in hidden layer. We calculate the square root of water plane area and midship area and cubic root of sectional areas. Then the calculated values are used to generate output layer using weight matrix B [Algorithm 3.3]. Similarly, square and cube are taken in the reverse process for calculating hidden layer from output layer.

After adjusting breadth and draft using back-propagation technique the new breadth and draft for the 28.2m cargo-passenger ship shown in table 5.6 become 6.56m and 1.83m, respectively. The half-breadth Table 5.7 is converted to Table 5.10 where the error in displacement reduces from 13.45% to 6.35% and the error in speed reduces from 11.45% to 9.45%.

Stn#	Base	WL1	WL2	WL3	WL4	WL5	WL6
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.000	0.000	0.000	0.000	0.653	2.064	2.479
1.0	0.000	0.000	0.990	1.743	1.978	2.399	2.583
1.5	0.000	1.095	1.816	2.208	2.225	2.553	2.712
2.0	0.772	1.877	2.281	2.427	2.581	2.692	2.797
2.5	1.518	2.172	2.568	2.727	2.851	2.885	2.933
3.0	2.184	2.596	2.855	2.941	2.985	2.998	3.048
4.0	2.499	2.676	2.965	2.991	3.055	3.072	3.107
5.0	2.545	2.724	3.016	3.031	3.088	3.097	3.107
6.0	2.401	2.663	2.879	2.954	3.019	3.067	3.107
7.0	1.778	2.297	2.584	2.705	2.769	2.859	2.960
7.5	1.067	1.746	2.103	2.320	2.476	2.642	2.729
8.0	0.658	1.261	1.638	1.893	2.118	2.351	2.535
8.5	0.177	0.727	1.145	1.413	1.728	1.973	2.215
9.0	0.000	0.263	0.651	0.911	1.179	1.490	1.801
9.5	0.000	0.000	0.000	0.194	0.576	0.822	1.255
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 5.10: Half-Breadth matrix for 28.2m Cargo-Passenger Ship with 6.56m Breadth and 1.83m Draft (Before Applying Genetic Algorithm).

5.3. Design of Hull Form using GAs

After adjusting Breadth and Draft, we get a design of hull form that is generated from length, new breadth and new draft by multiplying with their corresponding weight matrices and then taking average. This was the first candidate population in first generation. Then the other population of the first generation is selected by adding small offset with this first candidate population.

Ordinate of new candidate population = Ordinate of first Candidate population + offset value

A design is a two-dimensional table, the small offset is generated randomly within specific limits for every entry of the table. However, adding offset value with the table contents modifies every entry. The limits of the offset are chosen such a way that its positive limit equals its negative limit. By adding offsets, we generate *(2N-1)* population to make a total of *2N* candidate populations for first generation.

The candidate populations of the first generation don't have fitness as they don't have fair surface. So, surface fairing is performed for all candidate populations. Moreover, fitness is determined for every candidate populations. After fairing the surface and measuring fitness, *N* best-fit population is selected for the generation.

Now, to switch into next generation, another *N* populations were produced using cross over, mutation and add-alternative operators discussed earlier. Fitness of new population was calculated. Hence, populations in the current generation become *2N*. Among them, *N* best-fit populations are shifted to the next generation. The process continued until a population with acceptable fitness is found [Algorithm 4.1].

After application of Genetic Algorithm the final design of 28.2m Cargo-passenger ship is given in Table 5.11 where the error in displacement is 3.3% and in speed is 11.95%, i.e., the calculated displacement is 381 tons and the calculated speed is 17.61 knots.

Stn#	Base	WL-1	WL-2	WL-3	WL-4	WL-5	WL-6
0.0	0.000	0.000	0.000	0.000	0.000	1.751	2.892
0.5	0.000	0.000	0.000	0.000	1.557	2.551	2.955
1.0	0.000	0.000	1.005	1.951	2.253	2.756	3.000
1.5	0.000	1.154	1.998	2.504	2.451	2.903	3.082
2.0	0.753	2.104	2.602	2.798	2.957	3.075	3.153
2.5	1.699	2.452	2.857	3.004	3.152	3.181	3.207
3.0	2.201	2.755	3.075	3.183	3.233	3.235	3.241
4.0	2.653	2.800	3.185	3.197	3.251	3.265	3.280
5.0	2.653	2.800	3.185	3.197	3.251	3.265	3.280
6.0	2.503	2.781	3.052	3.141	3.196	3.257	3.280
7.0	1.625	2.303	2.701	2.875	2.952	3.075	3.174
7.5	0.825	1.751	2.203	2.507	2.725	2.926	3.025
8.0	0.398	1.201	1.677	2.004	2.301	2.625	2.872
8.5	0.051	0.651	1.204	1.565	1.976	2.325	2.604
9.0	0.000	0.302	0.725	1.052	1.401	1.825	2.237
9.5	0.000	0.000	0.202	0.461	0.803	1.175	1.752
10.0	0.000	0.000	0.000	0.000	0.000	0.250	1.000

Table 5.11: Half-breadth for the Ship with Length 28.2m, Breadth 6.56m and Draft 1.83m

5.3.1 Fairing the Hull Surface

After adding offset or performing GA operations among the population, the population looses it fairness on its surface. So, for the new population first task is to fair its surface. Ship hull surface is a complex structure and can't be fit in a least square equation. However, the suitable fairing method divides surface into many small surfaces. The surface between two control points is considered as a small surface. The fairing is done to maintain continuity between neighboring small surfaces. This method is called B-Spline Curve Fitting. Hence, B-Spline fitting can't guarantee elimination of unwanted spots. Comparing the neighboring control points can solve this problem. So, smoothing or fairing is performed in 2-ways comparing control points and using B-Spline curve fitting method.

(a) **Fairing by the Comparison of Control Points:**

Half-breadth of the ship increases or remains constants from any ends of the ship to the midship section and again from base-line to DWL. This knowledge can be applied to fair the surface. So, from base line to WL6, if a control has greater value from its next control point, then the value for next control point will be copied back to behind one.

Again, there are 10 stations and 6 substations in our analysis. The half-breadth increases or remains constant from station number 0 to station number 5 and decreases or remains constant from station number 5 to station number 10.

The algorithm is as follows:

```
for i = 1 to Number-of-WL + 1 do
        for j = 1 to Number-of-stn + Number-of-sub-stn + 1 do
                if A[ j ] > A[ j+i ] then
                        A[ j ] ←A[ j+i ]

for j = 1 to Number-of-stn + Number-of-sub-stn + 1 do
        for i = 1 to Number-of-WL + 1 do
                if i < (Number-of-stn + Number-of-sub-stn + 1)/2 then
                   if A[ i ] > A[ i+1 ] then
                        A[ i ] ←A[ i+1 ]
                else
                   if A[ i + 1 ] > A[ i ] then
        A[ i+1 ] ←A[ i ]
```

Algorithm 5.1: Comparison Based Fairing Algorithm

After this comparison operation, unwanted spots will be removed from the hull geometry.

(b) Fairing using B-Spline Curve Fitting Method

Using B-Spline Curve Fitting Method ensures continuity of the surface. The properties of this method is as follows [26]:

1. B-Spline are pieced together so they agree at their joints in three ways:

$$a)\quad B_i(1) = B_{i+1}(0) = \frac{P_i + 4P_{i+1} + P_{i+2}}{6} \quad \text{.........(5.3)}$$

$$b)\quad B_i'(1) = B_{i+1}'(0) = \frac{-P_i + P_{i+2}}{2} \quad \text{.........(5.4)}$$

$$c)\quad B_i''(1) = B_{i+1}''(0) = P_i - 2P_{i+1} + P_{i+2} \quad \text{.........(5.5)}$$

Where P_i are the control points and subscripts refer to the portions of the curve.

2. The portion of the curve determined by each group of four points is within the convex hull of these points.

An algorithm for drawing B-Spline curve is as follows:

Procedure B-Spline

$P_{-1} = P_{-2} = P_0$

$P_{n+1} = P_{n+2} = P_n$

for i = 0 to n-1 do

for u = o to 1 step 0.01 do

$$X = \frac{(1-u)^3}{6} X_{i-1} + \frac{(3u^3 - 6u^2 + 4)}{6} X_i + \frac{(-3u^3 + 3u^2 + 3u + 1)}{6} X_{i+1} + \frac{u^3}{6} X_{i+2}$$

$$Y = \frac{(1-u)^3}{6} Y_{i-1} + \frac{(3u^3 - 6u^2 + 4)}{6} Y_i + \frac{(-3u^3 + 3u^2 + 3u + 1)}{6} Y_{i+1} + \frac{u^3}{6} Y_{i+2}$$

end procedure.

Algorithm 5.2: B-Spline Fairing Algorithm

New control points *(X, Y)* will be generated after smoothing the curve using above algorithm. The points are inserted inside the equation and new point is found from calculated values of *X* and *Y*.

5.3.2 Fitness measurement

For the measurement of fitness, six co-efficient are used. These co-efficient are block co-efficient (C_b), midship co-efficient (C_M), prismatic co-efficient (C_P), water-plane co-efficient (C_{WP}), volumetric co-efficient (C_V) and vertical prismatic co-efficient (C_{VP}). For every type of ship, the particular co-efficient has a typical value; which is known as desired value. Other value is calculated for every co-efficient. Then fitness is measured by the equation

$$fitness(individual\ i) = \frac{1}{6}\sum_i (P_{ci} - P_{di})^2 \qquad (5.6)$$

Where $i = C_b, C_M, C_{WP}, C_{VP}$ and C_V. P_{di} is the desired value and P_{Ci} is the calculated value for parameter *i*.

Chapter 6

Results and Discussions

The aim of this thesis is to recover the original hull form automatically from a population determined by past experiences by specifying known form parameters. In a real design situation, the exact geometry of the form sought is not known in advance. Additionally, the parametrically specified form may not exist, meaning that there is conflict between requirements that must be resolved. However, since the purpose of this thesis is to design automatic hull form by examining the effectiveness of the search mechanism, results depend on automation quality, efficiency and accuracy.

6.1. Automation Quality

The technique described in this thesis is a fully automated hull form generation process for the first time. Though in 1998, R.W. Birmingham and T.A. Smith tried to automate hull form generation technique, their technique requires a initial sketch which made them partially successful [5]. In our thesis, we take initial design from test set of some previously designed ship. In learning mode, we studied several similar types of ships and produced weight matrices. These weight matrices are the basis of design and initial design has been done from these matrices. Therefore, we do not require sketch, we need only desired requirements, and then the final design with different co-efficient will be provided as output. However, the design is fully automated.

6.2. Efficiency

In this design process, we use pre-fitness criterion in design methodology. At first, we take some already designed ships and knowledge is earned from these ships. This knowledge has been applied to new design instead of starting from a blind point or taking randomized design. As a result, a great advance in efficiency has been found.

Moreover, a compromise is made using neural networks between breadth, displacement, depth and speed. This compromization algorithm drives the system to converge quickly into final solution, as conflict between them has been resolved. It also increases the accuracy of displacement from 91.13% to 97.34%. The result has been found when the number of ships is 21 and neural net performed 110 iterations in back-propagation mode. The technique also provides 94.12% accuracy in speed.

In our thesis, GA starts its walk from a population, which has approximately 70-80% fitness instead of starting from random points. Again, add alternative operator, a new powerful operator of GAs, has been used in this process. As a result, the system converges quickly. In this study, it is reported that the final solution has been found after 60 generations with population size 50, i.e., 60x50=3,000 individuals were considered and tested before getting the solution. This is a very good result comparing with R.W. Birmingham and T.A. Smith's experiment, where they use 300 generations with 100 population size, i.e., investigated and generated 300x100=30,000 individuals to get final solution. Hence, from these points of view, it might be mentioned that the proposed technique is obviously efficient.

6.3. Accuracy

All the co-efficients have particular typical values. These values differ for different type of ships. Here, we designed 30 cargo-passenger ships using GAs and calculated their co-efficient. Each of the ship is designed considering 60 generations with the population size of 50. Average values of co-efficient for these 21 ships is given below:

Parameters	Typical Values	Calculated Values	% Error
C_b	0.582	0.579	0.515
C_M	0.967	0.968	0.103
C_P	0.603	0.598	0.829
C_{WP}	0.725	0.728	0.413
C_{VP}	0.807	0.795	1.489
C_V	4.870	4.970	2.053
Speed(Knots)	20.000	19.120	4.400

Table 6.1: Comparison of calculated co-efficient values with typical ones

Therefore, the result is almost 98% to 100% accurate which is obviously acceptable.

6.4. Population Size versus Number of Generation Analysis

The population size versus number of generations needed to get 99.1% accurate result is given below:

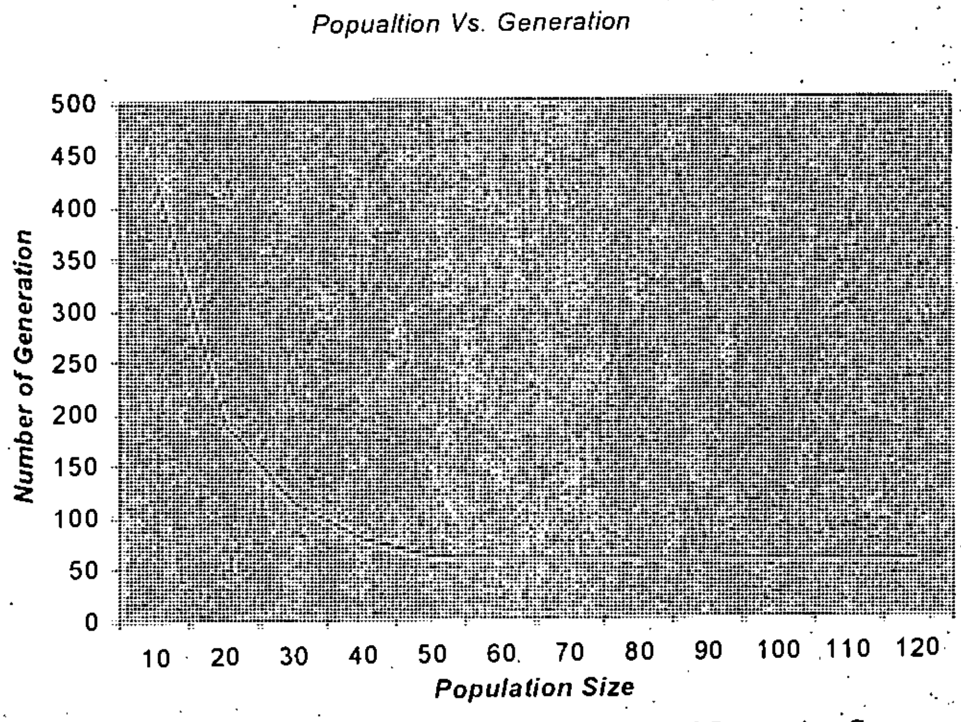

Figure 6.1: Population Size versus Number of Generation Curve.

The graph shows that better result might be found when the population size is between 50 to 120. However, with population size 50, we need 60 generations to get the final results.

Moreover, it is reported in this study that at primary stage fitness increases quickly with the increasing number of generation (with population size 50), but after soon it becomes slower. The result is presented in the following graph:

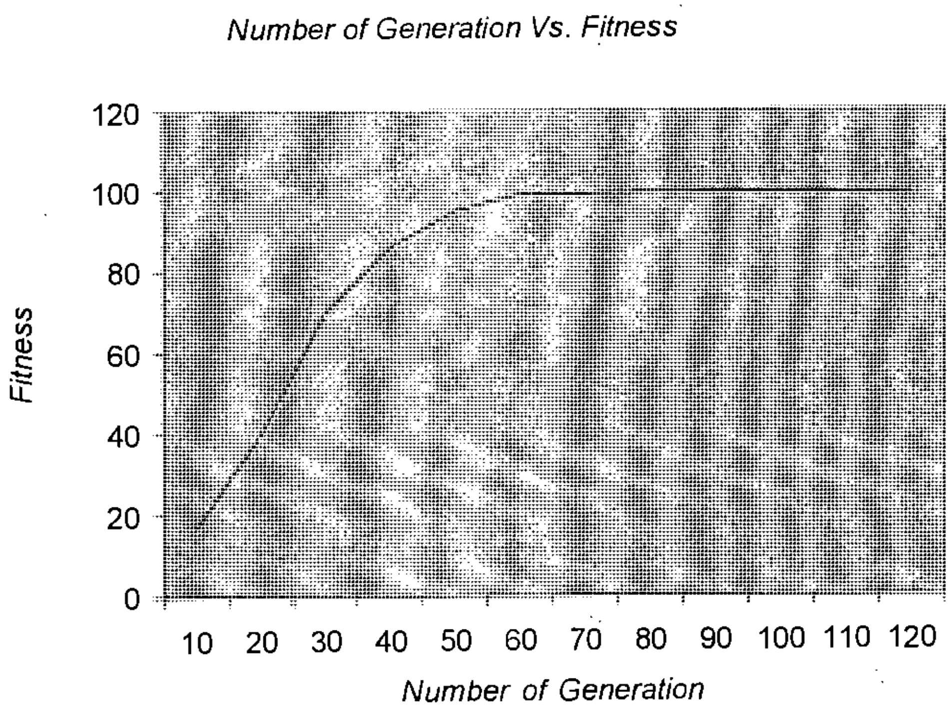

Figure 6.2: Number of Generation versus Fitness Curve

The graph shows sufficient average fitness of the individuals with minimum number of generations (60 generations).

Chapter 7

Conclusions and Future Works

The process of hull form synthesis can be automated by replacing the designer's guidance of developing a design with optimization techniques. The approach makes what are traditionally described as original and form transformation approaches part of a continuum. The same techniques can also be applied to the problem of fitting surfaces to sets of existing points.

This thesis outlines how Genetic Algorithms and Neural Networks can be used to implement such a procedure.

7.1. Summary

The main focus of this thesis is the design of a fully automated hull form generation technique and improvement of efficiency. The set of examples are used to automate the design in this thesis. In learning mode, linear relation $Y = bX$ is used for the purpose of automation. Again, two layer Neural Network is also used in learning mode, to get the breadth and draft automatically as well as improving performances. The process is completed by designing the hull form through the use of GAs.

Again in GAs, an offset value is used to generate initial population which is generated from previous knowledge instead of taking random value for better performance. Offset values are also used for mutation and add alternate operator. This summed offset error in this case is almost zero, indicating that all of the offset are within the envelope defined by the tolerances, in this case ±0.05m for all stages. Moreover, fairing methods are also used in this case. So, the hull form generated through this process is fully automated, accurate and having fair surface. The technique is also efficient one.

7.2. Future Works

There are still many interesting problems, which are worth continuing research, some of which are discussed as follows:

1) Use of Intelligent Methods for Generating Weight Matrices of Half Breadth

Instead of starting the GAs from random point, we use a pre-fit population by analyzing 21 cargo-passenger ships. The pre-fit population is found using weight matrices comparing half-breadth table with length, breadth, draft, etc. Hence, the weight matrices are considered as a pre-requisite knowledge for designing ship. However, this knowledge is earned through the equation $Y = bX$ which is a linear method. As a result, the pre-fit population has fitness approximately 70-80%.

Therefore, instead of using linear method an intelligent method can be used for generating pre-fit population.

2) Use of Variable Number Stations and Waterlines

In genetic algorithm, we use fixed size matrices for easier calculation. This also helps in generating pre-fit population. So, the user can't make a choice in the number of stations and in the number of waterlines. The process may be modified in such a way that the number of stations, number of sub-stations and number of waterlines will be taken as inputs and the hull form will be designed accordingly.

3) More examples might be examined to Generate Weight Matrix

In this thesis, only 21 ships are taken as examples for generating weight matrices which produce pre-fit population with 70-80% fitness. However, it might be assumed that if more examples are considered better weight matrices might be found.

4) Material of Hull Form might be considered

Hull form may be made by wood, aluminum, etc. The weight of the material differs significantly since thickness of hull with different materials is not same. Considering this complicated thing, the knowledge of Material Science is required. So, knowledge of Material Science may be used to design hull form more accurately.

5) Physical Strength might be considered

In this thesis, it is assumed that the material that is used to design hull form has infinite strength to hold every items, i.e., the strength is not a problem of consideration. However, it might be a problem in some cases. This leads to the technique for designing specific ship and not a general one. More general methods might be found taking the physical strength into consideration.

6) Optimization of the number of Station can be made

In our design, we have taken 10 stations for every type of ship without considering length and other parameters. If the number of station is taken based on the length and type of the ship then better result might be found. Hence, it might be analyzed that how many stations and sub-stations would give more accurate design for a particular type of ship with given length.

7) Estimation of Cost

One of the important considerations in engineering and designing a ship is estimating the cost of it. We simply ignore the cost of the ship in our design. Therefore, in future, cost estimation methods may be searched for.

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Appendix A

Design of a 31.5m Cargo-Passenger Ship

From Table 2.1(a), it is seen that the length to breadth ratio and breadth to draft ratio of a cargo passenger ship are 6.40 and 2.93, respectively. Hence, the breadth and draft of the 31.5m cargo passenger ship are 4.92m and 1.68m, respectively according to these standard ratios. Again, using equation 2.6, the typical value for displacement for this ship can be found which is 151.53 tons. The typical value of speed for a cargo-passenger ship is 20 knots.

Now, using equation 5.1 and Table 5.2, 5.3 and 5.4, we get the half-breadth matrix (design) shown in Table A.1. With this design, calculated displacement is 121.23 tons whereas calculated speed is 23.41 knots. Therefore, error in displacement is 20% and error in speed is 17.05%.

Stn#	Base	WL1	WL2	WL3	WL4	WL5	WL6
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.000	0.000	0.000	0.000	0.697	2.152	2.567
1.0	0.000	0.000	0.998	1.784	2.032	2.468	2.662
1.5	0.000	1.110	1.854	2.266	2.272	2.621	2.785
2.0	0.773	1.923	2.344	2.498	2.653	2.767	2.868
2.5	1.555	2.227	2.626	2.785	2.913	2.947	2.992
3.0	2.198	2.634	2.904	2.994	3.040	3.051	3.094
4.0	2.536	2.709	3.015	3.039	3.102	3.118	3.150
5.0	2.575	2.750	3.058	3.073	3.129	3.139	3.150
6.0	2.429	2.695	2.921	2.999	3.062	3.112	3.150
7.0	1.763	2.310	2.616	2.746	2.812	2.908	3.009
7.5	1.034	1.756	2.129	2.361	2.528	2.700	2.790
8.0	0.621	1.258	1.652	1.920	2.158	2.406	2.601
8.5	0.158	0.718	1.160	1.445	1.776	2.039	2.288
9.0	0.000	0.270	0.666	0.938	1.220	1.551	1.879
9.5	0.000	0.000	0.000	0.201	0.615	0.882	1.340
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A.1: Half-Breadth Matrix for 31.5m Cargo-Passenger Ship with Breadth 4.92m and Draft 1.50m

After adjustment of breadth and draft using back-propagation technique, the breadth and draft has been found as 7.00m and 2.0m. The new half-breadth matrix found with these newly calculated parameters is shown in Table A.2.

The displacement calculated using Table A.2 is 158.73 tons and the calculated speed is 19.56 knots. Therefore, the error in displacement reduces from 20% to 4.75% and speed from 17.05% to 2.2%.

Stn#	Base	WL1	WL2	WL3	WL4	WL5	WL6
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.000	0.000	0.000	0.000	0.792	2.467	2.964
1.0	0.000	0.000	1.185	2.085	2.366	2.869	3.090
1.5	0.000	1.311	2.173	2.641	2.663	3.054	3.244
2.0	0.924	2.246	2.729	2.902	3.087	3.220	3.346
2.5	1.816	2.598	3.072	3.263	3.411	3.452	3.510
3.0	2.615	3.107	3.416	3.519	3.572	3.587	3.648
4.0	2.990	3.202	3.549	3.579	3.656	3.676	3.718
5.0	3.046	3.261	3.609	3.628	3.696	3.706	3.718
6.0	2.873	3.188	3.445	3.535	3.613	3.670	3.718
7.0	2.130	2.750	3.093	3.237	3.314	3.421	3.542
7.5	1.279	2.090	2.516	2.776	2.962	3.160	3.265
8.0	0.790	1.511	1.960	2.266	2.534	2.812	3.032
8.5	0.212	0.870	1.371	1.691	2.067	2.359	2.649
9.0	0.000	0.314	0.779	1.089	1.409	1.781	2.153
9.5	0.000	0.000	0.000	0.230	0.688	0.982	1.498
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A.2: Half-Breadth Matrix for 31.5m Cargo-Passenger Ship with Breadth 7.00m and Draft 2.00m (Before application of Genetic Algorithm).

Taking Table A.2 as a first population another 99 populations are generated and best-fit 50 populations are taken for first generation. Using cross-over, mutation and add alternate operators, Genetic algorithm switches from generation to generation taking each time best-fit 50 populations. After 60 generation, the best-fit population of half-breadth matrix found is shown in Table A.3.

For the final design of 31.5m Cargo-Passenger ship, the displacement found 149.34 tons and speed is 19.87 knots. Hence, the error in displacement is 1.45% whereas the error in speed is 0.65%.

Stn#	Base	WL-1	WL-2	WL-3	WL-4	WL-5	WL-6
0.0	0.000	0.000	0.000	0.000	0.000	0.000	3.221
0.5	0.000	0.000	0.000	0.000	1.825	2.850	3.252
1.0	0.000	0.000	0.785	2.351	2.753	3.097	3.281
1.5	0.000	1.125	2.325	2.876	3.075	3.254	3.323
2.0	0.449	2.251	2.875	3.197	3.325	3.351	3.407
2.5	1.652	2.775	3.177	3.353	3.471	3.500	3.500
3.0	2.304	2.975	3.306	3.467	3.500	3.500	3.500
4.0	2.675	3.154	3.451	3.500	3.500	3.500	3.500
5.0	2.675	3.154	3.451	3.500	3.500	3.500	3.500
6.0	2.675	3.154	3.451	3.500	3.500	3.500	3.500
7.0	2.807	3.103	3.454	3.371	3.500	3.500	3.500
7.5	2.107	2.593	2.925	3.156	3.425	3.500	3.500
8.0	1.203	1.951	2.402	2.753	3.025	3.206	3.230
8.5	0.352	1.053	1.751	2.097	0.452	2.753	2.949
9.0	0.000	0.454	0.853	1.301	1.675	2.108	2.496
9.5	0.000	0.000	0.000	0.604	1.202	1.657	1.811
10.0	0.000	0.000	0.000	0.000	0.000	0.351	0.926

Table A.2: Half-Breadth Matrix for 31.5m Cargo-Passenger Ship with Breadth 7.00m and Draft 2.00m (After application of Genetic Algorithm).

Different co-efficients of the final design are:

Parameters	Typical Values	Calculated Values	% Error
C_b	0.582	0.579	0.515
C_M	0.967	0.968	0.103
C_P	0.603	0.598	0.829
C_{WP}	0.725	0.723	0.276
C_{VP}	0.807	0.815	0.991
C_V	4.870	4.563	6.304

Table A.4: Comparison of co-efficients for 59.2m Cargo-Passenger Ship.

Appendix B

Design of a 59.2m Cargo-Passenger Ship

From Table 2.1(a), it is seen that the length to breadth ratio and breadth to draft ratio of a cargo passenger ship are 6.40 and 2.93, respectively. Hence, the breadth and draft of the 59.2m cargo passenger ship are 9.25m and 3.16m, respectively according to these standard ratios. Again, using equation 2.6, the typical value for displacement for this ship can be found which is approximately 1007 tons. The typical value of speed for a cargo-passenger ship is 20 knots.

Now, using equation 5.1 and Table 5.2, 5.3 and 5.4, we get the half-breadth matrix (design) shown in Table B.1. With this design, calculated displacement is 934.45 tons whereas calculated speed is 21.87 knots. Therefore, error in displacement is 7.2% and error in speed is 9.35%.

Stn#	Base	WL1	WL2	WL3	WL4	WL5	WL6
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.000	0.000	0.000	0.000	1.222	3.781	4.519
1.0	0.000	0.000	1.772	3.153	3.586	4.354	4.695
1.5	0.000	1.967	3.278	4.001	4.018	4.628	4.916
2.0	1.375	3.397	4.137	4.406	4.682	4.883	5.065
2.5	2.747	3.933	4.642	4.925	5.150	5.211	5.292
3.0	3.905	4.667	5.142	5.299	5.380	5.401	5.482
4.0	4.492	4.803	5.339	5.381	5.494	5.524	5.582
5.0	4.566	4.880	5.419	5.446	5.547	5.564	5.582
6.0	4.308	4.780	5.175	5.312	5.427	5.514	5.582
7.0	3.146	4.104	4.638	4.865	4.981	5.148	5.328
7.5	1.858	3.119	3.775	4.180	4.470	4.773	4.932
8.0	1.125	2.241	2.932	3.403	3.818	4.251	4.593
8.5	0.291	1.283	2.057	2.554	3.134	3.592	4.031
9.0	0.000	0.477	1.177	1.654	2.148	2.726	3.302
9.5	0.000	0.000	0.000	0.353	1.072	1.537	2.337
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table B.1: Half-Breadth Matrix for 59.2m Cargo-Passenger Ship with Breadth 9.25m and Draft 3.16m

After adjustment of breadth and draft using back-propagation technique, the breadth and draft has been found as 11.2m and 3.02m. The new half-breadth matrix found with these newly calculated parameters is shown in Table B.2.

The displacement calculated using Table B.2 is 987.35 tons and the calculated speed is 18.77 knots. Therefore, the error in displacement reduces from 7.2% to 1.95% and speed from 9.35% to 6.15%.

Stn#	Base	WL1	WL2	WL3	WL4	WL5	WL6
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.000	0.000	0.000	0.000	1.237	3.873	4.642
1.0	0.000	0.000	1.841	3.254	3.697	4.486	4.833
1.5	0.000	2.040	3.388	4.125	4.153	4.771	5.069
2.0	1.433	3.506	4.264	4.538	4.824	5.032	5.226
2.5	2.835	4.057	4.794	5.089	5.321	5.384	5.472
3.0	4.061	4.836	5.322	5.484	5.566	5.589	5.680
4.0	4.655	4.982	5.527	5.573	5.692	5.723	5.786
5.0	4.738	5.068	5.617	5.646	5.751	5.768	5.786
6.0	4.469	4.958	5.363	5.504	5.624	5.713	5.786
7.0	3.292	4.270	4.811	5.040	5.160	5.329	5.517
7.5	1.963	3.245	3.915	4.326	4.620	4.931	5.095
8.0	1.204	2.339	3.046	3.527	3.950	4.389	4.736
8.5	0.318	1.344	2.133	2.638	3.230	3.693	4.146
9.0	0.000	0.491	1.215	1.703	2.207	2.795	3.381
9.5	0.000	0.000	0.000	0.363	1.087	1.555	2.370
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table B.2: Half-Breadth Matrix for 59.2m Cargo-Passenger Ship with Breadth 11.2m and Draft 3.02m (Before application of Genetic Algorithm).

Taking Table B.2 as a first population another 99 populations are generated and best-fit 50 populations are taken for first generation. Using cross-over, mutation and add alternate operators, Genetic algorithm switches from generation to generation taking each time best-fit 50 populations. After 60 generation, the best-fit population of half-breadth matrix found is shown in Table B.3.

For the final design of 59.2m Cargo-Passenger ship, the displacement found 983.53 tons and speed is 18.96 knots. Hence, the error in displacement is 2.33% whereas the error in speed is 5.2%.

Stn#	Base	WL-1	WL-2	WL-3	WL-4	WL-5	WL-6
0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5	0.000	0.000	0.000	0.000	1.203	4.001	4.649
1.0	0.000	0.000	2.901	3.999	4.553	4.890	5.175
1.5	0.000	3.548	4.452	4.897	5.154	5.298	5.375
2.0	2.403	4.351	5.075	5.300	5.425	5.475	5.450
2.5	3.602	5.001	5.351	5.548	5.600	5.600	5.600
3.0	3.602	5.350	5.600	5.600	5.600	5.600	5.600
4.0	3.602	5.350	5.600	5.600	5.600	5.600	5.600
5.0	3.602	5.350	5.600	5.600	5.600	5.600	5.600
6.0	3.602	5.350	5.600	5.600	5.600	5.600	5.600
7.0	3.602	5.350	5.600	5.600	5.600	5.600	5.600
7.5	3.997	4.953	5.255	5.375	5.425	5.502	5.525
8.0	3.154	4.175	4.562	4.875	4.993	5.095	5.152
8.5	1.203	2.925	3.551	3.896	4.201	4.425	4.557
9.0	0.000	1.596	2.254	2.703	3.051	3.357	3.596
9.5	0.000	0.425	0.851	1.207	1.553	1.776	2.075
10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table B.3: Half-Breadth Matrix for 59.2m Cargo-Passenger Ship with Breadth 11.2m and Draft 3.02m (After application of Genetic Algorithm).

Different co-efficients of the final design are:

Parameters	Typical Values	Calculated Values	% Error
C_b	0.582	0.577	0.859
C_M	0.967	0.964	0.310
C_P	0.603	0.599	0.663
C_{WP}	0.725	0.712	1.793
C_{VP}	0.807	0.791	1.982
C_V	4.870	4.603	5.483

Table B.4: Comparison of co-efficients for 59.2m Cargo-Passenger Ship.