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OPTIMIZATION OF SHIP HULL PARAMETER OF INLAND VESSEL WITH RESPECT TO REGRESSION BASED RESISTANCE ANALYSIS.

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ABSTRACT

This paper represents an integrated methodology for the preliminary optimum design parameters considering the existing constraints provided by Bangladesh Inland waterways Authority (BIWTA). This research also describes a parametric modeling optimization approach to the design of ship hull parameters to minimize the ship resistance as well as allows creating and varying ship hull parameters quickly and efficiently within the given constraints. The methodology of optimization process such as objective function, design variables and used constraints are described. The hull resistance is chosen as the objective function and ship length, breadth, draft and speed is selected for design variables. From the study it is shown that the methodology may be used in the preliminary design stages for selecting hull parameter of inland vessel operating in Bangladesh waterways.

Key words: Resistance, length, breadth, draft, speed, SQP

1. INTRODUCTION

Preliminary ship design is currently more art than science, heavily dependent on highly experienced naval architects [12]**.** In the early stages of conceptual and preliminary design, it is necessary to develop a consistent definition of a candidate design in terms of its dimensions and other descriptive parameters such as Length, Breath, Draught, Block coefficient, LCB, etc. This description can then be optimized with respect to some measures of merit. More detailed design development involves significant time, effort. It is important to be able reliably define and size the vessel at parameter stage. Because these parameters (length, breath, depth, draught, speed etc.) have influences on resistance, capital cost, maneuverability, longitudinal strength, hull volume, sea-keeping, transverse stability, freeboard, etc.

Optimization means finding the best solution from a limited or unlimited number of choices. Even if the number of choices is finite, it is often so large that it is impossible to evaluate each possible solution and then determine the best choice. The target of optimization is the objective function or criterion of the optimization. It is subject to boundary conditions or constraints. Constraints may be formulated as equations or inequalities. All technical and economical relationships to be considered in the optimization model must be known and expressed as functions. Some relationships will be exact and others will only be approximate, such as all empirical formulae, e.g. regarding resistance. Procedures must be sufficiently precise, yet may not consume too much time or require highly detailed inputs. Ideally all variants should be evaluated with the same procedures.

The result of the optimization model should be compared against built ships. Consistent differences may help to identify important factors so far neglected in the model. A sensitivity analysis concerning the underlying estimation formulae will give a bandwidth of 'optimal' solutions and any design within this bandwidth must be considered as equivalent. If the bandwidth is too large, the optimization is insignificant.

A critical view on the results of optimization is recommended. But properly used optimization may guide us to better designs than merely reciprocating traditional designs. The ship main dimensions should be appropriately selected by a naval architect who understands the relationships of various variables and the pitfalls of optimization. An automatic optimization does not absolve the designer and his responsibility. It only supports him in his decisions. The result of the optimization model should be compared against built ships. Consistent differences may help to identify important factors so far neglected in the model.

This paper will focus on parametric ship hull development and design optimization of hull parameters operating in inland waterways of Bangladesh.

2. METHODOLOGY

This methodology describes an automatic optimization procedure of hull parameter to minimize the ship resistance within certain given constraints. The methodology shall be valid for inland vessels are performed as followed:

(a) Determination of initial ship hull parameters (i.e. Length, Breath, draught, Speed etc)
(b) Other hull parameter components calculation.
(c) Resistance calculation with different methods.
(d) Setup constrains for hull parameter optimization.
(e) Using Algorithm for hull parameter optimization.

2.1 Ship Hull Parameter

2.1.1 Length

A general consideration of hull resistance versus length shows that frictional resistance increases with length as the wetted surface increases faster than the frictional resistance coefficient declines with Reynolds number. The wave resistance, however, decreases with length. The net effect is that resistance as a function of ship length typically exhibits a board, flat minimum. Since the hull cost increases with length, an economic choice is usually a length at the lower end of this minimum region where the resistance begins to increase rapidly with further length reduction. Below this length higher propulsion requirements and higher operating cost will then offset any further reduction in hull capital cost. A number of approximate equation exits in the literature for estimating vessel length from other ship characteristics. In Posdunine's formula,

$$\mathrm{L(m)} = \mathrm{C}\left(\frac{\mathrm{V_K}}{\mathrm{V_K}+2}\right)^2 \Delta^{1/3}$$

Where,

Δ = Displacement (tones) and
V_K = Speed (knots) and
C = a coefficient can be generalized from similar vessels.

Another welknown formula for estimating vessel length is Schneekluth's [12] formula,

$$\mathrm{Lpp\ (m)} = \Delta^{0.3} * V^{0.3} * 3.2 * \frac{C_B + 0.5}{\left(\frac{0.145}{Fn}\right) + 0.5}$$

Where:

L_{PP} = length between perpendiculars [m]
Δ = displacement [tonne]
V = speed (knot)
Fn = = Froude number, $V/\sqrt{g.L}$

The formula is applicable for ships with $\Delta \geq 1000$ t and $0.16 \leq Fn \leq 0.32$.

Various non-dimensional ratios of hull dimensions can be used to guide the selection of hull dimension or alternatively used as a check on the dimension selected based upon similar ships, functional requirements etc. Each designer develops his or her own preferences, but generally the length-breath ratio L/B, and the breath-draught ratio B/D, prove to be most useful.

2.1.2 Breadth

Where width can be chosen arbitrarily, the width will be made just as large as the stability demand. For ships with restricted dimensions (particularly draught), the width required for stability is often exceed. A lower limit for breadth comes from requiring a minimum metacentric height and indirectly, a maximum possible draught. The metacentric height requirement formulation is an inequality requiring values which are frequiently obtained for some ships.The length-breath ratio can be used to check independent choices of length and breadth with initial length, a choice of L/B ratio can be used to obtain an estimated breadth . The L/B ratio has significant influence on hull resistance and maneuverability (both the ability to turn and directional stability). With the primary influence of length on capital cost, there has been a trend toward shorter wider hulls supported by design refinement to ensure adequate inflow to the propeller. From Watson and Gilfillan [10] recommendation,

L/B = 4.0 for L ≤ 30 m
L/B = 4.0 + 0.025 (L – 30) for 30 ≤ L ≤ 130 m
L/B = 6.5 for 130 m ≤ L

2.1.3 Draught

The third most important non dimensional ratio is the breadth-draught ratio B/T. The breath-draught ratio is primarily important through its influence on residuary resistance, transverse stability, and wetted surface. In general, values range between $2.25 \leq B/T \leq 3.75$. The breath-draught ratio correlates strongly with residuary resistance, which increases for large B/T. Recommendation for maximum breath-draught ratio by Roseman etal. [8] Is

$$(B/T)_{max} = 9.625 - 7.5\, C_B$$

2.1.4 Other Hull Form Parameter

Other hull parameter components are calculated using following formulae:

2.1.4.1 Block Coefficient

Well-known Alexander's formula for block coefficient, C_B is given by

$$\mathrm{C_B} = \mathrm{K} - 0.5\frac{\mathrm{V_K}}{\sqrt{\mathrm{L_f}}}$$

Where, $K=1.33 - 0.54\frac{V_K}{\sqrt{L_f}} + 0.24\left(\frac{\mathrm{V_K}}{\sqrt{\mathrm{L_f}}}\right)^2$

2.1.4.2 Midship coefficient (C_M)

Mid ship coefficient C_M is determined from Schneekluth and Bertram's [10] formula

$$\mathrm{C_M} = 1.006 - 0.0056\mathrm{C_B}^{-3.56}$$

$$\mathrm{C_M} = (1 + (1 - \mathrm{C_B})^{3.5})^{-1}$$

2.1.4.3 Prismatic coefficient ($\mathrm{C_P}$)

Prismatic coefficient from empirical relation of parameter

$$\mathrm{C_P} = \frac{\mathrm{C_B}}{\mathrm{C_M}}$$

2.1.4.4 Water plane coefficient ($\mathrm{C_{WP}}$)

Water plane coefficient from Schneekluth's and Bertram's [9] formula

$$\mathrm{C_{WP}} = \mathrm{C_P}^{\frac{2}{3}}$$

$$\mathrm{C_{WP}} = \frac{(1 + 2\frac{\mathrm{C_B}}{\mathrm{C_M}^{\frac{1}{2}}})}{3}$$

And from Riddlesworth's formula

$$\mathrm{C_{WP}} = \frac{(1 + 2\mathrm{C_B})}{3}$$

2.1.4.5 Longitudinal Center of Buoyancy (LCB)

Longitudinal Center of Buoyancy from Schneekluth and Bertram's [9] formula

$$\mathrm{LCB} = 8.80 - 38.9\mathrm{Fn}$$
$$\mathrm{LCB} = -13.5 + 19.4\mathrm{C_P}$$

2.2 Speed

The speed can be decisive for the economic efficiency of a ship and influences the main dimensions inturn. The speed is determined largely in accordance with the ideas and wishes of the ship owner, and is thus outside the control of the designer. The optimum speed, in economic terms, can be related both to favourable and to unfavourable Froude numbers. In General the trial speed will be considered the normal basis for the optimization. However, the service speed could be included in the optimization as an additional condition.

2.3 Regression Based Resistance Method

The various methods used in the resistance calculation are described below.

2.3.1 Holtrop Method

According to Holtrop's [2,3,4] formula

$$\mathrm{R_{Total}} = \mathrm{R}_F\,(1 + K_1) + \mathrm{R}_{APP} + \mathrm{R}_W + \mathrm{R}_B + \mathrm{R}_{TR} + \mathrm{R}_A$$

Where,

$\mathrm{R_{Total}}$ = Total Resistance

$\mathrm{R_F}$ = Viscous Resistance

$1+K_1$ = Form factor describing the viscous resistance.

$\mathrm{R_{APP}}$ = Appendage Resistance

$\mathrm{R_W}$ = Wave Resistance

$\mathrm{R_B}$ = Bow Resistance

$\mathrm{R_{TR}}$ = Transom Resistance

$\mathrm{R_A}$ = Model ship correlation Resistance

Viscous resistance $\mathrm{R_F} = \mathrm{C_F} * \frac{1}{2}\,\rho * S * V^2$

Viscous Coefficient [7] $\mathrm{C_F} = \frac{0.075}{[Log_{10}(Rn-2)]^2}$

Reynolds Number, $\mathrm{R_n} = \frac{V*L}{\gamma}$

Where, γ= Viscosity of water

Detailed will be obtained from Holtrop [2, 3, 4]

2.3.2 Hollenbach Method

According to Hollenbach's [1] formula

$$\mathrm{R_R} = \mathrm{C_R} * \frac{\rho}{2} * \mathrm{V}^2 * (\frac{\mathrm{B} * \mathrm{T}}{10})$$

Where,

$\mathrm{R_R}$= Residual Resistance

$\mathrm{C_R}$= Coefficient of Residual Resistance

$\mathrm{C_R} = \mathrm{C_{R,\,Standard}} * \mathrm{C_{R,\,Fnkrit}} * \mathrm{k_L} * (\mathrm{T/B})^{b1} * (\mathrm{B/L})^{b2} * (\mathrm{L_{os}/L_{wl}})^{b3} * (\mathrm{L_{wl}/L})^{b4} * (1+(\mathrm{T_A} - \mathrm{T_F})/\mathrm{L})^{b5} * (\mathrm{D_P/T_A})^{b6} * (1+\mathrm{N_{Rudd}})^{b7} * (1+\mathrm{N_{Brac}})^{b8} * (1+\mathrm{N_{Boss}})^{b9} * (1+\mathrm{N_{Thruster}})^{b10}$

$\mathrm{C_{R,\,Standard}} = c_{11} + c_{12}\mathrm{F_n} + c_{13}\mathrm{F_n}^2 + \mathrm{C_B} * (c_{21} + c_{22}\mathrm{F_n} + c_{23}\mathrm{F_n}^2) + \mathrm{C_B}^2 * (c_{31} + c_{32}\mathrm{F_n} + c_{33}\mathrm{F_n}^2)$

$\mathrm{C_{R,\,Fnkrit}} = \max(1.0, (\mathrm{F_n}/\mathrm{F_{n,\,krit}})^{f1}$

$\mathrm{F_{n,\,krit}} = d_1 + d_2\mathrm{C_B} + d_3\mathrm{C_B}^2$

$\mathrm{K_L} = e_1\mathrm{L}^{e2}$

Detail description will be obtained from Hollenbach's [1].

2.3.3 Van Oortmerssen Method

According to Oortmerssen's [5, 6] formula

$$\frac{\mathrm{R_R}}{\Delta} = \mathrm{C_R} = \mathrm{C_1} * e^{-mF_n^2/9} + \mathrm{C_2} * e^{-mF_n^{-2}} + \mathrm{C_3} * e^{-mF_n^2} * \sin F_n^{-2} + \mathrm{C_4} * e^{-mF_n^2} * \cos F_n^{-2}$$

$m = 0.14347 * \mathrm{C_P}^{-2.1976}$

Where,

$\mathrm{R_R}$= Residual Resistance

Δ= Displacement of Ship

$\mathrm{C_R}$ = Coefficient of Residual Resistance

Detail description will be obtained from Oortmerssen's [5, 6].

2.3 SQP Algorithm

The sequential quadratic programming (SQP) method is a general method for solving nonlinear optimization problem with constrains. Let the optimization problem be written as

Minimize $\mathrm{F[X]}$

Subject to $\mathrm{h_j[X]} = 0, \quad \mathrm{j} = 1, \mathrm{M_e}$

$\mathrm{g_j[X]} \le 0, \quad \mathrm{j} = \mathrm{M_e} + 1, \mathrm{M_i}$

Where F is an objective function, and $\mathrm{h_i}$ and $\mathrm{g_i}$ are equality and inequality constrains, respectively. When the current design point is $\mathrm{X^{(K)}}$, the next design point $\mathrm{X^{(K+1)}}$ is determined as follows. First, the following quadratic programming problem is solved to obtain the modification of **d.**

Minimize

$$\nabla\mathrm{F[\,X(K)\,]^T} \cdot \mathbf{d} + \frac{1}{2}\mathrm{d^T\,H^{(K)}} \cdot \mathbf{d}$$

Subject to

$$\mathrm{h_j}\left[\mathbf{X^{(K)}}\right] + \nabla\mathrm{h_j}\left[\mathbf{X^{(K)}}\right]^{\mathbf{T}} \cdot \mathbf{d} = \mathbf{0}, \qquad \mathrm{j} = 1, \mathrm{M_e}$$

$$g_j\left[X^{(K)}\right] + \nabla\mathrm{g_j}\left[\mathbf{X^{(K)}}\right]^{\mathbf{T}} \cdot \mathbf{d} \le \mathbf{0}, \qquad \mathrm{j} = 1 + \mathrm{M_e}, \mathrm{M_i}$$

Here, the objective function F is approximated as the quadratic function of $\mathrm{X^{(K)}}$, and the constrains are approximated as the linear functions of $\mathrm{X^{(K)}}$. H is an approximation to the Hessian matrix of the Lagrangian

$$H = \nabla^2 F + \sum_{j=1}^{M_e} u_j \nabla^2 h_j + \sum_{j=1}^{M_i} v_j \nabla^2 g_j$$

Where u = $(u_1, u_2, u_3 \ldots\ldots\ldots.)^T$ and v = $(v_1, v_2, v_3 \ldots\ldots\ldots.)^T$ are the Lagrangian multipliers for equality and inequality constrains, respectively.

The next design point $X^{(K+1)}$ is obtained by the line search along the vector d. The step-size d is determined in such a way that the penalty function with r, being a penalty parameter where

u = $(u_1, u_2, u_3 \ldots\ldots\ldots.)^T$ and

v = $(v_1, v_2, v_3 \ldots\ldots\ldots.)^T$ are the Lagrangian multipliers for equality and inequality constrains respectively.

The next design point $X^{(K+1)}$ is obtained by the line search along the vector d. The step-size **d** is determined in such a way that the penalty function with r, being a penalty parameter becomes smaller than a set value.

$$F[X] + r\langle \sum_{j=1}^{M_e} |h_j[X]| + \sum_{j=M_e+1}^{M_i} |min(0, g_j[X])| \rangle$$

Finally, the next design point is computed by

$$X^{(K+1)} = X^{(K)} + \delta^{(K)} d^{(K)}$$

The Hessian matrix is updated using the Broyden, Fletcher, Goldfarb, and Shanon (BFGS), as follows:

$$H^{(K+1)} = H^{(K)} + \frac{\gamma\gamma^K}{q^T s} - \frac{H^{(K)} s s^T H^{(K)}}{s^T H^{(K)} s}$$

Where $s = X^{(K+1)} - X^{(K)}$,

$$q = \nabla_x L^{(K+1)} - \nabla_x L^{(K)}$$

$$\nabla_x L = \nabla F + \sum_{j=1}^{M_e} u_j \nabla h_j + \sum_{j=1}^{M_i} v_j \nabla g_j +$$

$$\gamma = \theta q + (1 - \theta) H^K s$$

$$\theta = \begin{pmatrix} 1.0 & if\ q^T s \geq 0.2 S^T H^{(K)} s \\ \dfrac{0.8 s^T H^{(K)} s}{s^T H^{(K)} s - q^T s} & if\ q^T s < 0.2 s^T H^{(K)} s \end{pmatrix}$$

2.4. Design Variables and Constraints

For the inland waterways of Bangladesh, the Length, Breadth, and Draught are very much limited and sometimes speed. Generally optimization of ship hull is carried out at a particular speed such as trial speed, service speed etc. It is also possible to perform optimization for multiple speeds by increasing the objectives of multi-objective optimization. Hull optimization is based on minimization of ship resistance with following criterion. Table 1. Shows the objective function, design variable and design constraints in the optimization process.

Table 1. Objective function, Design variable and Design constraints of SQP.

Objective Function	Design Variable	Design Constraints
Resistance Coefficient	Length (L)	0<L<75m
	Breadth (B)	0<B<13.5m
	Draft (T)	0<T<3.5m
	Speed	10<V<15 knots
		2000<Displacement<2500 m^3

3. RESULTS AND DISCUSSION

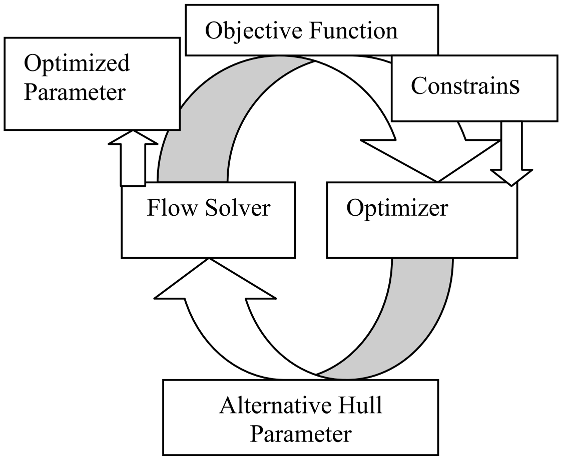

Figure-1: Optimization Process

A numerical method has been described for the hull parameter optimization of inland vessel operating in Bangladesh waterways with respect to ship resistance. Combining the numerical method for ship resistance with SQP program, improved design parameters can be generated through a series of iterative computations. The optimization process is described with above Figure-1.

Figure-2 shows the resistance vs. length and breadth of a typical ship for constant speed and draft. From this Figure it is shown that the resistance calculated by Holtrop method increases faster with the increase of breadth rather than ship length.

Figure 3 shows the convergence history of ship hull resistance in the optimization process of Holtrop, Hollenbach and Van Oortmerssen method. Table 2 describes the optimized ship hull parameters of Holtrop, Hollenbach and Van Oortmerssen method.

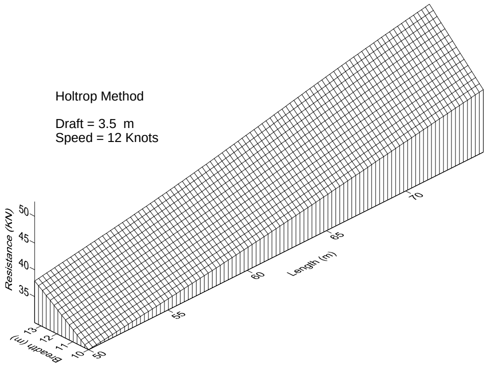

Figure-2: Resistance of a ship hull versus length and breadth by Holtrop method.

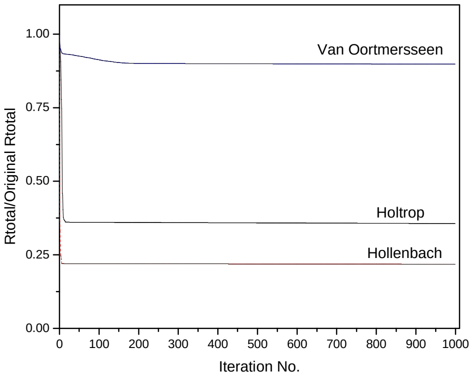

Figure-3: Convergence History of ship hull resistance by Holtrop, Hollenbach and Van Oortmerssen method

Table 2 Design parameters of optimized hull of different method

Ship Parameter	Initial Hull	Optimized Hull Parameter			
		Holtrop method	Hollenbach method	Van Oortmerssen method	
Length (m)	75.0	74.909	74.986	74.976	Design Variables and constrains for Optimization
Breadth (m)	13.5	11.04	13.056	12.72	
Draft (m)	3.50	3.037	2.986	3.342	
Speed (Knots)	15.0	10.00	10.00	14.10	
Block Coefficient	0.594	0.796	0.684	0.627	Others Calculated Parameters and constraints
Midship Coefficient	0.976	0.996	0.984	0.977	
Water Plane area Coefficient	0.734	0.865	0.793	0.757	
Prismatic Coefficient	0.608	0.799	0.695	0.643	
Displacement (m^3)	2105	2000	2000	2000	

4. CONCLUSION

An integrated methodology for the basic preliminary ship hull parameter evaluation and optimization of these parameters for inland waterways of Bangladesh has been presented. The waterways condition of Bangladesh has been limited the option of thinking about vessel of large dimensions. The main difficulty of the numerical optimization lies in formulating the objective function, design variables and all the constraints. The optimization problem has been carefully formulated to give a stable inspection of every approach. The constraints are based on the design parameter requirements. The objective function is normalized with respect to its initial value. For the optimization process, empirical formulae for the calculation of design parameter used. For more accurate or detailed optimization, require a more separate work. The methodology may be used in the preliminary design stages for selecting hull parameter of inland vessel operating in Bangladesh waterways.

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