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Reliability of attribute prediction in small craft concept design

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ABSTRACT: A multi-attribute concept design procedure, as developed at the University of Zagreb, is applied to the small craft. Specialized concept design models of several generic types, e.g. mono-hull ferry, catamaran ferry, fishing vessel, fast SAR, patrol and paramilitary craft, were developed and included into a multi-attribute design procedure. In the present paper we address concept design model of the fast mono-hull type service vessels. Calibration of the model is an important task if reliable results are expected. Here we will deal with the reliability of attribute prediction. Practical parametric equations for attribute prediction, based on the previous work, were developed from published empirical methods, from analytical first principle methods, and from the study of selected database vessels. The results of attribute prediction were systematically compared to database values. Best fitting equations are presented in order to make them widely available to small craft designers.

1 INTRODUCTION

1.1 *Background*

A multi-attribute concept design procedure is established as an aid in concept design of generic small craft type defined as: fast mono-hull of round bilge or hard chine form, with transom stern, with steel, aluminum or composite structure.

The procedure operates on the generic concept design model that is structured in advance and calibrated for the ship type in question.

1.2 *Concept design model*

At the level of concept design a parametric model is used. Direct "first principle" approach is not an option since hull form is defined only via dimension ratios and form coefficients, since design is not yet defined in enough detail.

In this paper we will demonstrate the concept design model for fast service vessels, named "SERVES". The types of vessels considered are e.g. patrol, police, SAR, customs, crew transfer, passenger, yacht, etc., consistent with database (Table 1).

Table 1. Types and number of vessel types in database.

Type of vessel	N	Type of vessel	N
CARGO	2	PATROL	70
CREW	5	PAX	12
FIRE	11	PILOT	20
FISH	3	RESEARCH	3
MEDIC	1	SAR	15
MIL	19	WORK	13
MYACHT	22	Total	196

1.3 *Multi-attribute design procedure*

For many years design optimization searched for unique optimum based on single criterion (e.g. minimal displacement). Development of operations research techniques leads to the possibility of having many optima. When dealing with multi-dimensional space of design attributes, Pareto approach selects only non-dominated ones by an objective procedure (Grubisic & Begovic, 2003). Selecting preferred design from the set of Pareto optimal designs has to be performed subjectively. This is why design is still dealing with human artistic talents. The idea is not to replace human designer by computer procedure but to use multi-attribute procedure to solve all objectively solvable conflicts and leave the rest (the most difficult ones) to the designer.

Each generic model consists of a number of modules that are responsible for predicting numerical values of design attributes. Comparison of the design attribute values is fundamental for decision making in the design space, through the process of elimination of dominated designs, resulting in multi-dimensional Pareto frontier. Thorough visualization of the design space helps the designer in decision-making focused on Pareto optimal designs only.

Design model is the core of the multi-attribute design procedure but design decisions are made outside the model. The black box approach would describe the design model as a transformer of input parameters into output attributes. Reliability of attribute prediction by the model is of paramount importance for the applicability of the whole procedure. Therefore, it is in the focus our interest in this paper.

1.4 *Parameters and attributes*

Design parameters define the problem (in this case, a ship) while design attributes describe the capabilities of the ship and serve as a basis in decision-making process.

Design parameters in our model comprise hull dimensions and coefficients, propulsion system, structural material, required capacities, etc.

Design attributes comprise maximal attainable speed, sailing range, sea-keeping attributes, cost from shipyard, etc.

1.5 *Variables and constraints*

Sub set of design parameters is varied while searching for optimal solutions, i.e., variables, e.g., length, beam, draft, depth, etc. Variables are controlled outside the model by the procedure or in some cases manually by the designer.

In the procedure of predicting design attributes the model generates many intermediate attributes that may not be required for selection purposes but that may be subject to restrictions. These attributes are used as constraints to eliminate undesirable designs (e.g., insufficient stability).

2 PARAMETRIC DESIGN MODEL

Parametric model was developed based on the database of 196 vessels (Table 1). The model is composed of parametric relations that predict attribute values based on input parameters or other attributes that were previously defined by the same model. Parametric equations are in greater part result of regression analysis of database vessels. Variability of the relations is described by standard deviation of the sample vessels.

Introducing standard deviation in the estimation process serves two purposes: firstly it demonstrates the variability of the particular parameter; secondly, since parameters are entered into relation that predicts attributes (or constraints) their variability may be estimated too.

Standard deviation is given for most parametric relations. It is common practice to estimate any parameter value to be within one standard deviation each side from the predicted value, e.g.:

$$L_{WL} \cdot 0{,}01 \cdot (100-\sigma) < L_{WL} < L_{WL} \cdot 0{,}01 \cdot (100+\sigma) \quad (1)$$

Sometimes it may be extended to two or even three standard deviations each way. In the practical implementation of the model in addition to the predicted value the upper and lower suggested values are given as guidance to designer. The procedure is used in two ways;

By imputing parameters of the known vessel it is possible to compare predicted values of attributes and so gain insight into reliability of vessel data.

By modifying suggested values of parameters it is possible to observe consistency and sensitivity of the model to input variation. At the same time a concept design of the vessel may be developed manually (without optimization).

When model is tested to designer's satisfaction it can be transferred into multi-attribute design procedure.

3 "SERVES" DESIGN MODEL

Design model "SERVES" is developed using attribute prediction methods (such as resistance, propeller, weights etc.) and parametric relations developed from database.

Database includes fast vessels having some of the generic characteristics needed for the service i.e. search and rescue, survey, pilot, patrol and other military and paramilitary service vessels, fire fighting, environmental and pollution control, etc. Some fast yachts and sport boats are also included in the database.

Formulations of the parametric relations used in the design model are developed from the available analytic and heuristic estimation methods for powering, sea-keeping, weight, cost estimating, etc. and are calibrated to fit database values.

For the purpose of testing the reliability of the model it was found convenient to program the formulae in spreadsheet. The advantage of spreadsheet approach is simple adjustments and additions to the procedure and quick graphical and tabular output that is easy to control.

Some important parts of the model are presented in sequel.

4 HULL PARAMETERS PREDICTION

Small vessels design starts from a set of requirements. The first one is usually the hull length (ISO 8666). Other parameters are related to length. When these parameters are selected, a number of further parameters are suggested and the design proceeds.

4.1 *Hull principal dimensions*

$$L_{WL} = 0{,}932 \cdot L_H - 0{,}576 \quad \sigma = 4{,}191\% \tag{2}$$

$$B_M = 0{,}932 \cdot {L_H}^{0{,}567} \quad \sigma = 11{,}216\% \tag{3}$$

Some parameters may be estimated using more than one relation. In this case the mean value is used. Beam at the section of maximal immersed area:

$$B_X = 0{,}900 \cdot B_M - 0{,}053 \quad \sigma = 3{,}967\% \tag{4}$$

$$B_X = 0{,}834 \cdot {L_{WL}}^{0{,}589} \quad \sigma = 11{,}331\% \tag{5}$$

Draft at the section of maximal immersed area:

$$T_X = 0{,}166 \cdot {B_X}^{1{,}214} \quad \sigma = 25{,}068\% \tag{6}$$

$$T_X = 0{,}128 \cdot {L_{WL}}^{0{,}725} \quad \sigma = 24{,}034\% \tag{7}$$

Depth at the section of maximal immersed area:

$$D_X = 0{,}497 \cdot {L_{WL}}^{0{,}564} \quad \sigma = 16{,}579\% \tag{8}$$

$$D_X = 0{,}548 \cdot {B_M}^{0{,}940} \quad \sigma = 17{,}342\% \tag{9}$$

$$D_X = 2{,}493 \cdot {T_X}^{0{,}582} \quad \sigma = 19{,}568\% \tag{10}$$

Transom immersion at rest:

$$T_{T(FNT=5)} = 0{,}7 \cdot \frac{{V_{\mathrm{MAX}}}^2}{962} \quad \sigma = 36\% \tag{11}$$

Full load displacement may be estimated from three relations:

$$W_{FL} = 0{,}058 \cdot {L_{WL}}^{2{,}256} \quad \sigma = 21{,}9\% \tag{12}$$

$$W_{FL} = 0{,}624 \cdot \left(L_{WL} \cdot B_X \cdot T_X\right)^{0{,}931} \quad \sigma = 21{,}31\% \tag{13}$$

$$W_{FL} = 0{,}459 \cdot \rho_{SW} \cdot L_{WL} \cdot B_X \cdot {F_N}^{-0{,}44} \quad \sigma = 28{,}33\% \tag{14}$$

Displacement volume is:

$$\nabla = \frac{W_{FL}}{\rho_{SW}} \tag{15}$$

Basic parameters defining hull dimensions are input by the designer within suggested minimal and maximal values.

4.2 *Hull form coefficients*

Hull form parameters developed by Begovic 1998 are used to define input for further hydrodynamic estimates.

$$C_P = 0{,}384 + 0{,}565 \cdot C_B \tag{16}$$

$$C_X = 0{,}29 + 0{,}918 \cdot C_B \tag{17}$$

Water plane related coefficients are found from:

$$C_{WP} = 0{,}47 \cdot C_P + 0{,}467 \tag{18}$$

$$C_{IL} = 1{,}66 \cdot C_{WP} - 0{,}73 \tag{19}$$

$$C_{IT} = 1{,}316 \cdot C_{WP} - 0{,}394 \tag{20}$$

Deadrise angle at the position of longitudinal center of buoyancy is found from relation (21):

$$\beta_X = 103{,}6 - 127 \cdot C_X \tag{21}$$

Centers of buoyancy and flotation are defined as:

$$X_{CB} = 63{,}21 - 28{,}44 \cdot C_P \tag{22}$$

$$X_{CF} = 24{,}19 - 0{,}396 \cdot X_{CB} \tag{23}$$

Height of center of buoyancy above base line is founded on the modification of Papmel's formula:

$$\overline{KB} = 0{,}961 \cdot T_X \cdot \left(1{,}048 - \frac{C_B}{C_B + C_{WP}}\right) \tag{24}$$

Immersed transom area is determined in static condition. A factor of 0,7 is applied to compensate for transom immersion due to dynamic trim:

$$\frac{A_T}{A_X} = 3{,}604 \cdot C_P - 1{,}941 \tag{25}$$

$$\frac{T_T}{T_X} = 0{,}028 + 0{,}986 \cdot \frac{A_T}{A_X} \tag{26}$$

Wetted surface is estimated by Taylor's formula where the coefficient is found by Begovic 1998.

$$C_S = 2{,}61 + \frac{\frac{B_X}{T_X} \cdot \left(\frac{B_X}{T_X} - 0{,}244\right)}{81} \tag{27}$$

$$S_{WS} = C_S \cdot \sqrt{L_{WL} \cdot \nabla} \tag{28}$$

All the relations are programmed in spreadsheet and used as guidance. A Townsin formula is found useful here although it was developed for large ships. The predicted value is compared to the block coefficient defined by volume, length, beam and draft that are input values.

$$C_B = 0{,}7 + 0{,}125 \cdot \tan^{1}\left(\frac{23 - 100 \cdot F_N}{4}\right) \quad (29)$$

Speed related Froude's numbers are found from:

$$F_N = \frac{0{,}5144 \cdot V_{\mathrm{MAX}}}{\sqrt{9{,}80665 \cdot L_{WL}}} \quad (30)$$

$$F_{N\nabla} = \frac{0{,}5144 \cdot V_{\mathrm{MAX}}}{\sqrt{9{,}80665 \cdot \sqrt[3]{\nabla}}} \quad (31)$$

5 SEA KEEPING MODEL

Sea keeping is obviously very important for "SERVES" vessels. There are human tolerances that should not be exceeded if effective operation of the vessel is expected. Estimating allowable crew exposure time, i.e. measuring sea-keeping quality of the vessel is solved by estimating vertical accelerations and subsequently estimating allowable crew exposure time according to ISO 2631/3.

5.1 *Acceleration prediction*

Acceleration prediction method, as amended by Lloyd's Register 1996, is used to predict an average of 1/100 of the maximal vertical acceleration (expressed in *g*) at the centre of gravity of the vessel in head sea:

$$a_{1/100} = 0{,}0015 \cdot \tau \cdot L_1 \cdot (H_1 + 0{,}084) \cdot (5 - 0{,}1 \cdot \beta_X) \cdot \Gamma^2 \quad (34)$$

Recalculated to the RMS value by equation we obtain RMS acceleration prediction as:

$$a_{RMS} = \frac{\tau \cdot L_1 \cdot (H_1 + 0{,}084) \cdot (5 - 0{,}1 \cdot \beta_X) \cdot \Gamma^2}{3737} \quad (32)$$

Where:

Where: $\Gamma = V_{\mathrm{MAX}} / \sqrt{L_{WL}}$; $L_1 = L_{WL}/B_x \cdot {B_X}^3/\Delta$;

and: $L_{WL}/B_X \geq 3$; $H_1 = H_{1/3}/B_X \geq 0{,}2$

$\beta_X \leq 30^\circ$ bottom deadrise angle at X_{CG};
$\tau \geq 3^\circ$ trim angle (temporarily set at 3 degrees)
The RMS acceleration is transformed to other statistics by the expression (33):

$$a_{1/N} = a_{RMS} \cdot (1 + \ln N) \quad (33)$$

We can now calculate a_{RMS} acceleration from $a_{1/100}$ by (34):

$$a_{RMS} = \frac{a_{1/100}}{5{,}605} \quad (34)$$

5.2 *Human tolerance to vertical acceleration*

Criterion of the human tolerance to vertical accelerations ISO 2631/3, is used to estimate maximal allowable time for the crew exposure to such accelerations. The tolerable exposure time in hours is approximated by the following relations for respective encounter frequency ranges:

$$0{,}1 \leq f_E \leq 0{,}315 \qquad t = \frac{0{,}5}{{a_{RMS}}^2} \quad (35)$$

$$0{,}315 < f_E < 0{,}63 \qquad t = \frac{14.486 \cdot f_E - 4.0631}{{a_{RMS}}^2} \quad (36)$$

Encounter frequency f_E in H_Z in head sea for the estimated modal period T_0 is defined as.

$$f_E = \frac{1}{T_0} - \frac{v \cdot \cos(\mu \cdot \pi/180)}{{T_0}^2 \cdot \frac{g}{2 \cdot \pi}} \quad (37)$$

The modal period in seconds for the Adriatic Sea is estimated by the following expression:

$$T_0 = 4{,}45 \cdot {H_{1/3}}^{0{,}406} \quad (38)$$

6 FREQUENCY OF WAVE HEIGHTS

Probabilities of exceeding significant wave heights in the Adriatic Sea are approximated the by simple Equation (39) and shown in Figure 1:

$$f(H_{1/3}) = \frac{103{,}13}{1 + \left(\frac{1 + H_{1/3}}{2}\right)^5} \quad [\%] \quad (39)$$

7 FREEBOARD

By analyzing freeboards at fore perpendicular from database vessels, the relation of the general exponential type was found applicable with coefficients as given in Table 2:

$$F_{FP} = a \cdot {L_{WL}}^b \quad (40)$$

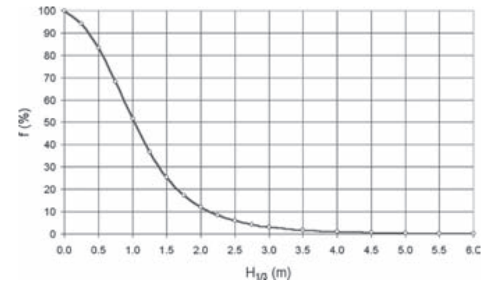

Figure 1. Probabilities of exceeding H1/3 in the Adriatic Sea.

Table 2. Freeboard at fore perpendicular.

Freeboard at F.P. (m)		
Navigating area	*a*	*b*
Protected waters	0,136	0,774
Coastal waters	0,206	0,707
Open ocean	0,329	0,642
Severe sea conditions	0,460	0,616

8 WEIGHT PREDICTION

Weight prediction method was studied in more details in Grubisic & Begovic 2009. Therefore, here only brief presentation is appropriate. Rule length and cubic number, respectively, are set as a basis for weight prediction.

$$L = 0{,}5 \cdot (L_H + L_{WL}) \tag{41}$$

$$C_N = L \cdot B_M \cdot D_X \tag{42}$$

Shell surfaces are estimated by:

$$S_1 = 2{,}8 \cdot \sqrt{W_{FL} \cdot L} \tag{43}$$

$$S_2 = 1{,}09 \cdot (2 \cdot L + B_M) \cdot (D_X - T_X) \tag{44}$$

$$S_3 = 0{,}823 \cdot L \cdot B_M \tag{45}$$

$$S_4 = 0{,}6 \cdot N_{WTB} \cdot B_M \cdot D_X \tag{46}$$

Reduced surface is:

$$S_R = S_1 + 0{,}73 \cdot S_2 + 0{,}69 \cdot S_3 + 0{,}65 \cdot S_4 \tag{47}$$

Hull structure weight numeral (analogous to Watson 1998) is corrected for displacement and for draft to depth ratio:

$$E_S = 2{,}75 \cdot S_R \cdot \left(0{,}292 + \frac{\nabla}{L_{WL}{}^2 - 15{,}8}\right) \cdot \left(\frac{T_X}{D_X}\right)^{0{,}244} \tag{48}$$

Hull material may be aluminum alloy or composite (FRP). Respective hull weight prediction is given by (49) and (50):

$$(W_{100})_{FRP} = \left(0{,}0135 \cdot G_f \cdot S_f - 0{,}0034\right) \cdot E_S{}^{1{,}33} \tag{49}$$

$$(W_{100})_{Al} = \left(0{,}002 + 0{,}0064 \cdot G_f \cdot S_f\right) \cdot E_S{}^{1{,}33} \tag{50}$$

Deckhouse weight is estimated by a form of cubic number for average deckhouse dimensions. Specific weight varies very little and may be taken as q = 21 kg/m^3 for aluminum and q = 23 kg/m^3 for FRP deckhouse structure, respectively.

$$W_{150} = q_{DH} \cdot L_{DH} \cdot B_{DH} \cdot H_{DH} \tag{51}$$

Propulsion machinery weight is divided in two parts. Weight of propulsion motor with appropriate gearbox is known since we start by defining candidate propulsion engine in advance. Therefore, engine weight (wet) including gears is defined by (52),

$$W_{250} = 1{,}07 \cdot N_{PR} \cdot W_{EGB} \tag{52}$$

The rest of propulsion machinery is related to ship size as given by (53)

$$W_{200-250} = \frac{C_N{}^{0{,}94}}{46} \tag{53}$$

Electrical power system weight is:

$$W_{300} = \frac{C_N{}^{1{,}24}}{592} \tag{54}$$

Electronic system weight is:

$$W_{400} = \frac{L^{2{,}254}}{1887} \tag{55}$$

Auxiliary machinery weight is:

$$W_{500} = \frac{(L \cdot B_M)^{1{,}784}}{1295} \tag{56}$$

Outfit weight is:

$$W_{600} = \frac{L^{2{,}132}}{103} \tag{57}$$

Special systems weight is:

$$W_{700} = \frac{C_N{}^{1{,}422}}{3000} \tag{58}$$

Light ship weight is obtained by summation of individual weights to which a margin is added. Here margin is presented as a single weight but it also can be distributed to individual component weights.

$$W_{LS} = W_{100} + W_{150} + W_{200-250} + W_{250} + W_{300} + W_{400} + W_{500} + W_{600} + W_{700} + W_{MAR} \quad (60)$$

Deadweight consists of crew and effects, fresh water, fuel oil and payload, as given by (61), while full load displacement is given by (62).

$$W_{DWT} = W_{PL} + W_{FO} + W_{FW} + W_{CR} \quad (61)$$

$$W_{FL} = W_{LS} + W_{DWT} \quad (62)$$

Since the full load displacement is known it is possible to solve equality constraint (i.e. Archimedes law) by defining residual weight found by subtracting all deadweight items, but one, from full load weight. In this way a fuel oil weight is chosen as residual weight (procedure was first suggested by Brower & Walker 1986).

$$W_{FO} = W_{FL} - \left(W_{LS} + W_{PL} + W_{FO} + W_{CR}\right) \quad (63)$$

From this fuel oil weight as defined by (63), the endurance range will be estimated and later used as attribute in decision-making.

9 RESISTANCE PREDICTION MODEL

Resistance prediction method was developed by Begovic 1998 from the data of 186 models of systematic series of fast craft. Resistance in calm sea condition follows an ITTC-57 approach.

Regression equation was developed after thorough investigation of possible solutions. Residual resistance is estimated by Equation (64) while appropriate coefficients are given in Table 6.

$$10^3 \cdot C_R = a_1 \cdot (M) + a_2 \cdot (M)^{a_0} + a_3 \cdot \frac{B_X}{T_X} + a_4 \cdot \frac{T_X}{B_X} + a_5 \cdot C_P + a_6 \cdot \frac{1}{C_P} + a_7 \cdot C_X + a_8 \cdot \frac{1}{C_X} + a_9 \cdot \frac{A_T}{A_X} + a_{10} \cdot C_S + a_{11} \cdot X_{CB} \quad (64)$$

Friction part is estimated by ITTC-57 formula with correlation addition.

$$C_F = \frac{0{,}075}{\log\left(R_N - 2\right)^2} \quad (65)$$

$$C_A = 0{,}0004 \quad (66)$$

$$C_T = C_F + C_R + C_A \quad (67)$$

$$R_T = 0{,}5 \cdot \rho \cdot v^2 \cdot S_{WS} \cdot C_T \quad (68)$$

Wetted surface is given by (28). The effective power is given by Equation (69).

$$P_E = 0{,}5 \cdot \rho_{SW} \cdot v^3 \cdot S_{WS} \cdot C_T \quad (69)$$

10 PROPULSION PARAMETRIC MODEL

Different propulsion solutions are possible and choice has to be made in order to produce realistic but not too complicated parametric model.

The non-cavitating propeller on inclined shaft (FPP) propulsion system is selected (Figure 2):

First estimate of propeller diameter may be done by a simple formula:

$$D_P = 12{,}54 \cdot \frac{\left(\frac{P_B}{V_{\mathrm{MAX}}}\right)^{0,25}}{\left(\frac{N_{ENG}}{G_R}\right)^{0,50}} \quad (70)$$

Propeller diameter is design parameter and so is the engine power (from the engine catalogue). The following value is calculated in order to eliminate revolutions from the equation:

$$\frac{K_Q}{J^3} = \frac{P_D}{2 \cdot \pi \cdot \rho_{SW} \cdot V_A{}^3 \cdot D_P^2} \quad (71)$$

Consequently the propeller is capable of producing thrust of:

$$T_{PR} = 2 \cdot \pi \cdot J_0^2 \cdot \eta_0 \cdot \rho_{SW} \cdot n_0^2 \cdot D_P^4 \cdot \left(\frac{K_Q}{J^3}\right) \quad (72)$$

Together the propellers are capable of overcoming resistance of:

$$R_{PR} = N_{PR} \cdot T_{PR} \cdot (1 - t) \quad (73)$$

Speed equilibrium is found from the intersection point of resistance and thrust force curves respectively. Overcoming the resistance hump is

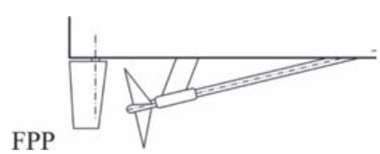

Figure 2. Propulsion configuration in the model.

controlled at the same time. Cavitation is checked by limiting maximal propeller load.

Optimal revolution rate is found from the relation:

$$n_0 = \frac{V_A}{J_0 \cdot D_P} \tag{74}$$

Since the purpose of multi-attribute optimization is to find optimal solutions, it is decided to use only data for optimal propellers. Therefore, parameters of the optimal propellers (i.e. having best efficiency η_0) are defined as dependent of K_Q/J^3. This is the so called "marine engineer's approach".

10.1 *Optimal fixed pitch propeller*

Optimal FPP is selected from the WB 5-75 methodical series of propellers. The equations for the optimal advance coefficient, optimal efficiency and optimal pitch ratio, respectively, are:

$$J_0 = 0{,}1353 \cdot \exp\left(0{,}62949 \cdot \frac{K_Q}{J^3}\right) \cdot \left(\frac{K_Q}{J^3}\right)^{-0{,}55706} \tag{75}$$

$$\eta_0 = 0{,}63 \cdot \exp\left(-2{,}393 \cdot \frac{K_Q}{J^3}\right) \cdot \left(\frac{K_Q}{J^3}\right)^{-0{,}05101} \tag{76}$$

$$\left(\frac{P}{D}\right)_0 = 0{,}1885 \cdot \exp\left(0{,}9183 \cdot \frac{K_Q}{J^3}\right) \cdot \left(\frac{K_Q}{J^3}\right)^{-0{,}5068} \tag{77}$$

Cavitation is checked by an adapted Keller's formula:

$$\frac{A_E}{A_0} = \frac{0{,}2855 \cdot T_{PR}}{{D_P}^2 \cdot \left(10159 + 1025 \cdot D_P\right)} \tag{78}$$

This approach to propeller design is greatly simplified. Also, it assumes that all propellers are 5-bladed and optimal. The advantage of this approach is that estimation is much more realistic than approximate regression formula.

11 EQUILIBRIUM SPEED

Equilibrium speed is found by intersecting required propulsive power curve from resistance and curve of propulsive power provided by propulsion system (Figure 3) and Table 6.

If the model is applied to testing known vessel the equilibrium speed when compared to known speed is in most cases within 1 knot either side.

12 EXAMPLE OF THE APPLICATION

Application of the model to design of service vessel is presented in short. When program is started designer enters parameter values as guided by the lower and upper suggested values from parametric relations with one standard deviation. The model calculates attribute values that may be inspected by designer and parameters adjusted in desired direction. Propulsion engine is treated as parameter, since it is selected from a catalogue

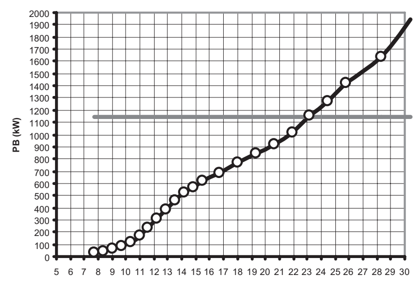

Figure 3. Speed prediction for given power.

Table 3. Design parameters.

Design parameters				Suggested range		
				mean-σ	mean	mean+σ
Hull length, ISO 8666	L_H =	19,80	m	17,03	17,78	18,52
Length on DWL	L_{WL} =	17,92	m	4,50	5,07	5,63
Beam molded	B_M =	5,49	m	4,05	4,73	5,08
Beam at DWL m. sec.	B_X =	4,62	m	0,79	1,05	1,33
Draft at DWL m. sec.	T_X =	1,00	m	0,27	0,42	0,57
Draft at transom	T_T =	0,73	m	2,01	2,58	3,19
Depth amidships	D_X =	2,86	m	28,83	39,10	51,62
Full load displ.	W_{FL} =	45,18	t	0,76	0,85	0,92
Propeller diameter	D_P =	0,86	m	–	–	–
Service speed	V_S =	20,0	kn			
Service type(LR SSC)	G_f =	1,20	–			
Service area(LR SSC)	S_f =	0,75	–			
Significant wave hight	H_S =	1,00	m			

Table 4. Propulsion system parameters.

Propulsion system			
Number of propulsors	N_{PR} =	3	
Engine make		DD	
Engine model		8V-92TI	
Rating (A,B,C,D,E)		E	
Brake power (1 engine)	P_{MCR} =	380	kW
Engine revolutions	n_{RPM} =	2300	rpm
Spec. fuel consumption at MCR	SFC =	225	g/kWh
Dry engine weight	W_{ENG} =	1871	kg
Reduction ratio:	R_{GB} =	2,140	
Gearbox weight	W_{GB} =	0	kg
Prop. revolutions	n_{PROP} =	1074	rpm
Weight (eng.+gearbox)	W_{EGB} =	1871	kg

Table 5. Design attributes.

Design attributes			
Max. speed at full load	V_{MAX} =	23,1	kn
Range at V_{MAX} and full load	R_{VMAX} =	198	NM
Free rolling period	T_R =	5,522	s
Average vert. acceleration at CG	a_{vcg} =	0,202	g
Average MSI amidships	MSI =	5,356	%
Cost of new vessel	C_{NEW} =	1,12	10^6EUR
Range at service speed	R_{VS} =	235	NM

Table 6. Coefficients in resistance prediction equation.

FN	a_0	(M)	$10^3(M)^a{}_0$	B_X/T_X	T_X/B_X	C_P	$1/C_P$	C_X	$1/C_X$	A_T/A_X	CS	XCB
0,300	–2,0033	–0,0302	0,1160	–0,2554	–2,2155	9,5150	–4,4203	0,9043	0,6740	0,1026	0,3102	1,2057
0,325	–2,1363	–0,1545	0,1299	–0,2169	–1,7831	13,2405	–2,4283	–2,4336	–0,5496	0,2162	0,2026	1,5535
0,350	–2,2091	–0,2648	0,1435	–0,2218	–2,2652	17,5872	0,6158	–6,1572	–2,2303	0,2420	0,1888	–0,7701
0,375	–2,3607	–0,3829	0,1972	–0,2112	–2,8829	19,3376	2,9282	–8,0751	–3,0708	0,3759	0,0319	–1,5740
0,400	–2,6227	–0,5824	0,3426	–0,1712	–3,1400	18,3604	4,6144	–7,0937	–2,4535	0,7070	–0,5766	–1,7701
0,425	–2,9501	–0,7867	0,7429	–0,2030	–3,6079	14,3357	5,0395	–3,9873	–0,7411	0,9529	–1,0032	–0,5568
0,450	–3,2556	–0,8459	1,7045	–0,2561	–4,2613	11,0344	4,7138	–1,6198	0,7122	0,8623	–1,2437	0,1638
0,475	–3,4680	–0,7567	3,1456	–0,2785	–4,2412	10,0301	4,2966	–2,0030	0,6803	0,6249	–1,3483	2,4205
0,500	–3,6144	–0,6287	4,7066	–0,3232	–4,0263	10,7938	4,4846	–3,7698	–0,2700	0,2803	–1,2244	3,1624
0,525	–3,6866	–0,4828	5,8084	–0,3647	–3,7365	11,7352	4,7535	–5,5669	–1,3682	–0,1246	–1,0204	3,0753
0,550	–3,7140	–0,3604	6,2901	–0,4222	–4,1540	11,8956	4,7434	–6,2087	–1,8846	–0,4675	–0,8470	2,7206
0,575	–3,7109	–0,2990	6,1513	–0,4210	–4,0295	11,2606	4,4412	–5,7545	–1,7466	–0,7423	–0,8773	2,4430
0,600	–3,6819	–0,2832	5,5494	–0,4048	–3,8506	10,2773	4,0439	–4,9607	–1,3513	–0,9304	–0,9174	2,5033
0,650	–3,5869	–0,1892	4,2117	–0,3528	–2,6535	11,4413	4,6059	–7,8489	–3,2987	–1,0453	–0,7941	5,7932
0,700	–3,5050	–0,1564	3,2362	–0,3291	–2,3234	8,2838	3,4592	–6,5322	–2,6076	–0,7594	–0,6514	7,7023
0,750	–3,4223	–0,1131	2,5297	–0,2335	–1,6660	6,2947	3,1352	–5,0405	–1,9353	–0,5998	–0,6994	4,9903
0,800	–3,3539	–0,1102	2,0077	–0,2224	–1,5763	3,8169	2,2106	–2,8089	–1,0797	–0,7109	–0,4811	4,0024
0,850	–3,2810	–0,1053	1,5927	–0,2047	–1,6509	2,4737	1,7671	–2,1359	–0,6994	–0,6380	–0,4611	4,8189
0,900	–3,2587	–0,0447	1,4585	–0,1272	–0,9127	–4,2954	0,1523	–1,8058	–0,8161	0,4907	–0,0122	13,8171
0,950	–3,2224	–0,0579	1,2518	–0,1391	–1,1900	–4,7218	–0,0114	–1,7593	–0,8418	0,4201	0,1479	14,7206
1,000	–3,1866	–0,0466	1,1347	–0,1514	–1,2209	–4,2391	0,3471	–2,7290	–1,3391	0,3523	0,2537	15,2100
1,100	–2,8618	0,0145	0,6633	–0,3661	–2,5015	–0,2994	0,8506	–3,2656	–2,2907	–1,2979	1,5258	5,8639
1,200	–2,7672	0,0456	0,6012	–0,3622	–1,8096	–2,9093	–0,4715	–4,0406	–2,9293	–2,9151	2,4136	12,2215

(*Continued*)

Table 6. (*Continued*).

Fnv	vms	vkn	Rn	C_F	C_R	C_T	R_T	P_E	QPC	P_D	P_B	dif	cross
0,6757	3,977	7,731	5,99E+07	2,25E–03	5,78E–03	8,03E–03	4941	19,7	0,55	35,7	1140	1104,3	0,00
0,7320	4,308	8,375	6,49E+07	2,22E–03	6,22E–03	8,44E–03	6095	26,3	0,55	47,7	1140	1092,3	0,00
0,7883	4,640	9,019	6,99E+07	2,20E–03	6,75E–03	8,94E–03	7494	34,8	0,55	63,2	1140	1076,8	0,00
0,8446	4,971	9,663	7,49E+07	2,17E–03	7,67E–03	9,84E–03	9463	47,0	0,55	85,5	1140	1054,5	0,00
0,9009	5,303	10,307	7,99E+07	2,15E–03	9,20E–03	1,14E–02	12429	65,9	0,55	119,8	1140	1020,2	0,00
0,9572	5,634	10,952	8,49E+07	2,13E–03	1,13E–02	1,34E–02	16584	93,4	0,55	169,9	1140	970,1	0,00
1,0136	5,965	11,596	8,99E+07	2,12E–03	1,36E–02	1,58E–02	21816	130,1	0,55	236,6	1140	903,4	0,00
1,0699	6,297	12,240	9,49E+07	2,10E–03	1,56E–02	1,77E–02	27260	171,7	0,55	312,1	1140	827,9	0,00
1,1262	6,628	12,884	9,99E+07	2,08E–03	1,67E–02	1,88E–02	32133	213,0	0,55	387,3	1140	752,7	0,00
1,1825	6,960	13,529	1,05E+08	2,07E–03	1,71E–02	1,91E–02	36086	251,1	0,55	456,6	1140	683,4	0,00
1,2388	7,291	14,173	1,10E+08	2,06E–03	1,69E–02	1,89E–02	39138	285,4	0,55	518,8	1140	621,2	0,00
1,2951	7,622	14,817	1,15E+08	2,04E–03	1,62E–02	1,82E–02	41257	314,5	0,55	571,8	1140	568,2	0,00
1,3514	7,954	15,461	1,20E+08	2,03E–03	1,52E–02	1,73E–02	42542	338,4	0,55	615,2	1140	524,8	0,00
1,4640	8,617	16,750	1,30E+08	2,01E–03	1,32E–02	1,52E–02	43995	379,1	0,55	689,3	1140	450,7	0,00
1,5766	9,280	18,038	1,40E+08	1,99E–03	1,16E–02	1,35E–02	45409	421,4	0,55	766,1	1140	373,9	0,00
1,6893	9,942	19,326	1,50E+08	1,97E–03	1,02E–02	1,21E–02	46655	463,9	0,55	843,4	1140	296,6	0,00
1,8019	10,605	20,615	1,60E+08	1,95E–03	9,00E–03	1,09E–02	47920	508,2	0,55	924,0	1140	216,0	0,00
1,9145	11,268	21,903	1,70E+08	1,93E–03	8,08E–03	1,00E–02	49476	557,5	0,55	1013,6	1140	126,4	23,07
2,0271	11,931	23,192	1,80E+08	1,92E–03	7,68E–03	9,59E–03	53147	634,1	0,55	1152,9	1140	–12,9	0,00
2,1397	12,594	24,480	1,90E+08	1,90E–03	7,10E–03	9,00E–03	55559	699,7	0,55	1272,2	1140	–132,2	0,00
2,2523	13,257	25,769	2,00E+08	1,89E–03	6,75E–03	8,64E–03	59071	783,1	0,55	1423,8	1140	–283,8	0,00
2,4776	14,582	28,345	2,20E+08	1,86E–03	5,60E–03	7,46E–03	61775	900,8	0,55	1637,9	1140	–497,9	0,00
2,7028	15,908	30,922	2,40E+08	1,84E–03	5,27E–03	7,12E–03	70082	1114,9	0,55	2027,0	1140	–887,0	0,00
													V_{MAX} =23,07

of candidate engines. Usually designer has quite limited choice of engines and preparing such catalogue is not difficult task. Since results are obtained quickly it is possible to try all candidate engines in short time. A design of fisheries inspection vessel for Adriatic Sea is shown in sequel (Tables 3, 4 and 5):

Design attributes as predicted by the model contain maximal speed that is found in Table 6.

The model quickly predicts attributes for a number of propulsion configurations, different structural materials, etc.

13 CONCLUSIONS

The proposed model of fast service vessels, "SERVES", may be used in several ways:

1. Control of vessel data before inclusion into the database, in order to check for possible errors of data from literature.
2. Concept design of new vessel by manually adjusting design parameters and judging design attributes.
3. Main purpose of the model is inclusion into multi-attribute design procedure. To this end it is possible to test the reliability of the model by comparison to the database vessels.
4. Finally, reliability of all prediction formulas and respective empirical or semi empirical formulas and methods may be tested and quick adaptations made.

The model is programmed in MS EXCEL in order to make it widely available and useful to small design offices where many design calculations are performed in spreadsheet form. The version that is included in the multi-attribute platform is reprogrammed in FORTRAN to make it compatible to the rest of our software.

14 NOMENCLATURE

A_T/A_X	Transom area ratio
a_{vcg}	Average vertical acceleration amidships (g)
B_X	Beam at DWL at section of max. immersed area (m)
B_M	Hull moulded beam
β_X	Dead rise angle amidships (^{0})
C_{NEW}	Acquisition cost of new vessel in 10^6 EUR
∇	Displacement volume (m^3)
D_P	Propeller diameter (m)
D_X	Hull depth (m)
$H_{1/3}$	Significant wave height (m)
MSI	Averaged motion sickness incidence (%)
L_H	Length over deck (ISO 8666) (m)
L_{WL}	Length on DWL at full load (m)
P_B	Total installed power (kW)
R_{VMAX}	Sailing range at maximal speed (NM)
R_{VS}	Sailing range at service speed (NM)
T_R	Free rolling period (s)
V_{MAX}	Maximal speed at full load (kn)
V_S	Service speed at full load (kn)
W_{FL}	Full load displacement (t)

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