Development of Basic Design Tool for High Speed Planing Craft

Naoki Tsuno* (Toyama National College of Technology, Japan)
Makoto Endo (Toyama National College of Technology, Japan)

Abstract

A basic design software tool for high speed planing crafts was developed. This basic design tool consists of following three functions;

1) To estimate adequate principal dimensions and hull elements for a high speed planing craft based on hull form statistical characteristics of the high speed planing crafts.
2) To create the Lines of the above craft based on the above estimated principal dimensions and hull elements.
3) To estimate resistance and propulsive performance of the above craft by means of the statistical approximate formulas on the resistance and propulsive performance for the high speed planing crafts.

The validation of the software was performed by comparing the estimated values with the measured values on principal dimensions, hull elements and performances of the real high speed planing crafts. It was become clear that the developed software as a basic design tool for high speed planing crafts had reached the stage for practical use.

1. INTRODUCTION

In Japan, the high speed planing crafts were used for fisheries, maritime industry and marine recreation sports, and many crafts are built every year. The high speed planing crafts had been usually designed by means of designer's empirical knowledge. Scientific verification and confirmation on resistance and propulsive performance of designed high speed planing crafts were hardly performed, because the cost for designing and building crafts was usually not enough to cover a cost amount for performing model tests and also a towing tank facility to perform experimental verification for the high speed planing crafts was hardly found.

In this study, a basic design software tool for high speed planing crafts was developed. The functions of this software are able to estimate principal dimensions, hull elements, resistance and propulsive performance of a high speed planing craft. The validation of the software was performed by comparing the estimated values with the measured values on principal dimensions, hull elements and performances of the real high speed planing crafts. The practical usefulness of the developed basic design software tool for high speed planing crafts was confirmed.

2. HIGH SPEED PLANING CRAFT

Fig. 1 shows a typical wave making resistance curve on a displacement hull[4]. As is evident from Fig. 1, when the Froude Number: Fn of the vessel is around 0.5, its wave making resistance reaches its peak. The top of the curve is called last hump. High speed planing craft were defined as crafts or boats, which run at a speed of exceeding the last hump with planing operation.

A typical hull form of high speed planing crafts is hard-chine hull. Photo 1 shows a front view of high speed planing craft. Fig. 2 and Fig. 3 show the Lines of the above craft which is drawn by a ship design CAD software: Autoship. The characteristic of the hull form is to produce lift force on the bottom, which bears the weight of high speed planing craft. The corner or edge between bottom plates and side plates is called as Chines.

* Advanced Course Student at Toyama National College of Technology

shomuka@toyama-nct.ac.jp

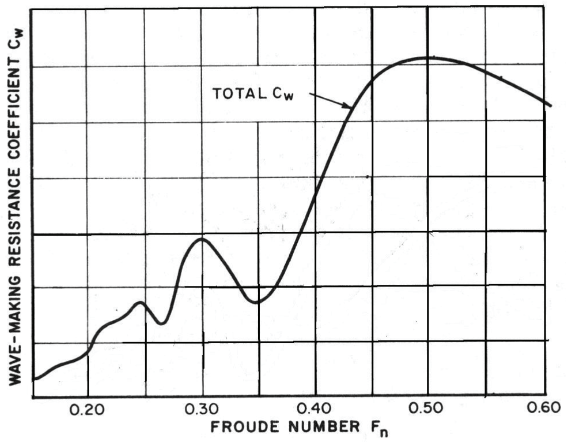


Fig.1 Wave making resistance[4)]

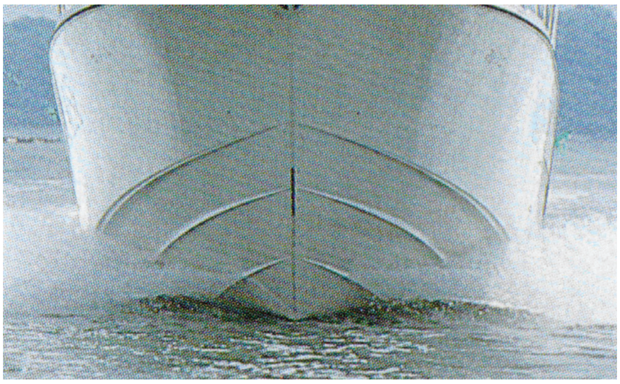


Photo 1 Front view of high speed planing craft

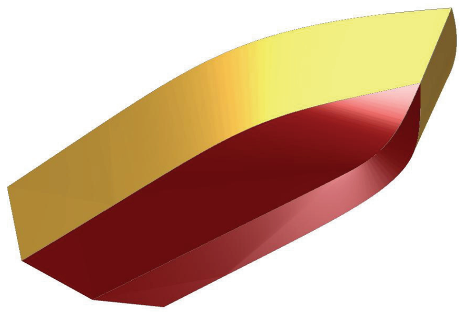


Fig.2 3D view of high speed planing craft

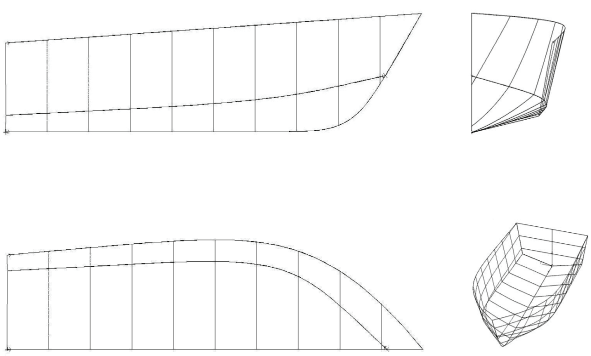


Fig.3 The Lines of high speed planing craft

3. CHARACTERISTICS OF HULL FORM AND PERFORMACE OF HIGH SPEED PLANING CRAFT

This section discusses characteristics of hull form (principal dimensions and hull elements) and performances (resistance and propulsive performance) of hard-chine craft[1),2),3)]. The definitions of the principal dimensions and hull elements (L, B, Bc, β , βt, Ff) are described in Appendix-1.

3.1 Statistical characteristics of hull form

3.1.1 Principal dimensions(L, Δ, Vs, B, D, d)

<u>Length: *L* and Displacement: Δ</u>

Length: L and Displacement: Δ are most important hull form elements, which have an influence on resistance performance of the high speed planing crafts. There is a strong correlation between Length: L and Displacement: Δ of the high speed planing crafts. Fig. 4 shows the above correlation.

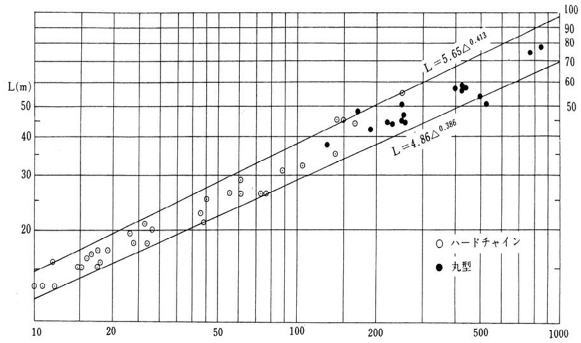


Fig.4 The correlation between Length: L and Displacement: Δ [1)]

<u>Length: *L* and Breadth: *B*</u>

Length: L and Breadth: B are hull form elements, which have an influence on stability of the high speed planing crafts. There is a specific correlation between Length: L and Breadth: B of the high speed planing crafts.

<u>Length: *L* and Depth: *D*</u>

Length: L and Depth: D are hull form elements, which control hull strength of the high speed planing crafts. There is a specific correlation between Length: L and Depth: D.

Figure A-1 to A-5 in Appendix-2 show correlations of principal dimensions. There are also specific correlations among other principal dimensions of the high speed planing crafts.

3.1.2 Hull elements on planing surface (*Bc*, *Bct*, β, βt)

The planing surface of the high speed planing craft is to produce the lift force which supports her weight. The planing surface is very important hull form elements to control the resistance performance of the high speed planing craft.

Chine Breadth: *Bc*

A rough area estimate of the planing surface of a high speed planing craft is found by the product of Chine Breadth: *Bc* and Length: *L*. Chine Breadth: *Bc* is an important element of the planing surface to produce enough lift force for the high speed planing craft. There is a specific correlation between Chine Breadth: *Bc* and Length: *L* of the high speed planing crafts. Fig. 5 shows the correlation between Chine Breadth: *Bc* and Length: *L*.

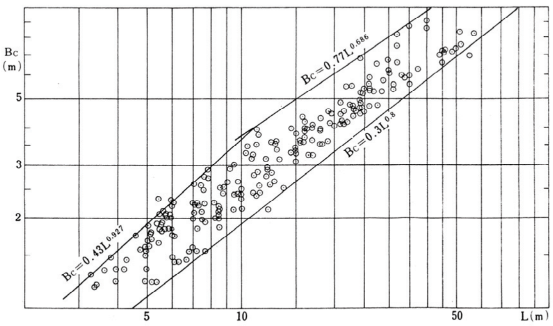


Fig.5 The correlation between Chine Breadth: *Bc* and Length: *L*[1)]

Deadrise angle: β, βt

The planing surface with no Deadrise Angles: β, βt is most effective at producing lift force for the high speed planing craft. But Deadrise Angles: β, βt of the above crafts are required in order to keep her course and secure her seakeeping quality in waves. There are specific correlations among Chine Breadth: *Bc*, Chine height: *hc* and Deadrise Angle at Transom: βt, which was shown in Fig. A-13 in Appendix-2, of the high speed planing crafts.

Breadth of Transom Chine: *Bct* and Length to Center of Gravity: L_G

Breadth of Transom Chine: *Bct* and Length to Center of Gravity: L_G have an influence on resistance performance. There is a specific correlation between Breadth of Transom Chine: *Bct* and Length to Center of Gravity: L_G.

Figure A-6 to A-13 in Appendix-2 show correlations of hull elements of the high speed planing crafts.

3.1.3 Hull elements on seakeeping (*Ff*, *Ffc*, α)

Freeboard of Fore Chine: *Ffc*, Fore Freeboard: *Ff* and Stem Slope: α of a high speed planing crafts are hull elements, which control her seakeeping quality in waves.

Freeboard of Fore Chine: *Ffc* and Fore Freeboard: *Ff*

Fig. 6 shows a correlation between Freeboard of Fore Chine: *Ffc* and Length: *L*.

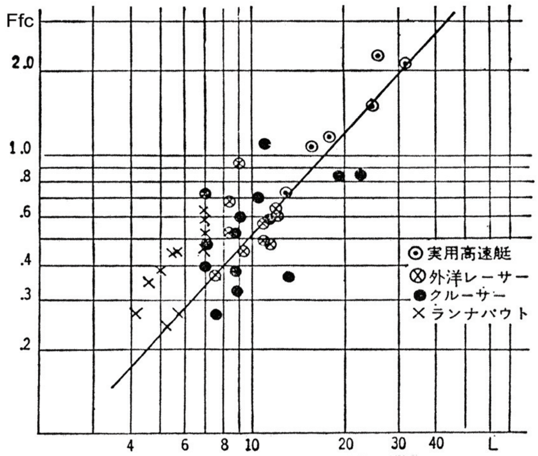


Fig.6 The correlation between Freeboard of Fore Chine: *Ffc* and Length: *L*[1)]

Fig. A-14 in Appendix-2 shows a correlation between Fore Freeboard: *Ff* and Displacement: Δ.

Stem slope: α of a high speed planing craft affects her seakeeping ability in waves. It is expected to reduce the spray which is occurred at high speed. Fig. A-15 shows a distribution of stem slope: α.

3.2 Resistance and propulsive performance of high speed planing craft

Resistance and propulsive performance of the high speed planing crafts can be statistically estimated from principal dimensions and hull elements[2),3)]. The resistance of high speed planing crafts consists of following two elemental resistances;

1) Hull resistance: R_H is an elemental resistance caused by the bare hull without any appendage like as a rudder and a shaft.

2) Auxiliary resistance: R_A is an elemental resistance caused by rudder(s), shaft(s) and shaft bracket(s).

Hull resistance: R_H can be calculated by means of a polynomial with fourteen terms on four variables, which are derived from the five hull elements. Auxiliary resistance: R_A can be also calculated by means of the frictional resistance including the form resistance on rudder(s), shaft(s) and shaft bracket(s).

3.2.1 Hull resistance: R_H

The polynomial which estimates hull resistance: Y per displacement is expressed in equation (1).

$$\begin{aligned} Y = &\alpha_1 \cdot X_1 + \alpha_2 \cdot X_2 + \alpha_3 \cdot X_3 + \alpha_4 \cdot X_4 + \\ &\alpha_5 \cdot X_1^2 + \alpha_6 \cdot X_2^2 + \alpha_7 \cdot X_3^2 + \alpha_8 \cdot X_4^2 + \\ &\alpha_9 \cdot X_1 \cdot X_2 + \alpha_{10} \cdot X_1 \cdot X_4 + \alpha_{11} \cdot X_1^3 + \\ &\alpha_{12} \cdot X_1^2 \cdot X_2 + \alpha_{13} \cdot X_1 \cdot X_2^2 + \alpha_0 \end{aligned} \quad (1)$$

Variables: X_1, X_2, X_3, X_4 are defined as the following equation (2).

$$\begin{aligned} X_1 &= 0.1(L_G/\nabla^{1/3} - 2.6589)/0.37900 \\ X_2 &= 0.1(L/L_G - 2.5729)/0.21541 \\ X_3 &= 0.1(\beta \mathrm{t} - 10.4429)/7.0137 \\ X_1 &= 0.1(Bct/\nabla^{1/3} - 1.2303)/0.15041 \end{aligned} \quad (2)$$

Fourteen coefficients: $\alpha_0 \sim \alpha_{13}$ are multiple regression coefficients, which are given as tabulated data[2)3)] on each Deadrise Angle of Transom: βt and Volume Froude Number: F_{nV}. If the displacement: Δ differs from 50t, the correction of frictional resistance is calculated by frictional resistance correction coefficient: C_{R_Δ}. This coefficients: C_{R_Δ} is also given as tabulated data[2)3)] on each Volume Froude Number: F_{nV}, Length: L, Displacement: Δ, and Volume Length Ratio: $L/\nabla^{1/3}$.
The total of hull resistance: R_H of the high speed planing craft is expressed in equation (3).

$$R_H = C_{R\Delta} \cdot \Delta \cdot Y \quad (3)$$

3.2.2 Auxiliary resistance: R_A

Auxiliary resistance: R_A is estimated from frictional resistance including form resistance on rudder(s), shaft(s) and shaft bracket(s), and expressed in equation (4).

$$R_A = FF_A \cdot C_F \cdot 1/2\, \rho\, S_A\, V_S^2 \quad (4)$$

FF_A (Form factor coefficient), S_A (total surface area of rudder, shaft and shaft bracket) and C_F (frictional resistance coefficient) are determined by following equations.

$$\begin{aligned} C_F &= 0.463 \left(\log_{10} R_{nA}\right)^{-2.6} \\ R_{nA} &= V_S \cdot L_A / \nu, \quad L_A = \sqrt{S_A / n} \\ FF_A &= (1+K) = 1.2 + 0.17\theta \end{aligned} \quad (5)$$

where n: Number of shafts
θ : Angle of inclination of shaft [deg].

3.2.3 Propulsive performance: η_{PC}

Propulsive performance: η_{PC} is expressed in formula (6).

$$\begin{aligned} \eta_{PC} &= \eta_t \cdot \eta_r \cdot \eta_o \cdot \eta_h \\ \eta_h &= (1-t)/(1-w) \end{aligned} \quad (6)$$

where η_t : Transmission efficiency = 0.95
η_r : Relative rotative efficiency
η_o : Propeller efficiency = 0.6
η_h : Hull efficiency
t : Thrust-deduction faction
w : Wake fraction.

η_r (Relative rotative efficiency), t (Thrust-deduction faction) and w (Wake fraction) are estimated from result of model test which are shown in Figure A-16, A17 and A-18.

4. BASIC DESIGN TOOL FOR HIGH SPEED PLANING CRAFT

In this section, a basic design software tool for high speed planing crafts is explained. This software is to estimate principal dimensions and hull elements and calculate resistance and propulsive performance.

4.1 Flow chart of basic design tool for high speed planing craft

Fig. 7 shows the flow chart of developed basic design software for high speed planing craft. Inputs of this software are the major specifications, which are Speed: Vs, Length: L or Displacement: Δ. Main functions of the developed software are as follows;

1) To estimate adequate principal dimensions and hull elements for a high speed planing craft based on hull form statistical characteristics of the high speed planing crafts.

2) To create the Lines of the above craft.

3) To estimate resistance and propulsive performance of the above craft by means of the statistical approximate formulas on the resistance and propulsive performance for the high speed planing crafts.

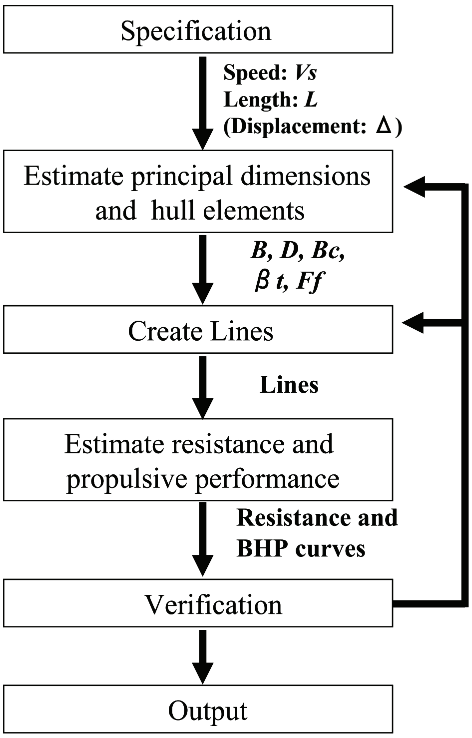


Fig.7 Flow chart of basic design process

4.2 To estimate adequate principal dimensions and hull elements for a high speed planing craft

In order to estimate adequate principal dimensions and hull elements for a high speed planing craft, the following approximate formulas, which typify hull form statistical characteristics of the high speed planing crafts, were derived from the figures shown in Fig. 4, Fig. 5, Fig. 6 and Appendix-2.

4.2.1 principal dimensions

1) Displacement: Δ

$$\Delta = 0.0159297 \times L^{2.59594} \qquad (7\text{-}1)$$

Equation (7-1) was derived from Fig. 4.

2) Breadth: B

$$B = 0.693944 \times L^{0.666051} \qquad (7\text{-}2)$$

Equation (7-2) was derived from Fig. A-1.

3) Depth: D

$$D = (D_1 + D_2)/2$$

$$D_1 = 0.240093 \times L^{0.782174} \qquad (7\text{-}3\text{-}1)$$

Equation (7-3-1) was derived from Fig. A-2.

$$D_2 = 0.49 \times B^{0.9776} \qquad (7\text{-}3\text{-}2)$$

Equation (7-3-2) was derived from Fig. A-3.

4) Draft: d

$$d = (d_1 + d_2)/2$$

$$d_1 = D - Fm_1 \qquad (7\text{-}4\text{-}1)$$

$$d_2 = Bc \times (0.0064286 \times Fn_\nabla{}^2 - 0.0607 \times Fn_V + 0.3043) \qquad (7\text{-}4\text{-}2)$$

Equation (7-4-2) was derived from Fig. A-10.

5) Draft of Transom: dt

$$dt = d \times (0.024 \times Vs / \Delta^{1/6} + 0.17) \qquad (7\text{-}5)$$

Equation (7-5) was derived from Fig. A-4.

6) Freeboard on Midship: Fm

$$Fm = (Fm_1 + Fm_2)/2$$

$$Fm_1 = 0.293 \times B \qquad (7\text{-}6\text{-}1)$$

Equation (7-6-1) was derived from Fig. A-5.

$$Fm_2 = D - d_2 \qquad (7\text{-}6\text{-}2)$$

4.2.2 Hull element on planing surface

1) Chine Breadth: Bc

$$Bc = (Bc_1 + Bc_2 + Bc_3)/3$$

$$Bc_1 = 0.3928 \times L^{0.8078} \qquad (7\text{-}7\text{-}1)$$

Equation (7-7-1) was derived from Fig. 5

$$Bc_2 = \Delta / (L \times 0.115 \times \Delta^{0.36} \qquad (7\text{-}7\text{-}2)$$

Equation (7-7-2) was derived from Fig. A-6.

$$Bc_3 = \Delta^{2/3} / (L \times 0.14 \times Fn_V{}^{-0.1454}) \qquad (7\text{-}7\text{-}3)$$

Equation (7-7-3) was derived from Fig. A-9.

2) Length to Center of Gravity: L_G.

$$L_G = L \times 0.46 \times Fn_V{}^{-0.1454} \qquad (7\text{-}8)$$

Equation (7-8) was derived from Fig. A-7.

3) Breadth of Transom Chine: *Bct*

$$Bct = \nabla^{1/3} \times 7.2976 \times 10^{-0.3039 \times L_G / \nabla^{1/3}} \quad (7\text{-}9)$$

Equation (7-9) was derived from Fig. A-8.

4) Deadrise Angle of Transom: βt

$$\beta t = 0.5 / 0.006 - \nabla / (L \times Bc \times d \times 0.006) \quad (7\text{-}10)$$

Equation (7-10) was derived from Fig. A-13.

5) Chine Height: *hc*

$$hc = 1.1 \times d \quad (7\text{-}11)$$

Equation (7-11) was derived from Fig. A-11.

6) Height of Transom Chine: *hct*

$$hct = (hct_1 + hct_2)/2$$

$$hct_1 = 0.8 \times dt \quad (7\text{-}12\text{-}1)$$

Equation (7-12-1) was derived from Fig. A-12.

$$hct_2 = Bct/2 \times \tan \beta t \quad (7\text{-}12\text{-}2)$$

7) Deadrise Angle: β

$$\beta = \tan^{-1}(2 \times hc / Bc) \quad (7\text{-}13)$$

4.2.3 Hull element on seakeeping

1) Freeboard of Fore Chine: *Ffc*

$$Ffc = 0.0289925 \times L^{1.16096} \quad (7\text{-}14)$$

Equation (7-14) was derived from Fig. 6.

2) Fore Freeboard: *Ff*

$$Ff = 0.559825 \times \Delta^{0.324944} \quad (7\text{-}15)$$

Equation (7-15) was derived from Fig. A-14.

3) Stem Slope: α

$$\alpha = 50 \quad (7\text{-}16)$$

Equation (7-16) was derived from Fig. A-15.

4.3 To create the Lines

The form of a boat hull is usually defined by the Lines which consist of a Body Plan, a Profile and a Half Breadth Plan. The form of a hard-chine craft can be defined with nine hull points, which are shown in Fig. 8. Nine points can be obtained from the above estimated principal dimensions and hull elements. By using the spline function to indicate the curves, the Lines were created. Fig. 9 shows the Lines as an output example of the software.

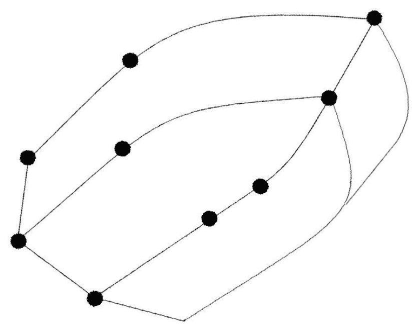


Fig.8 Nine points to define the hull form of high speed planing craft

4.4 To estimate resistance and propulsive efficiency

A software which estimates resistance and propulsive performance of the high speed planing crafts was developed. The functions of estimating resistance and propulsive performances of the crafts are as follows;

1) Resistance of the high speed planing craft is calculated by means of formula (1), (2), (3), (4) and (5). And EHP (Effective Horse Power) is also calculated.
2) Propulsive efficiency: η_{PC} is calculated by means of formula (6) and the data of Fig. A-16, A-17 and A-18. And BHP (Braked Horse Power) is also calculated.
3) Based on results of the above calculations, the curves of resistance and BHP are indicated.

Fig. 9 shows performance curves as an output example of the software.

5. VALIDATION OF BASIC DESIGN TOOL FOR HIGH SPEED PLANING CRAFT

In order to confirm the usefulness of the developed software, the validation of the functions of the developed software was performed.

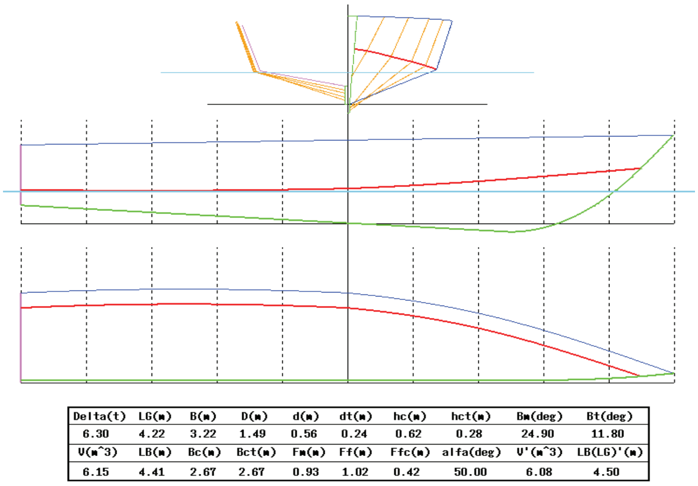
5.1 Validation of estimating function of principal dimensions and hull elements

In order to validate the function of estimating the principal dimensions and hull elements for high speed planing crafts, comparisons of the estimated values and the measured values on principal dimensions and hull elements of the real high speed planing crafts were performed. Table 1 and 2 show the above comparing results on two real high speed planing crafts, which were "YAYOI" and "SAZANAMI".

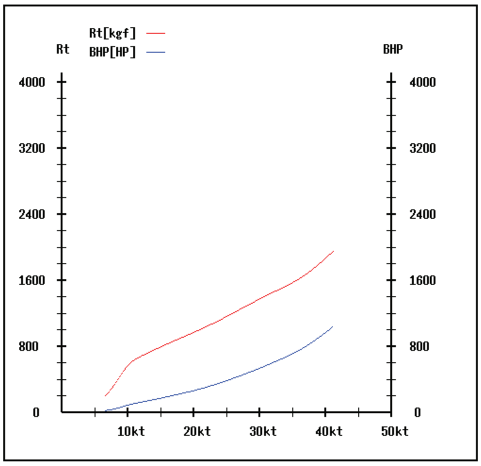
As may be seen from Table 1 on "YAYOI", there are differences in values of Chine Height: *hc* and Deadrise Angle of Transom: βt, which are hull elements concerning the planing surface. But no major differences in values of other hull elements are found.

As may be seen from Table 2 on "SAZANAMI", differences in values of some hull elements are found. But no major differences in values of other hull elements are found, too.

It was considered that the developed software could estimate the principal dimensions and hull elements of the high speed planing craft adequately.



Principal dimensions , hull elements and the Lines



Resistance and BHP

Fig.9 Output example of basic design tool

Table 1 Comparison of the measured values and the estimated values on principal dimensions and hull elements of "YAYOI"

ITEM	Measured data	Estimated data
Length(m)	18.00	18.00
Vs(knot)	17.40	17.40
Δ (m)	29.45	28.89
B(m)	4.80	4.76
D(t)	2.20	2.28
d(m)	0.80	0.90
Bc(m)	4.30	4.10
Bct(m)	4.10	3.80
hc(m)	0.60	1.0
hct(m)	0.05	0.30
dt(m)	0.35	0.40
Ff(m)	1.65	1.70
Ffc(m)	0.85	0.80
Fm(m)	1.40	1.40
β(deg)	15.59	25.80
βt(deg)	1.40	10.30
L_G(m)	8.10	7.70

Table 2 Comparison of the measured values and the estimated values on principal dimensions and hull elements of "SAZANAMI"

ITEM	Measured data	Estimated data
Length(m)	11.98	12.00
Vs(knot)	19.50	19.50
Δ (t)	16.50	10.10
B(m)	3.70	3.63
D(m)	1.22	1.70
d(m)	0.74	0.63
Bc(m)	3.18	3.07
Bct(m)	3.04	3.13
hc(m)	0.56	0.69
hct(m)	0.18	0.30
dt(m)	0.41	0.31
Ff(m)	0.80	1.19
Ffc(m)	0.35	0.52
Fm(m)	0.48	1.07
β(deg)	19.50	24.28
βt(deg)	6.68	10.83
L_G(m)	4.63	4.93

5.2 Validation of the function of estimating the resistance and propulsive performance

In order to validate the function of estimating resistance and propulsive performance on high speed planing crafts, comparisons of the estimated values and the measured values on BHP (Braked Horse Power) of the real high speed planing crafts were performed. Fig. 10 and Fig. 11 show the above comparing results on above two real high speed planing crafts.

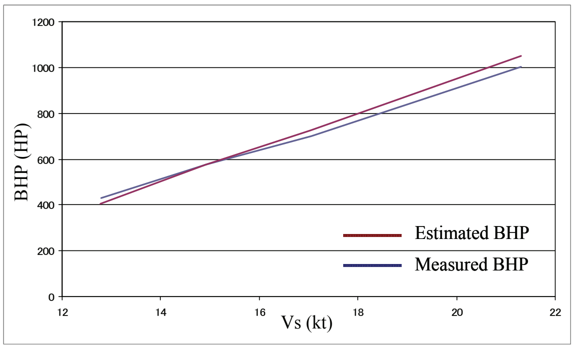


Fig.10 Comparisons of measured BHP and estimated BHP of "YAYOI"

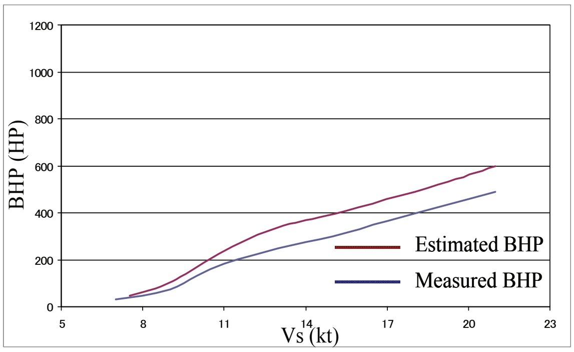


Fig.11 Comparisons of estimated BHP and measured BHP of "SAZANAMI"

The disparity between the estimated BHP and the measured BHP in both figures increased with increasing Speed: *Vs*. But, it was considered that the developed software could estimate the resistance and propulsive performance of the high speed planing craft adequately.

6. CONCLUSION

Authors conclude by listing important points of this study.

1) A software, which estimates principal dimensions and hull elements of a high speed planing craft, was developed.
2) A software, which creates the Lines of the above high speed planing craft, was developed.
3) A software, which estimates the resistance and propulsive performance of the above high speed planing craft, was developed.
4) The validation of the software was performed by comparing the estimated values with the measured values on principal dimensions, hull elements and performances of the real high speed planing crafts. It was become clear that the developed software as a basic design tool for high speed planing crafts had reached the stage for practical use.

REFERENCES

[1] Seiichi Niwa, "High Speed Boat Engineering", The Boat Association of Japan, Japan , 1972 (in Japanese)

[2] Seiichi Niwa, "New High Speed Boat Engineering (Resistance and Propulsion)", Ocean Policy Research Foundation, Japan, 2001 (in Japanese)

[3] Seiichi Niwa, "New High Speed Boat Engineering (Hull Form and Performance)", Ocean Policy Research Foundation, Japan, 2002 (in Japanese)

[4] E. V. Lewis, "Principles of Naval Architecture"、The Society of Naval Architects and Marine Engineers, 1988

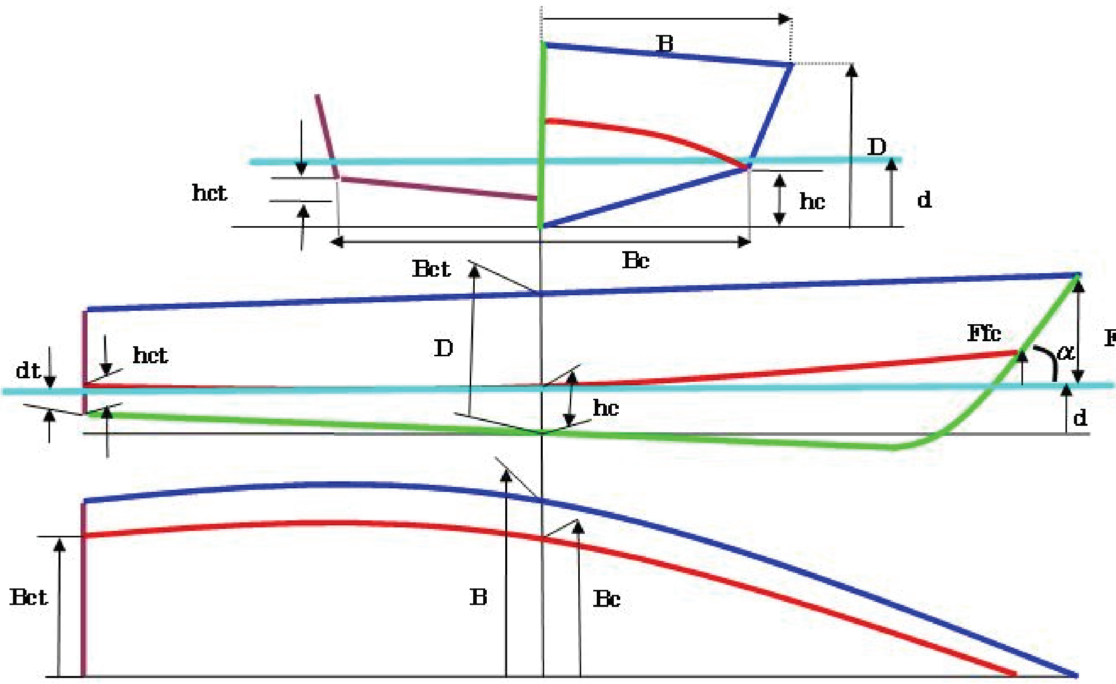
AUTHOR'S BIOGRAPHY

Naoki Tsuno studied Nautical Science at Toyama National College of Technology for 5 years. Now he has studied Maritime Technology as an advanced course student of the college. He will get a Bachelor's degree in Maritime Technology at the end of September in this year.

Makoto Endo studied Nautical Science at Tokyo University of Mercantile Marine. After working as a naval architect for 3 years, he has a place at the Nautical Department of Toyama National College of Technology as a professor since 1981. From 2002 to 2007, he was a chairman of Ship Handling Simulator Committee in Japan Institute of Navigation. He holds a Bachelor's degree and a Master degree in Navigation and a Doctoral degree in Engineering. His current research interests are safety evaluation of ship maneuverability, man-machine system analysis in ship handling, cooperative navigation system and ecological boat design.

Appendix-1 Definition of Principal Dimensions and Hull Elements on High Speed Planing Craft

L	: Length $[m]$
V_S	: Speed $[m/s$ or knot $]$
F_n	: Froude Number $Fn = Vs/(g \cdot L)^{1/2}$
R_n	: Reynolds Number
F_{nV}	: Volume Fn $F_{nV} = Vs/(g \cdot V^{1/3})^{1/2}$
Δ	: Displacement $[t]$
V	: Volume $[m^3]$
B	: Breadth $[m]$
Bc	: Chine Breadth $[m]$
Bct	: Breadth of Transom Chine $[m]$
D	: Depth $[m]$
d	: Draft $[m]$
dt	: Draft of Transom $[m]$
Ff	: Fore Freeboard $[m]$
Ffc	: Freeboard of Fore Chine $[m]$
hc	: Chine Height $[m]$
hct	: Height of Transom Chine $[m]$
Fm	: Freeboard of Midship $[m]$
β	: Deadrise Angle [deg]
βt	: Deadrise Angle of Transom [deg]
L_G	: Length to Center of Gravity $[m]$
α	: Stem Slope [deg]



Appendix-2 Correlations of Principal Dimensions and Hull Elements on High Speed Planing Craft

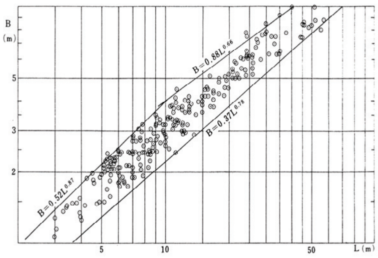


Fig.A-1 Breadth: *B* v.s. Length: *L* [1)]

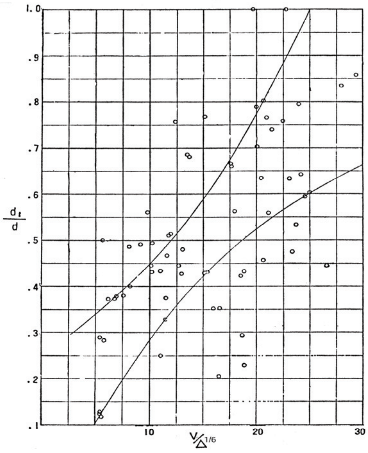


Fig.A-4 Draft of Transom: *dt* v.s. Speed: *Vs* [1)]

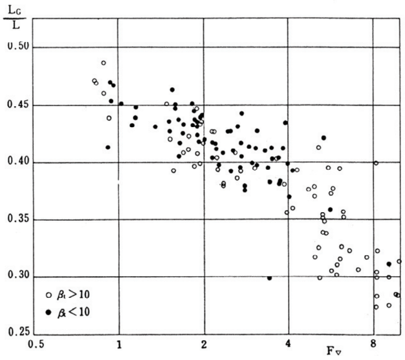


Fig.A-7 Length to Center of Gravity: L_G v.s. Volume Fn: F_{nV} [1)]

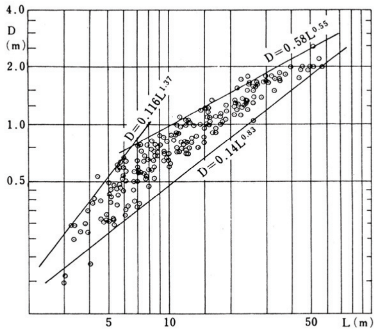


Fig.A-2 Depth: *D* v.s. Length: *L* [1)]

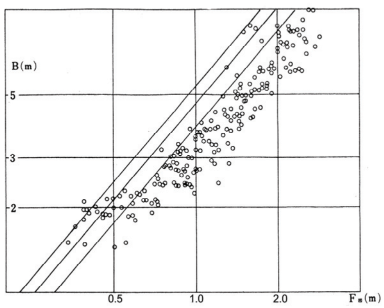


Fig.A-5 Breadth: B v.s. Freeboard of Midship: F*m* [1)]

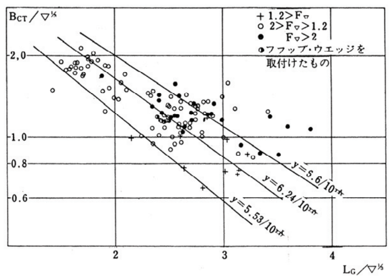


Fig.A-8 Breadth of Transom Chine: *Bct* v.s. Length to Center of Gravity: L_G [1)]

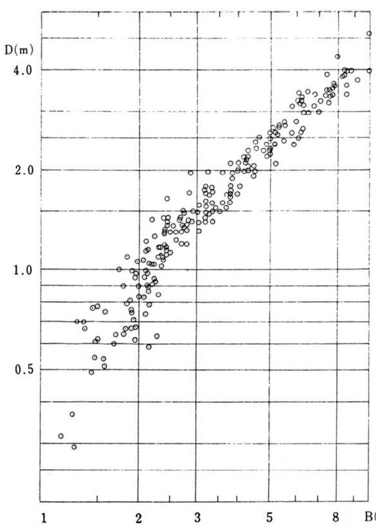


Fig.A-3 Depth: *D* v.s. Breadth: *B* [1)]

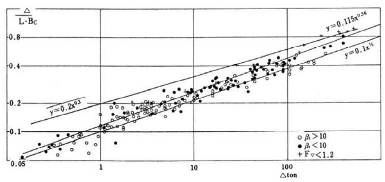


Fig.A-6 Chine Breadth: *Bc* v.s. Displacement: Δ [1)]

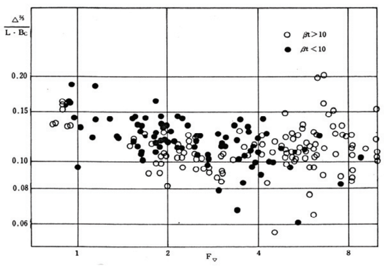


Fig.A-9 Chine Breadth: *Bc* v.s. Volume Fn: F_{nV} [1)]

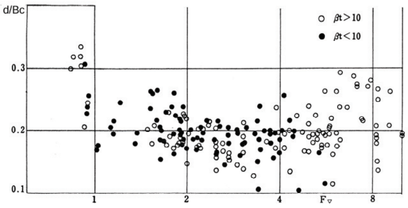


Fig.A-10 Draft: *d* v.s. Volume Fn: F_{nV} [1]

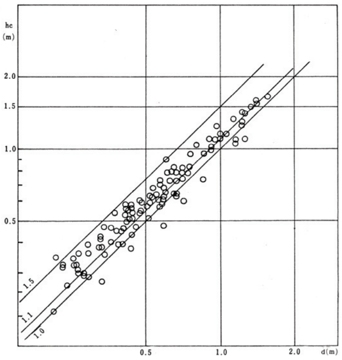


Fig.A-11 Chine Height: *hc* v.s. Draft: *d* [1]

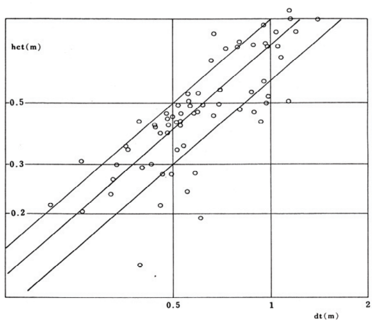


Fig.A-12 Height of Transom Chine: *hct* v.s. Draft of Transom: *dt* [1]

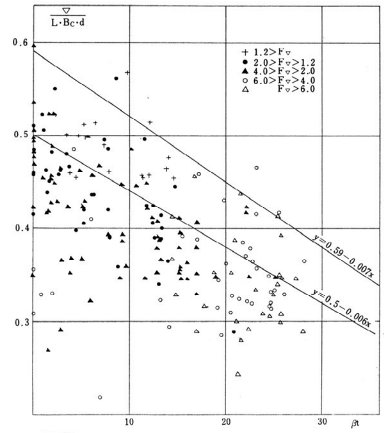


Fig.A-13 Deadrise Angle of Transom : βt [1]

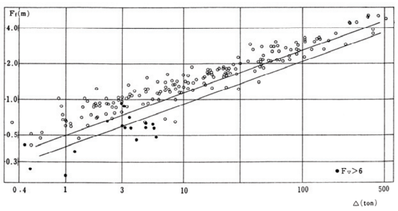


Fig.A-14 Fore Freeboard: *Ff* v.s. Displacement: Δ [1]

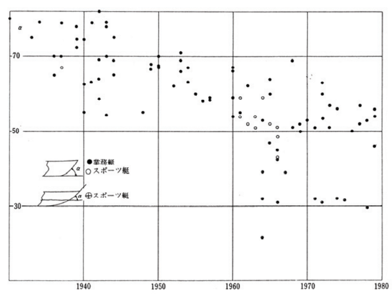


Fig.A-15 Stem Slope: α [1]

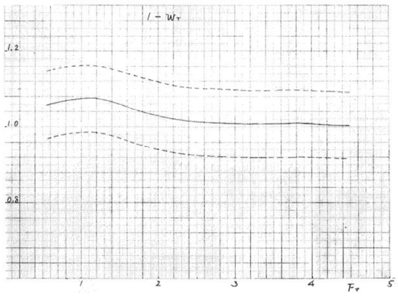


Fig.A-16 Wake: *w* v.s. Volume Fn: F_{nV} [3]

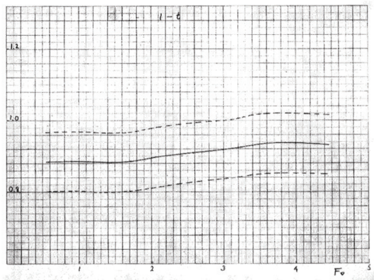


Fig.A-17 Thrust Deduction: *t* v.s. Volume Fn: F_{nV} [3]

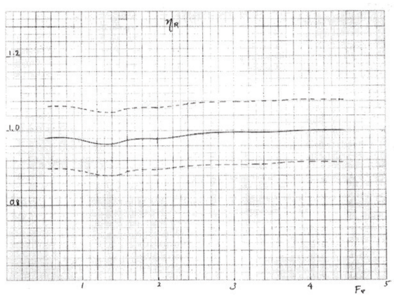


Fig.A-18 Relative Rotative Efficiency: η_o v.s. Volume Fn: F_{nV} [3]