THE EFFECT OF BILGE GEOMETRIES ON RESISTANCE IN DISPLACEMENT BOATS AND IMPORTANCE FOR THE SHIP INDUSTRY

S. Aydın Şalci,
Prof. Dr.
E-mail: salcia@itu.edu.tr
Munir Suner,
Lecturer, PhD Canditate
Istanbul Technical University, Maritime Faculty
E-mail: msuner@itu.edu.tr

Abstract. It is a fact that a bilge, which connects the board with bottom is an important part of ship geometry in ship building. The shape of bilge, which is supported by Marcin bracket inside and carries the bilge keel outside, has a considerable effect on the formation of bilge vortices, rolling motion, transverse geometric stability, mid-ship section coefficient and the ship resistance.
In this study the resistance and power alteration in alternative bilge geometries have been investigated by taking a ship form without deadrise as the main figure. The alteration of resistance and power have been studied by using the Ship Model Experiment Technics. Rectangle, double-chain and round forms were used as alternative bilge geometries.
Model experiments done in three different loading conditions, empty, loaded and excessively loaded. The results were transferred into the values of a ship by appliying the simialrity laws.
The effects of the bilge geometry are presented at the end of the study. Furthermore the effects of the results in ship building sector are disscussed as a conclusion.

1. INTRODUCTION

It is a fact that bilge, which connects the boards with bottom is an important part of ship geometry. The shape of bilge, which is supported by Marcin bracket inside and carries the bilge kneel outside, has a considerabl effect on the formation of bilge vortices, rolling motion, transverse geometric stability, mid-ship section coefficient and the ship resistance.

In this study, the resistance and power alteration in alternative bilge geometries have been investigated by taking a ship form whitout deadrise as the main figure. The alteration of resistance and power have been studied by using the Ship Model Experiement Technics. Rectangle, double-chin and round forms werw used as alternative bilge geometries. A wooden ship model whose lenght of load waterline was L*** = 1,640 meters and wose similarity ratio was $\alpha = 50$ was used in experiment.

Model experiments were done in three different loading conditions- empty, loaded and excessively loaded. There was no appendage on the model and the experiment was done without a trim. In order to observe the effect of bilge geometry better, the parallel body of ship was chosen comparatively large. According to the results of the experiment, double-chin form produced the minimum resistance after a certain value of velocity, 1 m/s.

As can be expected, the form which produced the maximum resistance was the rectangular form. The experiments were done in Ship Model Basin of Istanbul Technical University(I.T.U). The model ship was towed on smooth water conditions; the velocities were measured by a tachometer generator and the resistance was measured by Atwood dynamometer. The results of the experiments were transferred into those values of the ship by applying the similarity laws.

The calculations for resistance were realised in two different ways- one by Froude hypothesis and the other by Hughes hypothesis (Form Factor Method).

In the calculations done by Hughes hypothesis, the extrapolator diagram was modified by means of a mathematical transformation and the form factor was obtained. So by using a single model instead of an extrapolatorcurve which needs more than one model, it was possible to obtaine a form factor(but by the help of a transformed extrapolator). The changes(alternations) in resistance and power as a function of draught were studied for three different bilge geometries as well.

In order to provide flow similarity(Reynolds similarity) turbulance generator was placed at the bow of model. The diameter of the circular-section of trip wire which was used as the turbulance generator was determined by taking a boundary-layer thickness into consideration. In calculation the friction resistance, ITTC-1957 formula was used.

2. ANALYTICAL MODELLING

Total hydrodynamic resistance force in displacement boats is formed under the influence of a number of parameters.

$$R_t = f(V, L, Fr, Re, LCB, \frac{L}{B}, \frac{B}{T}, \alpha_E ...). \tag{1}$$

In order to determine the effect (influence) of each of these parameters on resistance, model series which are very common and can be taken as referance are chosen and systematical ship-model experiements are done. These experiments can be realized at the towing tank or at the circulating channel. In this study systematical experiements were done with a ship modelwhose paralel body lenght was rather long (Landing Craft) and these experiements were conducted at different loading conditions and with different bilge geometries. As a result, alterations in resistance were obtained. By applying the laws of similarity the data of the experiment was transformde into the values of the ship (prototype).

The analysis of total hydrodynamic resistance can be made in two different ways.

a) Froude Hypothesis:

$$R_t = R_f + R_r; \tag{2}$$

b) Hughes Hypothesis:

$$R_t = R_v + R_w. \tag{3}$$

In these equations,

$$R_t = total\ resistance$$
$$R_f = frictional\ resistance$$
$$R_r = resuduary\ resistance$$
$$R_v = viscous\ resistance$$
$$R_w = wave\ resistance$$

2.1. Froude Hyphothesis

$$Rt(Re, Fr) = Rf(Re) + Rr(Fr) \qquad [\text{Kafali},1],[\text{Kafali},2],[\text{Comstock},3] \tag{4}$$

$$Rf = Cf \cdot \frac{\rho}{2} \cdot v^2 \tag{5}$$

$Cf = 0,0075/(Log\ Re - 2)^2$ [*ITTC*-1957].

If $Fr_m = Fr_p$, then $(R_r/\Delta)_m = (R_r/\Delta)_p$ and when we write $\gamma = \rho \cdot g$ and

$$\frac{R_{rp}}{R_{rm}} = \Delta_p / \Delta_m = \gamma_p \cdot \nabla_p / \nabla_m, \tag{6}$$

then

$$\frac{R_{rp}}{R_{rm}} = \Delta_p / \Delta_m = \rho_p / \rho_m \cdot \alpha^3 \tag{7}$$

is obtained.

According to hyphothesis:

when $R_{tm} = R_{fm} + R_{rm}$ is written fort he model and $R_{tp} = R_{fp} + k.R_{rp}$ is written for the prototype (here k is a correlation factor which is constant, $k = 1,15$) then,

$$R_{fp} = C_{fp} \cdot \rho_p / 2 \cdot S_p \cdot v_p^{\ 2}, \tag{8}$$

$$R_{rp} = \rho_p / \rho_m \cdot \alpha^3 \cdot R_r, \tag{9}$$

$$R_{tp} = C_{fp} \cdot \rho_p / 2 \cdot S_p \cdot v_p^{\ 2} + 1.15 \cdot \rho_p / \rho_m \cdot \alpha^3 \cdot R_{rm} \tag{10}$$

is obtained.

In this equation, $S_p = \alpha^2 \cdot S_m$ and for the $Fr_{mp} = constant$

$$(V / \sqrt{L})_m = (V / \sqrt{L})_p \to (V_p / V_m) = (\sqrt{L_p} / \sqrt{L_m}) = \sqrt{\alpha}\,; \tag{11}$$

$$V_p = \sqrt{\alpha} \cdot V_m. \tag{12}$$

On the other hand,

$$R_{rm} = R_{tm} - R_{fm} = R_{tm} - C_{fm} \cdot \rho_m / 2.S_m \cdot v_m^{\ 2}; \tag{13}$$

$$\left(C_f\right)_{m,p} = 0{,}0075 / \left[log\left(Re\right)_{m,p} - 2\right]^2 \quad \text{[ITTC-1957]}. \tag{14}$$

In this equation

Re: Reynolds number, $Re = v \cdot \dfrac{L}{\vartheta}$;

Fr: Froude number, $Fr = \dfrac{V}{\sqrt{L}}$;

Cf: Coefficient of frictional resistance;
ρ : Specific density of fluid;
S : Wetted surface area;
V: Forward velocity of body (knot), (1 knot $\approx$ 0,5144 m/s);
v : Forward velocity of body (m/s);
ϑ : Kinemati viscosity of fluid;
g : Gravitaitonal acceleration, $g = 9{,}81$ m/s^2;
L : Body lenght (ship or its model);
Δ : displacement.

2.2. Hughes Hypothesis

In this hypothesis, the total hydrodynamic resistance is divided into resistance components as, $R_t(Re, Fr) = R_v\left(Re\right) + R_w\left(Fr\right)$, [1], [2], [3].

According the hypothesis, form factor is defined as

$$K = \frac{R_{vp}}{R_{fp}} - 1 = \frac{C_{vp}}{C_{fp}} - 1. \tag{15}$$

Form factor gives the transformation (passage) between two or three dimensional surfaces. Extrapolator diagram is needed to find *K*.

Therefore, by writing

$$R_{vp} = R_{fp}\left(K+1\right); \tag{16}$$

$$R_{tp} = R_{vp} + R_{fp} \tag{17}$$

and by taking Froude Similarity,

$$Fr_m = Fr_p \rightarrow C_{wp} = C_{wm}; \tag{18}$$

$$C_w = R_w / \rho/2.S.v^2; \tag{19}$$

$$R_{tp} = \left[C_{tm} + (1+K)\left(C_{fg} - C_{fm}\right)\right] \cdot \rho_p / 2 \cdot S_p \cdot v_p^{\ 2} \tag{20}$$

are obtained. In this equation;

K = Form factor;

C_v = Coefficient of viscosity resistance;

C_t = Coefficient of wave resistance.

In order to calculate the form factor, point $C_w = 0$ is to be determined in $C_t = f\left(Re\right)$ diagram. At this point, visosity resistance curve is the envelope ot totalt resistance curve. If $Re = Re^*$ at this point, then

$$Re = Re^*;\ C_{wm} \rightarrow 0 :\ C_{tm} = C_{wm} = \left(1+K\right)C_{fm} \tag{21}$$

and the variable transformation

$$\text{Log}\, Re - 2 = x \text{ and } x^{-2} = X. \tag{22}$$

When $C_t = f\left(X\right)$ modified extrapolator diagram is drawn, then C_f : ITTC -1957 curve and also C_v vicosity resistance curve are turned out to be straight lines passing through the origin. In this diagram C_v curve is straight line whih is tangent to C_t total resistance curve nd whic passes through the origin, the touching point is $Re = Re^*$.

In this diagram, $\left.\left(\frac{\partial C_t}{\partial X}\right)\right\|_{x=0} = \tan\Theta = 0.075 = \text{constant} \rightarrow \Theta = 4.289^\circ$ is obtained.

3. EXPERIMENTAL MODELLING

3.1. Experimental Data

The model used in the experimetn was wooden and painted, with no appendages and bulb and had an α = 50 similarity ratio and was in paralel floating condition (no trim). A turbulance generator trip wire wwith a 1.5 mm diameter was pled at the bo of the model to provide Reynolds flow similarity.

The ship model was towed in three different loading conditions coded as WL 3, WL 4 and WL 5.

With the application of similarity las, transfer from the model to the prototype was made by taking the standard conditions for sea water and dimensions of model ship as

$t_p = 15\,C^\circ \rightarrow \rho_p = 104{,}61\,kg.s^2.m^{-4}, \quad v_p = 0{,}1191.10^{-5} m^{-2}.s^{-1}$

$L_m = 1{,}620, \quad \Delta_m = 16{,}564\,kg, \quad S_m = 0{,}524\,m^2, \quad \rho_m = 101{,}84\,kg \times s^2, \quad V_m = 0{,}11.10^{-5} m^2.s^{-1}$

The results of experiment are as follows for rectangular, double-chin and round geometry in Table 1, 2 and 3.

Table 1

Ship with rectangular bilge geometry

Vm (m/s)	WL 3 (kg)	WL 4 (kg)	WL5 (kg)
0.40	0.038	0.040	0.048
0.50	0.050	0.055	0.065
0.60	0.068	0.076	0.088
0.70	0.085	0.099	0.120
0.80	0.115	0.130	0.165
0.90	0.155	0.175	0.227
1.00	0.215	0.250	0.325
1.10	0.287	0.350	0.437
1.20	0.375	0.480	0.574
1.30	-	0.695	0.815

Table 2

Ship with double chin bilge geometry

Vm (m/s)	WL 3 (kg)	WL 4 (kg)	WL5 (kg)
0.40	0.040	0.045	0.050
0.50	0.052	0.056	0.065
0.60	0.068	0.075	0.087
0.70	0.088	0.097	0.116
0.80	0.115	0.130	0.156
0.90	0.150	0.188	0.210
1.00	0.210	0.255	0.305
1.10	0.305	0.368	0.468
1.20	0.416	0.495	0.588
1.30	0.515	0.643	0.700

Table 3

Ship with round bilge geometry

Vm (m/s)	WL 3 (kg)	WL 4 (kg)	WL5 (kg)
0.40	0.035	0.043	0.051
0.50	0.050	0.058	0.051
0.60	0.068	0.078	0.095
0.70	0.090	0.110	0.125
0.80	0.120	0.143	0.163
0.90	0.155	0.194	0.228
1.00	0.215	0.277	0.320
1.10	0.305	0.380	0.476
1.20	0.407	0.498	0.585
1.30	0.590	-	-

The experimental data was pbtained in smooth water surface (no waves) conditions. Fort he to towing experiments following one another, enough time was given to maket he water surface smooth again.

3.2. Results

The results of the experiment can be evaluated in several different ways by using the methods mentioned in analytical modelling and by using the laws of similarity.

Model resistance characteristics for each bilge geometry – Fig. 1, double hull resistance coefficient curve for WL4 – Fig. 2, form factor change according to draft for each bilge geometry – Fig. 3, prototype resistance characteristic – Fig. 4 and power- draft linkages – Fig. 5 are presented.

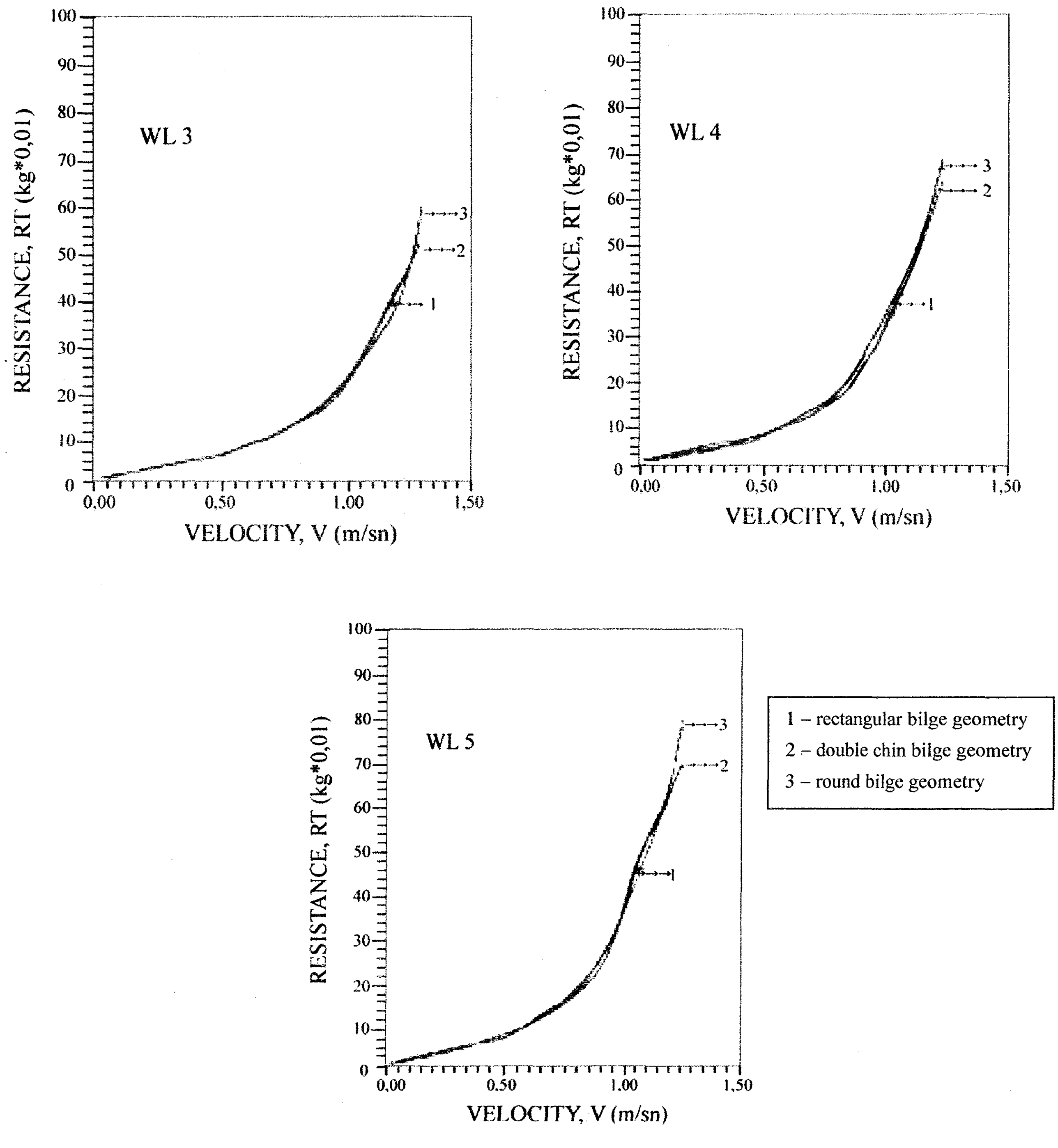

Fig. 1. Model Resistance Characteristics for each bilge geometry

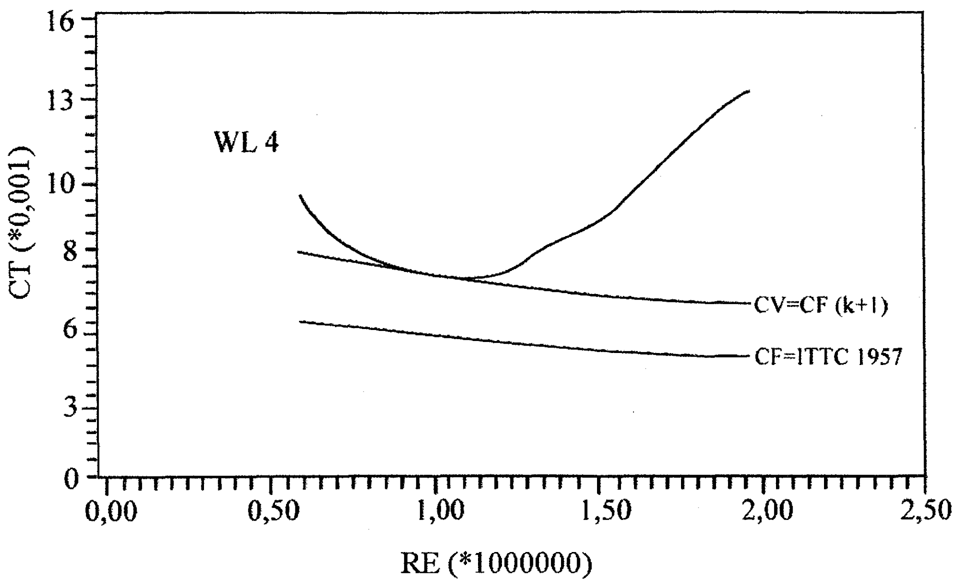

Fig. 2. Double chin bilge resistance coefficient curve for WL4

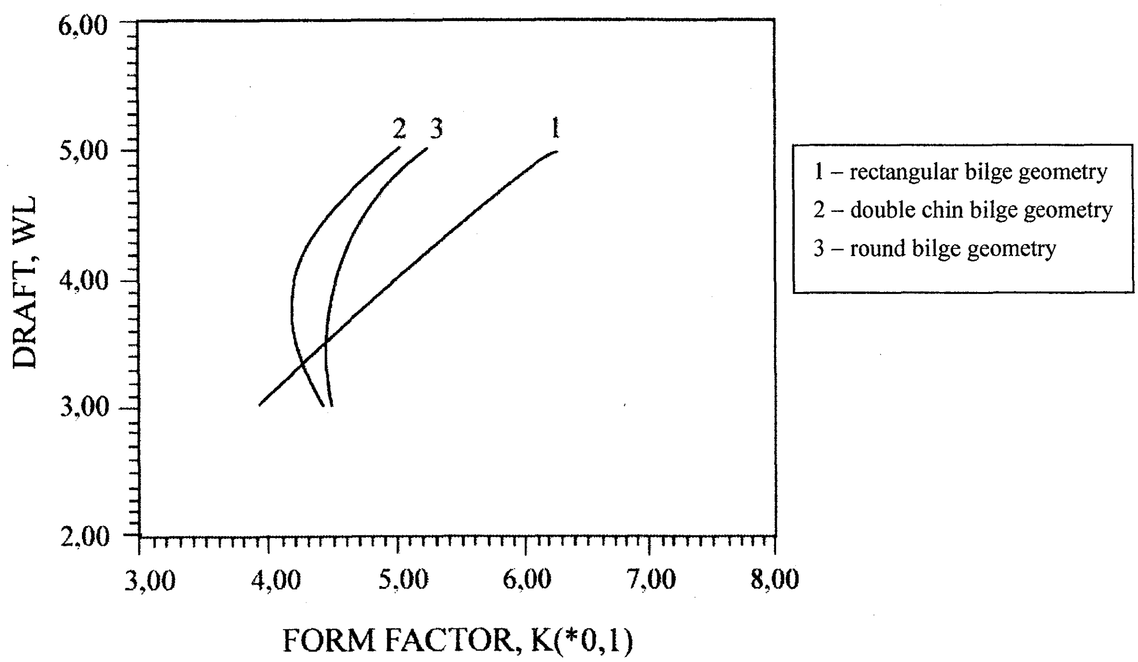

Fig. 3. Form Factor change according to draft for each bilge geometry

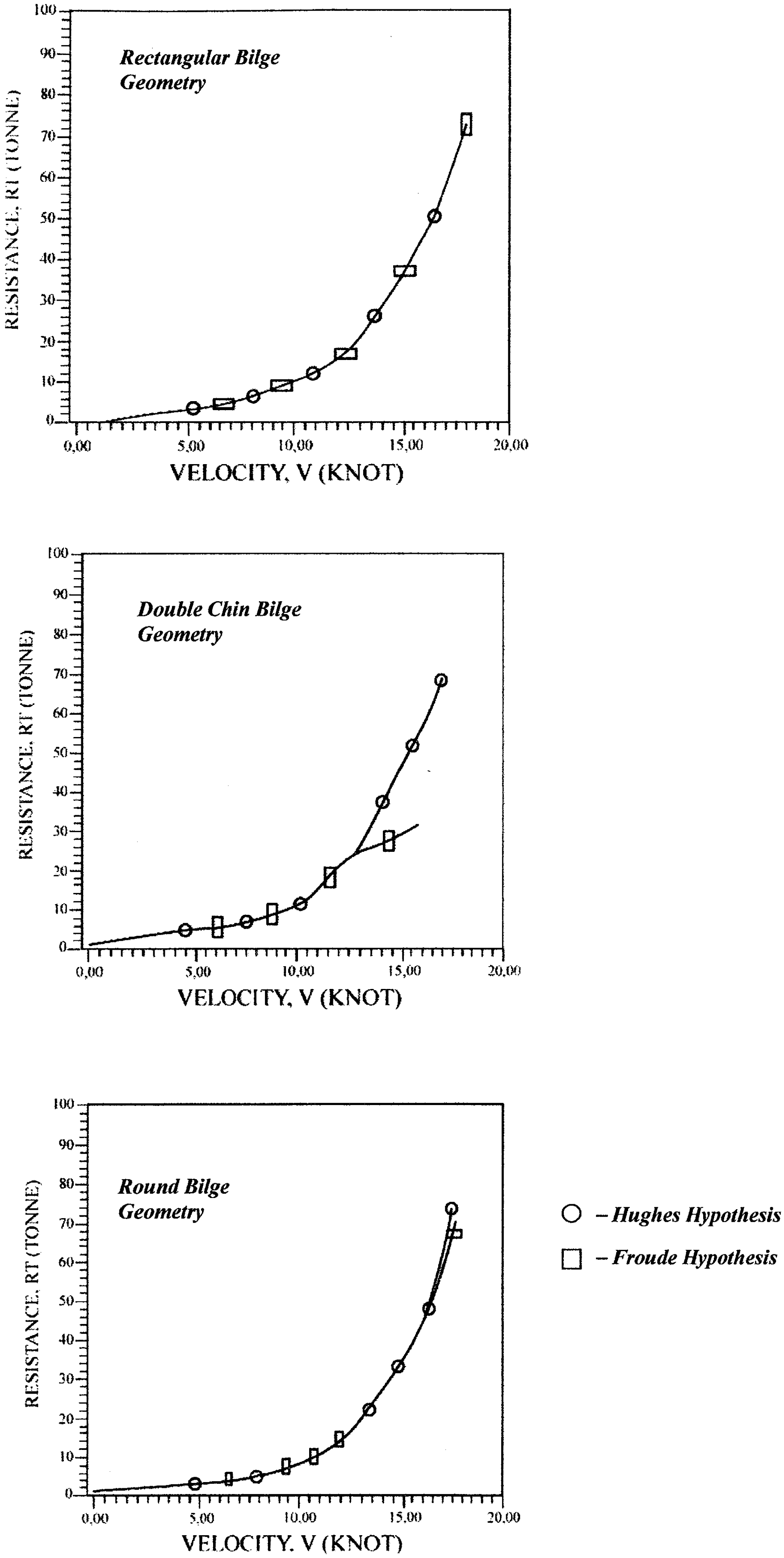

Fig. 4. Prototype resistance of WL4 for each bilge geometry, rectangular, double chin and round respectively

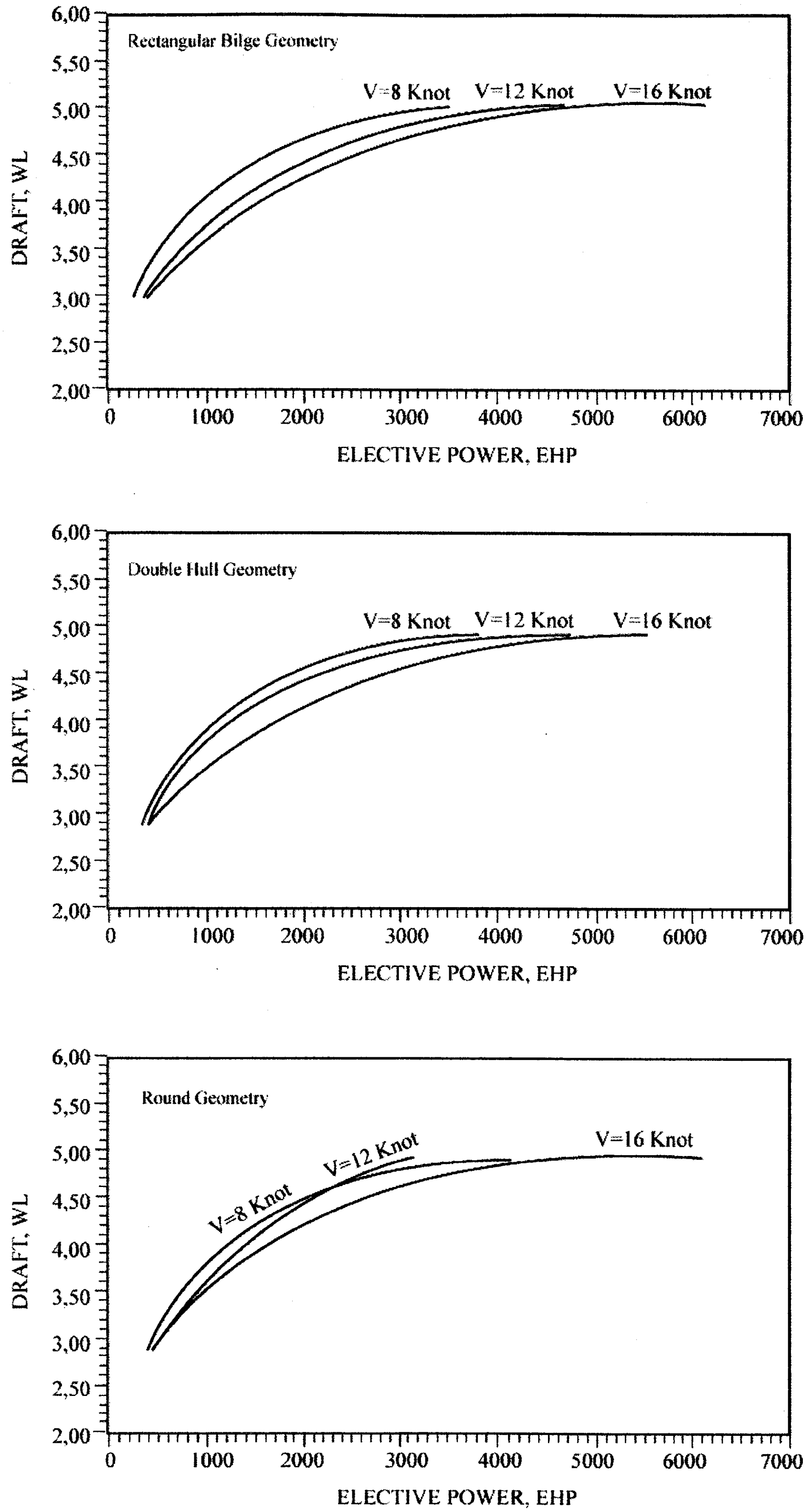

Fig. 5. Draft-Power Characteristics for each bilge geometry

4. CONCLUSION

In literature various ways are introduced to reduce the resistance in ships. In this study the bilge geometry which is one of the key element for the cross section geometry of ship is investigated to understand its effects on ship resistance. The results are presented. It is seen that bilge geometry is directly effect the resistance of the ship. In this context bilge geometry is also directly effect the ship operations by reducing the operational costs.

ACKNOWLEDGEMENT

We would like to a special thank to Ms. Pelin Yilmaz who is Phd Candidate in Shanghai Maritime University and research assistant in Istanbul Technical University Maritime Faculty, for her endeavours in this study.

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