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Hull Form Development for an AFRAMAX Tanker with a Composite Stern Frameline Concept

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Abstract

Hull form development for an AFRAMAX tanker characterized by the form parameters of $C_B \simeq 0.8$, $L/B \simeq 5.5$, $B/T \simeq 3.5$, has been carried out by the application of 'Composite Stern Frameline Concept'.

The viscous resistance of the new form was much smaller than that of the conventional form. Form factor of the new form was only 0.18 compared to 0.30 for the conventional hull form. Nevertheless the propulsive efficiency was slightly lower and thus the required propulsion power was smaller by 5~6% at both full load and ballast condition.

In addition, it is confirmed that introduction of the form factor method such as ITTC'78 method is highly advisable because there is a great risk of the underpredicting full scale resistance of the hull form whose form the extrapolation of moel resistance to full scale is to be based on Froude method with the correlation allowances usually applied to conventional hull forms.

1. Introduction

In developing hull forms for slow, full ships such as tankers and bulk carriers, it has been known to be extremely difficult to make innovative hull forms which have excellent resistance performance and excellent propulsion performance at the same time. Hull forms adopting conventional V-shaped framelines in the afterbody generally show excellent resistance characteristics but very poor propulsive efficiency. Above all, since there is a great risk of cavitation and vibration problem due to its inhomogeneous wake field in the propeller plane, conventional V-shped afterbodies become very rare nowadays. Hull forms adopting conventional U-shaped framelines in the afterbody frequently require less propulsion power than the hull forms with the V-shaped aftrbody because though the resistance is larger but the propulsive efficiency is very much higher, and moreover, it is known to have more uniform wake field.

The present trend in the afterbody design of slow full forms is towards selecting moderate

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U-shaped framelines together with Hogner type stern bulb(normally open water type stern) to improve the resistance perfomance of the U-shaped afterbody further and to secure uniform wake field.

Barge type framelines(also called as 'Buttock-flow' type framelines), which are different from conventional framelines, have been proved to have even better resistance characteristics than the V-shaped framelines an have lately attracted considerable attention. However, it has reported that in spite of the amazing reduction in resistance, the requird propulsin power of the hull form with the Barge-shaped afterbody could hardly become smaller than those of the conventional hull forms due to dramatic deterioration in the propulsive efficiency[1].

A Barge-shaped afterbody is known to bring better performance results, if it is applied to the hull forms of shallow draguht vessels or hull forms with extreme fullness in the afterbody. However, it is not considered to be generally used in place of the moderate U-shaped frameliness.

Moderate U-shaped framelines are known to be the best among conventional framelines and may be regarded as a modified version of U-shaped framelines, where the section in upper region is made to be much more V-shaped and a bit more V-shaped in lower region in way of skeg, compared to U-shaped frameline, to reduce the resistance, specifically viscous resistance, while trying to keep the excellent propulsive efficiency of U-shaped afterbody.

The resistance performance of a moderate U-shaped afterbody is generally inferior to that of a V-or Barge-shaped afterbody. However, it is very difficult to improve the resistance performance of a moderate U-shaped afterbody while keeping its excellent propulsive efficiency.

A new type of afterbody, where major part of the hull was V-or Barge-shape and the lower hull just in front of propeller was U-or moderate U-shaped, was proposed by the authors and the results of its applicatin to the hull forms of a Panamax bulk carrier and a VLCC have been reported already[2].

It has been confirmed through various hull form developments until recently that the new afterbody, or Composite afterbody, can replace the moderate U-shaped afterbody of slow, full hull forms.

In this study, Composite afterbody concept has been applied to the hull form of a Aframax tanker featured by the form parameters of $C_B \simeq 0.8$, $L/B \simeq 5.5$, $B/T \simeq 3.5$. Since a hull form with a Composite afterbody has been developed successfully, it has been confirmed that the Composite afterbody is also very suitable for hull forms of wide, shallow draugft vessels.

To investigate the resistance and propulsion characteristics of the new hull form in comparison with other conventionl hull form, a hull with a moderate U-shaped afterbody developed by one Japanese yard in 1990[3] has been selsected and the performance of the two hull forms were evaluated both by model tests and by viscous flow cal culations.

Viscous resistance of the new hull form was very much lowr than that of the conventional hull form with a moderate U-shaped afterbody and the propulsive efficiency of the new hull is slightly worse. Thus, effective horse power is smaller by approximately 9.6% delivered horse power is smaller by approximately. 4.8% at full load, and effective horse power and delivered horse power are smaller by approximately 10.1% and 4.8% respectively at ballast.

In addition, it has been confirmed that the introduction of form factor is highly advisable because there is a great risk of the underpredicting full scale resistance of the hull form whose form factor is considerably smaller than those of conventional hull forms, if the extrapolation of model resistance to full scale is to be based on Froude method with the correlation allowance usually applied to conventional hull froms.

2. Hull Form Characteristics

2.1 Main Particulars of the Two Hull Forms

Main particulars of the new hull form with a Composite afterbody and the conventional hull form with a moderate U-shaped afterbody are as shown in Table 1.

Table 1 Principal particulars of the new hull form and conventional hull form

	New		Conventional	
	Full Load	Ballast	Full Load	Ballast
L_{pp}(m)	234.00	234.00	234.00	234.00
B (m)	42.60	42.60	42.70	42.7
d_F/d_A(m)	12.19/12.19	5.7/8.7	12.19/12.19	5.7/8.7
L/B	5.49	5.49	5.48	5.48
B/d_{mean}	3.49	5.92	3.50	5.93
C_B	0.803	0.751	0.804	0.744
C_W	0.889	0.844	0.907	0.835
C_M	0.996	0.994	0.990	0.983
C_P	0.806	0.756	0.812	0.757
lcb (% of L_{PP} forward form midship	3.3	1.9	3.0	3.0
Wetted surface area(m^2)	13427.0	10721.0	13325.0	10538.0
Vs(knots)	15.0	-	15.0	-

2.2 Characteristics of the New Hull Form

The new hull form has the features of a U-shaped forebody with bulbous bow, whcih is commonly aopted to the slow, full ships built by Daewoo, and a Composite afterbody with Hogner type bulb.

(1) Forebody

As the longitudinal center of buoyancy(lcb) of the new form has been selected to be approximately. 3.26%(L_{pp}, forward from midship), i.e. the forebody is made to be very full, U-type frameline, which has excellent resistance characteristics when applied to particularly full foredies, has been applied to the forebody. Major geometrical features of the forebody are summarized as follows;

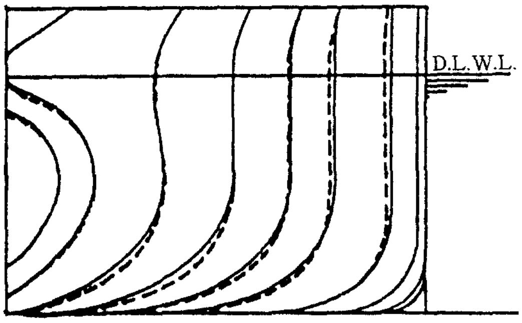
(a) Design load waterline is elliptic and the longitudinal distribution of displacement as typified by the curve of cross-sectional areas is so designed as to make relatively fine shoulder and smaller entrance.

(b) To arrange the cargo tanks and the ballast tanks in double sides economically, the forebody framelines are tyically U-shaped.

(c) Bulbous bow is designed with 0-type bulb. The waterlines of the bulb are connected to those to the main hull with very smooth variation of curvature, i.e. the bulb is designed not as an appendage but as a mere extension of the main hull with protruding profile(implicit-type bulb).

Large bulb area(the bulb area at F.P is approximately. 13.7% of Am) is selected together with implicit type bulb and elliptic LWL to reduct the displacement in way of the forward shouder without increasing the bluffness of the entrance to greatly improve the slenderness.

The original forebody was modified as shown in Fig.1 to improve the overall flow pattern in the forebody.



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———————— FINAL

Fig.1 Forebody body plan of the new hull form

(2) Afterbody

The basic concept of a Composite afterbody is to combine Buttock flow-type and U-type framelines. Lower part of the hull in front of propeller(part S) is made to be similar to a U-shaped or moderate U-shaped afterbody, and the remaining part(part M), which is much bigger than part S, is similar to a V-shaped or Barge-shaped afterbody. Thus a Composite afterbody have good resistance performance, which is the features of a V-or Barge-shaped afterbody, and at the same time good propulsive efficiency and homogeneous wake distribution, which are the features of a U-shaped or moderate U-shaped afterbody.

Resistance and propulsive characteristics of a Composite afterbody may vary according to the proportion of the size of part S to that of part M. When part S(U-shaped) is increased in size the propulsive efficiency will be improved but the resistance performance will deteriorate. In contrast, when part S is decreased in size and major portion of the afterbody is made similar to Buttock-flow type afterbody like MARAD hull form as shown in Fig.2, resistance performance will be improved but thepropulsive efficiency will deteriorate.

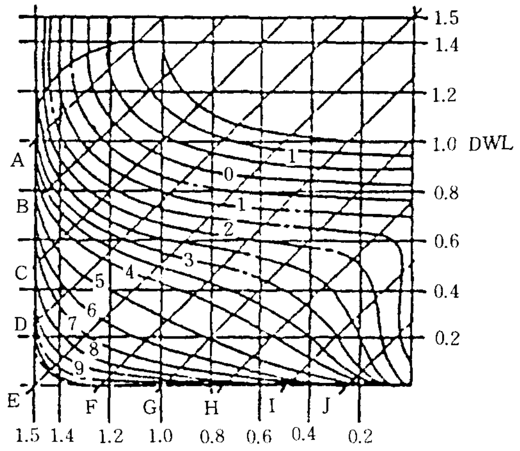


Fig.2 Afterbody bodyplan of MARAD Sories

Therefore to determine the optimal Composite frameline shape appropriate for the form parameters of the Aframax tanker, systematic approach, such as varing the shape and size of part S and M and carring out model tests for every hull variation, should be considered. However, as it requires too much time and costs to carry out such comprehensive systematic model tests, more practical approach based on experience has been selected.

As it is empirically believed to be more important to secure better resistance performance in developing a hull form for such an Aframax tanker, the size of Part S is kept to be rather small and the afterbody has been designed as follows;

(a) The horizontal slope of the frameline is smaller than that of VLCC hull form(Fig.3) with a Composite afterbody. Typical Buttock-flow type framelines are used.

(b) To improve the resistance performance, part S is made to be as small as possible provided there are no significant problems with regard to the main engine and cargo pump installation.

(c) Hogner type bulb is applied to obtain uniform wake field and to improve propulsive efficiency.

(d) To secure proper distance between the hull and propeller, transom is lifted above DLWL.

(e) Sectional area curve(Cp-curve) is made similar to that of existing hull forms with a Composite afterbody.

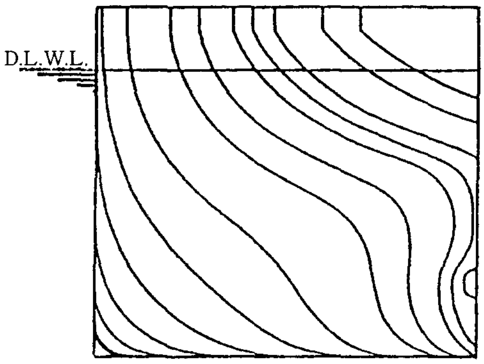


Fig.3 Composite type afterbody for a VLCC

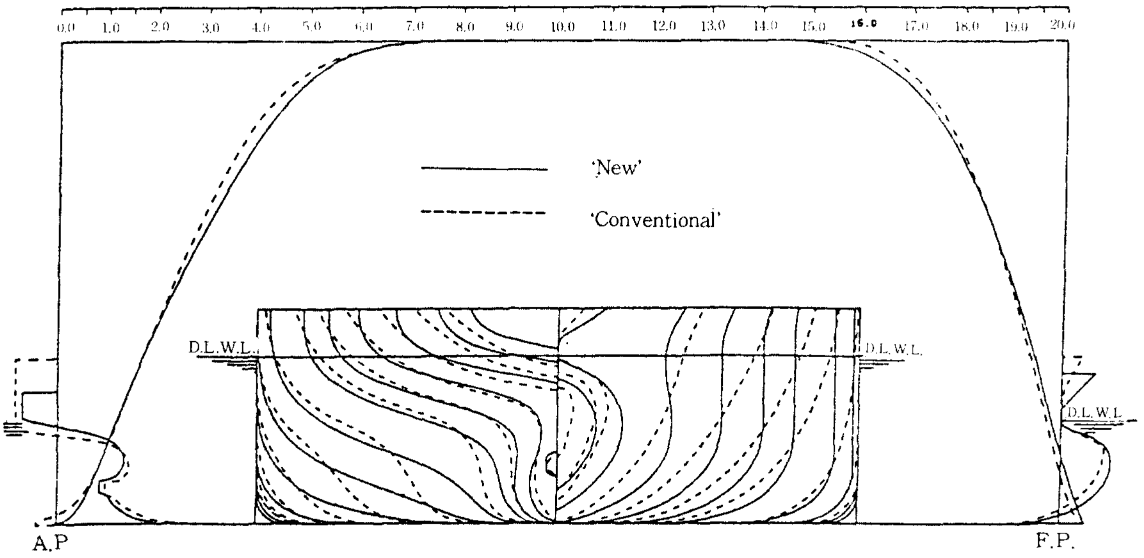


Fig.4 Comparison of hull forms and Cp−Curves

Body plans, profile and sectional area curve of the new hull form are shown in Fig.4.

2.3 Characteristics of the Conventional Hull Form

The conventional hull form is composed of V-shaped forebody with high-nose type bulb and moderate U-shaped afterbody with stern bulb. Body plans, aft and forward profile and sectional area curve are shown in Fig.4. The geometrical features of the conventional hull form are as follows:

(1) Forebody

(a) Typical V-shaped frameline, which is frequently applied to container ships, is selected.

(b) High-nose type bulb, which goes well with V-shaped forebody, is applied.

(c) Just the same as in the forebody of the new hull form, the waterlines of the bulb are connected to those of the main hull with very smooth transition(implicit type bulb).

(2) Afterbody

(a) Typical moderate U-shaped framelines are applied.

(b) Open water type stern frame is adopted.

(c) Hogner type stern bulb is applied to obtain uniform wake distribution.

3. Performance Evaluation by Theoretical Calculations and Model Tests

3.1 Theoretical Calculations

Viscous flow calculations have been carried out by RANSTERN code[4] to investigate and compare the flow phenomena and resistance characteristics of the two hull forms on theoretical basis. The rsults are summarized in Table 2 and Fig.5

As shown in Table 2, the calculted viscous resistance of the new hull form is smaller than that of the conventional hull form by approximately. 19%. This may show that the form resistance of the hull form with a Composite afterbody could be very small as in the hull forms with a V-shaped or Barge-shaped afterbody. The calculated streamlines of the new hull form on body surface shown in Fig.5 seem to smoothly follow the hull surface along buttock-lines, while the path of the calculated streamlines of the conventional hull

Table 2 Results of calculation(full load, V_s=15.0 knots)

Hull Form / item	New	Conventional	Diff.(%)
Reynolds No.	9609600	9609600	–
$(C_{PV}+C_F)\times 10^3$	3.034	3.192	4.8
$C_{FO}\times 10^3$	2.996	2.996	–
$C_{TM}\times 10^3$	3.643	4.068	10.4
$(1+k)_{prediction}$	1.033	1.276	19.1
$(1+k)_{experiment}$	1.183	1.300	9.0

$$C_{PV},\ C_F,\ C_{FO},\ C_{TM}=\frac{R_{PV}, R_F,\ R_{FO},\ R_{TM}}{1/2\ S_M\ V_M^2}$$

C_{PV} : calculated viscous pressure resistance coefficient of a model

C_F : calculated frictional resistance coefficient of a model

C_{FO} : frictional resistance coefficient of a plate

C_{TM} : measured total resistance coefficient of a model

K : form factor

C_{PV}, C_F, $(C_{PV}+C_F)$: calculated within the range of 0.3 $L_{PP}-L_{PP}$ from F.P.

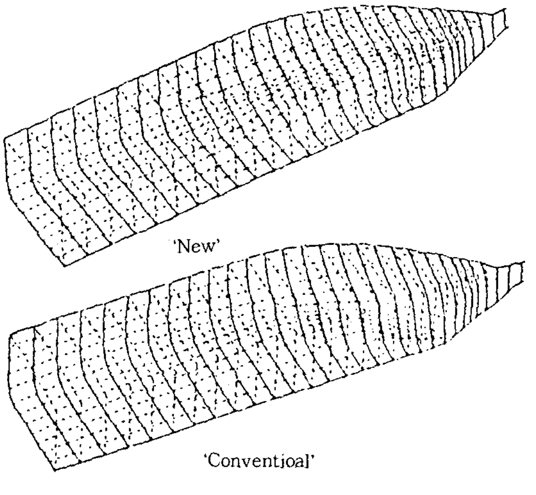
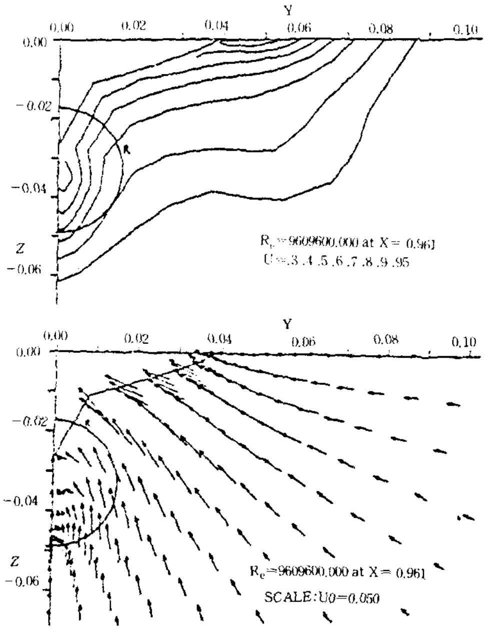


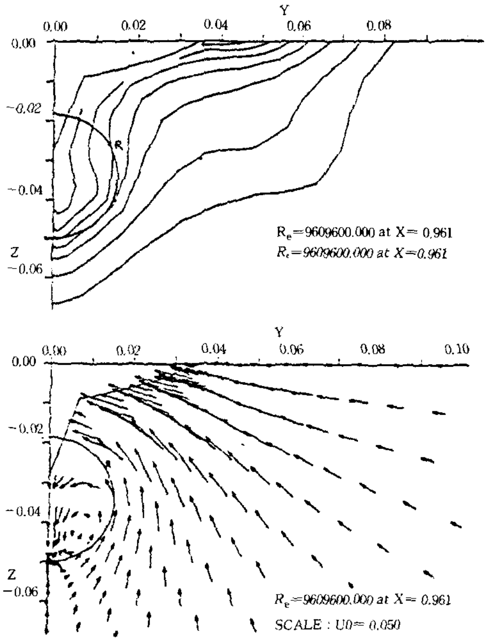
Fig.5 Calculated streamlines on the surface of the two hull forms

form seem to be more complicated.

Calculated wake distributions in propeller plane are shown in Fig.6 Much more strong bilge vortices are found in the conventional hull form with a



"New hull form"



"Conventional hull form"

Fig.6 Nominal wake distributions and transverse velocity vectors at the propeller plane moderate U-shaped afterbody of very high turn of bilge.

It is concluded from the viscous flow calculations that the flow pattern in the afterbody of the new hull form is typical buttock-flow pattern: bilge vortices are not strong: an above all viscous resistance is comparatively small.

3.2 Model Tests

The new hull form with a Composite afterbody was tested at Korea Research Institute of Ships and Ocean Engineering(KRISO). Form factor of the final hull from turned out to be only 0.183, so it was confirmed that the viscous resistance, which predominates in total resistance of slow, full ship forms, was far smaller than that of conventional hull forms. The quasi-propulsive coefficient was approximately. 0.75, thus propulsion performance of the new hull form was also proved to be very good.

The conventinal hull form with a moderate U-shaped afterbody, whose model tests were carried out in Akashi Model Basin(ASMB) in Japan in 1990 and whose powering performance was proved to be good, was tested again in KRISO to keep consistency in model prediction.

Full scale performances of the two hull forms were predicted by both KRISO Standard Prediction Method, which is similar to ITTC'78 Method except resistance extrapolation, and ITTC'78 Performance Prediction Method.

In KRISO Method, model resistance is extrapolated to full scale based on Froude method. The correlation allowance coefficient(C_A), which is regarded as a function of ship length only, is used. In our study, C_A for both hull forms should be approximaltely same when KRISO Method is applied, which may lead to erroneous assessment of the performance of the two hull forms whose form factors are considerably different with each other. Thus ITTC'78 method is also applied, where C_P and C_N are fixed to 1.0.

(1) Analysis of the Test Results at Full Load

Model tests for both hull forms were carried out during August, 1990 and the full scale performances were predicted by both KRISO method and ITTC'78 mothod. The results are summarized in Table 3 and Fig.7. In general, the new hull form showed excellent resistance performance and its propulsive efficiency was not bad either, while the conventional hull form revealed excellent propulsive efficiency.

(a) Form factor of the conventional hull form is 0.300, while the form factor of the new hull form is 0.183. It is proved that the buttock-flow type framelines applied in part M of the Composite afterbody to reduce the viscous resistance. Especially the form resistance is actually effective as expected.

(b) The observed overall wave patterns seemed to be good for both hull forms. Wave resist-

Table 3 Results of model tests(full load, Vs=15.0, knots)

Method / item	ITTC'78		KRISO	
	New Hull Form	Conventional Hull Form	New Hull Form	Conventional Hull Form
$C_{TS}\times10^3$	2.153	2.401	1.967	2.396
$C_W\times10^3$	0.105	0.187	–	–
$\Delta C_F\times10^3$	0.263	0.259	–	–
k	0.183	0.300	–	–
$C_R\times10^3$	–	–	0.652	1.083
$C_A\times10^3$	–	–	−0.200	−0.200
W_S	0.320	0.344	0.305	0.314
t	0.221	0.178	0.221	0.178
η_H	1.146	1.253	1.121	1.197
η_D	0.755	0.796	0.754	0.776
EHP(PS)	9,263	10,252	8,463	10,232
DHP(PS)	12,273	12,886	11,231	13,182

Table 4 Stock propeller characteristics

Diameter(M)	Z	A_E/A_O	(P/B)mean	Scale ratio
8.2	4	0.431	0.721	32.8

ance of the new hull form with a U-shaped forebody was smaller than that of the conventional hull form with a V-shaped forebody.

(c) The effective horse power of the new hull form is smaller by approximately 9.6% at 15 knots at full load condition due to the drastic improvement in resistance performance.

(d) Hull efficiency of the conventional hull form is 1.253, which is attributed to extremely low thrust deduction fraction of 0.178.

(e) Propulsive efficiency of the conventional hull form is better than that of the new hull form by approximately 5.4%.

To sum up, though the propulsive efficiency of the conventional hull form is somewhat better, the required propulsion power of the new hull form is smaller by approximately 4.8% at 15 knots due to significant improvement in the resistance performance. As shown in Fig.7, the effective horse power and delivered horse power of the new hull form are much smaller over whole speed range.

(2) Analysis of the Test Results at Ballast

As shown in Table 5, the test results at ballast is similar in pattern to those at full load. The new hull form has excellent resistance performance, while the conventional hull form has excellent propulsive efficiency.

(a) Form resistance of the conventional hull form is very big. The form factor is 0.36, which is much bigger than the form factor of 0.300 at full load. The form factor of the new hull form is 0.190, which is slightly bigger than the form factor at full load, so the form resistance of the new hull form still very small.

(b) Wave resistance of the new hull form is smaller.

(c) Conventional hull form have relatively high effective wake fraction and very small thrust

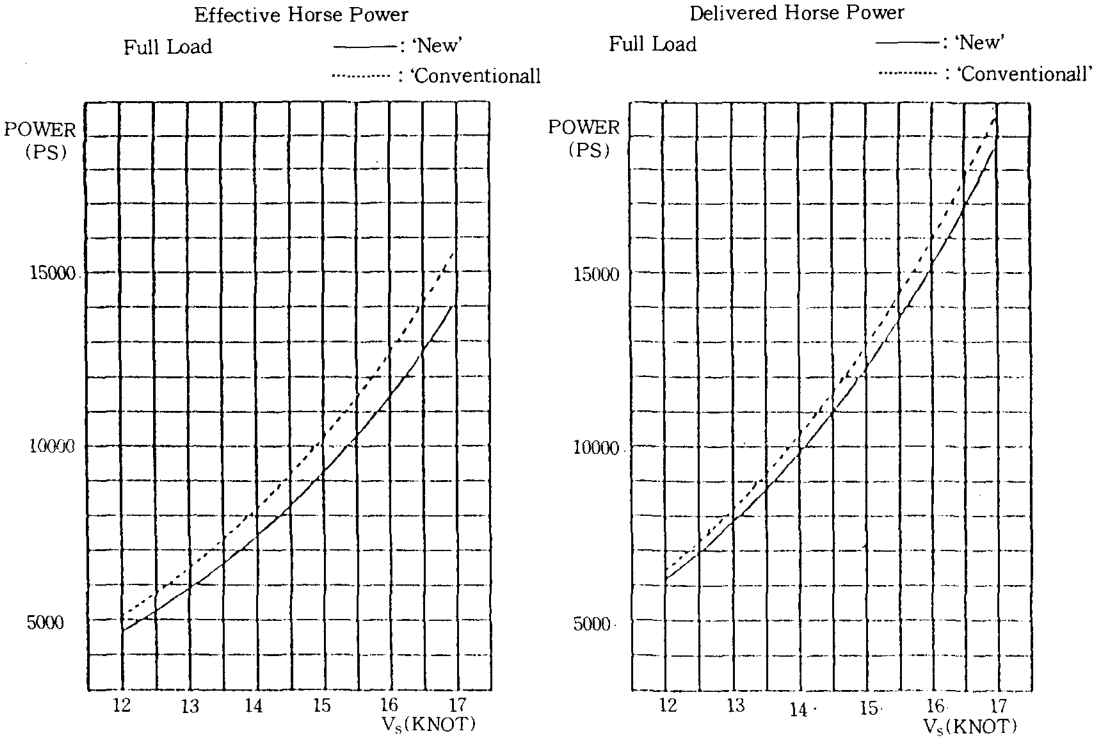


Fig.7 Speed – power curves

deduction fraction, thus hull efficiency is very high(η_H=1.295).

To sum up, the results at ballast show similar trends as in full load, conventional hull form with a moderate U-shaped afterbody have excellent propulsive efficiency. Nevertheless the effective horse power and delivered horse power of the new hull form are smaller by approximately 10.1% and by approximately 5.8% respectively due to remarkable improvement in resistance performance.

Table 5 Results of model tests(ballast, Vs=16.0, knots)

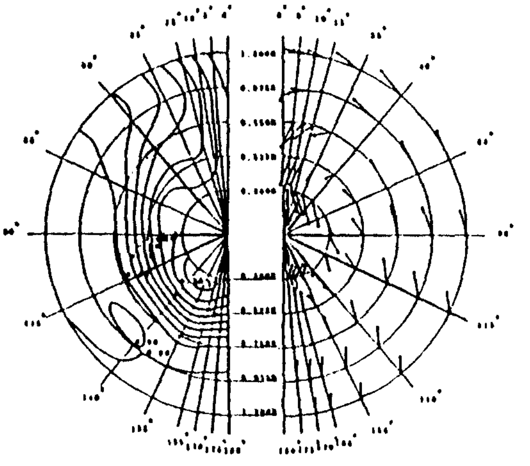
Method / item	ITTC'78		KRISO	
	New Hull Form	Conventional Hull Form	New Hull Form	Conventional Hull Form
$C_{TS}\times10^3$	2.436	2.759	2.353	2.931
$C_W\times10^3$	0.346	0.411	-	-
$\Delta C_F\times10^3$	0.268	0.270	-	-
k	0.190	0.360	-	-
$C_R\times10^3$	-	-	0.910	1.480
$C_A\times10^3$	-	-	-0.100	-0.100
W_S	0.357	0.377	0.340	0.351
t	0.231	0.193	0.231	0.193
η_H	1.195	1.295	1.165	1.243
η_D	0.779	0.816	0.772	0.787
EHP(PS)	10,159	11,306	9,810	12,011
DHP(PS)	13,048	13,855	12,761	15,264

(3) Comparison of Measured Wake Field

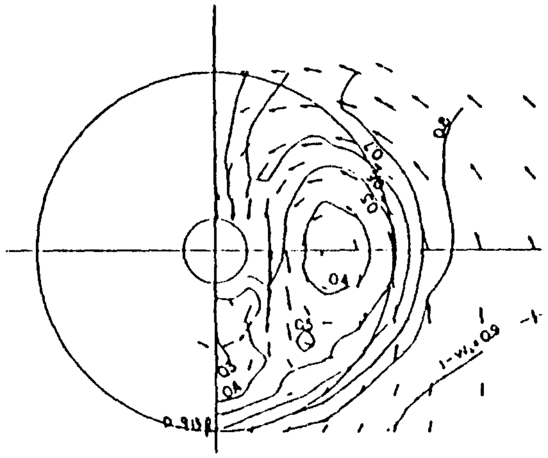
ISO-axial velocity contours in the propeller plane are as shown in Fig.8.

The conventional hull form shows a typical wake distribution of U-shaped afterbodies, where strong bilge vortices are found as usual and wake distribution is quite homogeneous.

The wake distribution of the new hull form seems to be quite different from those of V-or Barge-shaped afterbodies. Bilge vortices are also generated due to the special features in the shape of part S(U-shaped and bulbous). The bilge vortices seem to be not strong as to increase the viscous resistance significantly but effective enough to make homogeneous wake distribution. Therefore it is concluded that favorable wake fields can be obtained by shaping a hull form as depicted in the example of the Composite afterbody.



New hull form : W_N=0.434



Conventional hull form : W_N=0.482

Fig.8 Iso-axial velocity contours(V_x/ V) on propeller plane

3.3 Review of the Resistance Extrapolation Methods

The form factors of the two hull forms, analysed on the basis of the measured model resistance, are shown in Table 6.

Table 6 Measured from factors(k)

Condition / Hull form	Full Load	Ballast
New	0.183	0.190
Conventional	0.300	0.360

The effective horse power and delivered horse power of the two hull forms predicted by both ITTC'78 method and KRISO standard method are summarized in Table 7.

Table 7 Comparison of the predicted results

Method	Condition / Power	Full Load(15knots)		Ballast(16knots)	
		EHP(PS)	DHP(PS)	EHP(PS)	DHP(PS)
New Hull Form	KRISO	8,463	11,231	9,810	12,716
	ITTC'78	9,263	12,273	10,159	13,048
	DIFF.(%)	8.6	8.5	3.4	2.5
Conventional Hull Form	KRISO	10,232	13,182	12,011	15,264
	ITTC'78	10,252	12,886	11,306	13,855
	DIFF.(%)	0.2	−2.3	−6.2	−10.2

$$\text{DIFF.}(\%)=\frac{(\text{ITTC'78}-\text{KRISO})}{\text{ITTC'78}}\times 100$$

According to the above Table 7, significant difference is found between the resistance predicted by ITTC'78 method and the one by KRISO method, especially when the form factor is much smaller or bigger than average.

As pointed out by the authors in [5], above trends is caused by the differences in the model-ship correlation methods. In KRISO method, model resistance is extrapolated to full scale by Froude method, where flat plate friction line (ITTC'57 model-ship correlation line) is used as extrapolator, and full scale resistance is finally adjusted by the amount of correlation allowance, which is obtained from the analysis of statistical data and normally regarded as a function of ship length only. The correlation allowances in Froude method should not be only a function of ship length. But because it is impossible to formulate C_A taking other form parameters into consideration, C_A is regarded as a function of ship length or ship length and fullness parameter such as C_B.

Therefore there is a great risk of too optimistic prediction by Froude method when the measured form factor is much smaller than average. However, this is significantly improved by the application of Hughes method.

When the geometrical charcteristics of the hull forms are so much differnt as exemplified in this study, it is believed to be more reliable to predict the full scale resistance by form factor method than by Froude method.

4. Conclusion

By the application of Composite afterbody concept, which was evolved through the hull form development of a Panamax class bulk carrier and a VLCC, to an Aframax tanker characterized by the form parameter of $C_B \simeq 0.8$, $L/B \simeq 5.5$, $B/T \simeq 3.5$, a successful hull form, which has both good resistance and good propulsive performance at the same time, has been developed, thus proving the concept is also suitable for wide, shallow draft vessel.

To investigate the resistance and propulsion characteristics of the new hull form with a Composite afterbody, a conventional hull form with a moderate U-shaped afterbody, whose performance was proved by model tests, had been selected and the performances of the two hull forms were evaluated both by model tests and by theorectical calculations. It is clearly confirmed that the performance of the new hull form is excellent.

In addition, problems with regard to the resistance extrapolation methods have also been investigated. The results of this study are summarized as follows;

(1) In developing a hull form for a Aframax tanker, Buttock-flow type framelines as in MARAD series hull forms together with small, slender

skeg give better resistance performance than moderate U-shaped frameline at both full load and ballast condition. Form factor of the Composite afterbody is much smaller than that of a well-developed moderate U-shaped afterbody, thus improving resistance performance by around 10%. And by shaping the skeg part properly propulsive efficiency may be kept to be not much worse than that of a moderate U-shaped afterbody.

(2) Relatively homogeneous wake distribution which will not cause any problems with regard to propeller cavitation and ship hull vibration can be obtained by selecting Hogner type stern bulb and careful shaping of part S.

(3) As the form factors of the hull forms of nearly same form parameters may differ significantly depending on the shape of the afterbody, there is a great risk of too much optimistic prediction of full scale resistance of a hull form whose form factor is much smaller than average if full scale resistance is predicted by Froude method and correlation allowance, C_A, without taking geometrical features into account.

Since it is impossible to derive C_A in Froude method where the geometric features are considered, the extrapolation method adopting form factor such as ITTC'78 method is highly recommended. It is confirmed that the problem of the too much optimistic prediction can be avoided by using ITTC'78 performance prediction method.

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