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A Study for Hull Form Design of the SWATH Ship

by

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반잠수쌍동선 선형설계에 관한 연구

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Abstract

This paper presents hull form design details and performance characteristics of the SWATH ship 'SEON JIN' built as an underwater test support ship. The hull form is developed systematically varing sets of 11 form parameters which define a unique hull under waterline. Using this geometry variation scheme we have generated a number of alternatives and selected the final hull which fulfills the design objectives and matches the design constraints. After selecting the final hull form we have investigated performances thoroughly through model tests, and confirmed through sea trials that the performance goals be achieved.

요 약

본 논문은 국내 최초로 개발된 300톤급 반잠수쌍동선형 해상시험선의 선형설계 및 성능분석 결과에 대하여 기술한다. 선형의 수면하부 형상을 정의할 수 있는 11가지 형상인자를 도입함으로써 체계적인 형상변경이 가능토록 하였으며, 이를 통해 복수개의 선형을 도출한 후 설계목표 및 설계 제한조건과 부합되는 최종 선형을 선택하였다. 설계선형의 제반 성능을 이론 및 수조모형시험을 통해 상세히 검증하였으며 실선시험에 의해 목표 성능이 발휘됨을 입증하였다.

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1. Introduction

This paper presents the SWATH hull form design details and the results of the application to the ship 'SEON JIN'. [1]

We had developed the SWATH hull form design technique, composed of hull form generation program(SWAGEN), effective horsepower prediction program(SWAD) and ship motion characteristics prediction program(SWAVE, SWAHO).

The hull form is developed systematically varing sets of 11 form parameters by SWAGEN and the performance characteristics of the selected hull form is investigated by SWAD, SWAVE and SWAHO.

With this design tool, we have generated a number of alternatives and selected the final hull which fulfills the design objectives and matches the design constraints.

After selecting the final hull form we have investigated performances thoroughly through theoretical analysis, model tests, and full scale sea trials.

We have applied the above design procedure to the ship 'SEON JIN' and presented the results in this paper.

The SWATH ship 'SEON JIN' built as an underwater test support ship has been in operation since April 1993.

2. Hull Form Design System

Due to the simplicity of the SWATH hull form, it can be defined uniquely using only a few geometric parameters, and thus systematic variation of hull form is much easier than for conventional displacement ships. In the present study we have extracted 11 dimensional form parameters which define a unique hull geometry under the following restrictions :

- o strut type is single, not tandem
- o both lower hull and strut take the form of elliptical nose, straight middle body, and parabolic tail configuration
- o shape of lower hull section is circle
- o strut thickness is not varied along depth

All of these 11 parameters are of length dimension making it easy for a designer to recognize how hull form is varied, but systematic hull variation is rather difficult. So another set of 10 nondimensional parameters and one dimensional parameter, displacement, is introduced for systematic hull form variation, mapped one to one to the above set of lengthwise dimensional parameters. [2]

This geometry generation scheme(SWAGEN) is computer-coded with an effective horsepower prediction program(SWAD) based on the thin ship theory [3], with a calculation scheme of approximate heave, pitch and roll natural periods, and with a motion characteristic prediction program(SWAVE, SWAHO) based on the strip theory. [6]

Fig. 1 shows the details of design procedure.

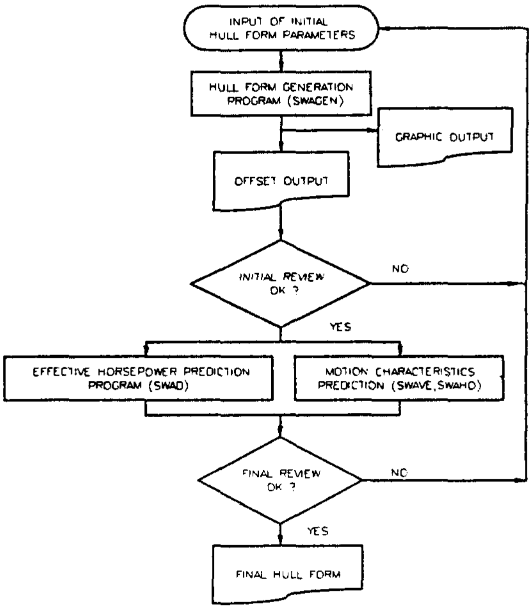


Fig. 1 The design procedure of SWATH ship

3. Application to Design of 'SEON JIN'

The requirements generated from her mission as an underwater test support ship are as follows :

- displacement of about 300 tons
- working deck area aft is about 15×15 M^2
- maximum speed of 20 kts
- cruising range is 1000 nm at 16 kts
- significant pitch and roll at zero speed are to be less than 3 deg. up to sea state 4 (significant wave height 2 M)
- turning radius is no more than 6L at maximum speed
- intact and damage stability is to satisfy the requirements of DDS-079-1

The hull form design objectives chosen on the basis of these requirements are enumerated in the order of priority :

- minimize the distance between LCB and LCF to restrict heave-pitch coupling
- make the pitch natural period greater than 9 seconds to avoid the half-power bandwidth of sea state 4
- minimize the gap between LCB and LCG to decrease the space needed to ballast
- maximize GMT and GML to suppress heel and trim while moving heavy equipments
- minimize the effective horsepower at 20 kts

We have focused our design efforts mostly on improvement of the seakeeping performance at zero speed.

The performances of propulsion and turning are not reflected directly on the design goals of bare hull, but we select some design constraints instead; propeller diameter to be no greater than 85% of lower hull diameter for acceptable hull efficiency, the tail part of lower hull to have smooth curvature, and rudder to have sufficient area to guarantee the required turning capacity.

The set of 11 dimensional parameters defining a unique hull is depicted in Fig. 2 along with its equivalent set of nondimensional parameters. Most of design constraints are generated from the requirements on general arrangement :

- displacement of about 300 tons
- width of the main deck is to be about 15M
- length overall (length of the main deck) to be about 35 M
- minimum strut thickness of 0.8 M for personal passage

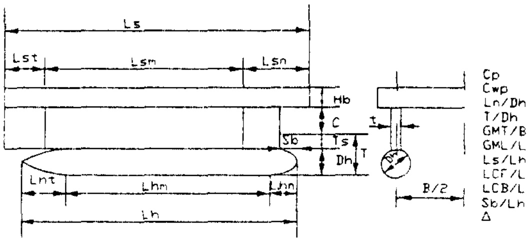


Fig.2 Hull form parameters

The particulars of the initial hull form and the finally seelcted hull form are compared in Table 1.

We have chosen the hull form of SWATH-8 designed by USCG as the initial hull form.

Comparing design objectives, the initial hull form has a large distance between LCB and LCF. Hence the pitch response is very large at sea state 4, zero speed and low speed because of heave-pitch coupling.

The initial hull form has the pitch natural period greater than 9 seconds to avoid the half power bandwidth of sea state 4 and the good resistance performance at 20 kts.

On the other hand, the weight distribution as the result of the main subsystem design and the general arrangement has the large difference with an initial estimation and hence the serious problem of a large shift of LCB aftward is occured.

The above mentioned problem cannot be

solved by the small variation of the initial hull form and the generation of a new hull form is needed basically.

Accordingly, the design procedure is divided into two stages to extract the hull form satisfied the design objectives and the requirement from the initial hull form.

o large shift of LCB aftward and minimize distance between LCB and LCF

o decrease EHP at 20 kts through the increase of lower hull slenderness

For more details from selection of the initial hull to generation of the final hull see Reference. [4]

Fig. 3 shows the final hull form. As shown in Table 1, (LCF-LCB)/Ls and LCB changes are drastic and GMT/B increases slightly. The pitch period shows small decrease contrary to the design objective though its effect on seakeeping is expected to be minor. The effective horsepower, however, increases by 160 HP unfortunately. The large shift of LCB aftward and the decrease of Lh/Dh are the main causes for this undesirable result.

Table 1. Particulars of the initial and the final hull form

	INITIAL	FINAL
Lhn (m)	2.30	8.95
Lhm (m)	23.50	18.00
Lht (m)	6.80	5.05
Lh (m)	32.60	32.00
Dh (m)	2.28	2.45
Lsn (m)	10.40	10.00
Lsm (m)	17.00	17.50
Lst (m)	4.70	5.00
Ls (m)	32.10	32.50
t (m)	0.80	0.80
Ts (m)	1.24	1.05
T (m)	3.52	3.50
Sb (m)	2.30	1.40
B (m)	12.30	12.30
△ (ton)	297.4	307.1
Cp	0.879	0.833
Cw	0.882	0.883
Lh/Dh	14.3	13.1
T/Dh	1.54	1.43
t/Dh	0.35	0.33
GMT/B	0.155	0.175
GML/Ls	0.215	0.225
EHP (HP)	2539	2697
T_P (sec)	9.08	8.65
T_H (sec)	6.62	6.68
T_R (sec)	11.72	11.05
(LCF-LCB)/Ls	0.088	0.041
LCB (m)	13.50	15.11

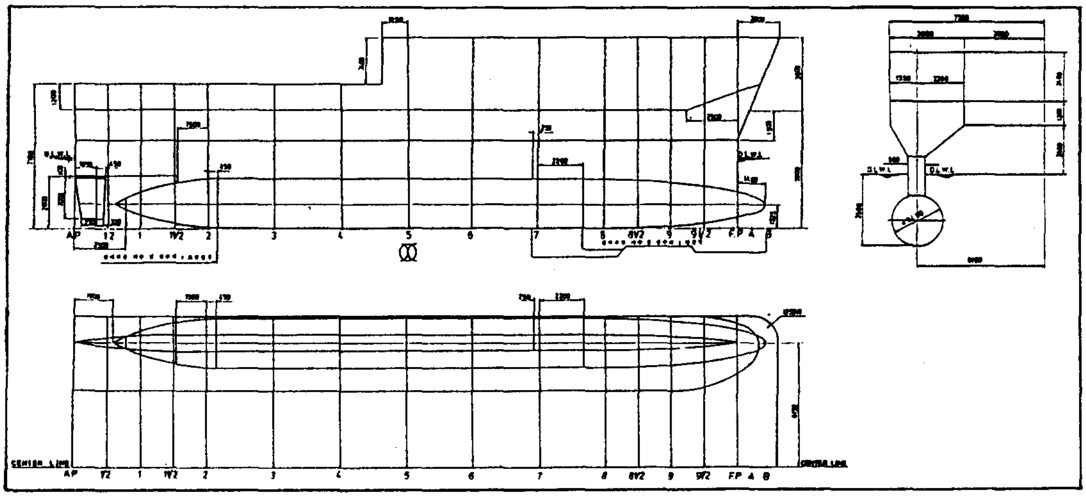


Fig. 3 Final hull form

4. Hydrodynamic Characteristics Analysis

Fig. 4 shows resistance coefficients obtained from the thin ship theory and from the 1/10 model tests[5]. To maintain draft and even trim the model was loaded with weights and connected to the carriage with exactly vertical thread. As we can see two results show good agreement.

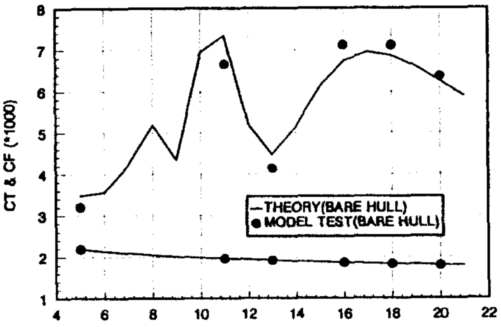


Fig. 4 Resistance coefficients (draft 3,5m)

In Fig. 5 model test results of propulsion characteristics are displayed. The model was fixed in the same way as in resistance tests. Principal particulars of the model propeller and its open water performance curve are presented in Table 2 and Fig. 6. The quasi-propulsive efficiency η_D at speeds above 15 kts is below 0.65 despite the high hull efficiency η_H. This is mainly due to the low propeller efficiency η_O which is designed to simulate a controllable pitch propeller. The wake fraction ω shows curious result at 5 kts and is to be discarded from consideration.

Fig. 7 compares DHP of model tests with that of full scale sea trials. The characteristic curve of the full scale propeller at the design pitch ratio 1.1 is presented in Fig. 8, which the Omaker supplied. The full scale DHP is greater than the model test result by 6 ~ 9 % at speeds over 15 kts.

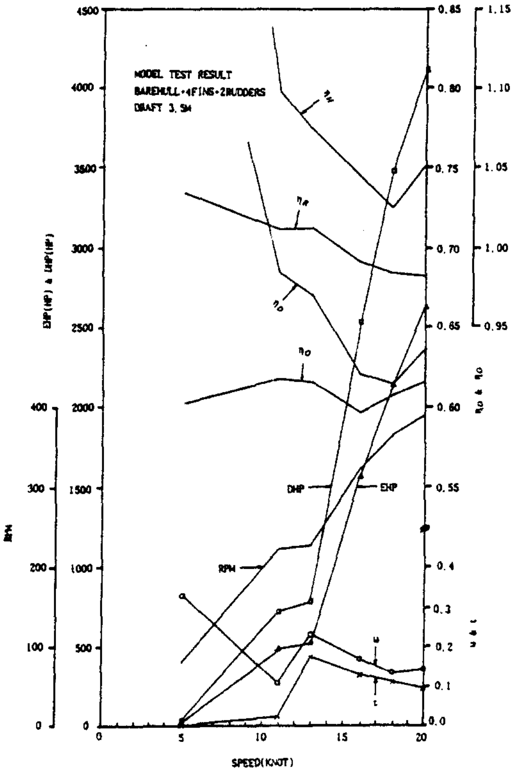


Fig. 5 Propulsion characteristics (draft 3.5m)

Table 2 Principal particulars of model propeller

Scale Ratio	10.0
Diameter, D	200.0 mm
No. of Blades, Z	4
Expanded Area Ratio, A_E/A_O	0.754
Pitch Ratio at 0.7R, $(P/D)_{0.7R}$	0.9678
Section Type	NACA
Direction of Rotation	HP215(R/H), HP216(L/H)
Hub/Dia. Ratio, d/D	0.3
Tip Skew Angle, θ_{TIP}	17.04 Degree
Tip Rake	0 mm
Material	Aluminum
Chord Length at 0.7R	95.78 mm
Blade Thickness at 0.7R	2.60 mm

Considering draft difference of 0.2 M, equivalent to 5% increase of wetted surface area, and the difference in wave condition, these two results seem to be almost identical.

In sea trials, fins were fixed as in model tests and trim was measured less than one degree above 15 kts.

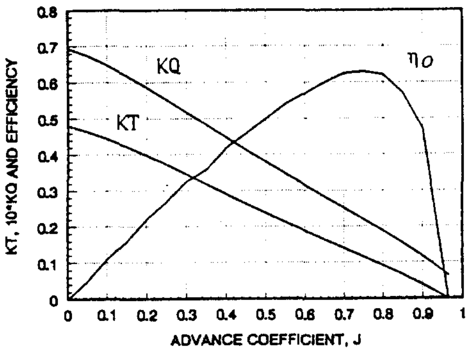


Fig.6 Open water characteristic curve of model propeller

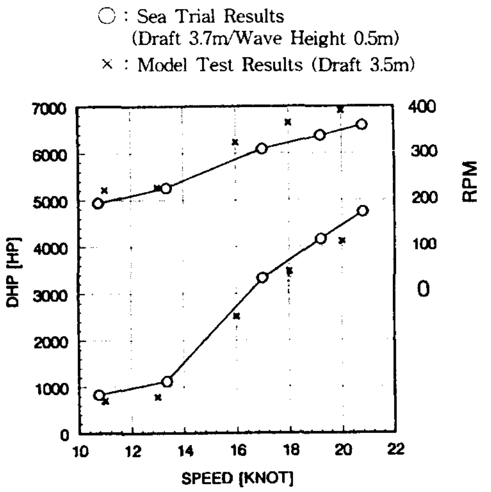


Fig.7 Delivered horsepower and propeller RPM

Fig. 9 through Fig. 13 show regular wave responses of the strip theory [6] and of the model test. [7] Test results are depicted with dots. The 1/10 model was self-propelled and only sway and yaw modes were restricted in head and following wave tests.

In head waves two results show good agreement while large discrepancy occurs in following waves at 16 and 20 kts. At zero speed, however, we can see good agreement of both heave and pitch even in following waves. Roll response in Fig. 13 shows much difference between theory and test results. The roll stiffness GMT is very sensitive to the change of vertical center of gravity KG, while in model tests KG differs by 1 M, 20% of total value, from the required KG. We think this is the main reason for the roll discrepancy.

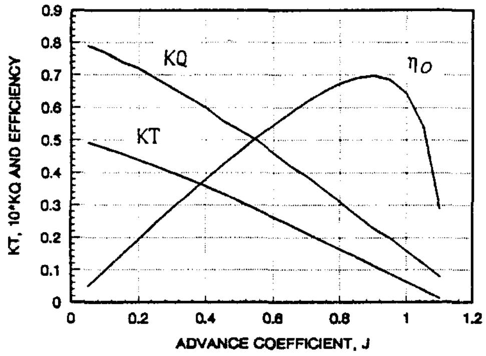


Fig.8 Open water characteristic curve of full scale propeller

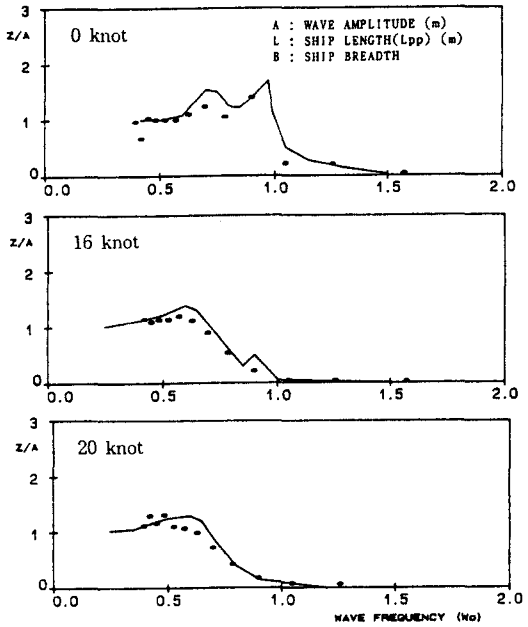


Fig. 9 Heave in head waves

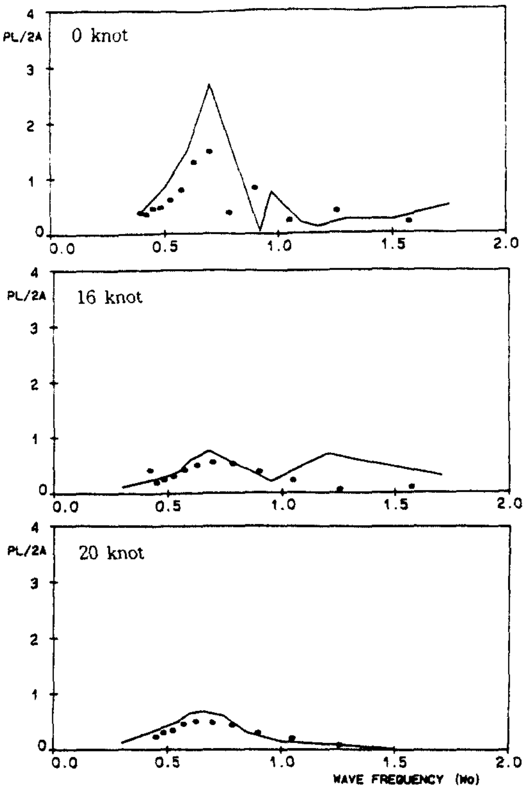


Fig. 10 Pitch in head waves

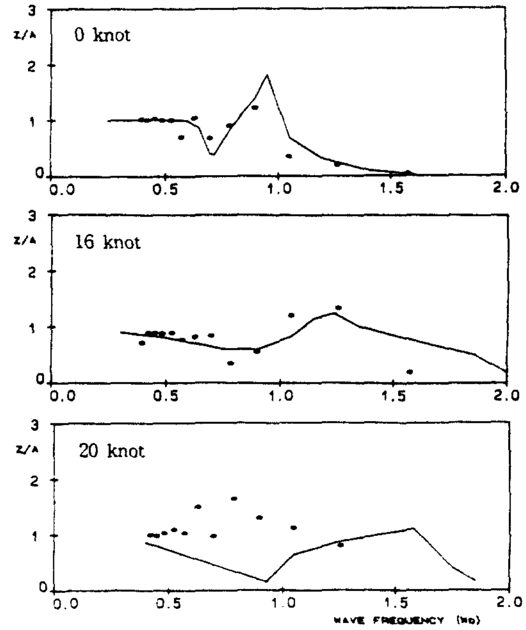


Fig. 11 Heave in following waves

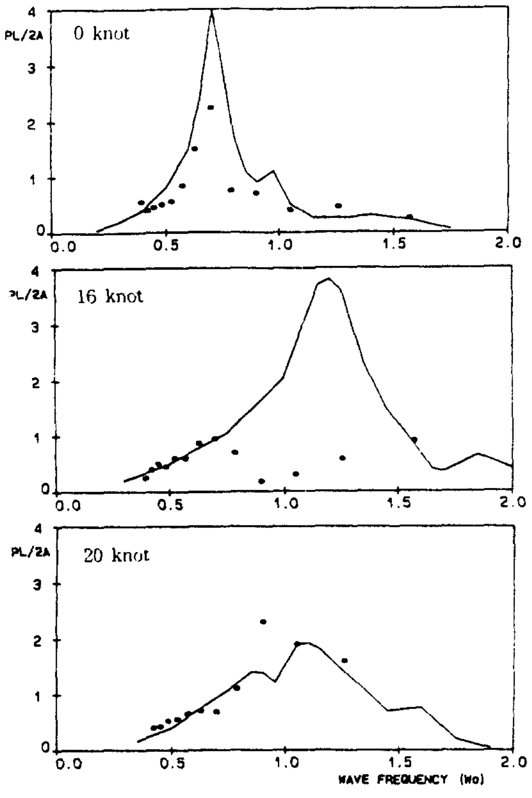


Fig. 12 Pitch in following waves

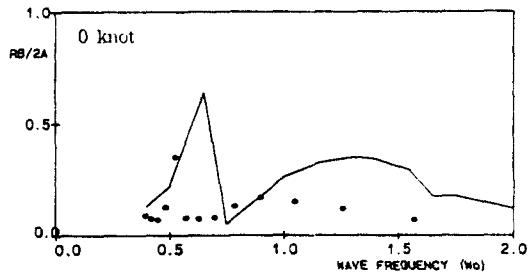


Fig.13 Roll in beam waves

Figs. 14, 15 and 16 show irregular wave responses of pitch and roll. The theoretical results are obtained using ITTC wave spectrum on the assumption of long-crested waves. The measured wave spectrum in zero speed tests, Fig. 14, is presented in Fig. 17(a) and the spectrum for Fig. 15 and 16, 16 kts tests, is presented in Fig. 17(b). The significant wave heights are both at 1.6 M

, equivalent to low sea state 4, for the two cases.

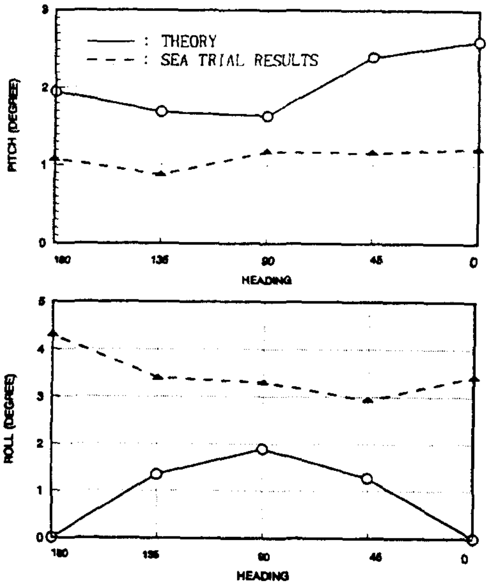


Fig.14 Pitch and roll significant amplitudes without fin control (0kts/ H1/3 1.6M)

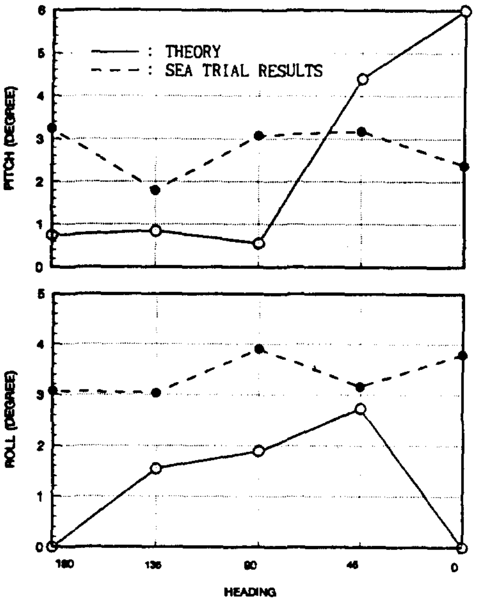


Fig.15 Pitch and roll significant amplitudes without fin control (16kts/ H1/3 1.6M)

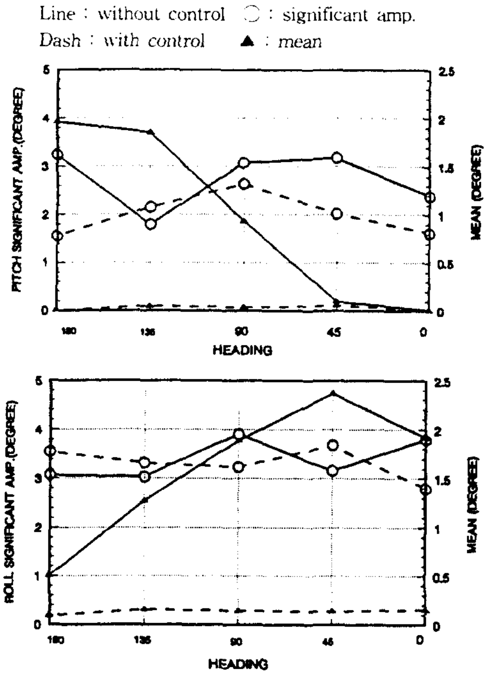


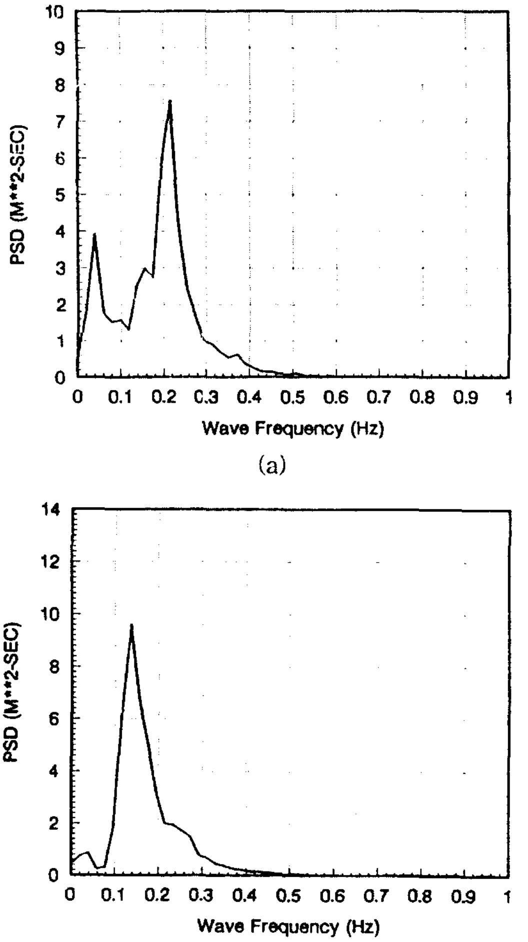
Fig.16 Pitch and roll with and without fin control, sea trial results (16kts/ H1/3 1.6M)

From Fig. 14 we can see that sea trial results of pitch are smaller than theoretical results while the tendancy is reversed for the roll responses. The measured wave spectrum, Fig. 17(a), shows peak value at 0.2 Hz (1.25 rad/sec), but the peak of the ITTC spectrum occurs at 0.16 Hz (1.0 rad/sec).

This causes the above pitch difference. The difference of roll stems mainly from the swell component as shown in Fig. 17(a). During these 0kts sea trials the wind velocity was measured 30 ~ 40 kts, the value equivalent to sea state 6 if fully developed, and the raw data of roll, Fig. 18, shows long period fluctuation due to wind effects. The large projected area of our vessel is a primary cause for the undesirable situation.

Fig. 15 shows pitch and roll responses at 16 kts. There seems to be no consistency between theory and sea trial results. The contradictory such as long-crested us real short-crested waves, the difference of wave spectrum configuration, wind effects, and deficiency of the strip theory in following seas, act in all to make comparison impossible.

Fig. 16 is presented to display fin control effects. Mean values decrease absolutely showing marvellous performance of command following. The effects on decreasing significant amplitudes is minor, but the amount of decrease would be magnified if sea state became more rough.



(a)

(b)

Fig.17 Measured wave spectrums

During sea trials vertical accelerations of CG were measured also and shown to be very small, less than 0.08g regardless of ship's heading and speed.

In Table 3 we present linear hydrodynamic derivatives obtained from the empirical formulas [8] and the 1/10 model tests. [9] Even though the empirical formulas are based on the data of only 4 SWATH models, the agreement is remarkable. The large difference of R/L at 13 kts, hollow zone of wavemaking, is supposed to be caused by drastic distortion of wave patterns.

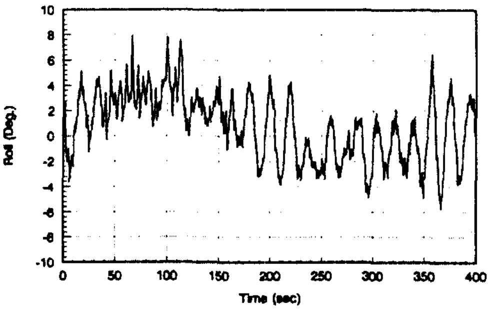


Fig.18 Time series of roll, sea trial result (0kts/ head sea/ H1/3 1.6M)

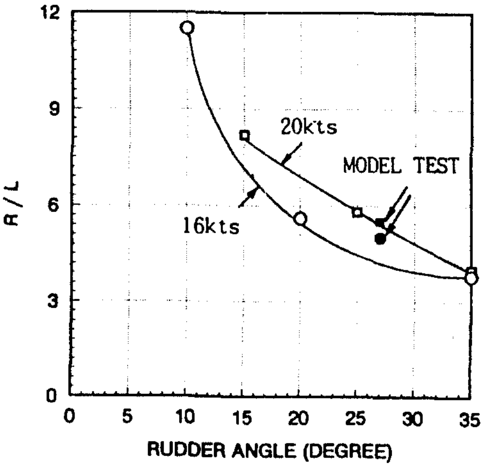


Fig.19 Turning radius

Fig. 19 shows turning radius measured in sea trials overlapped with model test results at rudder angle of 27 degrees. It shows reasonable tendancy and the agreement

Table 3. Linear hydrodynamic derivatives

V (Fn)	13 kts (0.38)		16 kts (0.47)		20 kts (0.58)	
	Empirical	Model Test	Empirical	Model Test	Empirical	Model Test
Yv	-0.09	-0.082	-0.05	-0.059	-0.06	-0.098
Nv	-0.0018	-0.038	-0.020	-0.060	-0.028	-0.052
Yr	0.025	0.031	0.028	0.023	0.017	0.0093
Nr	-0.019	-0.019	-0.023	-0.028	-0.023	-0.018
Y_δ	0.012	0.015	0.013	0.015	0.011	0.011
N_δ	-0.0056	-0.0073	-0.0056	-0.0082	-0.0046	-0.0063
C	0.0017	0.0020	0.0013	0.0019	0.0013	0.0013
R/L(δ 27°)	6.98	3.70	5.42	5.00	4.93	5.40

between sea trial and model test results is good.

5. Concluding Remarks

The hull form design details and performance characteristics are presented for the SWATH ship 'SEON JIN'.

The hull form is developed systematically using sets of form parameters which define a unique hull under waterline. Compared with the initial hull, the final hull shows small LCF-LCB gap, large LCB shift aftward, consequently suppressing heave-pitch coupling and minimizing the need for ballast, respectively. The effective horsepower, however, increases by 6% due to the LCB shift aftward and the decrease of Lh/Dh. Even with this defect, we have confirmed through model tests and sea trials the design objectives be fulfilled.

The important results acquired from the present work are ;

○the thin ship theory results of resistance show good agreement with model test results

○model test results of DHP almost equal sea trial results

○regular wave responses of heave and pitch from the strip theory show good agreement with model test results in head and following seas except the case of following sea with speed

○the empirical formulars, model tests and sea trials give similar results of turning radius above hollow speed

○exact realization of KG is the key to successful aquisition of roll data in model tests

○wind effects are very crucial on roll responses for small SWATH ships, thus, in design stage minimize the projected area above waterline and /or suppress the KG increase

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