EFFECT OF STERN WEDGES AND ADVANCED SPRAY RAIL SYSTEM ON CALM WATER RESISTANCE OF HIGH-SPEED DISPLACEMENT HULL FORMS

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ABSTRACT

The research work presented here is conducted as part of Systematic Series Development of AMECRC. This paper attempts to present the results of the calm water tests of Model 13 of AMECRC Systematic Series with different combinations of spray rails with stern wedges. The stern wedges were faired into the bilge's and had 0°, 4°, 7° and 10° angle relative to the hull surface. The wedge length was fixed at 2% L_{PP}. Considerable performance improvements (residuary resistance reduction in excess of 10% at higher speeds) were recorded.

1 INTRODUCTION

1.1 BACKGROUND

The series of high-speed displacement hull forms is obtained from two parent hulls by systematic variation of three hull form parameters - L/B, B/T and C_B [7]. The series' parameter space and fourteen models built to date are presented in Figure 1.1.

During the course of experimental investigation of the systematic series development, it was decided to look at the possibilities for resistance performance improvement in calm water. A literature survey regarding this was published in [4]. Based on this, research into the combined effects of spray rails and stern wedges was suggested as the most promising area for further research. However, literature claims for large reductions in required power were considered with caution and it was decided to conduct the initial testing with one model (Model 13). The results of these tests are presented in this paper.

1.2 LITERATURE OVERVIEW

ITTC (1984) [9] suggests that semi-displacement round-bilge hulls should be tested with spray rails, in order to avoid substantial increase of the wetted surface area which could reach 50 to 60 % of the wetted surface area at rest. The effect of stern wedges and controllable flaps (trim tabs) is discussed in seven papers reviewed in [4]. The benefits reported are a 5% decrease in resistance for $0.4<Fn<0.45$ and up to 11% for $0.5<Fn<0.9$, [10]. Also, stern wedges smoothly faired into the bilge's (Figure 1.2) were found to be more efficient than the constant-cross-section type.

Muller-Graf in [13] claims that well shaped and properly arranged spray rails, if combined with a transom wedge, are the most effective devices to reduce the hull resistance of given semi-displacement round bilge hulls. It is also stated that the advanced spray rail system

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(ASRS), developed in the Berlin Model Basin, combined with a wedge, leads to remarkable power savings, which are larger than those obtained by each component solely. Additionally, the seakeeping qualities of round bilge hulls are improved by this special spray rail system and the apparent loss of metacentric height of this hull type at high speeds can be reduced considerably.

2 TESTING

2.1 TESTING PROCEDURE

The tests were conducted at model scale range of 0.6 to 3.9 m/sec corresponding to Fn varying from 0.15 to 0.98. In order to ensure high reliability of the test results three runs were performed at each speed. After careful comparison of the measured speed, drag and trim, the average of the two closest runs was used in all further analyses. The tests consisted of resistance and trim measurements. Turbulence stimulation was achieved using studs located at 10% of the waterline length aft of the forward perpendicular. The studs had a diameter of 3mm, a height of 3mm and were spaced 20 mm apart. Drag effects of studs have not been accounted for in the analysis of results.

In addition, an attempt was made to investigate if the wedge presence influences the vessel's performance through the change of trim only. Based on tests of the model free to trim and at fixed trim, Karafiath in [10] claims that modification of the flow field around the afterbody also plays an important part. Briefly, the idea was to compare the model's performance with a wedge in a free-to-trim condition, with the performance of the model at the same, fixed trim without the wedge. After some tests and data analysis, the presence of 'cross-talk' in the strain gauge was found, which prevented derivation of valid conclusions. In particular, the measurements of the horizontal (drag) forces were affected by vertical forces in the strain gauge during the fixed-trim tests.

Model 13, which was chosen for the tests, had parameters as shown in Table 2.1.

2.2 STERN WEDGE SETUP

Initially it was planned to test Model 13 with trim tabs instead of a wedge, as that testing setup enables quick change of test condition (change of the tabs' inclination angle). However, the following problems were encountered during preparation for the tests:

- Manufacturing of the trim tabs.
- The model's buttock lines had different slopes close to the transom and generating trim tab surface as the extension of the hull surface would result in a 'twisted' surface.
- The rounded shape of the model's transom would create 'gaps' between the trim tabs and the hull, at different tab inclinations.

Also, the trim tab installation affects the waterline length and that has a significant effect on the vessel's performance, even at zero inclination angle, as can be seen in Figure 2.1, from [8]. On the other hand, the wedge installation has no influence on the waterline length and could potentially provide 'clearer' information about its influence on the performance. Also, the bare hull condition could be considered as a 'zero' wedge condition.

When the wedge installation was reconsidered, a promising solution for a reasonably quick, accurate and repeatable installation technique was found. In Figure 2.2 a definition of wedge geometry is presented. Wedge angle α is measured relative to the buttock line slope. Equation (1) were used to calculate z_W, the vertical coordinate of the wedge's aft edge. This calculation was repeated for several buttock lines and the space curve representing the wedge's aft edge was obtained.

$$\beta = \tan^{-1}\left(\left|\frac{z_0 - z_1}{x_0 - x_1}\right|\right) \qquad (1)$$

$$z_w = z_1 + (x_0 - x_1)\cdot\tan(\beta - \alpha)$$

Based on the available literature the following wedge parameters were selected:

$L_{WEDGE} = 2\%\ L_{PP} = 32$mm (model scale)

$\alpha = 0$ °(bare hull), 4°, 7° and 10°

in [10], Karafiath also suggests that the wedges are more effective when they are smoothly faired into the bilges, in comparison with constant cross-section ones. With this in mind, the wedge shape was completely defined. The forward edge of the wedge was created as an 'embedded' curve on the hull surface, from hull offsets [7]. Using Autoship software it was possible to generate a developable surface between the forward and the aft edge of the wedge, as illustrated in Figure 2.3. The initial idea was to make the wedge surface from a thin plate and to fix it to the hull. The fixing problem was intended to be solved by addition of a transom template which would be connected to the wedge at the wedge's aft edge. Practical problems encountered lead to a solution of a transom template with a wedge made from plasticine. Sliding wedge angle templates along the hull shaped the wedge, while at the same time the template was sliding along the transom template edge. This way of wedge implementation ensured reliable, accurate and repeatable wedge installation. Also, its application is reasonably fast, as was necessary in order to avoid wasting of testing time.

2.3 SPRAY RAILS SETUP

Spray rails were generated according to the geometry description of the Advanced Spray Rail System, presented in [13], Figures 2.4 and 2.5.

The spray rails had a triangular cross-section with constant bottom width $b_{SR} = 0.0055\ L_{WL}$, which measures 8.8mm in model scale. The bottom angle β, between the bottom of the rail and the horizontal line, decreased from 30° at the bow to 8° at the end of the rails.

Two space curves were generated for the bottom surface of each of the spray rails. The first one was embedded on the hull surface according to Figure 2.5. The second one was then created, knowing b_{SR} and β at any given station. Finally, a developable surface between these curves was created using Autoship software.Again, some practical problems were faced during the spray rails manufacture. Intended installation by means of tabs connected to the spray rails' surfaces had to be abandoned. Fixing of the surfaces to the hull by plasticine was possible, but a more reliable (and slightly more complex) way of installation was selected in the end - a mould was made. Figure 2.6 shows the mould of the upper spray rail. The bottom surface of the spray rail is cut from a thin plate and supported by plasticine. The angle templates can be seen on the upper side. The spray rails were made from 'plasti-bond' (two component epoxy resins). The final configuration is shown in Figure 2.7.

3 RESULTS

The results are presented in Figures 3.1 to 3.2. The bare hull condition was marked as zero wedge condition. Comparison of the results relative to the bare hull condition is presented in Figure 3.2. The matrix of tests performed is shown in Table 3.1. As mentioned previously, the wedge length was 2% of L_{PP}.

4 CONCLUDING REMARKS AND RECOMMENDATIONS

The design of a stern wedge involves sizing the wedge and selecting the most suitable shape. In the research presented here a constant wedge length of 2% of L_{PP} was used and three wedges angles up to 10° were tested.

Stern wedge design is a compromise between improving high-speed performance and minimizing the low-speed performance penalty. The mission requirements for a particular vessel will dictate the relative importance of the low-speed and high-speed performance. The wedge increases transom immersion. This tends to delay the transition between fully wetted transom flow at low speed and fully 'dry' transom at high speed.

Figures 3.1 and 3.2 clearly present the influence of the spray rails, wedges and their combination on the performance of the tested model. From these Figures it is possible to see the effect of different setups on the hull's resistance, rise of center of gravity and running trim.

Between a Fn of 0.37 and 0.41 the vessel's resistance reaches the bare hull level. Above this speed wedge benefits are clear. In the hump region (Fn = 0.50 - 0.55) the benefits are consistent and provide between 5 and 12% decrease in the model's residuary resistance (higher decrease with an increase of the wedge angle).

The effect of the 'spray-rails-only' configuration shows benefits only for Fn between 0.68 and 0.85. The combined effect of 'wedge-plus-spray-rails' configuration shows clear advantage over the 'wedge-only' configuration for speeds above Fn = 0.65. That should be attributed to the lift of the spray rails, which becomes more significant for Fn above 0.65.

In conclusion, the tests presented here demonstrated clear benefits available by installation of wedges (residuary resistance reductions of 13 to 20% were experienced at higher speeds). Therefore this area of research promises to be very valuable for designers of naval vessels.

It is suggested that future research should extend the range of the wedge angles, as the tests done indicate that the optimal angle is greater than 10°. Milward in [12] indicates that the benefits from wedge installation depend on the vessel's length-beam ratio. Therefore, it is also suggested that some additional testing should be done with systematic series model(s) with different L/B. Model 13 has L/B = 6.

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6 NOMENCLATURE

α	=	Wedge angle
β	=	Transversal slope of spray rail
B	=	Model beam
b_{SR}	=	Spray rail beam
C_F	=	ITTC ship-model correlation line
C_R	=	Residuary resistance coefficient
DWL	=	Design waterline
Fn	=	Froude number
L	=	Model length
L/B	=	Length-beam ratio
LCG	=	Longitudinal center of gravity
L_{PP}	=	Length between perpendiculars
L_{WEDGE}	=	Stern wedge length
L_{WL}	=	Waterline length
AME CRC	=	Australian Maritime Engineering CRC Ltd.
ASRS	=	Advanced Spray Rail System
FFG	=	Guided Missile Frigate
IR	=	Internal (AMECRC) Report
ITTC	=	International Towing Tank Conference

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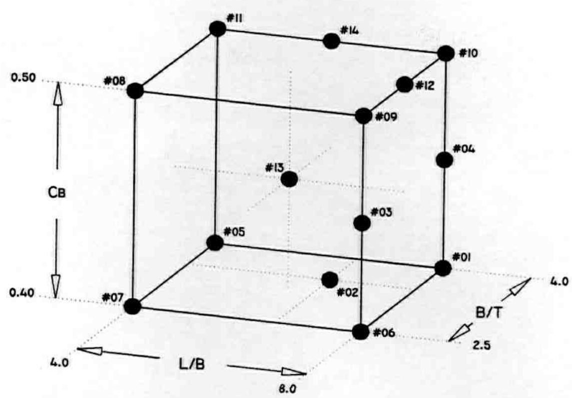

Figure 1.1: AMECRC Systematic Series Parameter Space[7]

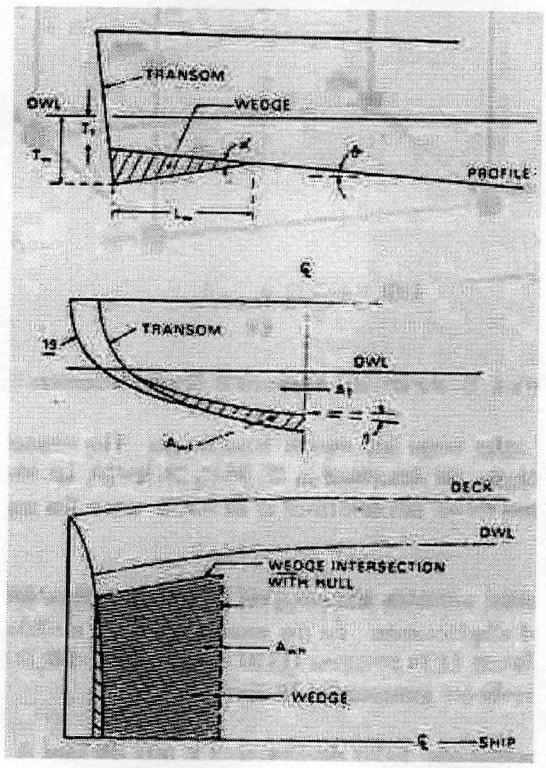

Figure 1.2: Definition of wedge geometry

L (m)	1.6
B (m)	0.267
T (m)	0.082
Displacement (kg)	15.777
Wetted Surface Area (m^2)	0.4384
L/B	6.0
B/T	3.25
C_B	0.45

Table 2.1: Hull Form Parameters of Model 13

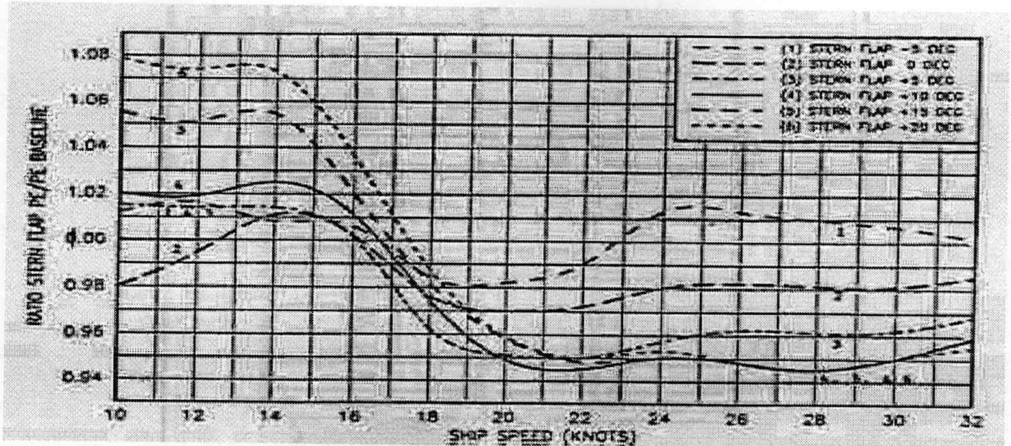

Figure 2.1: Stern flap angle variation on effective power for FFG-7 Class [8]

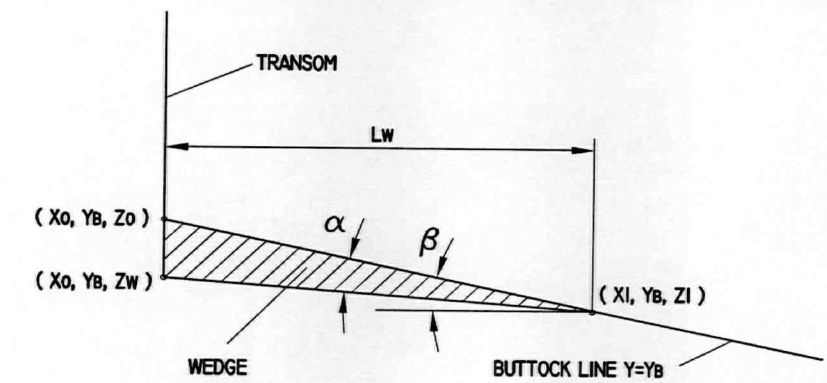

Figure 2.2: Wedge definition

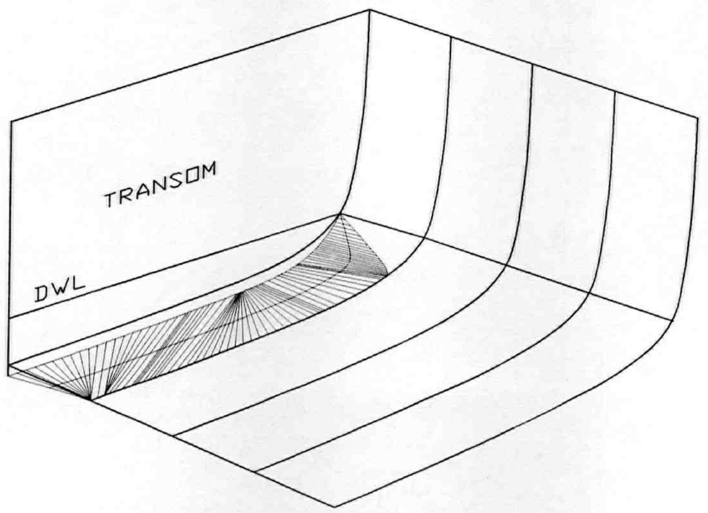

Figure 2.3: Wedge as developable surface

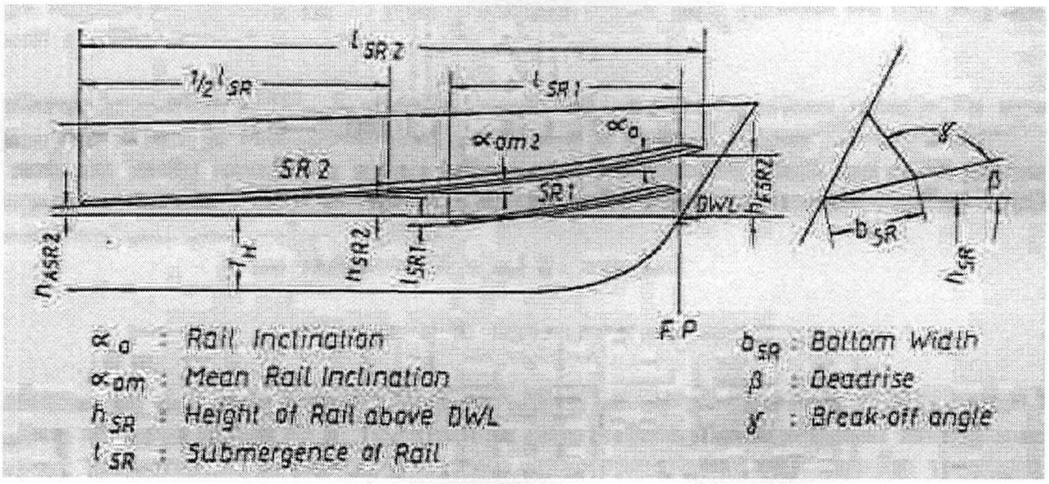

Figure 2.4: Geometry of Spray Rails [13]

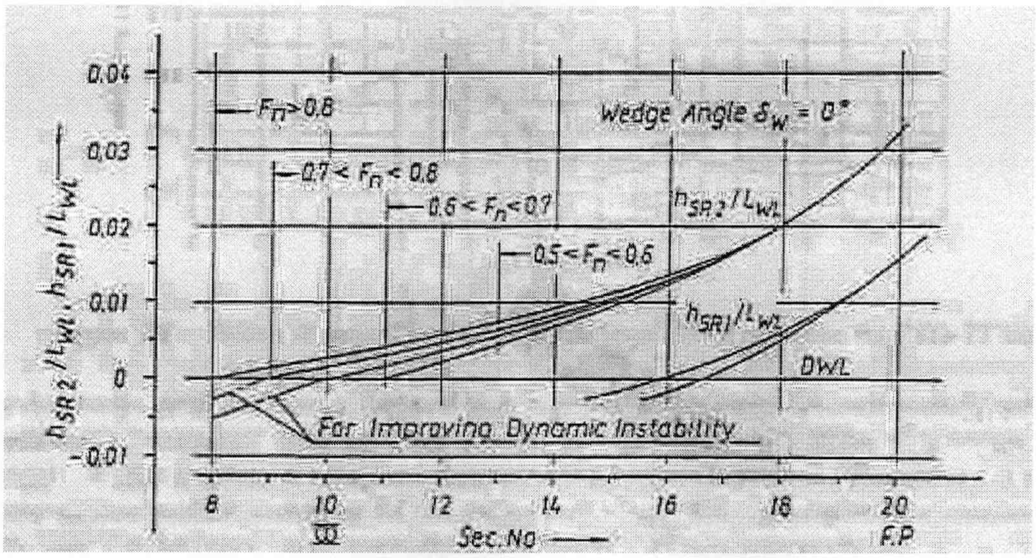

Figure 2.5: Relative heights of Advanced Spray Rails above DWL [13]

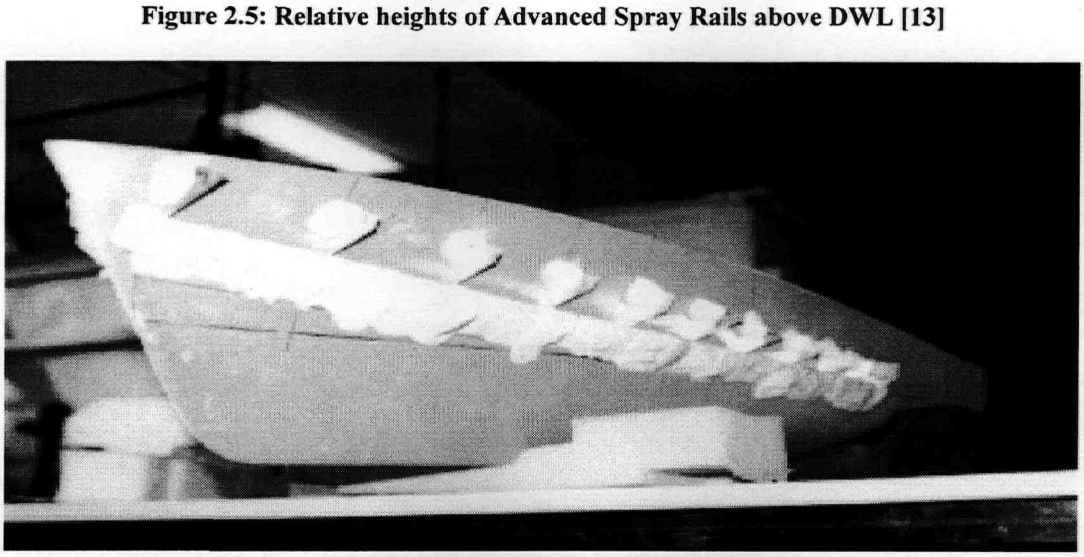

Figure 2.6: Mould for the Upper Spray Rail

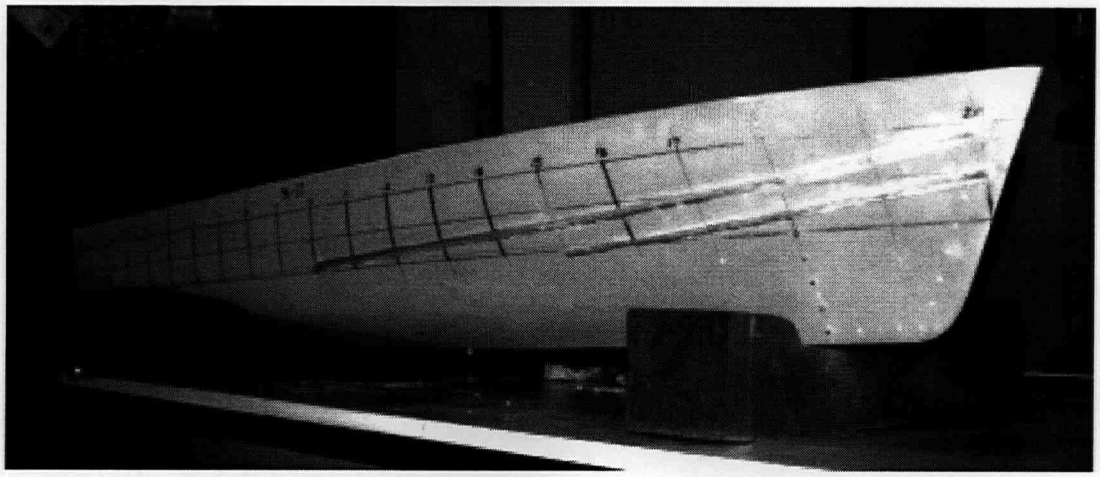

Figure 2.7: Spray Rails on Model 13

Wedge angle	Without Spray Rails	With Spray Rails
0°	•	•
4°	•	•
7°	•	•
10°	•	•

Table 3.1: Test Matrix for Model 13

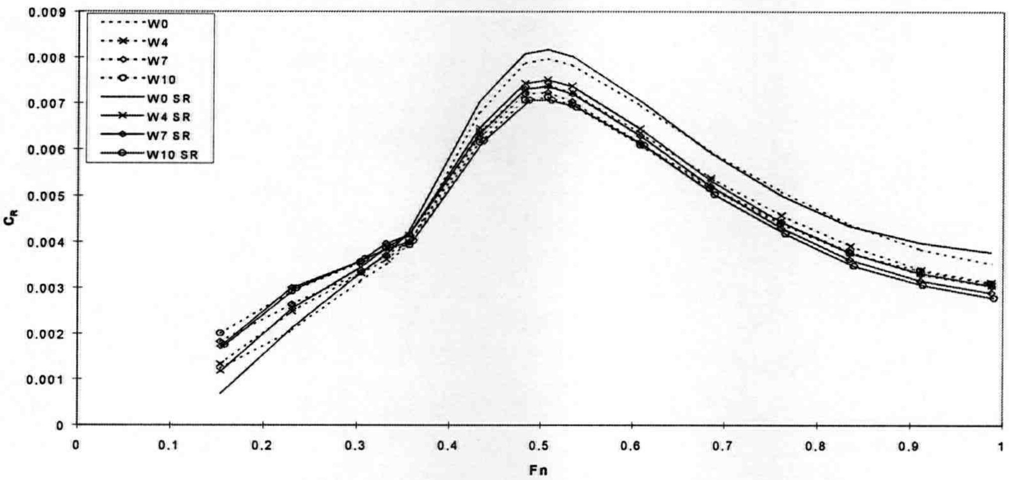

Figure 3.1: C_R-Fn plot of Model 13

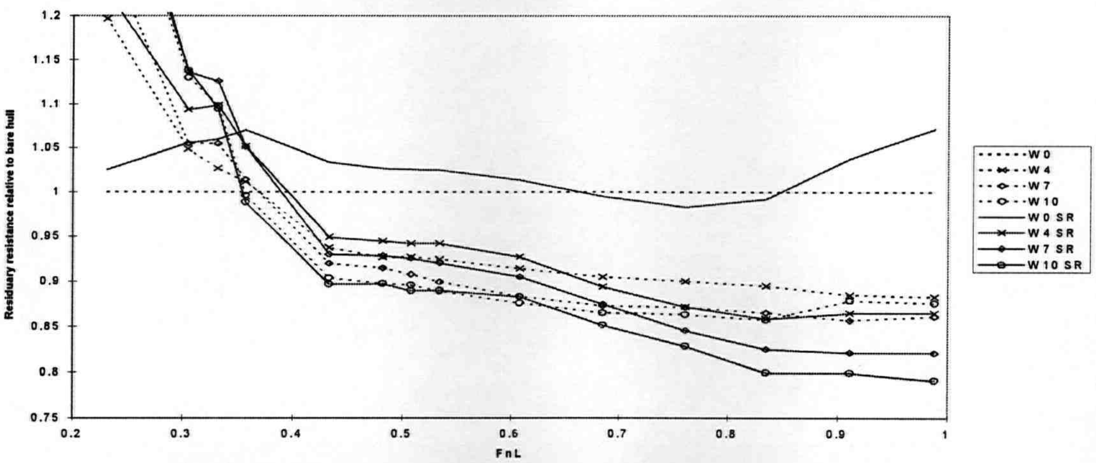

Figure 3.2: C_R comparison - relative to the bare hull of Model 13