SSSU 106
ISSN 0140 3818

UNIVERSITY OF SOUTHAMPTON

DEPARTMENT OF SHIP SCIENCE

FACULTY OF ENGINEERING AND APPLIED SCIENCE

RESISTANCE EXPERIMENTS ON A HIGH SPEED DISPLACEMENT CATAMARAN OF SERIES 64 FORM

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Ship Science Report 106

January 1999

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NOMENCLATURE

Symbols and some values used in the report:

Demihull	One of the hulls which make up the catamaran
Fn	Froude Number, $\left[v / \sqrt{gL}\right]$
Rn	Reynolds Number, $\left[vL / \nu\right]$
v	Velocity $[ms^{-1}]$
L, L_{BP}	Demihull length between perpendiculars [m]
A	Static wetted surface area $[m^2]$
B	Demihull maximum beam [m]
T	Demihull draught [m]
S	Separation between catamaran demihull centrelines [m]
∇	Volume of displacement $[m^3]$
Δ	Mass displacement in freshwater [kg]
C_B	Block coefficient
C_P	Prismatic coefficient
$L / \nabla^{1/3}$	Length : Displacement ratio, $\left[L / \nabla^{1/3}\right]$
R_T	Total resistance
C_T	Coefficient of total resistance $\left[R_T / 0.5\, \rho A v^2\right]$
R_R	Residuary resistance
C_R	Coefficient of residuary resistance $\left[R_R / 0.5\, \rho A v^2\right]$
C_F	Coefficient of frictional resistance [ITTC-57 Correlation line]
1+k	Form factor
β	Viscous resistance interference factor
τ	Wave resistance interference factor
g	Acceleration due to gravity $[9.80665\ ms^{-2}]$
ρ	Density of fresh water $[1000\ kg/m^3]$
ν	Kinematic viscosity of fresh water $[1.141 \times 10^{-6}\ m^2s^{-1}$ at $15^{\circ}C]$

1. INTRODUCTION

Work on the resistance of high speed displacement catamarans has been ongoing over a number of years at the University of Southampton in an effort to improve the understanding of their resistance components and to provide design and validation data, Refs. 1, 2.

This report describes further model tests on a catamaran in calm water. The experimental programme is a development of and complements earlier work, Refs. 1, 2, in which an extensive series of model resistance tests were carried out on catamarans derived from the NPL round bilge series, Ref. 3. The model in the current work is based on the SERIES 64 round bilge hullform, Ref. 4, and is designated Model 5s. It corresponds to Model 5b in the earlier series, Ref. 2, having a Length-Displacement Ratio ($L/\nabla^{1/3}$) of 8.5 and a Breadth-Draught Ratio (B/T) of 2.0. The model was tested in monohull form and at two hull separations in catamaran configuration, in each case over a speed range up to a Froude Number of unity.

The information collected and presented in this report contributes to a further understanding of the resistance of catamarans and provides resistance data for practical use at the preliminary design stage.

The work described formed part of a wider research programme, funded by EPSRC and Industry and managed by Marinetech South Ltd. The wider programme entailed experimental and theoretical work on the seakeeping performance of catamarans which work is the subject of separate reports.

2. DESCRIPTION OF MODEL

Details of the model used in the investigation are given in Table I. The model was built using an epoxy-foam sandwich skin. This provided a good strength to weight ratio since the same model would subsequently be used for seakeeping tests.

The model was of round bilge form with transom stern, Fig. 1, and was derived from the SERIES 64 round bilge series, Ref. 4. The model was firstly tested as a monohull and, in the catamaran configurations, with Separation:Length ratios (S/L) of 0.2 and 0.4.

The model towing force was in the horizontal direction. The towing point in all cases was situated at the longitudinal centre of gravity and at an effective height one third of the draught above the keel. The models were fitted with turbulence stimulation comprising trip studs of 3.2mm diameter and 2.5mm height at a spacing of 25mm. The studs were situated 37.5mm aft of the stem. No underwater appendages were attached to the model.

3. FACILITIES AND TESTS

3.1 General

All the model experiments were carried out in the Southampton Institute test tank which has the following principal particulars:

Length	:	60.0m
Breadth	:	3.7m
Water Depth	:	1.85m
Maximum Carriage Speed	:	$4.6ms^{-1}$

The tank has a manned carriage which is equipped with a dynamometer for measuring model total resistance together with various computer and instrumentation facilities for automated data acquisition.

Calm water total resistance, running trim and sinkage experiments were carried out for the model. All tests were carried out where possible over a speed range up to a little over Fn = 1.0. Over the Froude Number range 0.1 to 1.0 the corresponding Reynolds Number (Rn) range for the model was 0.5×10^6 to 5.5×10^6.

3.2 Trim and Sinkage Measurements

Trim and sinkage were monitored for all the tests. Trim (positive bow up) was measured by means of a potentiometer mounted on the tow fitting; accuracy of the measurement was within $\pm 0.05°$. Sinkage (positive downwards) was measured by means of a linear displacement potentiometer with a measurement accuracy within ± 0.1mm.

4. DATA REDUCTION AND CORRECTIONS

All resistance data were reduced to coefficient form using fresh water density (ρ=1000 kg/m^3, model speed (v) and static wetted surface area (A) noting that the sum of the wetted areas of both hulls was used in the case of the catamarans.

$$\text{Resistance Coefficient} = \text{Resistance}/0.5\rho A v^2$$

Total resistance measurements were corrected to a temperature of 15°C. Corrections due to the effect of turbulence studs were found to be small and were not applied. Similarly, for the reasons described in Ref. 2, no corrections were made for tank blockage or shallow water effects. More detailed accounts of these corrections, and the justification for using static wetted area, are given in Ref. 5.

5. PRESENTATION OF DATA

The basic presentation of the experimental data adopted in the earlier work, Refs. 1 and 2, is summarised as follows:

$$C_{T_{cat}} = (1+\phi k)\sigma\, C_F + \tau C_W \qquad (1)$$

where:

C_F is obtained from the ITTC-57 correlation line.
C_W is the wave resistance coefficient for the demihull in isolation.
(1+k) is the form factor for the demihull in isolation.
ϕ is introduced to take account of the pressure field change around the demihull.
σ takes account of the velocity augmentation between the two hulls and would be calculated from an integration of local frictional resistance over the wetted surface.
τ is the wave resistance interference factor.

It is difficult to separate the two factors ϕ and σ by experimental measurements. For practical purposes, therefore, ϕ and σ are combined into a viscous resistance interference factor β. Where:

$$(1+\phi k)\sigma = (1+\beta k) \qquad (2)$$

whence:

$$C_{T_{cat}} = (1+\beta k)C_F + \tau C_W \qquad (3)$$

Noting that for the demihull in isolation, $\beta = 1$ and $\tau = 1$.

In the current work, wave pattern measurements were not carried out, hence estimates of the form factor (1+k) or (1+βk) for this specific SERIES 64 model (model 5s) were not made.

The measured experimental data are presented in Figs. 2 to 6. Figs. 2 to 4 give the total resistance data for the demihulls (or monohulls) in isolation and for the catamaran configurations. Estimates of (1+k) or (1+βk) for NPL hull form model no. 5b, taken from Ref. 2, are also included in the diagrams.

Results of the trim and sinkage measurements are presented in Figs 5 and 6.

From a practical viewpoint it is not necessary to confine the user to particular values of (1+k) or (1+βk). For this reason, residuary resistance coefficients C_R (derived from C_T - C_{FITTC}) have been calculated from the experimental data and are presented in Fig 7 for the monohull and catamarans. These curves provide the data in a form suitable for practical powering applications and an overall comparison of the residuary components for various hull configurations. The user is able to choose a suitable (1+k) or (1+βk) from Ref. 2 or other sources. For an estimate of the ship total resistance coefficient it can be shown that, for the monohulls:

$$C_{T_{ship}} = C_{F_{ship}} + C_{R_{model}} - k(C_{F_{model}} - C_{F_{ship}}) \qquad (3)$$

and for catamarans:

$$C_{T_{ship}} = C_{F_{ship}} + C_{R_{model}} - \beta k(C_{model} - C_{F_{ship}}) \qquad (4)$$

Use of these equations requires a knowledge of model C_F. Based on the model length of 1.6m and a kinematic viscosity for fresh water of 1.14 x 10^{-6} it can be shown that based on Froude Number (Fn):

$$C_{F_{model}} = \frac{0.075}{[\log_{10}(Fn \times 5.56x10^6) - 2]^2} \qquad (5)$$

Residuary resistance interference factors, used later in comparing the performance of the various hull configurations, are presented in Fig 8.

The experimental data for C_T, trim and sinkage for all model configurations over a range of speeds, together with residuary resistance coefficients C_R derived from these data, are tabulated at the back of the report in Tables II, III and IV.

6. DISCUSSION OF RESULTS

6.1 Total Resistance

Figures 2, 3 and 4 show the experimental results for the monohull and catamaran tests. These are a broadly consistent set of results and provide the total resistance for the monohull and catamaran hull separations tested. It is noted that the total resistance curves are of similar shape with the main resistance hump reducing as hull separation is increased.

6.2 Running Trim and Sinkage

The interference effects on the running trim and sinkage are shown in Figs. 5 and 6. The overall results and trends are broadly similar to other round bilge hulls such as those reported in Ref. 2.

It is seen that trim angle rises sharply between Fn = 0.3 and Fn = 0.6 and the catamaram displays higher trim angles than the monohull over the whole speed range.

Running sinkage increases over the speed range Fn = 0.2 to 0.5, but decreases above Fn = 0.5, with the small hull separation displaying the largest changes.

6.3 Residuary Resistance

The experimental results are presented in terms of residuary resistance coefficient C_R in Fig. 7, where the residuary coefficient has been derived from C_T - C_{FITTC}. As discussed earlier, this presentation is used in order to provide a readily available tool for powering purposes and a means of comparing different hull forms and hull separations.

The results in Fig. 7 indicate that as hull separation is increased, the resistance decreases and the main resistance hump occurs at decreasing Froude Number. It is noted that in the higher speed range, changes in hull separation tend to have a relatively small effect. There is however an increase in residuary resistance for the catamaran compared with the monohull.

6.4 Residuary Resistance Interference Factors

The results for the ratio of catamaran residuary resistance coefficient to monohull residuary resistance coefficient for the catamaran configurations are shown in Fig. 8. As has been found earlier, Ref. 2, there are significant oscillations in the interference factor in the lower Froude Number range, with a slight shift in the phasing with change in S/L and a general decrease in amplitude of interference factor as S/L is increased. In the higher Froude Number range, S/L has a much smaller effect on the interference.

6.5 Comparisons with NPL Hull form Data

In Figs. 9 and 10 the SERIES 64 form results are compared with the NPL hull form data reported in Ref. 2.

The results in Fig. 9 indicate that the residuary resistance for both hull forms is broadly similar, both in monohull and catamaran modes. At lower speeds the results cross over, but the results for the NPL form are generally lower over the higher speed range which might be expected with its higher Cp form.

The interference factors in Fig. 10 show the same trends for both hull forms. The maximum interference levels are similar, although there is some shift in the Fn range over which the maximum interference occurs. These results do indicate the potential for the use of generalised interaction factors which would be used in association with the known resistance for the monohull. Such interaction factors would be dependent on principal parameters such as length:displacement ratio, but may not be influenced significantly by the particular hull shape used.

6.6 Viscous Resistance and Form Factors

Estimates of ship total resistance coefficient can be made using equations 3 to 5 in Section 5 in which a form factor may be applied. As reported in Section 5, in the current work, wave pattern measurements were not carried out, hence estimates of the form factor (1+k) or (1+βk) for this specific SERIES 64 model (model 5s) were not made.

It is considered that suitable approximate values of (1+k) and (1+βk) may be obtained from Ref. 2 for the NPL Series type hull form. The most significant difference between the NPL and Series 64 forms (considering the same length:displacement ratio of 8.5) concerns prismatic coefficient which is 0.693 for the NPL form and 0.633 for the SERIES 64 form used. The results of the work reported in Ref. 6 indicate a relatively small change in form factor for a significant change in Cp for the NPL form. This supports the assumption that the NPL form, of the same length:displacement ratio, would provide a suitable approximate value of form factor for the SERIES 64 form.

The results from Ref. 2, using the appropriate NPL hull form, model 5b, would suggest suitable form factors as follows:

For	monohull	:	$(1+k) = 1.26$
	S/L = 0.4	:	$(1+\beta k) = 1.40$
	S/L = 0.2	:	$(1+\beta k) = 1.41$.

7. CONCLUSIONS

7.1 The results of the investigation provide an extension to the available resistance data for this vessel type.

7.2 The results are broadly similar to those for other round bilge hull forms. In particular, the catamaran/monohull resistance interference factors are similar to other forms. This offers the potential for the development of general interference factors which would not have a significant dependence on the particular hull shape.

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L(m)	1.6m
L/B	12.8
B/T	2.0
$L/\nabla^{1/3}$	8.5
C_B	0.537
Cp	0.633
Cm	0.848
$A(m^2)$	0.261
LCB [%x]	-6.4%

Table 1: Details of Model 5s (based on SERIES 64 form)

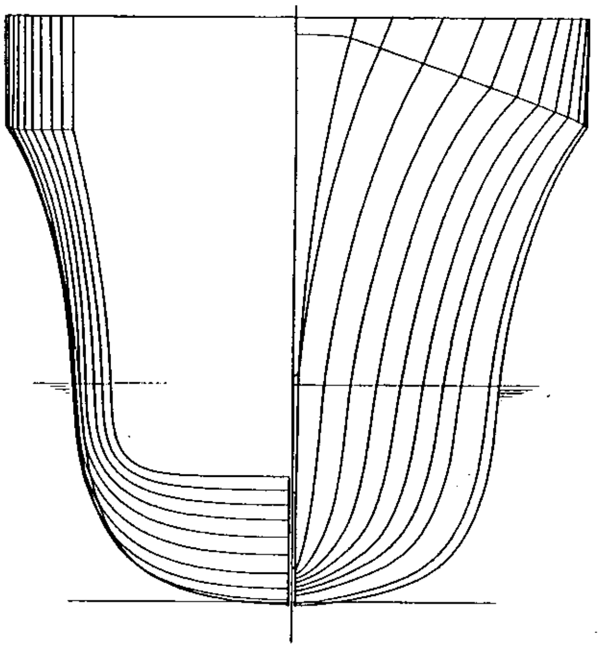

Fig. 1: Model 5s Body Plan (based on SERIES 64 form)

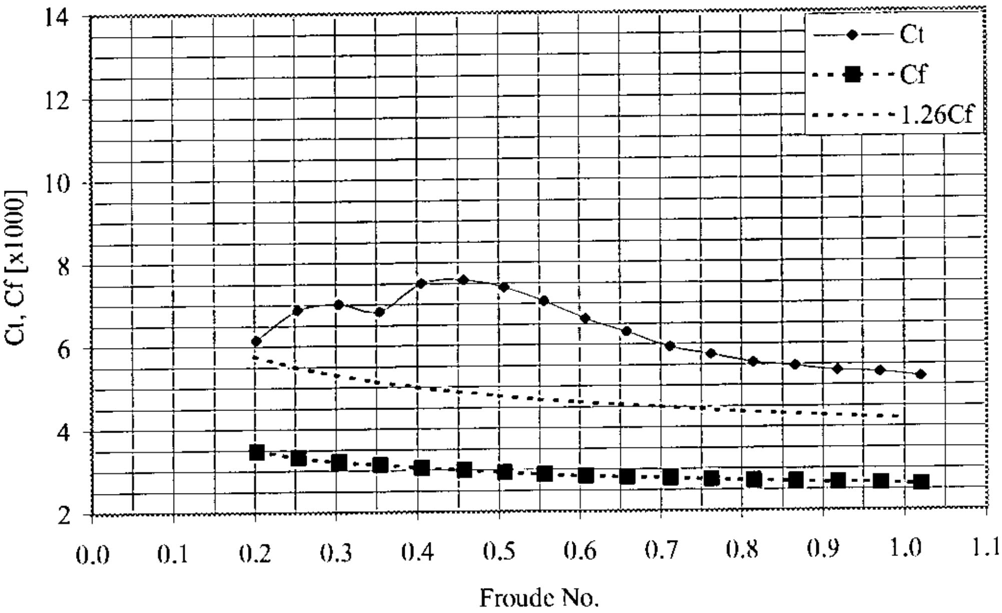

Fig 2. Resistance Components: Series 64, Monohull

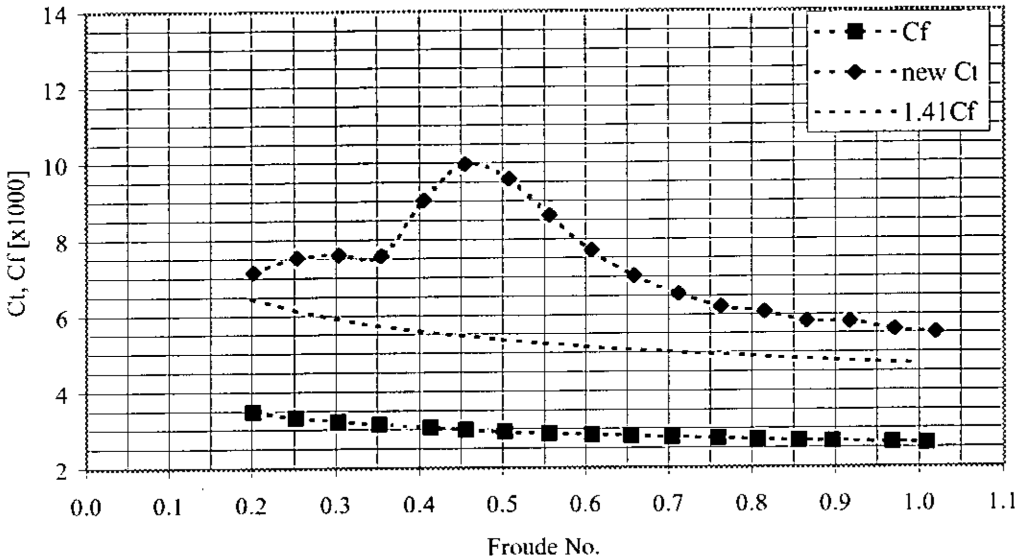

Fig 3. Resistance Components: Series 64, S/L=0.2

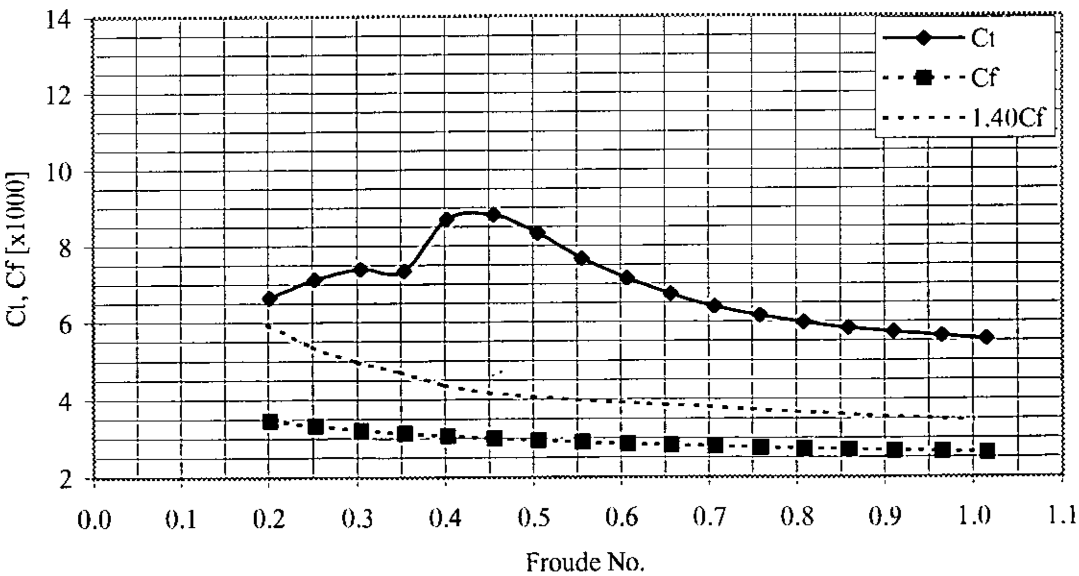

Fig 4. Resistance Components: Series 64, S/L=0.4

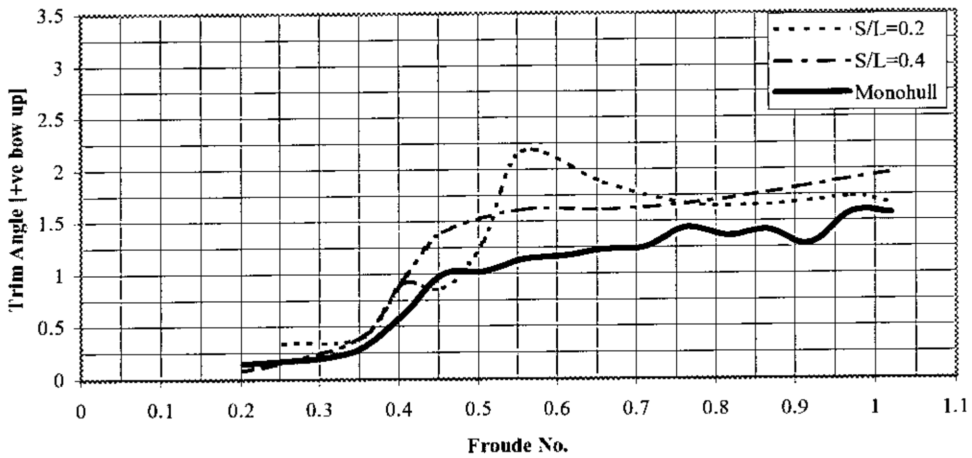

Fig 5. Running Trim: Series 64

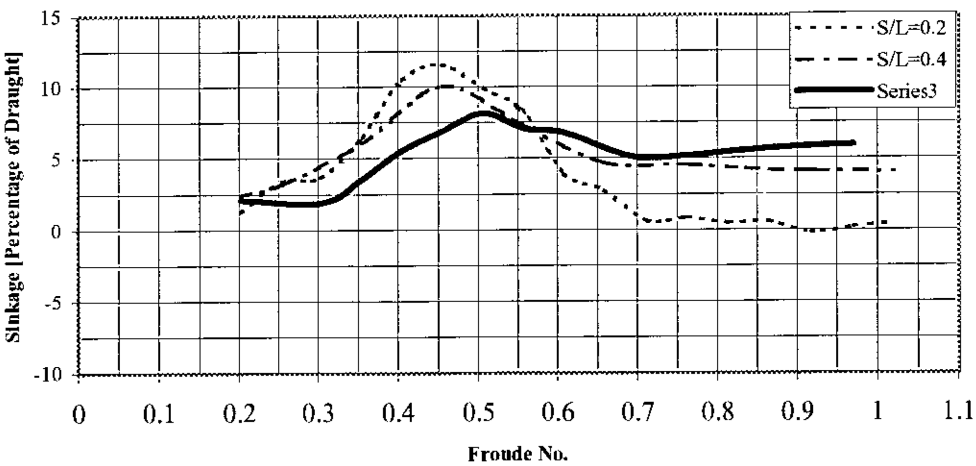

Fig 6. Running Sinkage: Series 64

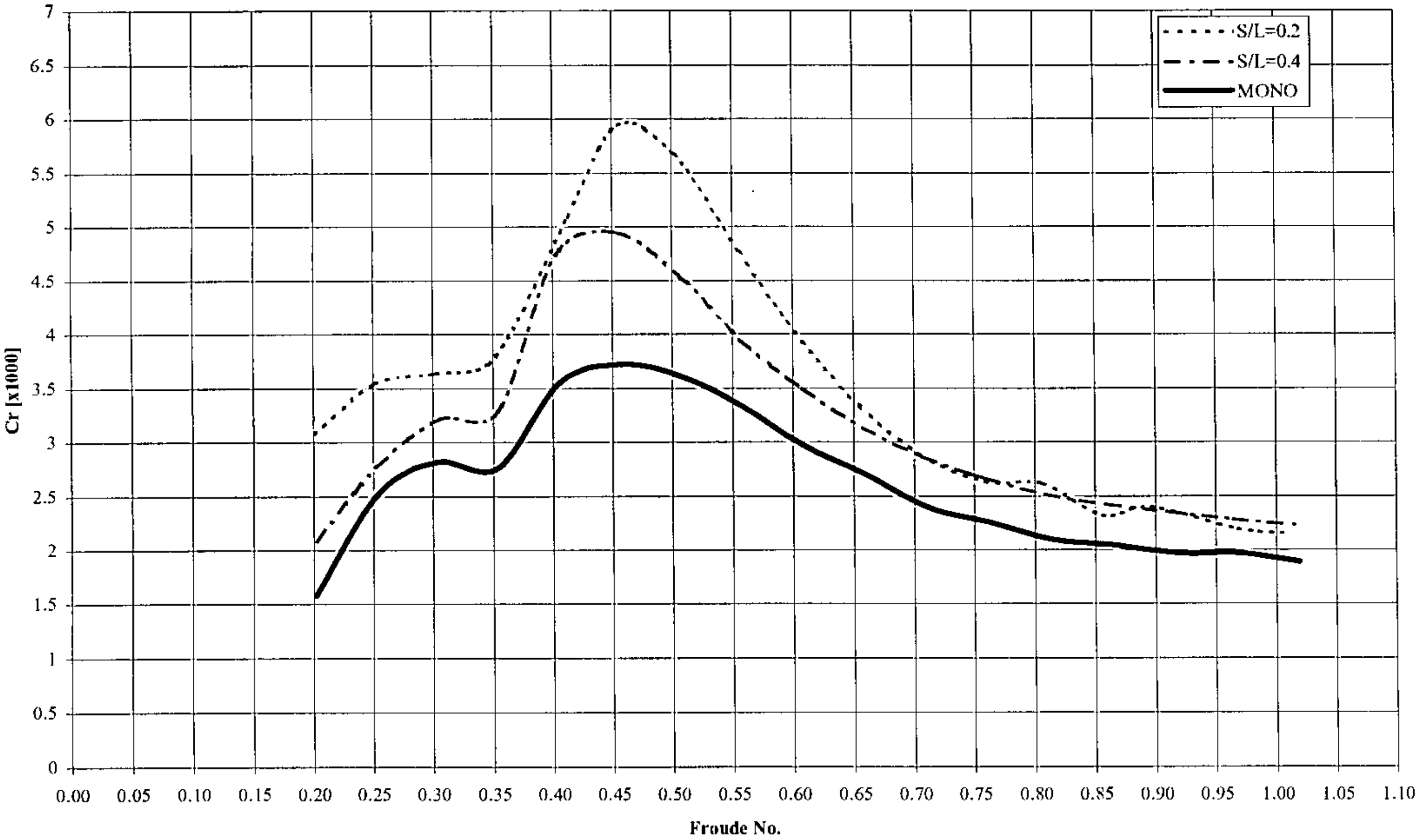

Fig 7. Residuary Resistance: series 64

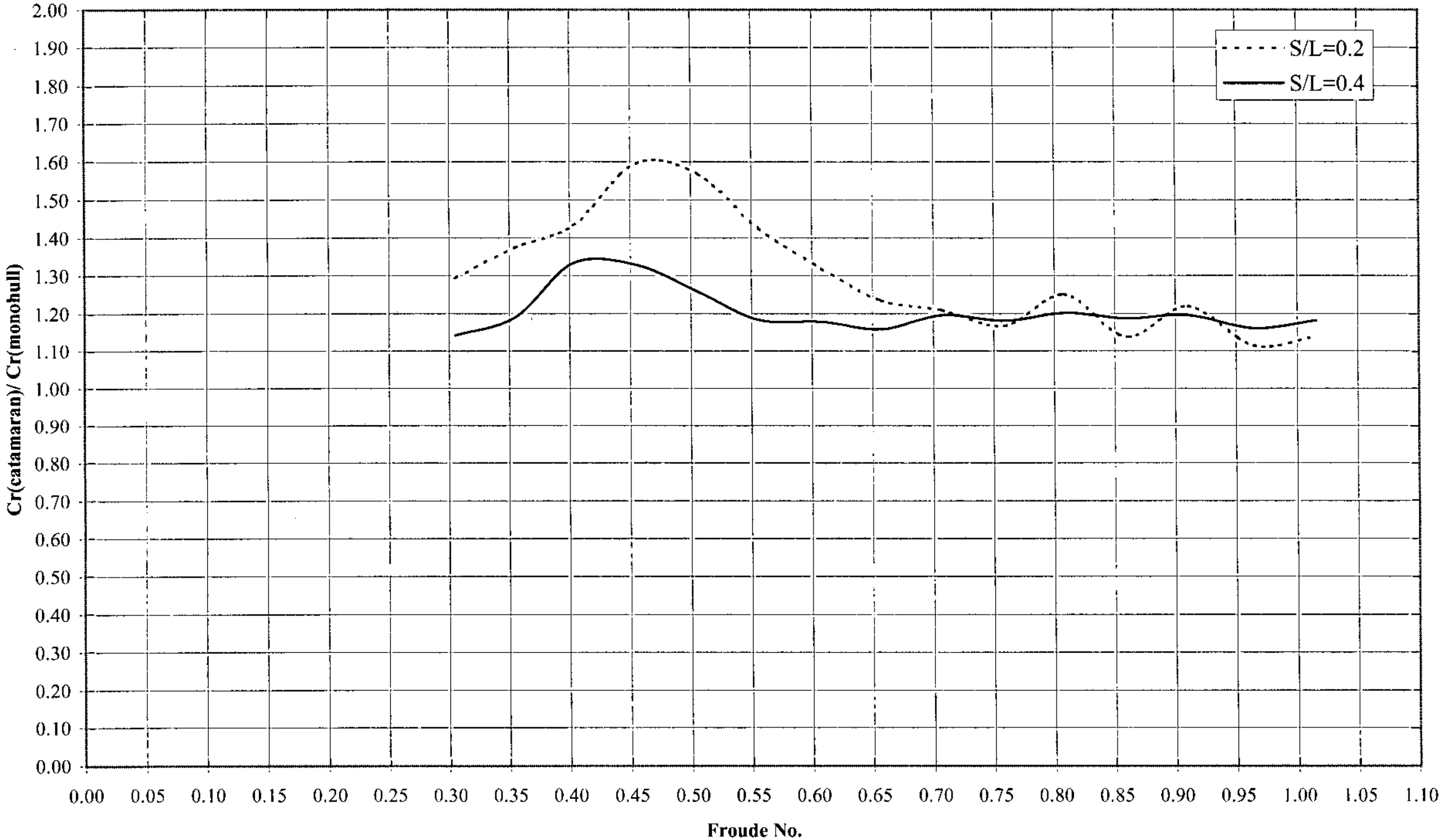

Fig 8. Residuary Resistance Interference Factor: Series 64

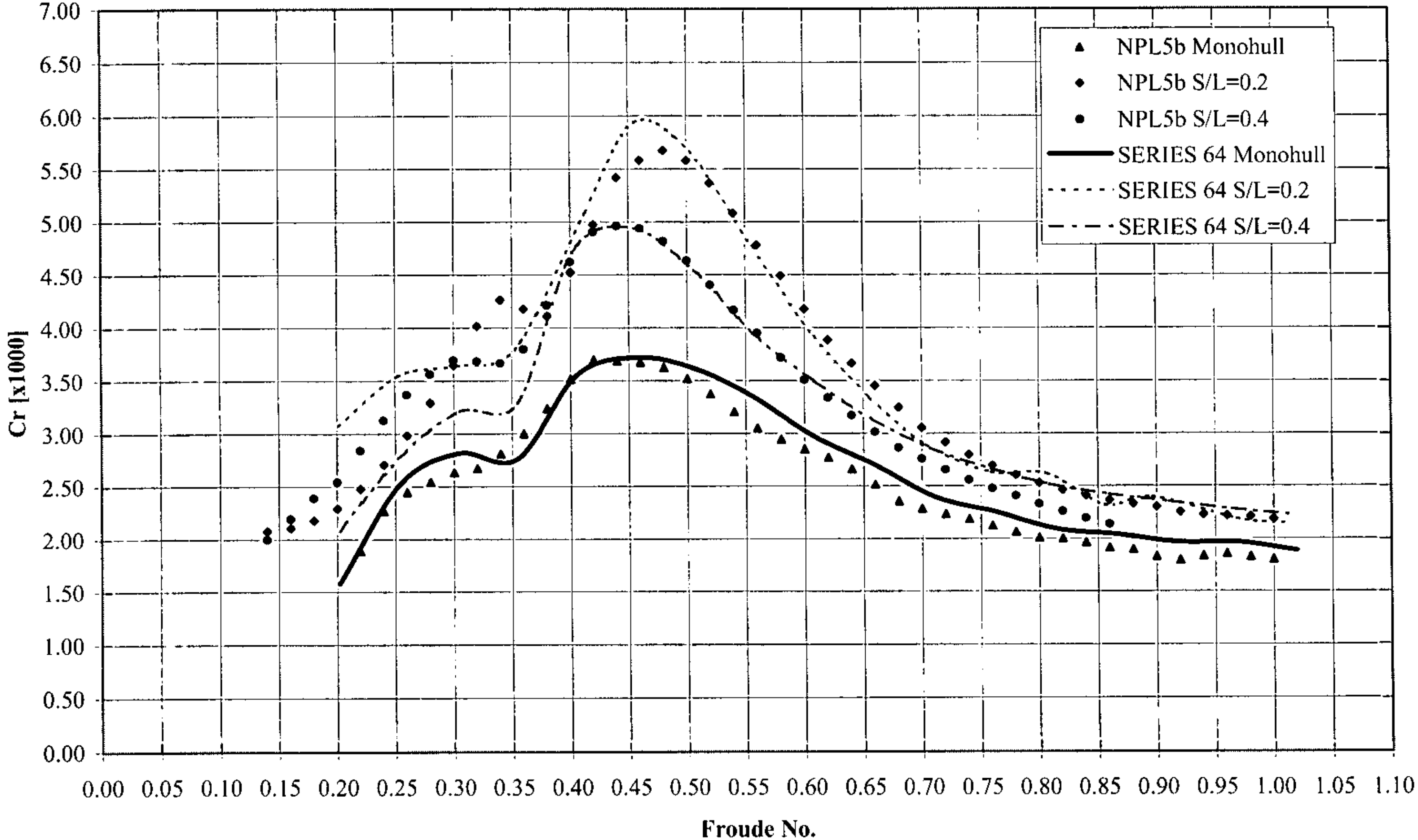

Fig 9. Residuary Resistance: series 64 and NPL model 5b

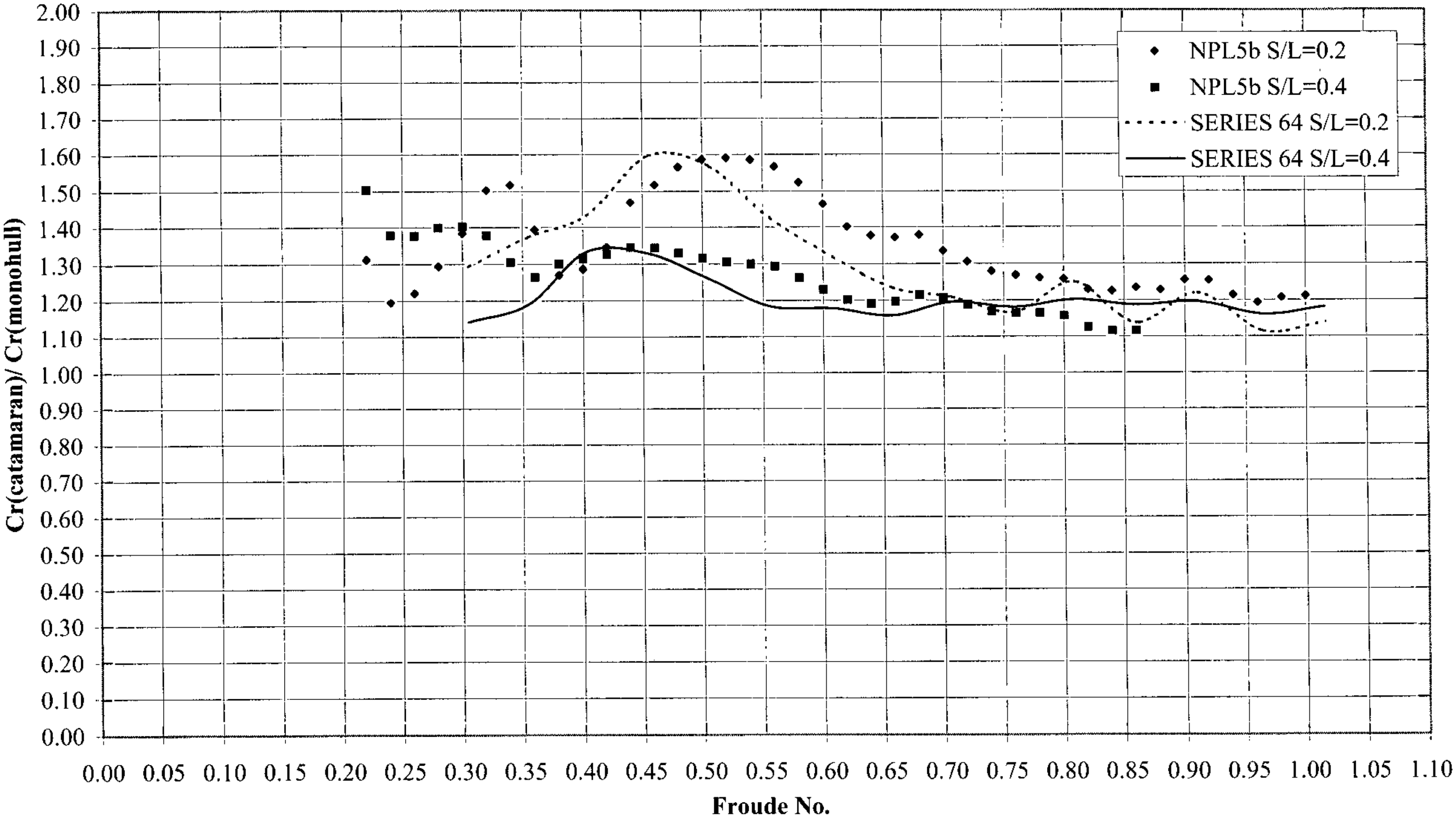

Fig 10. Residuary Resistance Interference Factor: Series 64 and NPL model 5b

Table II: SERIES 64 Experimental Results

Fn	MONO		0.2		0.4	
	C_T	C_F	C_T	C_F	C_T	C_F
0.20	6.148	4.582	7.148	4.582	6.652	4.582
0.25	6.820	4.370	7.503	4.370	7.090	4.370
0.30	7.002	4.208	7.596	4.208	7.385	4.208
0.35	6.846	4.077	7.579	4.077	7.359	4.077
0.40	7.439	3.969	8.880	3.969	8.554	3.969
0.45	7.576	3.878	9.878	3.878	8.795	3.878
0.50	7.426	3.798	9.642	3.798	8.400	3.798
0.55	7.107	3.728	8.753	3.728	7.766	3.728
0.60	6.694	3.666	7.851	3.666	7.237	3.666
0.65	6.362	3.611	7.153	3.611	6.808	3.611
0.70	6.021	3.560	6.663	3.560	6.484	3.560
0.75	5.803	3.514	6.304	3.514	6.229	3.514
0.80	5.610	3.472	6.122	3.472	6.034	3.472
0.85	5.489	3.433	5.907	3.433	5.890	3.433
0.90	5.389	3.397	5.811	3.397	5.778	3.397
0.95	5.328	3.363	5.683	3.363	5.676	3.363
1.00	5.249	3.331	5.555	3.331	5.583	3.331

Coefficients x10^3

Table III: Series 64 Running Trim and Sinkage

Fn	MONO		0.2		0.4	
	sinkage	trim	sinkage	trim	sinkage	trim
0.20	2.124	0.145	1.263	0.272	2.419	0.087
0.25	0.815	0.468	3.238	0.310	3.116	0.155
0.30	1.802	0.499	3.656	0.348	4.514	0.274
0.35	3.374	0.593	6.239	0.387	5.912	0.394
0.40	5.332	0.873	10.055	0.854	8.085	0.876
0.45	6.759	1.254	11.436	0.867	10.000	1.350
0.50	7.986	1.320	10.149	1.253	9.362	1.532
0.55	7.260	1.423	8.514	2.170	7.507	1.596
0.60	6.862	1.468	4.612	2.106	6.199	1.603
0.65	5.926	1.523	2.953	1.896	4.892	1.610
0.70	5.186	1.553	1.101	1.794	4.712	1.634
0.75	4.529	1.693	0.786	1.691	4.531	1.659
0.80	6.034	1.684	0.587	1.674	4.378	1.706
0.85	6.023	1.700	0.529	1.657	4.224	1.754
0.90	6.860	1.710	0.065	1.685	4.105	1.819
0.95	6.557	1.762	0.033	1.713	4.075	1.889
1.00	7.523	1.820	0.413	1.669	4.046	1.960

(Sinkage: Percentage of draught [increase in draught +ve]
Trim: Degrees [bow up +ve])

Table IV: SERIES 64 Residuary Resistance (Ct - Cfittc)

C_R			
Fn	**MONO**	**0.2**	**0.4**
0.20	1.566	2.566	2.070
0.25	2.450	3.133	2.720
0.30	2.794	3.388	3.177
0.35	2.769	3.501	3.281
0.40	3.469	4.911	4.585
0.45	3.699	6.000	4.918
0.50	3.627	5.843	4.602
0.55	3.379	5.025	4.037
0.60	3.028	4.184	3.571
0.65	2.751	3.543	3.197
0.70	2.461	3.103	2.924
0.75	2.289	2.790	2.715
0.80	2.139	2.650	2.562
0.85	2.056	2.474	2.457
0.90	1.992	2.414	2.382
0.95	1.965	2.320	2.313
1.00	1.917	2.223	2.252

Coefficients $x10^3$