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EXPERIMENTAL INVESTIGATION ON TWO DISPLACEMENT CATAMARANS: SYSTEMATIC VARIATION OF DISPLACEMENT, CLEARANCE AND STAGGER.

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SUMMARY

The aim of this study has been the evaluation of the effects of varying longitudinal stagger, transverse separation and displacement on the resistance of two symmetric hull forms suitable for catamaran configuration over a speed range corresponding to Fn < 0.5.

To achieve this aim at the *Dipartimento di Ingegneria Navale di Napoli (DIN)* an intensive experimental investigation has been carried out on two models in three configurations: monohull, symmetric and staggered catamaran.

In particular, for one model, 6 clearances in the symmetrical configuration and 4 longitudinal staggers have been tested; for the other one 3 clearances and 3 staggers have been tested.

The influence of displacement on resistance has been evaluated by testing the models for three different displacements.

NOMENCLATURE

Demihull: One of the hulls which make up the catamaran;
Stagger: Longitudinal shift between demihulls
L; L_{WL}: Length on waterline
b: Breadth of demihull
B: Breadth of catamaran
T: Draught
S: Separation distance between centrelines of demihulls
S_W: Wetted surface area (static condition)
A_T: Transom stern area
A_M: Area of midship section
∇ : Displacement volume
$L/\nabla^{1/3}$: Length-displacement ratio
V: Speed
Fn: Froude Number
Rn: Reynolds Number
L_{CB}: Distance of Centre of Buoyancy from transom
C_B: Block Coefficient
C_P: Prismatic Coefficient
C_T: Total Resistance Coefficient (Resist/$0.5\rho S_W V^2$)
$C_{T\nabla}$: Total Volumetric Resistance Coefficient (Resist/$0.5\rho\nabla^{2/3}V^2$)
C_F: Frictional Resistance Coefficient (ITTC '57)
C_R: Residuary Resistance
IT: Total Interference Factor
λ: Staggered Catamaran Efficiency Factor
U_{CT}: Total Uncertainty
B_{CT}: Bias Limit
P_{CT}: Precision Limit

1. INTRODUCTION

The interest in catamarans has grown in the last decades. In fact, this kind of ship is often chosen for building ferries and workboats. Not many systematic experimental investigations have been carried out to evaluate the influence of displacement and separation on the resistance of catamarans. On this subject the two most important research studies are by Molland et al. in [1] [2] on round bilge hulls and the comprehensive study on the systematic series "Series 89" of hard chine catamaran hull, reported by Muller-Graf et al. in [3].

Drastic reduction of resistance is possible when using a staggered catamaran configuration (also called asymmetric in this paper). In this configuration the demihulls have a longitudinally shift between them. The working principle is based on the advantages gained from the positive interferences of the transversal waves systems generated by the shifted demihulls. It is easy to observe that the wave systems generated by the demihulls have equal size and phase and, in the tunnel of symmetric catamarans, the amplitudes of the transversal waves add up constructively and almost doubles. But applying a sizeable shift between the transverse wave systems of demihulls, the resulting wave pattern is largely reduced, also reducing the wave resistance.

In [4] Söding reported the results of the numerical investigation on the catamaran *Supercat-Haroula* and highlighted a reduction of up to 50 % of total resistance with a 50 % L_{WL} stagger for Fn = 0.4. Theoretical results were also confirmed by an experimental investigation carried out on a SWATH model.

2. DESCRIPTION OF MODELS

The two tested models C932 and C925 [5], illustrated in Figures 1 and 2, have symmetric hull form and transom stern. Their hull surfaces are also developable. The model C932 presents three hard chines, while the model C925 only one.

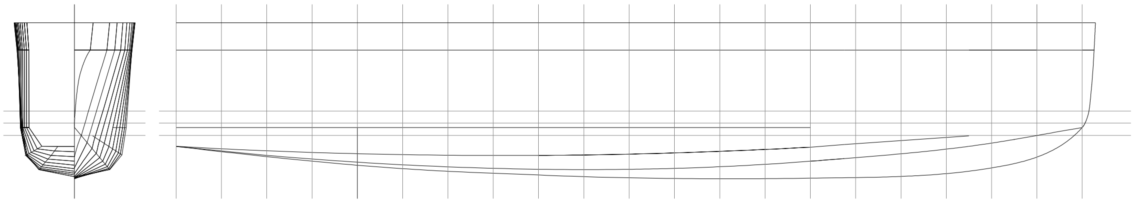

Figure 1: [Model C932]

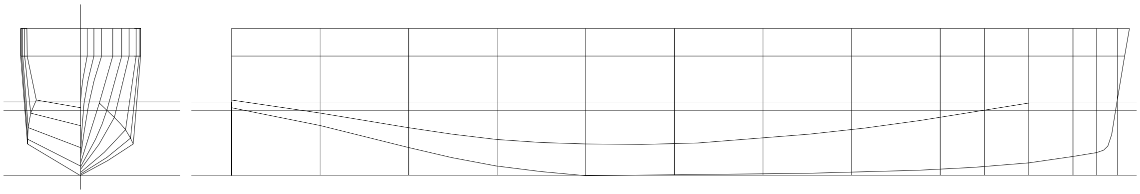

Figure 2: [Model C925]

For the experimental tests wooden models were used, their length was 3.4 meters for the C932 and 3.0 meters for the C925.

The tested configurations and displacements are reported in Table 1. In Tables 2a and 2b main particulars of both models are indicated. Figure 3 shows the sectional area curves of both models for $L/\nabla^{1/3} = 4.66$.

		$L/\nabla^{1/3}$	S/L		Fn
Symmetric	C932	4.66; 5.08; 5.74	0.24; 0.27; 0.30; 0.33; 0.36; 0.41; :		0.2÷0.7
	C925	4.66; 4.92	0.24; 0.30; 0.36; :		0.2÷0.6
		$L/\nabla^{1/3}$	S/L	Stagger (%L_{WL})	Fn
Staggered	C932	4.66; 5.08; 5.74	0.30	6; 10; 20; 30	0.3÷0.5
	C925	4.66	0.30	10; 20; 30	0.2÷0.6

Table 1: [Towing tank test program]

$L/\nabla^{1/3}$ (catanaran)	4.66	5.08	5.74
$L/\nabla^{1/3}$ (demihull)	5.87	6.39	7.23
∇_{CAT} [m^3]	0.368	0.284	0.194
L_{WL} [m]	3.341	3.336	3.320
b_{WL} [m]	0.401	0.397	0.384
T [m]	0.251	0.207	0.161
C_M	0.808	0.774	0.741
C_B	0.549	0.518	0.473
C_P	0.679	0.670	0.638
L_{CB}/L_{WL} [m]	0.427	0.432	0.442
L_{WL}/b_{WL}	8.353	8.400	8.646
b_{WL}/T	1.594	1.918	2.385
A_T/A_M	0.520	0.420	0.250
S_{WCAT} [m^2]	4.184	3.588	2.908
$S_W/\nabla^{2/3}$	8.15	8.30	8.68

Table 2a: [C932 – Main particulars]

$L/\nabla^{1/3}$ (catamaran)	4.66	4.92
$L/\nabla^{1/3}$ (demihull)	5.87	6.20
∇_{CAT} [m^3]	0.266	0.216
L_{WL} [m]	3.000	2.954
b_{WL} [m]	0.393	0.390
T [m]	0.250	0.221
C_M	0.766	0.743
C_B	0.451	0.424
C_P	0.589	0.571
L_{CB}/L_{WL} [m]	0.480	0.500
L_{WL}/b_{WL}	7.634	7.574
b_{WL}/T	1.572	1.765
A_T/A_M	0.032	0.0
S_{WCAT} [m^2]	3.308	2.926
$S_W/\nabla^{2/3}$	6.35	6.45

Table 2b: [C925 – Main particulars]

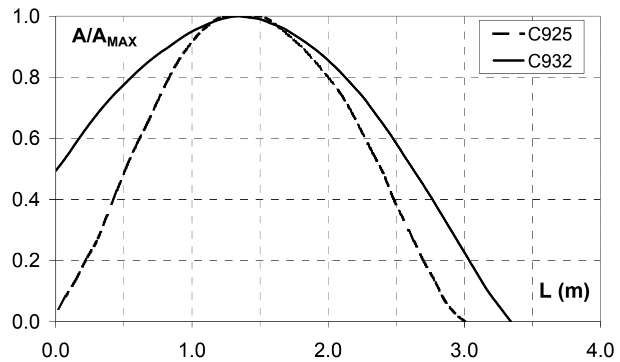

Figure 3: [Sectional Area Curve - $L/\nabla^{1/3} = 4.66$]

3. FACILITIES AND TESTS

All the model experiments were carried out in the towing tank of the *Dipartimento di Ingegneria Navale* of the

Università degli Studi di Napoli "Federico II", which has the following dimensions:

Length	136.0	m
Breadth	9.0	m
Water Depth	4.5	m

In all the test cases the towing force was horizontal and applied to the catamaran centreplane. The application point of the towing force was placed 100 mm forward the forward perpendicular and 554 mm from the base line for C932 and 396 mm for C925.

Total resistance and running trim were measured for each run. Resistance measurements were made with a 50 kg load cell (accuracy: ± 0.003 kg). The running trim was measured by a servo inclinometer (accuracy ± 0.01 degrees).

Both the models were not fitted with turbulence stimulators. The Reynolds number ranges were:

C932: $3.0 \times 10^6 \div 11.0 \times 10^6$
C925: $3.0 \times 10^6 \div 9.0 \times 10^6$.

All the resistance coefficients have been calculated considering the static wetted surface.

Viscous blockage effects and shallow water effects were found to be negligible, hence, no corrections were applied to the results.

4. SYMMETRIC CATAMARANS

From the experimental towing test results, for both the models, the residuary coefficients, C_R, and the total interference factors, IT, have been calculated.

4.1 RESIDUARY RESISTANCE

For both the models the experimental measurements of the resistance tests and the fair curves are presented as C_R versus Fn graphs. Data are plotted for demihull and for all catamaran configurations.

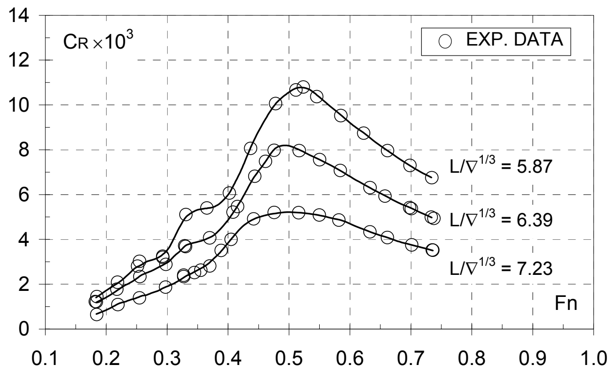

Figure 4: [C 932 – Demihull]

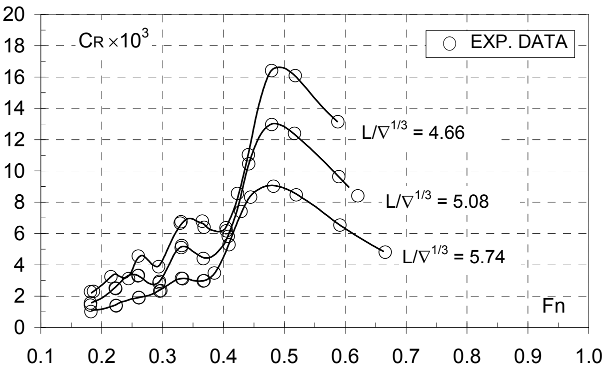

Figure 5: [C 932 – S/L = 0.24]

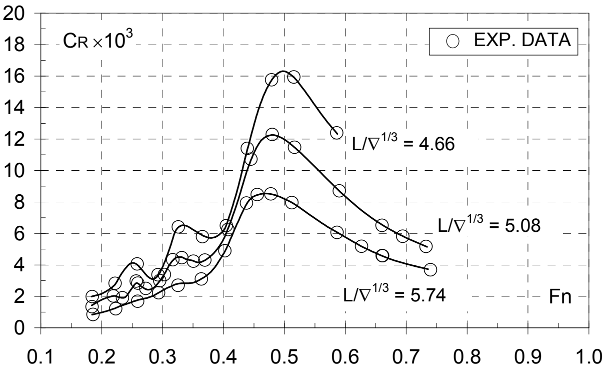

Figure 6: [C 932 – S/L = 0.27]

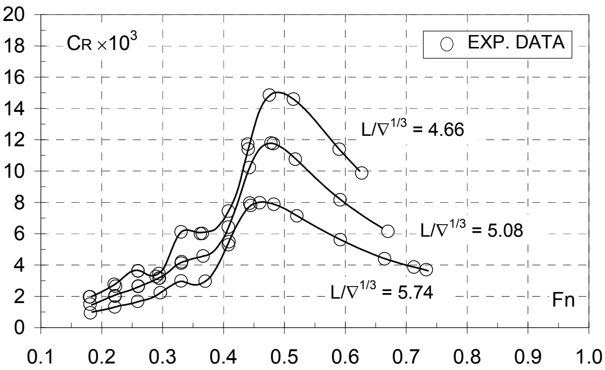

Figure 7: [C 932 – S/L = 0.30]

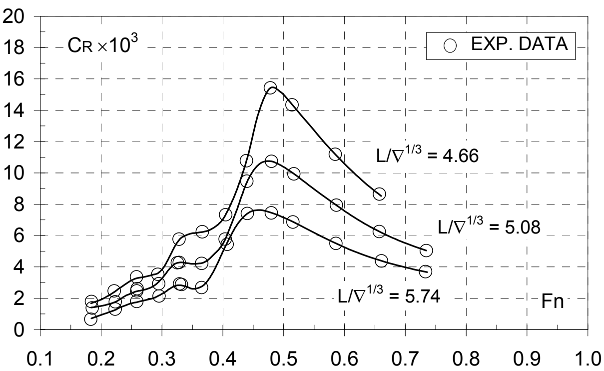

Figure 8: [C 932 – S/L = 0.33]

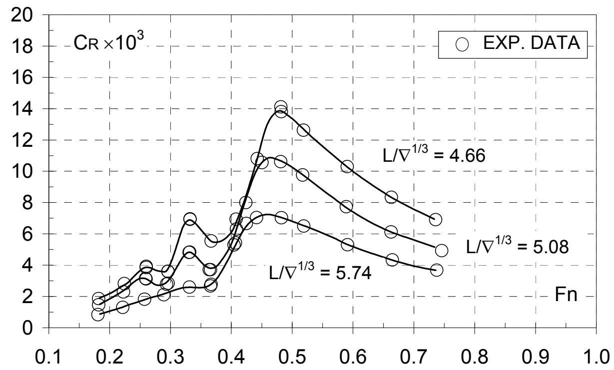

Figure 9: [C 932 – S/L = 0.36]

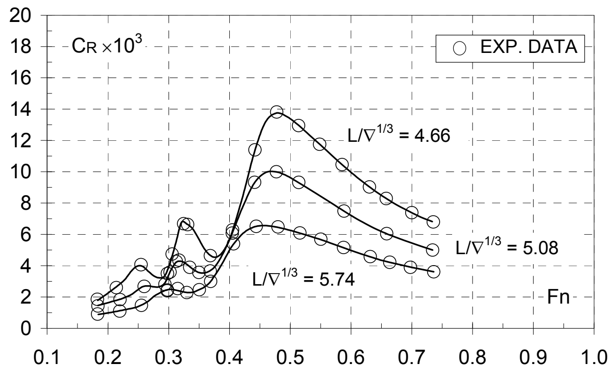

Figure 10: [C 932 – S/L = 0.41]

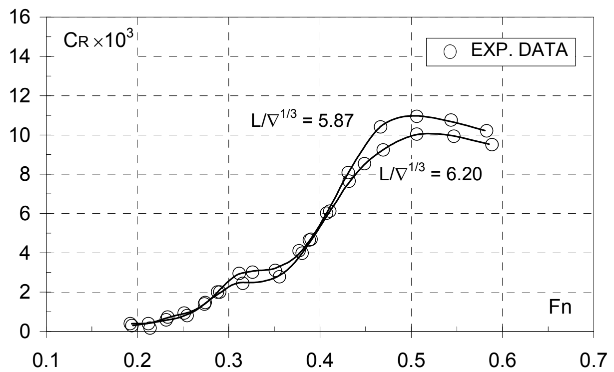

Figure 11: [C 925 – Demihull]

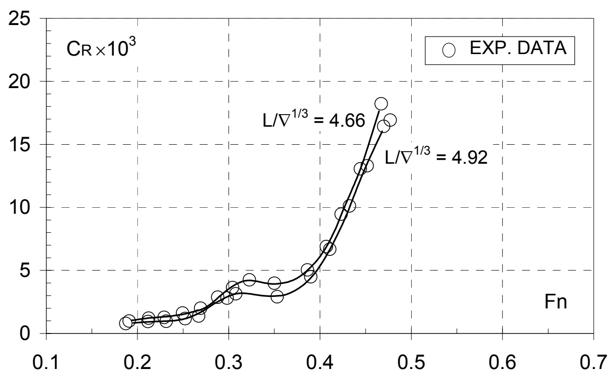

Figure 12: [C 925 – S/L = 0.24]

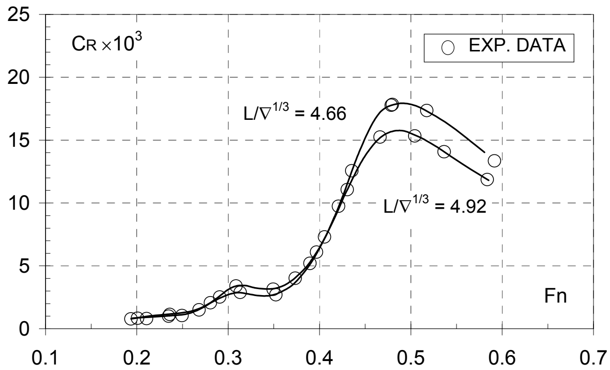

Figure 13: [C 925 – S/L = 0.30]

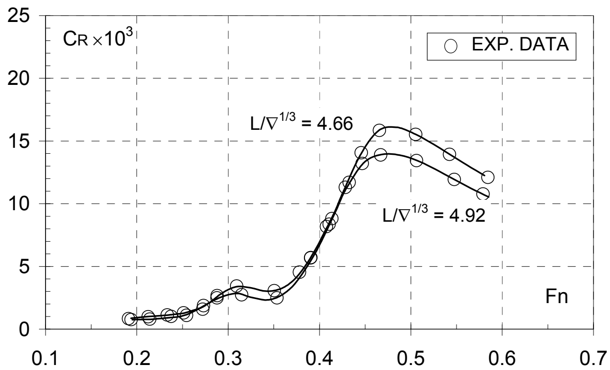

Figure 14: [C 925 – S/L = 0.36]

The previous figures show that:

- for $Fn > 0.40$ the curves become more regular and
- for higher values of S/L ratio correspond smaller values of C_R;
- for $Fn < 0.45$ the curves relative to catamarans present more undulations with higher amplitude than demihull's curves;
- low value of $L/\nabla^{1/3}$ amplify the phenomena above observed.

The interference phenomena, cause of these differences, will be evaluated in paragraph 4.4.

4.2 RUNNING TRIM

Regarding the running trim angles, next figures show that:

- for $Fn < 0.35$ the differences between catamarans and demihulls are negligible;
- around $Fn = 0.35 \div 0.40$ all catamaran and demihull configurations show a sudden increase of the trim;
- for $Fn > 0.40$ catamarans of both models display an higher running trim than the demihull;
- these trends increase when hull separation is reduced and displacement increased.

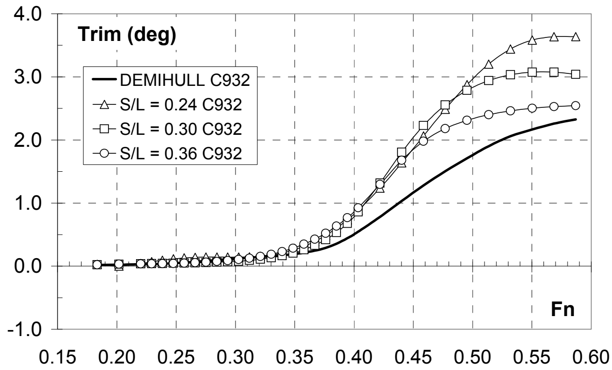

Figure 15: [Running trim angle C932 – $L/\nabla^{1/3} = 4.66$]

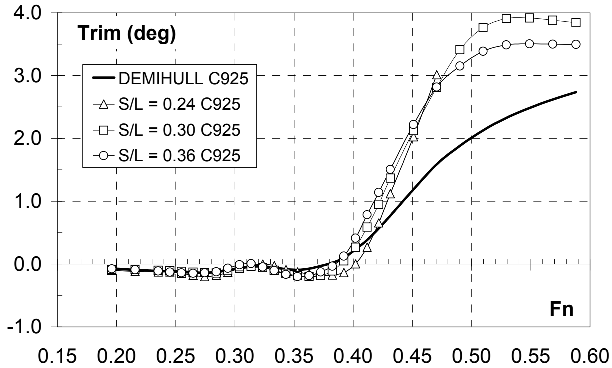

Figure 16: [Running trim angle C925 – $L/\nabla^{1/3} = 4.66$]

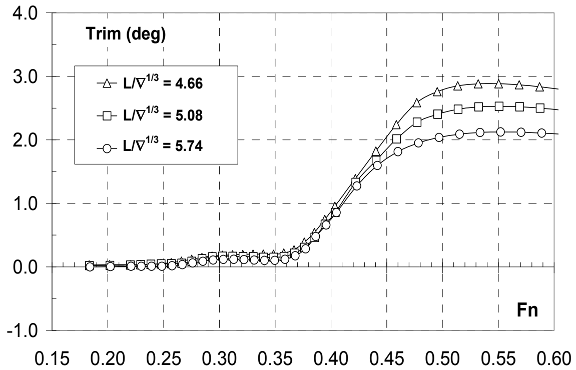

Figure 17 [Running trim angle C932 – S/L = 0.33]

4.3 MODEL COMPARISON

Catamarans and demihulls of both the models have been tested at $L/\nabla^{1/3} = 4.66$ and S/L = 0.24, 0.30 and 0.36.
A comparison of the volumetric resistance coefficients $C_{T\nabla}$ was made to evaluate the different hydrodynamic behaviour of the models. From Figure 18 it is possible to note that the curves of all the configurations present similar trends:

- for Fn < 0.40 demihull and catamaran configurations of C925 present lower $C_{T\nabla}$ (probably due to the smaller transom area of C925);
- for 0.40 < Fn < 0.45 the curves are superimposed;
- for Fn > 0.45 the C932 catamaran coefficients are lower in spite of similar values of demihull curves.

Regarding the last observation, it is possible to note that, as observed for running trim, also for $C_{T\nabla}$ over Fn = 0.45, catamarans of both models display an higher value than the demihull. Evidently, the connection between running trim and total resistance, typical for displacement fast hulls, is very critical for catamaran configuration.

For C932, in this speed range a greater A_T value reduces running trim and improves performances.

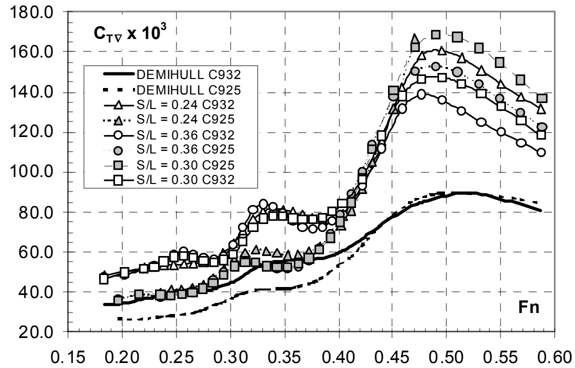

Figure 18: [$C_{T\nabla}$ comparison]

4.4 INTERFERENCE PHENOMENA

In [1] and [2] the authors explain that interference phenomena are generated by variation of velocity field around demihulls, change of Form Factor value and superimposition of wave patterns.

Coherently to this breakdown, the interference factors have to be evaluated considering the viscous and the wave components separately. These procedures are of great scientific interest, but they need to measure directly the viscous and wave components. For catamarans these methodologies are really complex and the obtained data could be not reliable (especially for the viscous component). Moreover, errors in the evaluation of these components could amplify scale effects in model-ship correlation.

For this reason in this work to evaluate the interference phenomena, the ratio IT has been chosen:

$$IT = \frac{C_{TCAT}}{C_{TDH}} = \frac{R_{TCAT}}{2R_{TDH}}$$

For the calculations, the values of the resistance have been read from the fair curves.

Since the IT factor is calculated with the total resistance, it depends on viscous resistance. So IT factor changes if different ship scales are considered. The reported values are referred to the model scale and to fresh water at 15°C.

The IT factor curves of both models are shown for each displacement and S/L.

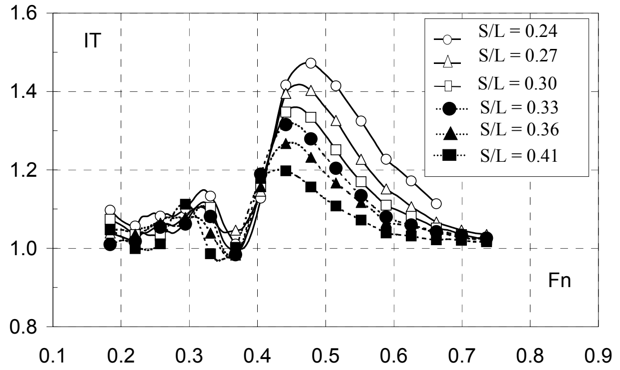

Figure 19: [C 932 – $L/\nabla^{1/3}$ = 5.74]

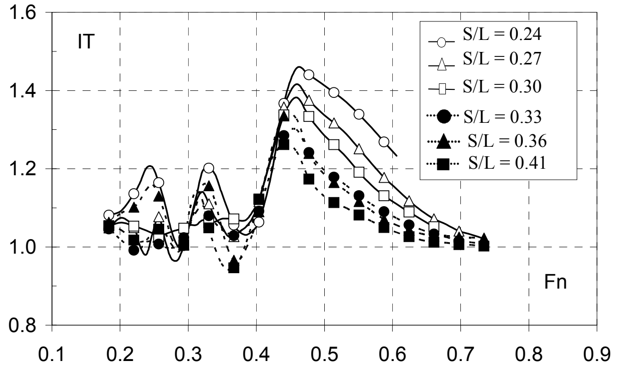

Figure 20: [C 932 – $L/\nabla^{1/3}$ = 5.08]

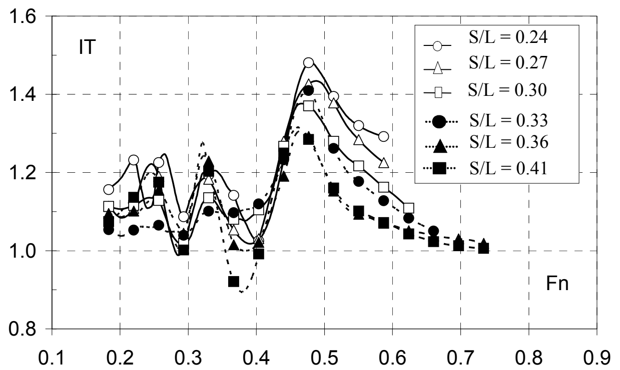

Figure 21: [C 932 – $L/\nabla^{1/3}$ = 4.66]

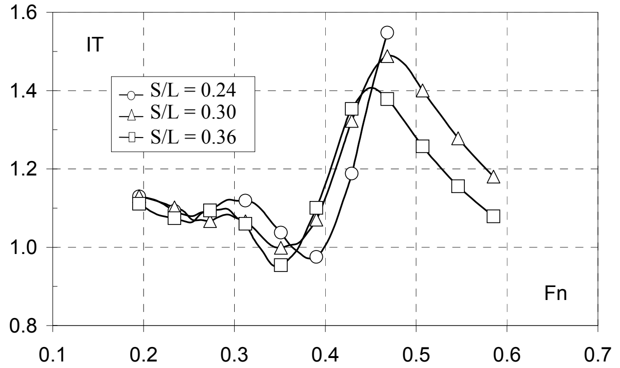

Figure 22: [C 925 – $L/\nabla^{1/3}$ = 4.92]

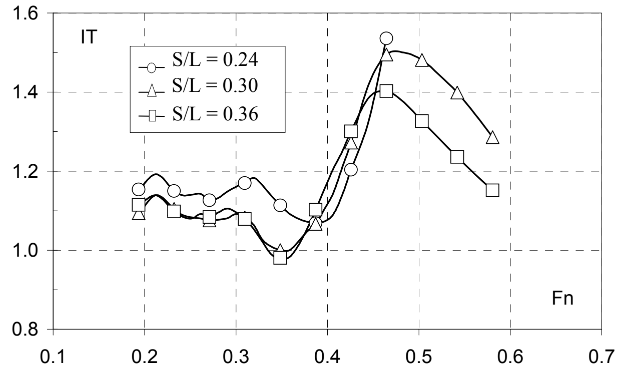

Figure 23: [C 925 – $L/\nabla^{1/3}$ = 4.66]

Examining the IT factor curves, it is possible to note:

- for Fn < 0.35 the curves present undulations and it is not possible to identify a law describing the dependence of IT from displacement and S/L;
- around Fn = 0.35 ÷ 0.45, IT is smaller than one for higher S/L ratio;
- for Fn > 0.5 the IT curves converge to the unit.

The remarkable differences of the IT values for different configurations makes it difficult to evaluate the performance of a specific catamaran by the interference factors of other configurations (displacement or S/L).

5. STAGGERED CATAMARANS

In this paragraph experimental towing test results of the staggered catamaran configurations of both models are reported as C_R, λ, and IT.

5.1 RESIDUARY RESISTANCE

In the following figures the experimental data and the fair curves are presented. It is possible to note that reducing $L/\nabla^{1/3}$, curve undulations and C_R values increase.

Observing the staggered catamaran diagrams, the resistance coefficients have remarkable reductions increasing the longitudinal stagger.

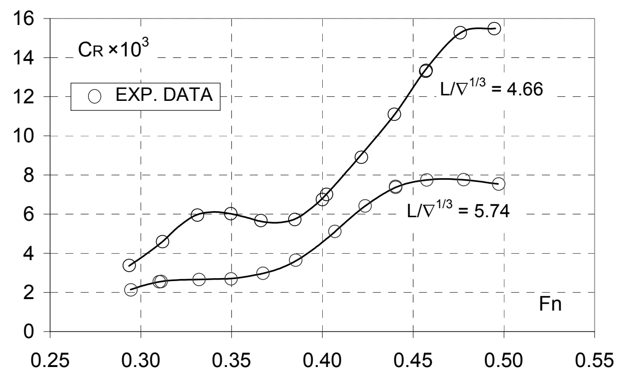

Figure 24: [C 932 – Stagger 6 %]

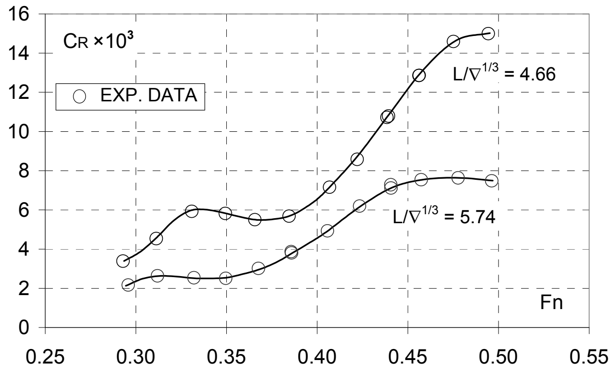

Figure 25: [C 932 – Stagger 10 %]

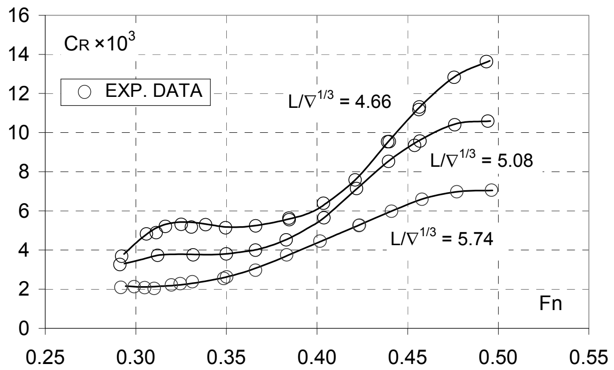

Figure 26: [C 932 – Stagger 20 %]

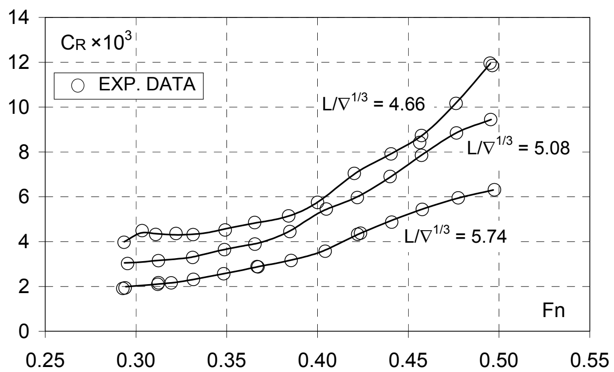

Figure 27: [C 932 – Stagger 30 %]

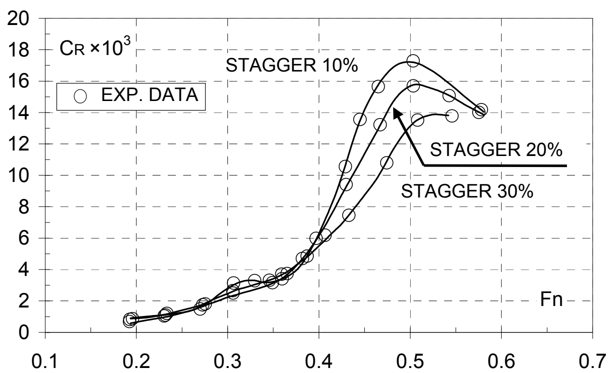

Figure 28: [C 925 – $L/\nabla^{1/3} = 4.66$]

For the higher values of stagger, the asymmetric configurations present lower running trim angles than the corresponding symmetric catamarans. It is due to the reduced wave pattern and the increased moment to trim.

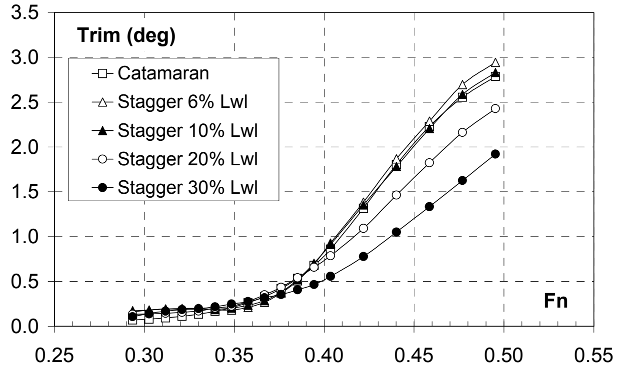

Figure 29: [C 932 – $L/\nabla^{1/3} = 4.66$]

5.2 INTERFERENCE PHENOMENA

The performance evaluation of the staggered configuration has been carried out by means of λ factor. Its expression is:

$$\lambda = \frac{C_{TCATstaggered}}{C_{TCAT}}$$

As observed for IT factor, also λ is dependant by the ship dimension. λ values are referred to the model scale and to fresh water at 15°C.

In the following figures the calculated λ factors are shown.

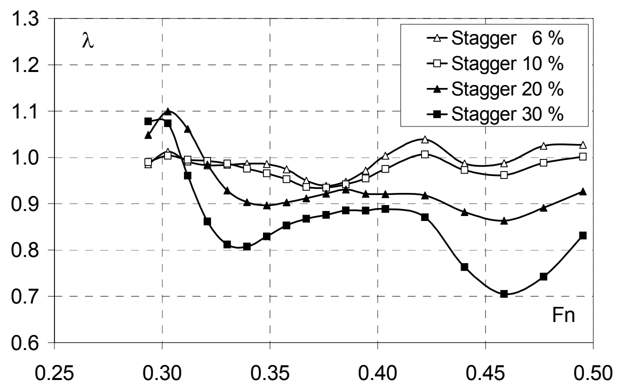

Figure 30: [C 932 – $L/\nabla^{1/3} = 4.66$]

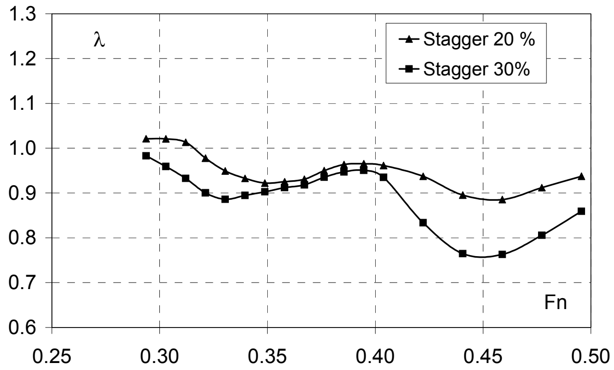

Figure 31: [C 932 – $L/\nabla^{1/3} = 5.08$]

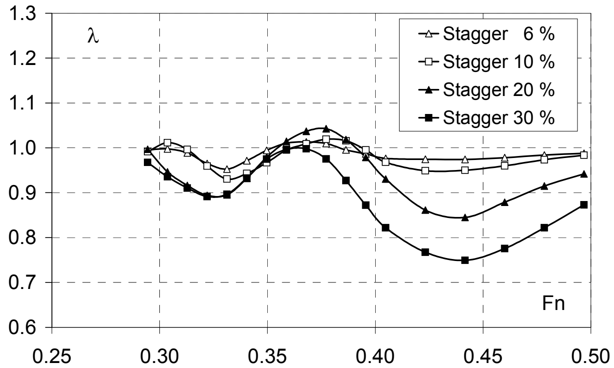

Figure 32: [C 932 – $L/\nabla^{1/3} = 5.74$]

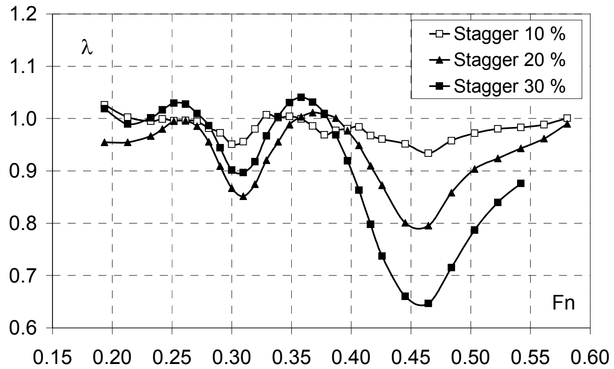

Figure 33: [C 925 – $L/\nabla^{1/3} = 4.66$]

The figures show that λ can have quite different values changing configuration and hull form. Therefore, the use of λ values of a particular configuration (displacement, stagger, hull form) to evaluate the performance of other configurations can generate significant errors. Nevertheless, examining the trends of the curves it is possible to express the following considerations:

- around Fn = 0.45, the λ curves of both models have a minimum;
- between Fn = 0.35 and 0.40, the stagger advantage is reduced or disappeared;
- in a wide speed range, for increasing stagger, the λ factors indicate a remarkable resistance reduction;
- the undulations of λ curves are amplified by increasing stagger and displacement.

It is interesting to note that where λ curves present higher undulation, the C_R curves do not show similar trends. Probably the viscous phenomena have a strong influence on λ values.

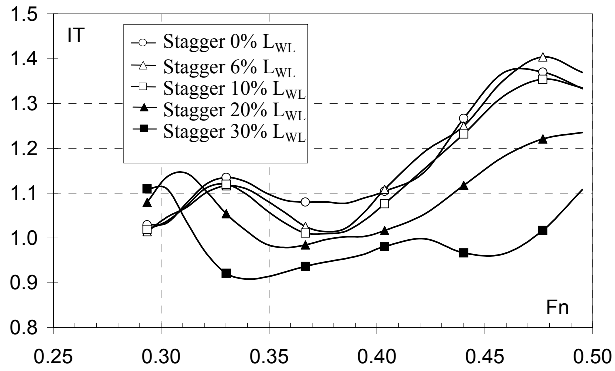

Figure 34: [C 932 – $L/\nabla^{1/3} = 4.66$]

In the Figure 34 the performance of the staggered catamaran and the demihull are compared through the IT factor:

$$IT = \frac{C_{TCAT_{staggered}}}{C_{TDH}}$$

Into a wide speed range the staggered configurations can balance or improve the symmetric catamaran's performances (often worse than demihull). As it was to be expected the greatest improvements, up to 9% of resistance reduction, are reached for the greatest stagger and displacement (Figure 34).

6. CONCLUSIONS AND RESEARCH DEVELOPMENTS

- Two displacement catamarans have been tested at same $L/\nabla^{1/3}$, S/L and stagger. Residuary resistance coefficient and interference factors, IT and λ, are reported.
- It has highlighted that the great influence on catamaran's performance due to clearance, stagger and displacement, causes inaccuracies if the interference factors measured for a configuration are applied to evaluate the performance of a different solution (i.e. different displacement, clearance, stagger or hull form).
- For Fn > 0.40 interference phenomena become less sensitive to speed variation.
- The experimental data obtained highlight the great potentiality of stagger configuration. It has been measured resistance reductions up to 30 % vs. symmetric catamaran and up to 9 % vs. demihull.

The research is in progress with experimental investigation on a third catamaran model.

To evaluate the feasibility of the staggered configuration, a preliminary design of water bus in inland waters have been realized [6] and sea-keeping model tests are planned.

A further interesting development of the research would be the design of demihulls which amplify the advantages of staggered configuration. In particular, it should be considered demihulls with different hull form, optimised holding in due consideration their longitudinal positions in the wave pattern.

7. UNCERTAINTY ANALYSIS

An uncertainty analysis of the experimental towing test results was carried out in accordance with the ITTC recommended procedures [7]. The uncertainty assessment of the total resistance coefficient, C_T, was conducted for a catamaran configuration (S/L = 0.30 and $L/\nabla^{1/3} = 5.075$) of the model C932 and for three model speeds V = 1.892, 2.098, 2.734 m/s (corresponding to Fn = 0.331, 0.375 and 0.478).

The accuracy of a measurement indicates the closeness of agreement between an experimentally determined value of a quantity and its true value. Error is the difference between the experimentally determined value and the true value.

The total error, U, is composed of two components: a precision (random) component, P, and a bias (systematic) component, B. An error is classified as precision if it contributes to the scatter of the data; otherwise, it is a bias error. In general, the uncertainty of a quantity is a function of the value of that quantity.

The applied procedure, provided by the ITTC, estimates the uncertainty in an experimental result at a 95 per cent confidence level, meaning that the true value of the quantity is expected to be within the ±U interval about the experimentally determined value 95 times out of 100. The bias limit, B_{CT}, of the total resistance coefficient are estimated for the individual measurements systems: hull geometry B_S, (model length and wetted surface), speed B_V, resistance B_{Rx} and temperature/density $B\rho$. The total bias limit reduces its influence when increasing the value of the total resistance coefficient.

The precision limits are determined for single or multiple runs. In any case the precision limit is determined by the standard deviation of the total resistance coefficients calculated from multiple tests. For this reason 5 sets of tests were carried out with the model removed and reinstalled between each set of measurements. In each test at least 3 speed measurements were performed, giving in total a minimum of 15 resistance measurements for each investigated speed. This is the best way to include random errors in the set-up such as model misalignment, trim, heel etc.

The following figures show the graphs of the variations of the total uncertainty, the bias and precision limit versus the number of tests. It is possible to note that the bias limit is constant regardless of the number of tests, while the precision and the uncertainty are decreasing if the number of repetitions increases. Reducing the speed, the relative contribution of the bias limit to the total uncertainty becomes predominant, also for the single test. The total error goes from 3.5 ÷ 4.0 % of C_T for the lowest speed to 1.0 ÷ 1.4 % for the highest speed.

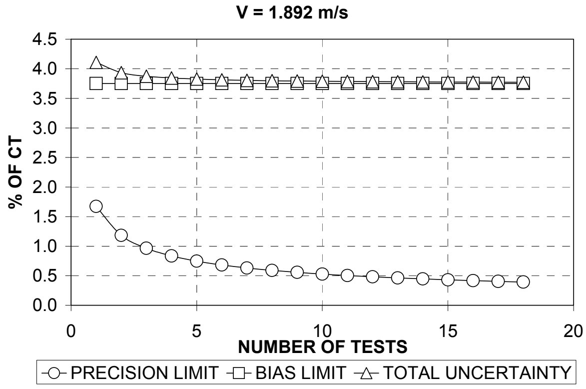

Figure 35: [C932 – $L/\nabla^{1/3} = 4.66$, S/L = 0.30, Fn = 0.331]

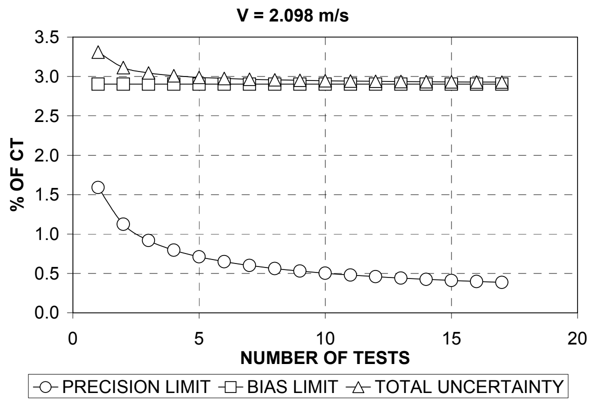

Figure 36: [C932 – $L/\nabla^{1/3} = 4.66$, S/L = 0.30, Fn = 0.375]

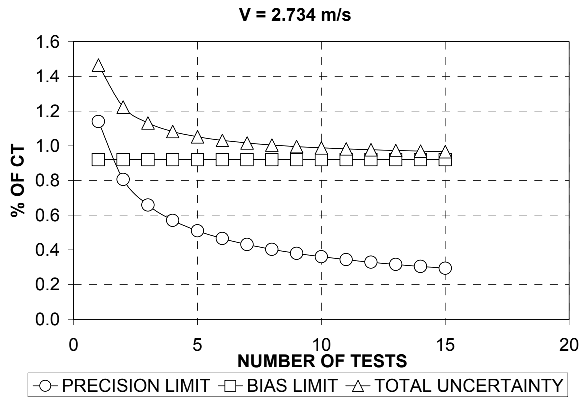

Figure 37: [C932 – $L/\nabla^{1/3} = 4.66$, S/L = 0.30, Fn = 0.478]

8. REFERENCES

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