MEDIUM SPEED CATAMARAN WITH LARGE CENTRAL BULBS: EXPERIMENTAL INVESTIGATION ON RESISTANCE AND VERTICAL MOTIONS

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SUMMARY: It has been noticed from tests made on a medium speed catamaran model, with central bulbs placed between the demi-hulls [1], that resistance and motion reduction are affected by bulb size and its placing. By using small size bulbs, moderate reductions are obtained, especially on heavier and larger hulls. By comparing the results obtained on different displacement catamaran models, but having the same main size and the same bulbs, larger motion reductions have been noticed on the lightest model. For this reason, it has been decided to extend the investigation on a medium speed catamaran, by using larger central bulbs and placing also flat plate dampers on the same bulb. The results obtained have been positive and demonstrate the effectiveness of this solution. A detailed description of the catamaran hull and its bulbs will be reported and the most relevant results obtained from the model tests will be shown and discussed.

1. INTRODUCTION

The catamaran orders continue to prevail on HSC (High Speed Craft) market for short and medium distance navigation Forty-eight fast ferries were delivered during 2006, the highest annual number since 49 delivered in 2003 [2]. The 66 vessels on order on December 31 is the highest number since 2001. Among these craft, catamaran orders exceed other craft types; 56 catamarans and 6 wavepiercing catamarans on 66 are 94% of total orders and 39 catamarans and 1 wave piercing catamaran on 48 are 83% of total deliveries.
Catamaran size is increasing in time and the new ships (Wave Piercing type) have a length over 110 m and a payload over 1600 tonnes.
The catamaran hulls are particularly suited for passenger transportation for their large deck area (20% to 40% larger if compared to a corresponding mono-hull of the same displacement), large internal volumes and large transverse stability. They are used not only for passenger transportation at high speed, but also in operations in open oceans, in which weather conditions expose them to violent motions, for which these craft are not explicitly suited. These problems occurred during the first operative year of HSNS Hayes (T – AGOR 16), an oceanographic catamaran [3], and have been solved in part by installing a cross hydrofoil between the hulls; in this case, the relative bow motion was reduced about 30% and consequently the slamming occurrence was reduced likewise.
Also the navies are displaying an increasing interest in catamarans in comparison to other solutions [4] [5], especially for large and fast landing boats for transportation of troops. The installation of a central bulb between the hulls improves the resistance and seakeeping characteristics of the vessel; this choice is called Bulb – Cat solution. The central bulb can be fixed to the hull, but a solution considering its vertical mobility can produce very positive results.
The Author examined the reduction in vertical motions of a catamaran when installing a central bulb [1, 6 and 7] on a medium and on a high speed catamaran model. The results obtained in the tests made in the specific investigations varied according to the bulb geometry and its longitudinal and vertical position between the demi-hulls. The best results allowed the maximum pitch reduction up to 50% and the maximum heave reduction up to 70% when compared to the original hull. These reductions, however, do not happen simultaneously at the same speed and in the same testing condition. In ref. [1], in which the results obtained by testing the heaviest model are reported, two geometrical parameters are defined, that is:

V_R : Volume ratio between the bulb volume and the catamaran volume;
A_R : Area ratio between the bulb cross area and the catamaran internal cross area between the hulls.

At the smallest ratio corresponds a less bulb motion damping efficiency.
Starting from this result, it was decided to extend the investigations on the heaviest catamaran model by placing one thicker central bulb.

2. THE TESTED HULL

The tested hull is that of an oceanographic vessel, having the following main features.

Length over all L_{OA} (m) :	38.5
Length at the waterline L_{WL} (m) :	36.0
Breadth of the demi-hull B_D (m) :	3.675
Breadth of the Catamaran B (m) :	12.0
Design draught T (m) :	2.498
Depth moulded D (m) :	4.926
Displacement Δ (t) :	300
Wetted surface W.S. (m^2) :	383.27
Block coefficient C_B :	0.451
Midship section coefficient C_X :	0.754
Waterplane area coefficient C_W :	0.765
Longitudinal Centre of Buoyancy (%) LCB :	-6.599
V max (knots) :	23.0
Corresponding Froude Number FN :	0.63

The catamaran hull is shown in figures 1A and 1B. The hull model (mono-hull and catamaran) have been built on 1:20 scale and tested in the towing tank of Trieste University in resistance and seakeeping in regular waves. The catamaran demi-hulls have been placed at a distance S defined by the ratio S/L_{WL} = 0.225, which was the same used also for the wedge catamaran [6, 7] hull. S is the separation distance between the demi-hulls centre line.

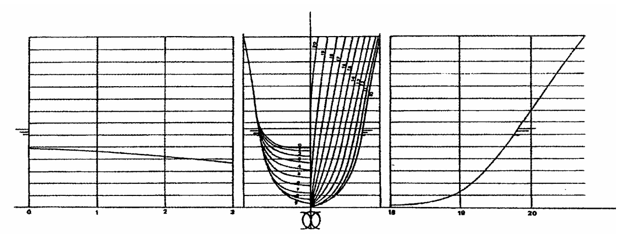

Figure 1A: The mono-hull body plan.

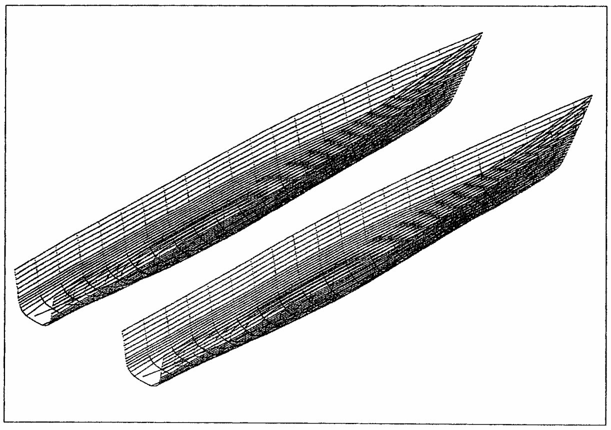

Figure 1B : The catamaran arrangement.

3. THE CENTRAL BULBS

The central bulbs are appendages for displacement catamarans, used to reduce the vertical motions and, when feasible, also the resistance. They had :

a) to be passive, that is had not to require energy for their operation;
b) to be of low cost, to be used on new vessels, but also suitable for refitting the existing vessels;
c) to be effective on the vertical motions reduction;
d) to reduce or maintain, into a limited increase, the vessel resistance;
e) not to interfere with the vessel operation, that is not to limit the mooring or docking capabilities.

The appendages used for the experiences are streamlined bodies obtained from the systematic Series 58 of the D.T.M.B. [8]. In this case, only one bulb was used, and precisely the model 4155, having the following features : L_B/D_B = 5.0; C_P = 0.65. It was the thickest model adopted for the investigations with catamaran hulls and central bulbs.
The bulb length was L_B = $L_{WL}/5$. The tests have been made in the original catamaran draft condition, that is the model displacement was increased with the displacement volume of the appendage and the connecting plate between the bulb and the hull.
The longitudinal and vertical positions of the bulb were defined from the experiences gained in the previous tests. In figure 2, a 3D representation of the central bulb placed between the demi-hulls of a catamaran is shown.
The connection between the hull and the appendages was made with a flat plate having a length equal to $L_B/2$ and a thickness of 1.5 mm; the plate vertical wedges were tapered, so as to reduce the resistance. The leading edge of the plate was placed at 0.20 L_B from the nose of the appendage.

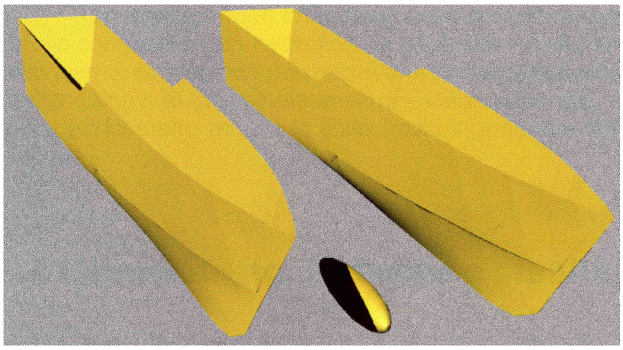

Figure 2 : Catamaran model with central bulb

4. THE TESTED CONDITIONS

4.1 TEST WITH THE BULB 4155

As previously reported, the catamaran model was tested only with the bulb 4155. This bulb is shown in figure 3 when mounted on the model. It was placed in two different positions, called respectively condition A and condition B, defined as:
Condition A : the bulb 4155 axis is placed at –T/2 on the model and its nose is tangent to the hull fore perpendicular (figure 4);
Condition B : the bulb 4155 is placed 10 mm above model bottom and its nose is tangent to the fore perpendicular (figure 4).
The bulb was always submerged, because the model depth was 127 mm and the bulb diameter was 72 mm.
The model was fitted with turbulence stimulators. The resistance tests have been made in the FN interval between 0.2 and 0.8, whereas the seakeeping tests in the FN interval between 0.2 and 0.6.

4.2 TEST WITH THE BULB 4155 WITH FINS

After having completed the tests in condition A and B, it was decided to mount two side flat fins on the bulb

(figure 5A, 5B)., to improve the bulb effectiveness in vertical motion damping. The tests have been repeated in the new conditions, called C and D, defined as :
Condition C : the axis of the bulb 4155 with fins is placed at –T/2 on the model and its fore nose is tangent to the catamaran fore perpendicular;
Condition D : the bulb 4155 with fins is placed 10 mm above model bottom and its nose is tangent to the hull fore perpendicular (figure 4).

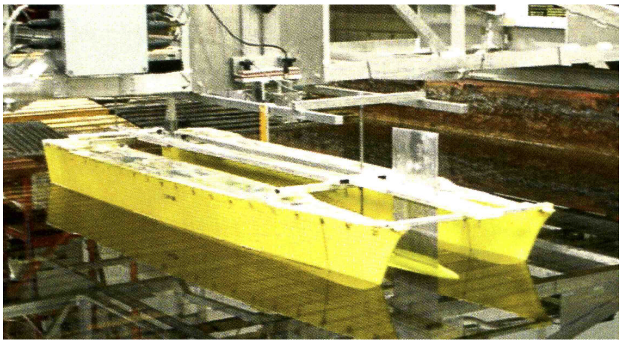

Figure 3 : The model ready for the tests.

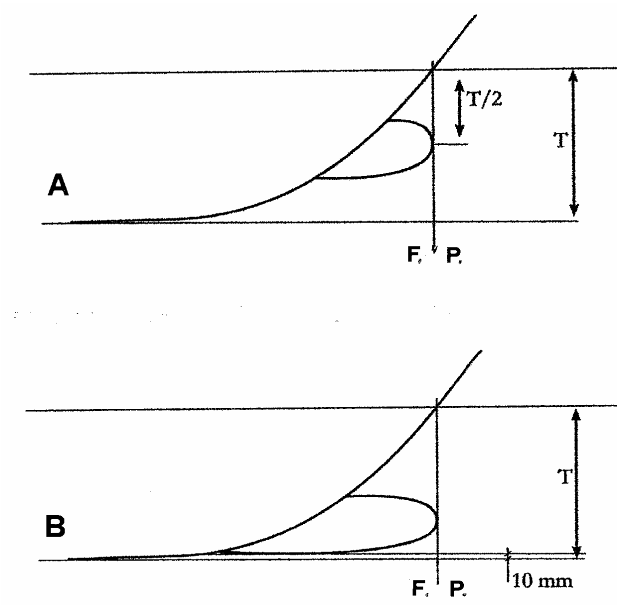

Figure 4 : The tested conditions A and B (C and D).

5. THE RESISTANCE RESULTS

Catamaran resistance is strongly affected by speed, on hull lines and on separation ratio S/L; these parameters affect the resistance components, that is the wave component and the viscous one. The latter component can be calculated by means of the form factor K, but this parameter is not easily obtained through the experiments because the tested hull presents a wide transom stern, which affects the resistance measurements at low speeds.
A.F. Molland at al. [9] suggested testing the model in bow down conditions, but this method cannot be used with central bulbs, because the appendage inclination increases the resistance and overestimates the K value. For this reason it was decided to resort to I.T.T.C. '57 methodology.

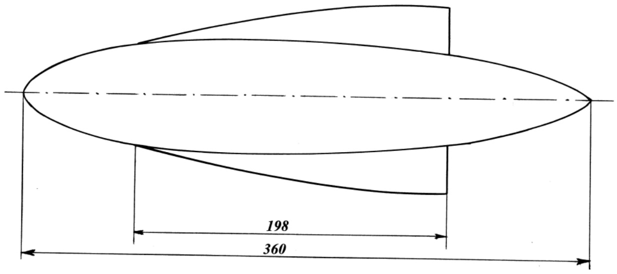

Figure 5A : The appendage 4155 with fins.

Figure 5B : The appendage placed on the model.

When using this classical method, the residuary resistance coefficients will be used to compare the hull performances directly. Another parameter used is the interference factor I.F., which can be defined as :

$$I.F. = C_R \text{ catamaran}/C_R \text{ demi-hull} .$$

The resistance of the catamaran demi-hull must be measured and then used for the comparisons of the tested configurations. Small values of I.F. and, when possible I.F. < 1 are searched.
The results obtained for the four configurations A, B, C and D are shown in figures 6 and 7. In figure 6 the residuary resistance coefficient is shown, whereas in figure 7 the interference factor I.F. is reported.

6. THE SEAKEEPING INVESTIGATION

As previously reported, the seakeeping tests have been made in regular waves, in a velocity field defined by FN values ranging between 0.2 and 0.6. The waves generated had a constant h_W/λ ratio equal to 1/80 (h_W is the wave height; λ is the wave length), whereas the λ/L_{WL} ratio has been varied between 0.5 and 2.0. The model has been ballasted in order to have a model radius of gyration $\rho = k_{yy}/L_{WL}$ close to 0.25.

The results obtained are shown as pitch motion transfer function ζ_5/ka and as heave motion transfer function ζ_3/a. The results obtained are shown in figures 8 to 19.

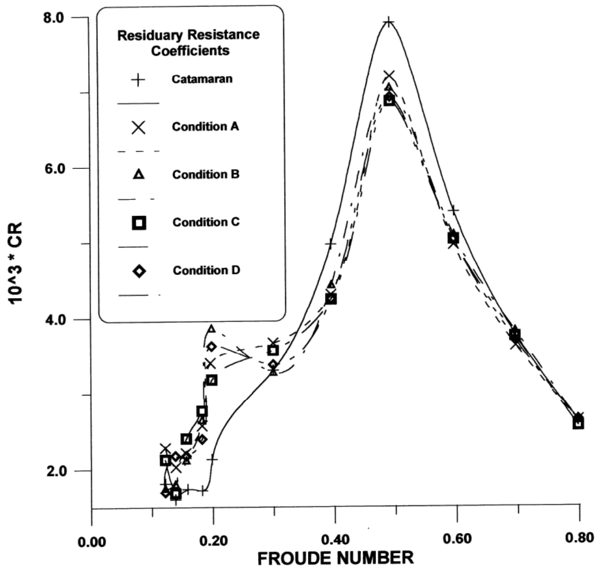

Figure 6 : The residuary resistance coefficient.

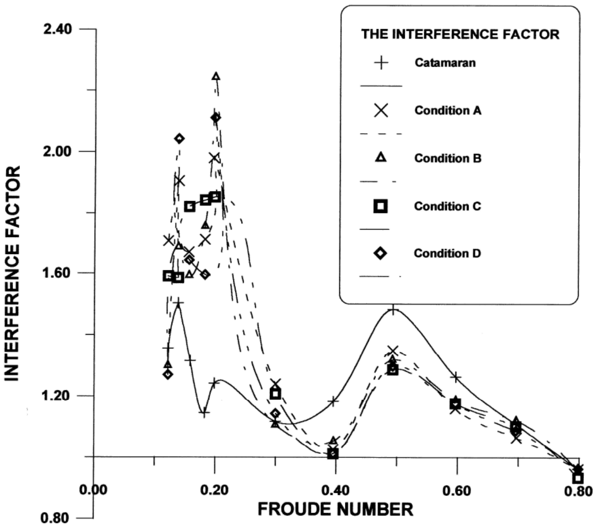

Figure 7 : The interference factor of the tested conditions.

From these figures it is possible to compare the motion differences between the catamaran hull and the catamaran with the bulb 4155 without and with the flat flaps, placed respectively in condition A and B (C and D with the flaps). In figures 8 and 9, the pitch and heave motion of the catamaran without appendages are shown; the results are plotted against the values $\omega_e\sqrt{(L_{WL}/g)}$, where ω_e is the wave encounter frequency and L_{WL} is the model waterline length. The results obtained with the investigated conditions A, B, C and D will be shown against the ratio λ/L_{WL} at FN = constant, for a better result comparison. In figures 10 ÷ 19, the vertical motion results of the catamaran hull and of the tested conditions A, D, C and D are compared at FN = constant.

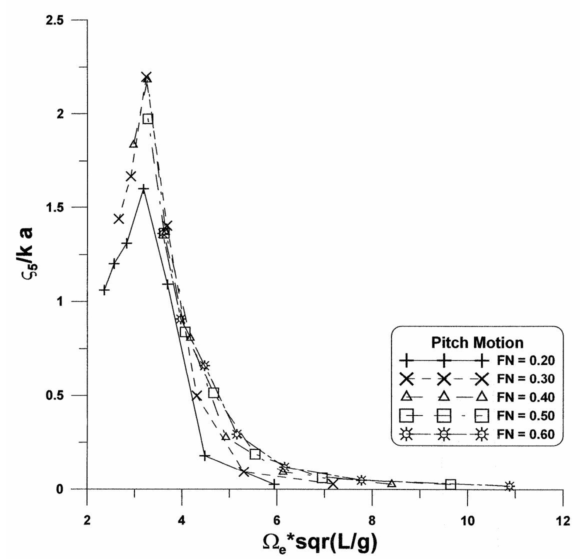

Figure 8 : Catamaran pitch motion.

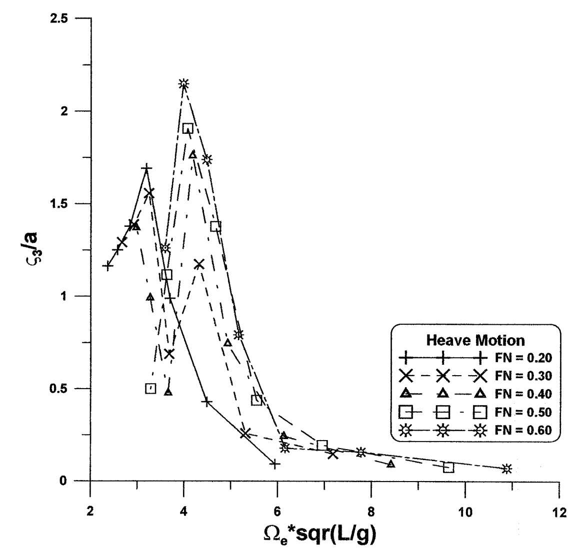

Figure 9 : Catamaran heave motion.

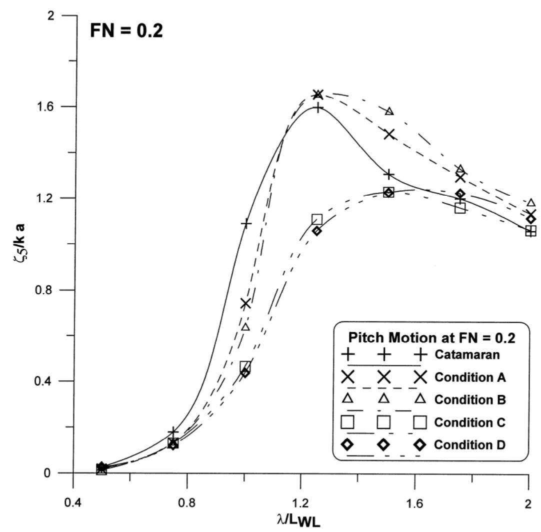

Figure 10 : Pitch motion at FN = 0.20

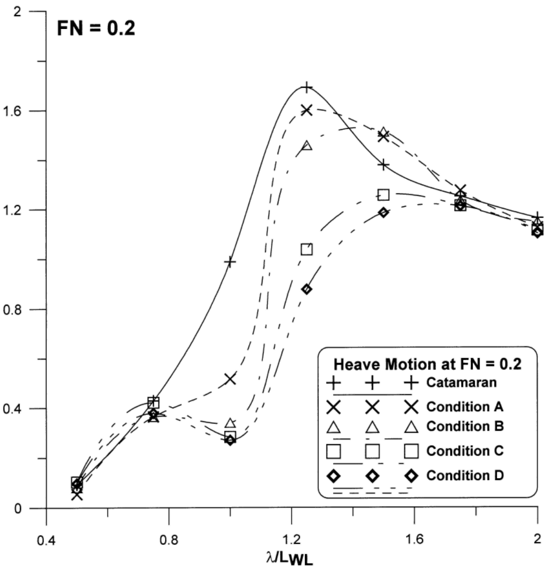

Figure 11 : Heave motion at FN = 0.2

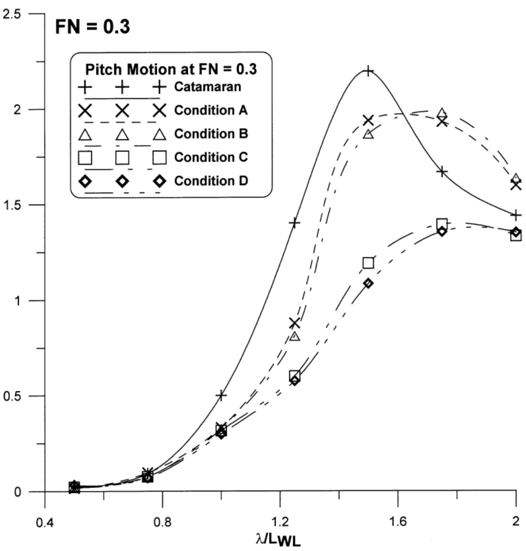

Figure 12 : Pitch motion at FN = 0.3

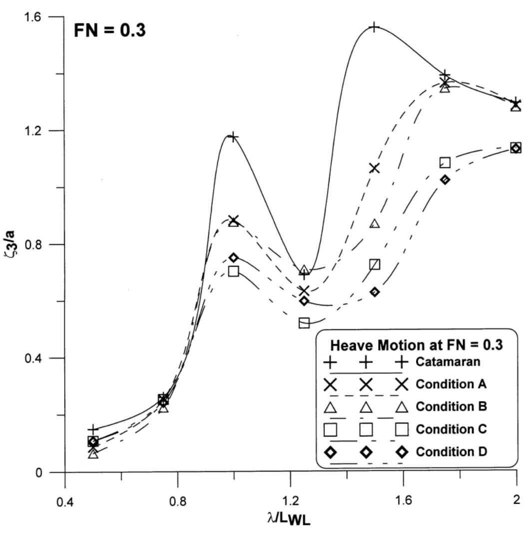

Figure 13 : Heave motion at FN = 0.3

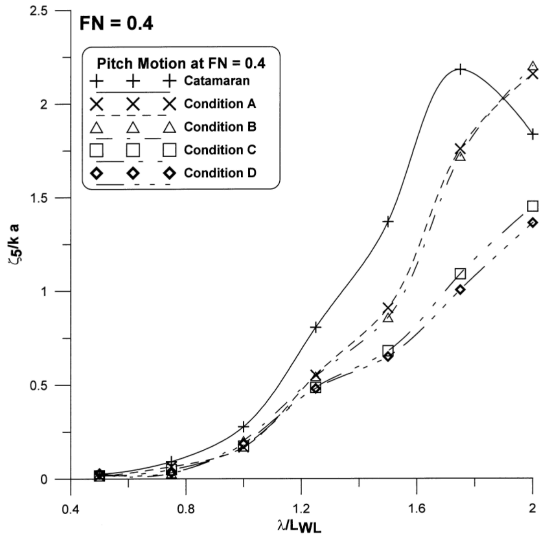

Figure 14 : Pitch motion at FN = 0.4

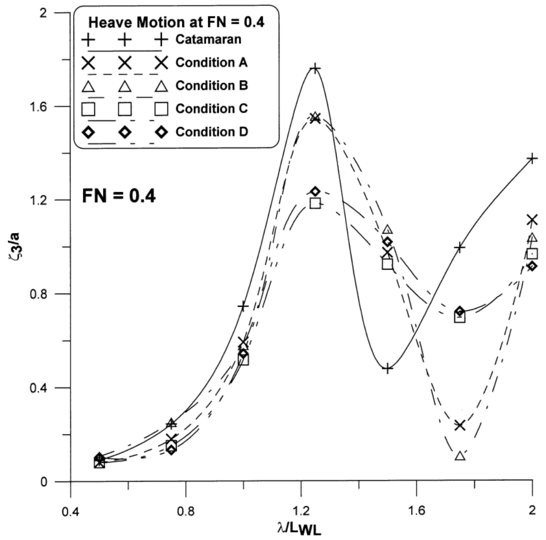

Figure 15 : Heave motion at FN = 0.4

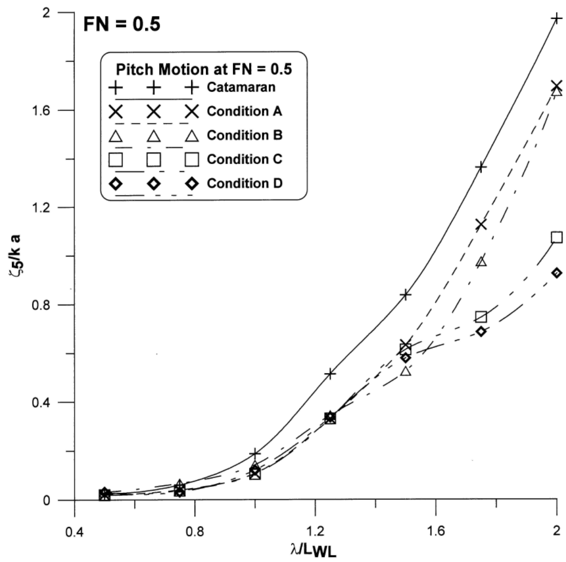

Figure 16 : Pitch motion at FN = 0.5

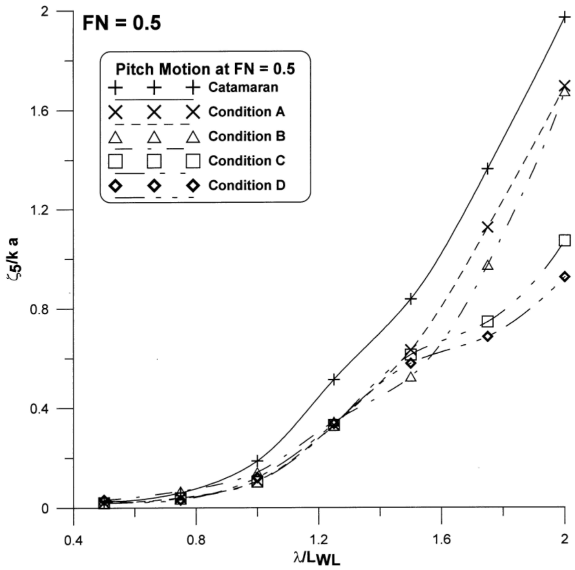

Figure 17 : Heave motion at FN = 0.5

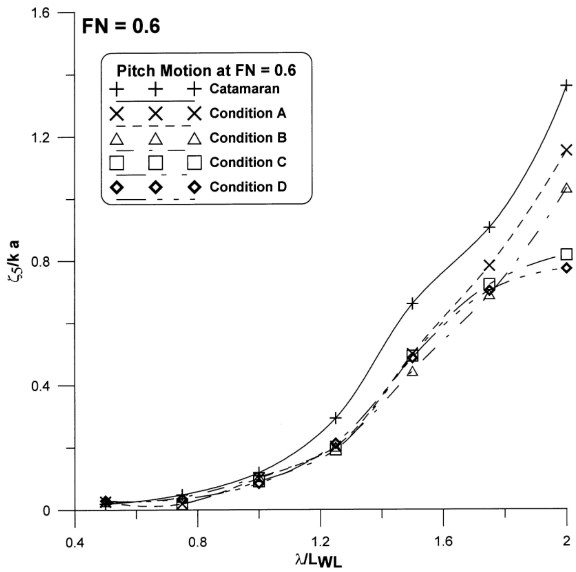

Figure 18 : Pitch motion at FN = 0.6

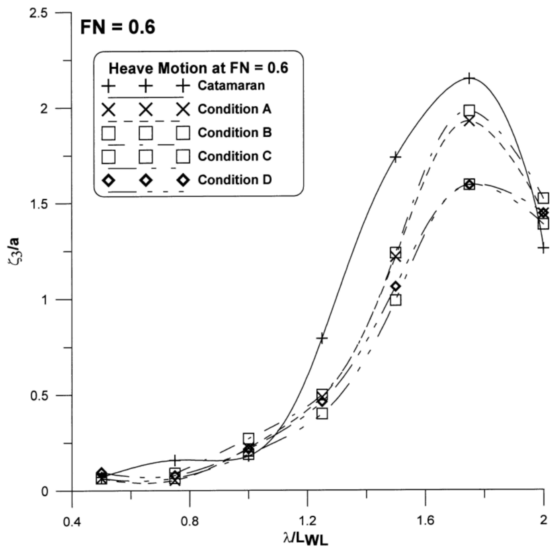

Figure 19 : Heave motion at FN = 0.6

7. DISCUSSION OF TEST RESULTS

7.1 RESISTANCE TEST

The presence of the bulb 4155 between the demi-hulls of the investigated catamaran in the positions called A and B (C and D with the bulb with flaps) generated :

a) a general reduction in the residuary resistance coefficients and, consequently of the interference factor I.F. for FN > 0.30.

b) an increase in the resistance, due to the bulb, for FN < 0.30.

The interference factor is I.F.≈ 1 for FN values 0.4 and 0.78, especially for the conditions C and D.

In the FN interval between 0.70 and 0.80 the effect of the bulb on the resistance is inappreciable.

7.2 SEAKEEPING TESTS

The seakeeping results obtained for the catamaran hull are shown in figures 8 and 9. The heaving RAO shows the existence of a double peak, which can be a common result for multi-hulls, but is less frequent for catamarans, although similar results can be found also for catamarans [10]. When placing the central bulbs, this phenomenon recurs, especially at the smaller Froude Numbers (0.2 ÷ 0.4).

The limited λ/L_{WL} ratio of tests (max. $\lambda/L_{WL} = 2.0$) did not allow to evaluate the physical phenomena for which the ratio $\zeta_3/a \rightarrow 1.0$, especially for higher Froude Numbers (a : wave amplitude; λ : wave length).

The pitch RAO is in general more regular.

The results obtained for the conditions A, B, C and D, compared with the original hull, are shown in figures 10 ÷ 19.

The presence of the central bulb 4155 without fins reduces the pitch motion amplitude in quite all the tested conditions, but this reduction is not very remarkable. By comparing these results with those obtained with the bulb 4156, reported in ref. [1], it is noticeable that the motion damping effects are similar. The larger volume of the bulb 4155 does not affect the vertical motions significantly, but acts similarly as the bulb 4156. We can define :

Condition E : the position of the bulb 4156 placed at -T/2, corresponding to the condition A of the bulb 4155, and :

Condition F : the position of the bulb 4156, placed 10 mm above the model bottom, corresponding to the condition B of the bulb 4155.

The geometrical parameters V_R and A_R (= bulb cross area / W T; W is the minimum distance between the inner sides of catamaran, at the waterline; T is the hull depth) of the Bulb – Cat configurations are :

	Bulb 4156	Bulb 4155
V_R	2.215 %	3.193 %
A_R	7.446 %	10.722 %

The RAO's comparison of the test data obtained for the conditions A, B, E and F show small variations on the vertical motions. In figures 20 and 21, a comparison between the results obtained for FN = 0.4 is shown. Similar results have been originated also for the other Froude Numbers.

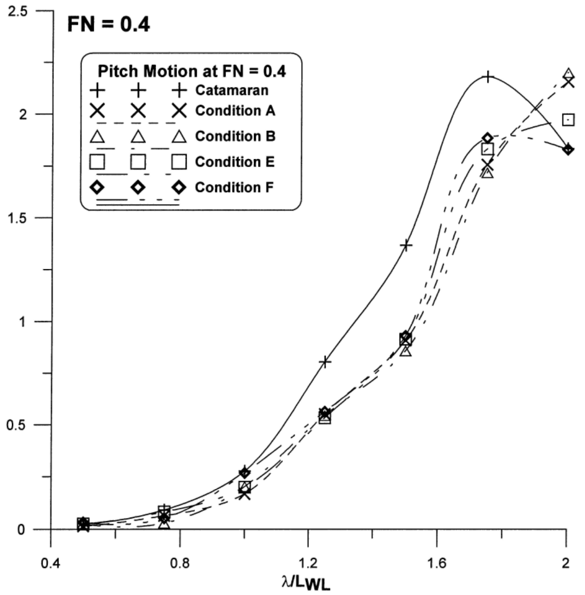

Figure 20 : Pitch motion at FN = 0.4

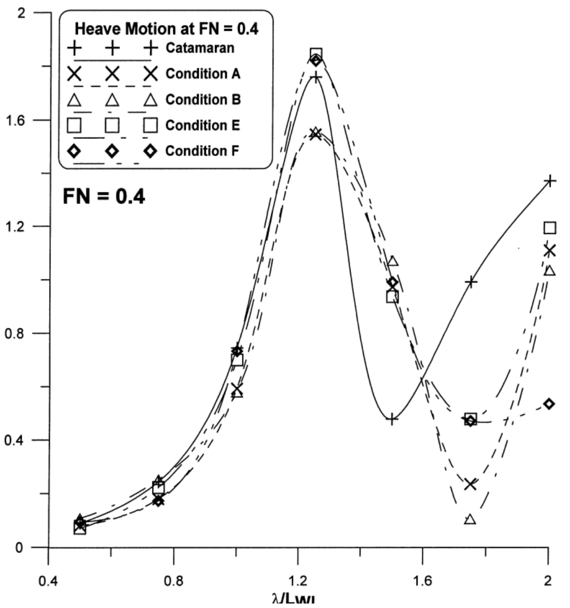

Figure 21 : Heave motion at FN = 0.40.

On the contrary, the installation of two side fins on the bulb 4155 (conditions C and D) reduces much more the vertical motions, as noticeable from the figures 10 ÷ 19. The largest variations happen at smaller Froude Numbers and at highest λ/L_{WL} ratios, although also in different cases the motion damping is appreciable. The pitch amplitude reduction is, in some cases, higher to 50% of the original motion, both for pitch and heave; larger and more regular reductions are found for pitch motions.

The bulb depth does not influence the motions very much; in general the deeper bulb damps more the motions, especially the pitch, but for the heave this is true in 70% of the examined cases.

The installation of an appropriate central bulb on a catamaran hull can reduce the vertical motions, without affecting its resistance. The use of a streamlined bulb on which a set of fins can be applied increases this damping effect significantly.

8. REFERENCES

[1] Zotti, I., "Experimental Investigation on Resistance and Vertical Motions on a Medium Speed Catamaran with Central Bulbs", Proc. of NAV 2006 International Conference, Vol. 1, pp. 1.6.1 ÷ 1.6.11, Genova, 21 – 23 June 2006, Italy

[2] 2006 Deliveries and Orders, Fast Ferry International, January – February 2004, pp. 17.

[3] Hadler, J.B., Lee, C.M., Birmingham, J.T., Jones, H.D., "Ocean Catamaran Seakeeping Design, based on the Experiences of USNS Hayes", Trans. S.N.A.M.E. n. 82, pp. 126 – 161, 1974.

[4] Gee, N., Machell, M., "A Potential Solution to Littoral Warfare Requirements", Proc. of High Speed Craft : Design & Operation", International Conference, The Royal Institution of Naval Architects, 17 – 18 November 2004, London, U.K., pp. 131 – 142.

[5] Allison, J.L., Forstell, B.G., Lavis, D.R., Purnell, J., "The Influence of new Technology on the Design and Manifacture of High Speed Craft with special Reference to recent Monohulls, Multihulls, Air Cushion Vehicles and Surface Effect Ships", Proc. of High Speed Craft : Design & Operation, International Conference, The Royal Institution of Naval Architects, 17 – 18 November 2004, London, U.K., pp. 1 -19.

[6] Zotti, I., "Hydrodynamic Improvements of Catamaran Hulls when using Streamlined Bodies of Revolution", Proc. of the 7th Conference on Fast Sea Transportation (FAST 2003), Ischia, Session A1, pp. 9-18, Oct. 2003.

[7] Zotti, I., "Hydrodynamic Experiments on a Catamaran Hull with a Central Bulb, considering its Resistance and Seakeeping Performances", Proc. IMAM 2006, vol. 1, pp. 337 – 344, Lisbon, 26 – 30 Sept. 2005.

[8] Gertler, M., "Resistance Experiments on a Systematic Series of Streamlined Bodies of Revolution for Application to the Design of High-Speed Submarines", Report C-297, David Taylor Model Basin, April 1950.

[9] Molland, A.F., Wellicome, J.F., Couser, P.R., "Resistance Experiments on a Systematic Series of High

Speed Displacement Catamaran Forms: Variation of Length – Displacement Ratio", Trans. R.I.N.A., pp. 55 – 71, 1995.

[10] Yum, D.J., Min, K.S., Song, K.J., Lee, H.Y., "Theoretical Prediction of Seakeeping Performance and Comparison with Sea Trial Results for High – Speed Foil Catamaran Ship", Proc. 3rd Conference on Fast Sea Transportation (FAST 1995), Lubeck – Travemunde, pp. 1053 – 1063, 1995.

9. ACKNOWLEDGMENTS

The Author is grateful to Dr. Eng. Jure Rogelja for his collaboration during the tests.

10. NOMENCLATURE

a:	Wave Amplitude (m);
A_R :	Area Ratio;
B :	Catamaran Breadth (m);
B_D :	Breadth of the demi-hull;
C_B :	Block Coefficient;
C_P :	Prismatic Coefficient;
C_R :	Residual Resistance Coefficient;
C_X :	Midship Section Coefficient;
C_W :	Waterplane Area Coefficient;
D :	Depth Moulded (m);
D_B :	Bulb Diameter (m);
FN :	Froude Number;
g :	Gravity Acceleration (m/s^2);
h_W :	Wave Height (m);
K :	Hull Form Factor;
k :	Wave Number;
k_{yy} :	Mass Radius of Gyration (m);
I.F. :	Interference Factor;
L_B :	Bulb Length (m);
L_{OA} :	Length over all (m);
L_{WL} (or L)	Length at the Waterline (m);
LCB :	Longitudinal Centre of Buoyancy (%);
S :	Separation between Demi – Hulls (m);
T	Hull Draught (m);
V :	Ship Speed (knots);
V_R :	Volume ratio;
W	Minimum Distance between inner sides of Catamaran (m);
WS :	Hull Wetted Surface (m^2);
λ :	Wave Length (m);
ρ :	Dimensionless Radius of Gyration;
ζ_3 :	Heave Amplitude (m);
ζ_5 :	Pitch Amplitude (° or radians);
ω_e (or Ω_e) :	Wave Encounter Frequency;
Δ :	Hull Displacement (N or t);