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Staggered Catamarans: experimental data and feasibility study for environment friendly service

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ABSTRACT: In the last years, displacement hulls for intermediate Froude numbers (Fn < 0.6) have been studied at the *Dipartimento di Ingegneria Navale* of the *Università degli Studi di Napoli* FEDERICO II (*DIN*).

Amongst the solutions tested, asymmetric multihulls seem to be quite interesting. Particularly, the scarce amount of experimental data available for staggered catamarans led to a research program in the towing tank, to evaluate the relation between total resistance of ship, stagger of demihulls and displacement.

In this paper we will present the experimental data obtained in the first step of the carried out research. Particularly, hull performances evaluated for three Length to Displacement Ratios ($L/\nabla^{1/3} = 4.62, 5.08, 5.76$) and four staggers (6, 10, 20, 30% of L_{WL}) are shown for Fn < 0.5.

The obtained results highlighted the suitability of the studied solutions for inland waterways and especially for urban services, where low environmental impact (wave wash and atmospheric pollution) is growing in social interest. The feasibility of the tested solutions was evaluated through a case study about passenger ferries in urban service. In the paper, general arrangements and cost considerations are presented.

1 INTRODUCTION

1.1 *The characteristics and requirements of the urban ferries*

The urban transport ferries have peculiar requirements: besides the usual safety of the passengers and a positive profit margin for the owners, very good manoeuvring and drastic low environmental impact are also required.

A characteristic of these vessels is the shifting location of the centre of gravity due to the movement of the passengers, for example during the boarding and de-boarding from the vessel, also for the presence of standing passengers during the voyage.

The designers have to optimize the hull forms and the propulsion systems considering that the service speed is not constant but it is characterized by quite long transient periods.

With regard to the environmental impact it is required the maximum possible reduction of wave wash and exhaust emissions. A wave making reduction also results in reduction of both resistance and installed power.

1.2 *Previous researches developed at the DIN*

In general the urban ferries are rather small and they have to keep speed limits, so it is not possible to perform total or partial hydrodynamic lift.

As a result these vessels have high values of Length to Displacement Ratio and Froude number in displacement range.

In the last years vessels having these characteristics were studied at the *DIN*. In particular, a research on a vessel actually in service for the urban transport in the Canal Grande of Venice is reported in (Miranda et al. 1998). While in (Migali et al. 2001), (Capizzano et al. 2002) and (Migali & Pensa 2005) the results of investigations about the influence of the hull forms on the resistance of displacement hulls and demihulls characterized by high values of Length to Displacement Ratio ($L/\nabla^{1/3} = 6 \div 10$) and service speeds corresponding to Fn range 0.35–0.65 are reported.

In this paper the results of a research motivated by the growing request of vessels having low resistance and the experience gained on this subject are reported.

2 THE STAGGERED CATAMARAN CONFIGURATION

2.1 *Staggered catamaran*

In the past, many authors studied this particular catamaran arrangement as depicted in Figure 1. It is based on the benefits due to the positive interferences of the transversal waves systems generated by the longitudinally shifted demihulls of the catamaran.

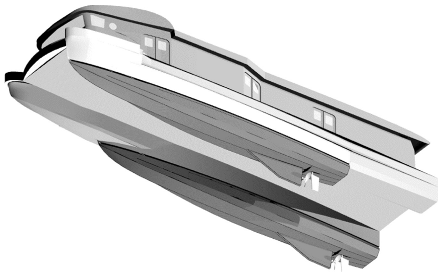

Figure 1. Isometric hull view.

One of the most recent work on the possible reduction of the wave resistance is described in (Söding 1997).

The results of the numerical investigation conducted on the catamaran *Supercat-Haroula* with a 50% L_{WL} stagger, highlighted a total resistance reduction of 53% for the speed corresponding to Fn = 0.4. These theoretical results were also confirmed by an experimental investigation carried out on a SWATH model having the demihulls shifted by the same longitudinal stagger value.

Söding explained the obtained results considering that the wave systems generated by the demihulls have equal size and phase and in the tunnel the amplitudes of the transversal waves add up constructively and almost doubles. Considering that the wave energy is proportional to the square of the wave amplitude, two demihulls would generate four times the wave resistance of a single catamaran hull. On the other hand, if a phase shift of 180 degrees between the transverse wave systems of both catamaran hulls is applied, the transverse waves are largely reduced, also reducing the wave resistance.

This way the longitudinal shift of the demihulls should depend on wave length (i.e. on the vessel speed). Increasing relative speed of vessel, the wave length increases and the optimum stagger could reach values which are not feasible for a full size vessel.

2.2 *Test program and experimental results*

At the *DIN,* extensive experimental investigation was carried out on staggered catamarans to verify the resistance reduction predicted by theoretical methods. The experimental programme consisted in the valuation of the interference effects in the case of smaller longitudinal stagger values (Stagger = 6, 10, 20, 30% of L_{WL}) selected to study more feasible configurations.

All the experiments were carried out in the *DIN* Towing Tank (136.0 m long, 9.0 m width, 4.5 m depth) on the catamaran model (L_{WL} = 3.341 m), having symmetrical demihulls, named C932. This model was developed for conventional vessels in the early years of the '90s.

Three Length to Displacement Ratios ($L/\nabla^{1/3}$ = 4.66, 5.08 and 5.74) and one separation to length ratio (S/L = 0.30) were tested. The investigated speeds corresponded to a Fn range 0.3 to 0.5 (Rn $5.4 \times 10^6 \div 8.34 \times 10^6$).

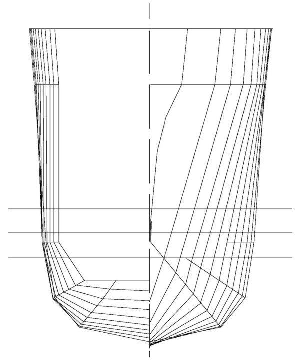

Figure 2. Body plan of the demihull (Model C932).

Table 1. Demihull model's principal dimensions.

$L/\nabla^{1/3}$	5.87	6.39	7.23
∇ [m^3]	0.184	0.142	0.097
L_{WL} [m]	3.341	3.336	3.320
C_B	0.549	0.518	0.473
C_P	0.679	0.670	0.638
L_{WL}/b_{WL}	8.331	8.400	8.646
b_{WL}/T	1.594	1.918	2.385
$S_W/\nabla^{2/3}$	6.47	6.59	6.89
L_{CB}/L_{WL}	0.427	0.432	0.442
L_{CF}/L_{WL}	0.428	0.416	0.410
A_T/A_M	0.52	0.42	0.25
$L/\nabla^{1/3}_{Catamaran}$	4.66	5.08	5.74

In Figure 2 the body plan of the model C932 is shown. Experimental methodology, results and data analysis of the standard and staggered catamaran configuration are extensively reported in (Caprio et al. 2005).

The demihull model characteristics of the tested displacements are given in Table 1.

The experimental results show a total resistance reduction in the case of the staggered configuration. At some speeds the total resistance of the catamaran, having a 30% L_{WL} stagger, is reduced to more than 25% of that of the standard catamaran.

In Figures 3, 4 and 5 the comparisons of the CT_M curves are shown for each tested displacement.

3 THE PRELIMINARY DESIGN OF THE VESSEL

3.1 *The mission profile*

To evaluate the realistic possibility of a vessel having a staggered catamaran configuration, the preliminary

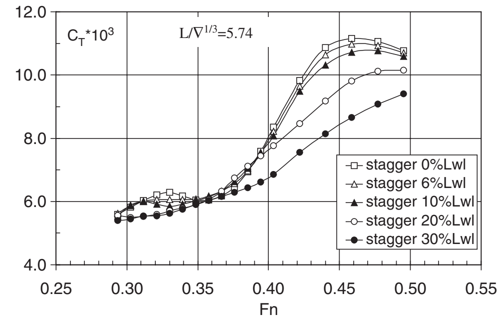

Figure 3. Comparison of the total resistance coefficients ($L/\nabla^{1/3} = 5.74$).

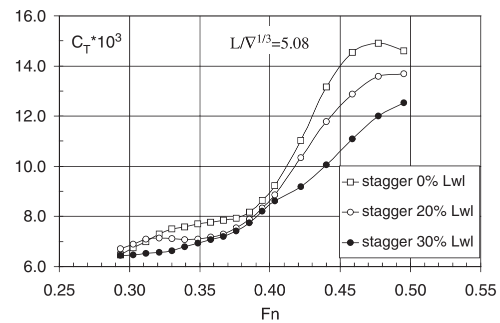

Figure 4. Comparison of the total resistance coefficients ($L/\nabla^{1/3} = 5.08$).

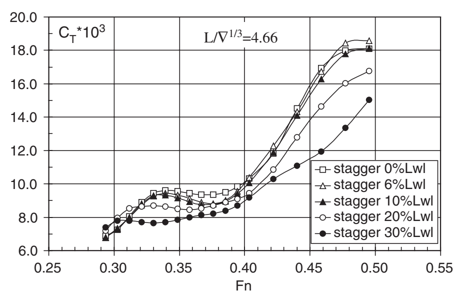

Figure 5. Comparison of the total resistance coefficients ($L/\nabla^{1/3} = 4.66$).

design of a ferry carrying out 170 passengers (90 seats and 80 standing room) sailing in protected water was developed.

The required service speed of the vessel has to be at least 8.1 kn ≡ 15 km/h, which is a typical average speed of the public road transport in a metropolitan area.

In order to make the design as convincing as possible, two different routes were fixed for the passenger transport service of the vessel. The possible opera-

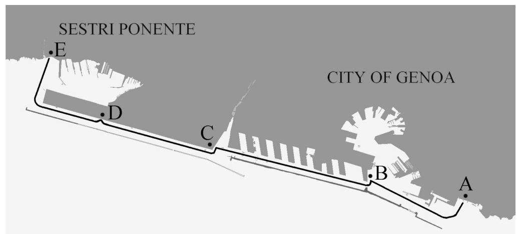

Figure 6. The route of the *Linea 1*.

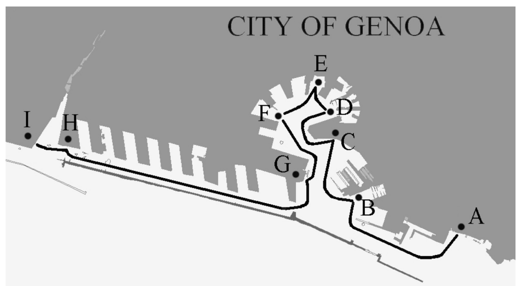

Figure 7. The route of the *Linea 2*.

tional area is the calm water canal of the Genoa harbour. The first route, named *Linea 1*, covers a distance of 6.1 nm with 5 stops, including the termini.

In Figure 6 the positions of the *Linea 1* stops are shown.

The second route, named *Linea 2* has a length of 5.8 nm and it presents 9 stops.

This route is characterized by more stops and two speed limits. The aim of this hypothesis is to favour the installation of a hybrid diesel-electric engine system, which is described in (Balsamo & Quaranta, in prep). In Figure 7 the positions of the *Linea 2* stops are indicated.

The distances between the stops and the travelling times of both the routes are reported in Table 5.

3.2 *The vessel description*

For the designed ferry, shown in Figure 1, aluminium alloy was selected as construction material. To make the building process easier and to cut the building costs, the hull and superstructure surfaces are developable. Weight estimates, centre of gravity locations and the structural design are described in (Coppola 2005).

In the preliminary design the propulsion system is also studied. In (Balsamo & Quaranta, in prep) the weights and the dimensions of the selected propulsion systems (both diesel and hybrid diesel-electric) are reported.

The hybrid diesels-electric system presents electric engines, batteries and diesel engines. The power of the electric engines is the maximum one required during the navigation. These engines are supplied by batteries charged by the diesel engines sized on medium value of the required power.

Stability and hydrostatic calculations are referred to actual lightship and deadweight data.

In Table 2 the vessel's main dimensions are reported, while in Table 3 a synthetic weight breakdown is shown.

Table 2. Vessel's main characteristics.

	Cat. Diesel	Cat D-Electric.
L_{WL} [m]	21.60	21.60
B_{WL} [m]	7.00	7.00
B_{MAX} [m]	7.25	7.25
∇_{MAX} [m^3]	34.5	34.5
No. of Passengers	170	130
No. of Crew	2	2
Fuel capacity [l]	2000	1300
Service speed [kn]	11.4	8.0–10.9
P_B diesel [kW]	2 × 90	2 × 45
P_B electric [kW]	/	2 × 83
No. of Engines	2	2
Range (No. round trips)	30	6

The general arrangement, depicted in Figure 8, shows the chosen solutions to reduce the movements of the passengers and also to allow an easy boarding and de-boarding process.

Table 3. Preliminary weight breakdown and KG location.

Weight [t]	Cat. Diesel	Cat D-Electric.
Hull	12.2	12.2
Outfit and accommodation	1.5	1.5
Auxiliary systems (bilge, fire protection and electrical machinery, air-conditioning units)	1.4	1.4
Propulsion and steering systems	2.3	5.7
Rescue and safety systems	0.60	0.60
Weight margin (15%)	2.7	3.2
Fuel	1.7	0.5
Crew	0.2	0.2
Passengers	12.8	9.7
Total	35.3	35.3
KG full load (m from B.L.)	2.47 (only Diesel)	

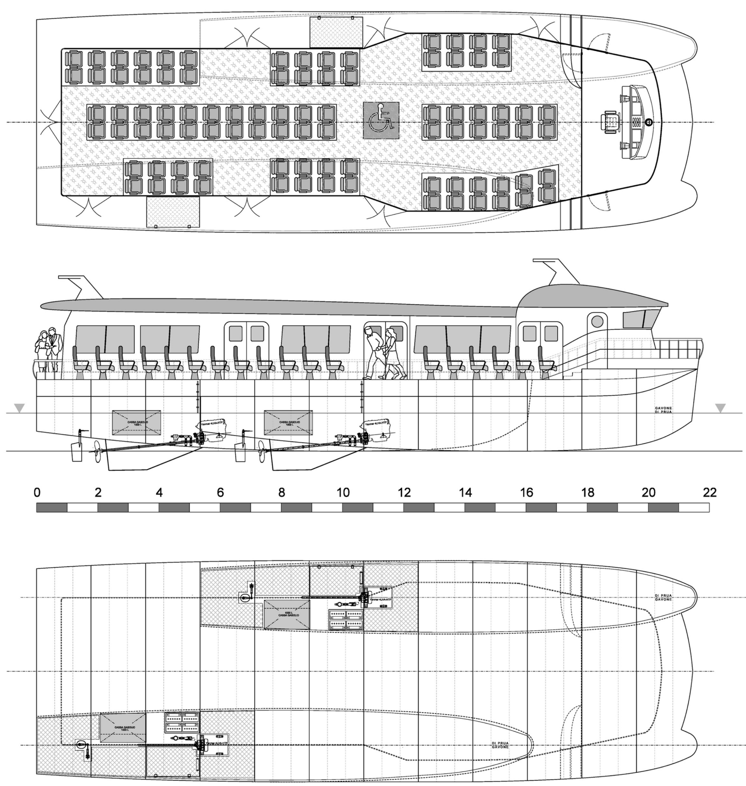

Figure 8. General arrangement.

As showed in figure 1, two gondolas, rising out of the water for the upright vessel, were realized to reduce the undesired ship movements due to asymmetric hull arrangement.

3.3 *Stability*

The intact stability was verified only in the case of the diesel propelled vessel, because such configuration presents the greater number of passengers and a greater height of the centre of gravity above the baseline, KG. The calculations were carried out using the software "*Autohydro*" by *Autoship System Corporation.* The recommended stability requirements were the statutory limit criteria for inland and protected water: the initial metacentric height, GM, to be at least 0.3 m and the minimum distance of the freeboard deck from the water at final equilibrium (after passenger crowding) to be at least 0.2 m.

Due to the vessel asymmetry, both the criteria were verified considering the vessel heeled to port and starboard.

Different passenger loading scenarios were analyzed to simulate the progressive boarding or de-boarding. A density of four passenger per square metre was considered. All the passenger crowding cases are depicted in Figure 9.

The critical KG is 6.3 m, due to the homogeneous lateral crowding at the aft hull side.

In Table 4 the equilibrium transversal angles, φ, and longitudinal angles, θ, are reported for each case considering the estimated actual centre of gravity locations.

3.4 *Performances*

In Figures 3, 4 and 5, the resistance reductions for some configurations and speeds are evident and remarkable. The ratio between the resistances of the staggered and standard catamaran configurations are shown in Figure 10. The best performance is obtained by the 30% L_{WL} stagger arrangement at the Froude number of 0.46, corresponding to $V_S = 11.4$ kn for the designed vessel.

The total resistance curve of the vessel, RT, obtained by increasing the bare hull resistance of 5% for the air and appendages resistance, is shown in Figure 11. No added resistance for shallow or restricted water was considered.

The brake power, P_B, was obtained by assuming a constant total efficiency, OPC, of 0.55 over the entire speed range. Its curve is depicted in Figure 12.

An estimate of the travelling times is conducted using both the experimental results and a simulation of the accelerations of the vessel.

In (Balsamo & Quaranta, in prep 2005) this analysis is described and a summary of the travelling times and distances between stops for both the routes is reported in Table 5.

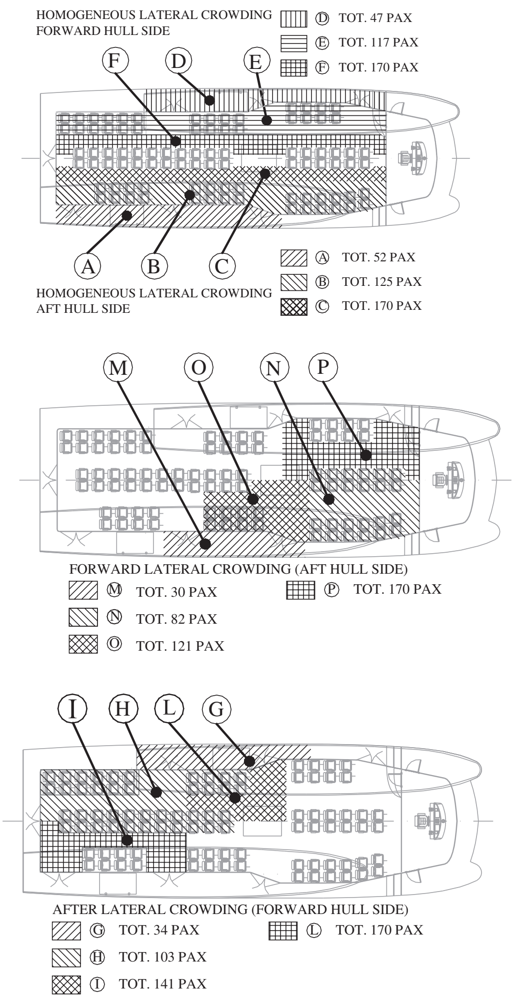

Figure 9. Passenger crowding scenario.

Table 4. Equilibrium angles.

Cases	θ [deg]	φ [deg]
A	fwd 0.17	stbd 2.60
B	fwd 1.03	stbd 5.58
C	fwd 1.02	stbd 6.05
D	aft 0.51	port 2.81
E	aft 0.50	port 4.58
F	aft 0.43	port 4.94
G	aft 0.36	port 2.02
H	aft 1.19	port 3.35
I	aft 1.95	port 3.37
L	aft 1.78	port 3.62
M	fwd 0.51	stbd 1.97
N	fwd 1.65	stbd 3.74
O	fwd 2.39	stbd 5.43
P	fwd 2.86	stbd 4.70

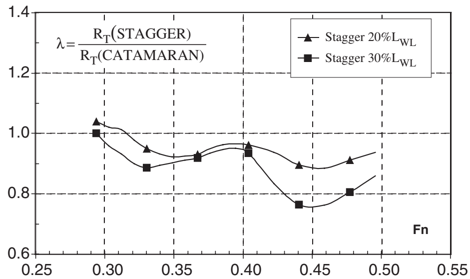

Figure 10. Resistance ratio.

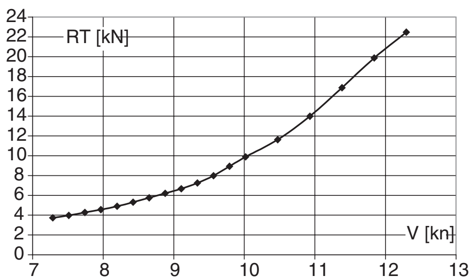

Figure 11. Total resistance.

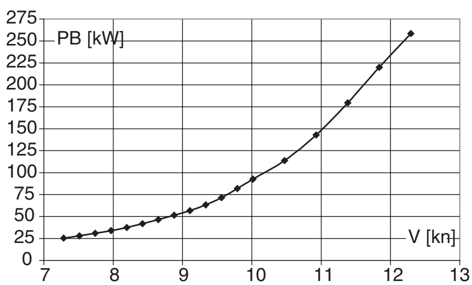

Figure 12. Brake power.

3.5 *Cost estimate*

A building cost estimate was carried out using some formula described in (Karayannis et al. 1999). The costs are expressed in euro.

The aluminium alloy cost and the labour cost are evaluated respectively 4000 €/t (an increment of 15% for the material scrap is included) and 28 €/hrs. The estimate of the labour hours for the hull building was 600 hr/t, which is the minimum value proposed by Karayannis, thanks to developable surfaces and to the reduced outfit needed by the urban service.

According to these assumptions and referring to the installed power and weights, the calculated costs are reported in Table 6.

Table 5. Voyage breakdown.

Stop	Dist. [nm]	Time [min]	V_{MAX} [kn]	Progressive Distance	Progressive Time
Linea 1					
A	0.00	0	11.4	0.00	0
B	1.88	13	11.4	1.88	13
C	1.39	11	11.4	3.27	24
D	1.30	10	11.4	4.57	34
E	1.51	11	11.4	6.08	45
Linea 2					
A	0.00	0	10.9	0.00	0
B	1.23	11	8.0	1.23	11
C	0.55	7	8.0	1.78	18
D	0.45	7	8.0	2.23	25
E	0.22	5	8.0	2.45	30
F	0.55	7	8.0	3.00	37
G	0.52	7	8.0	3.25	44
H	2.05	15	10.9	5.57	59
I	0.26	6	10.9	5.83	65

Table 6. Building costs.

ITEM	Diesel [k€]	Diesel-Elec. [k€]
1 Hull and superstr.	254	
2 Painting	50	
3 Outfit	162	
3 Engines	45	170
4 Aux. syst. and rudd.	50	
5 Margin (15%)	80	103
Total	641	790

Table 7. Comparison of cost and power for different public transport vehicles.

Vehicle N° pax.	Cost [k€]	PB [kW]	k€ Np	kW Np
Cat. Dies. 170	641	180	3.8	1.1
Cat. D-Elec. 130	790	90	6.1	0.7
Bus 120	300	160 ÷ 210	2.5	1.3 ÷ 1.8
Bus 80	190	120 ÷ 140	2.4	1.5 ÷ 1.8
Tramway 150	1050	212	7.0	1.4
Trolley Bus 90	400	145	4.4	1.6

In Table 7 typical data of cost and power per passenger of different road vehicles are reported. A plausible comparison between marine and road vehicles is performed.

4 CONCLUSIONS

In this study the possible application of a staggered catamaran hull form vessel was evaluated, in order to take advantage of the possible reduction of the resistance and wave making and the consequent hydrodynamic and air pollution reductions.

To reduce the possible disadvantage in rough sea, a passenger service was considered in protected water: in this particular case the calm water canal of the Genoa harbour was chosen.

To satisfy the mission profile, a preliminary design was carried out with weight, power and cost estimates. A particular evaluation was carried out on vessel motions due to the progressive passenger boarding and de-boarding process.

The obtained results are remarkable in comparison to road vehicles for public transport.

In particular:

- the required power is restrained to the examined speeds;
- the asymmetrical configuration does not compromise the vessel's stability;
- the cost per passenger is comparable with that of public road transport vehicles;
- the installed power and the fuel consumption are very interesting;
- the exhaust emissions are limited, due to reduced power and to the absence of transitory acceleration, a common fact on public transport vehicles;
- the vessel service speed is not less than the average speed of the public transport vehicles of many great cities.

Moreover, must be remarked that the tested hulls were conceived for a service of different kind. So a dedicated hull form would require lesser propulsive power. For the abovementioned reasons, the research is now entering into its second phase: the design of hull forms optimized for this staggered configuration. In particular, the reduction of divergent wave pattern is actually under evaluation, because this wave system is less likely to be influenced than the transversal wave system.

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