18th International Conference on Ships and Shipping Research 2015, June 24th – 26th, Lecco, Italy

M. Altosole and A. Francescutto (Editors)

MONOTRICAT® HULL, FIRST DISPLACEMENT NAVAL HULL NAVIGATING AT SPEEDS OF PLANING HULLS, ON SPRAY SELF-PRODUCED, AT HIGH HYDRODYNAMIC EFFICIENCY AND ENERGY RECOVERY

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ABSTRACT

From the '50s, with the introduction of the first semi-planing hull of Nelson, which allowed to navigate with a certain tranquility at speeds higher than those of traditional hulls, and with the subsequent availability of more powerful engines, have been reached a speed equal to Fn greater than 0.6, which defines planing hulls. It was created so a clear distinction between displacement and planing hulls, in relation to the performances. The need to have naval units displacing faster has pushed the ship design to achieve increasingly high performance hulls, also focusing on the use of lightweight materials such as aluminum and more powerful engines, etc., but without substantially changing the traditional forms of hull. The patented hull Monotricat high hydrodynamic efficiency and energy saving represents the overcoming of this distinction between displacement and planing hulls, because, unlike previous solutions, is configured as the first hull that combines the characteristics of displacement and planning hull, since it presents an innovative architecture that could be defined as a hybrid between a monohull and catamaran, navigating on spray self-produced. This presentation will show how the hull Monotricat is the first displacement hull that can navigate at both displacement and planning speeds, with a resistance curve almost straight, maintaining the characteristics of a displacement hull. For these reasons the Monotricat hull is able to ensure: safety, comfort navigation, best seakeeping and maneuverability in restricted waters, stability, reduction of resistance to motion, cost management, regularity on the routes even in adverse weather-sea. These characteristics of the hull have been studied, tested and validated by leading research institutes and universities with more ameliorative results in each subsequent experimentation, reported in the present work, which demonstrated a greater hydrodynamic efficiency compared to conventional hulls tending to 20%.

1. INTRODUCTION

The water transport at high speed was always pursued by shipbuilders. Achieving this goal has committed designers in defining the lines of the hull, the strengthening of the engines on board, and in the development of new engines. The development of the Monotricat project with its new lines involved in the course of the experimentation the optimization of the shape of the hull not only for the running resistance, but also for the seakeeping, maneuverability, safety and cost management while respecting the environment.
This new architecture of naval hull, Realized and internationally patented, born from 15 years of studies and research breaks all the conventional schemes as it consists of a thin and very

ISBN 978-88-940557-1-9

immersed bow inserted in a catamaran having very thin hulls that delimit a central tunnel beneath the waterline, in which the wave engendered from the bow is conveyed associated with the formation of foam. Then, part of the kinetic energy of the wave is transformed into pressure energy with the result of obtaining a lifting of the stern, while the foam, interposed between the hull and the water, it breaks in good part the "boundary layer" getting a reduction of the viscous resistance. Therefore the reduction of the resistance is obtained through the recovery of the energy contained in the wave engendered from the bow and exploiting the spray associated with it, while with the increase of speed the hydrodynamic effect raises the bow compensating lifting stern.
Peculiarity of this hull is always navigate in displacement for it to produce the wave formation of the bow. Therefore the hull Monotricat can be defined as the first naval unit high hydrodynamic efficiency and energy recovery that navigates on a formation of spray self-produced as will be explained in the paragraph "Innovation".

2. INNOVATION OF NEW ARCHITECTURE OF HULL

The above is realized through an innovative architecture of naval hull completely out of all the conventional schemes, since it is properly of a hybrid between a conventional monohull and catamaran. This hull consists of a bow deep V with an angle which gradually increases towards the stern of up to 180 °. Are flanked by two side blades with the aim to capture and contain the wave formation created by the bow and the spray associated with it. Its distinguishing feature is the presence of a central tunnel under the waterline in the rear of the hull, while the front part, the hull has a bow V-shaped deep and thin. This architecture provides the hull excellent leadership skills, stability in the seakeeping in adverse weather conditions for the effect wave-piercing, and capacity to maneuver in tight areas.
Inside the tunnel is conveyed wave engendered by the bow with the formation of foam associated. Then, part of the kinetic energy of the bow wave captured under the hull is transformed into pressure energy with the result of obtaining a lifting of the stern section; simultaneously hydrodynamic thrust allows the bow to lift up and to maintain a structure that varies between 1 and 2 degrees approximately, while the foam, interposed between the hull and the water, it breaks in good part the "boundary layer" obtaining a reduction of viscous drag. These drivers allow the hull of not being sensitive to the movement of loads; for this reason the hull remains almost stable, so is called "mono-stab". It can be said also that the hull Monotricat behaves as a hull ASV (Air Support Vessel) without the need to "pump" air under it. These phenomena are accentuated with increasing speed. It is therefore evident that the reduction of the resistance is obtained in proportion with the increase of the speed and whose resistance curve, will always be a nearly straight line.
The hull Monotricat thus appears to be a hull very safe by virtue of its width (about + 20%). The bow thin type "wave piercing" makes it very comfortable even in adverse sea and weather conditions; is in fact able to deal with adverse sea conditions better than other hulls; recovery of wave formation associated with sprays make the hull Monotricat very efficient in both speed displacement that planing.

3. EXPERIMENTATION PERFORMED

This new architecture of the hull has been repeatedly tested for 15 years both at leading research institutes and Italian and foreign university, with evidence in Towing Tank and testing CFD (Computational Fluid Dynamics) conducted with HPC (High Performance Computing), both with self-propelled models navigating long from 4 to 8 meters tested in open water (sea, lakes and rivers).
The experimentation carried out so far has produced excellent results every ameliorative, widely tested and certified at the Towing Tank of Rome INSEAN CNR and at the Towing Tank at the University of Trieste. The simulations in C.F.D. technology HPC (High Performance Computing) made it possible to confirm the evidence in Towing Tank simulating phenomena that insist under this new hull. Studies in C.F.D. were conducted at the University of Stockholm - Dip. HPC in 2014 where it was possible to compare the results in CFD with those obtained in Towing

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Tank on the 2010 model, and then was reached to achieve scalability between tests in CFD and previous results in Towing Tank, demonstrating that there are under this hull phenomena that occur under it and allowing it to be so efficient. At this point it was possible to continue the optimization of the hull in CFD at an Italian research center, getting a model optimized hull with related performances, and simulations in reaching a speed of 3.4 FNV, while the so-called resistance curve results to be almost a straight line.
In detail, the studies and experiments carried out so far have been:
a) Test in Towing Tank and test in open water:
- Institute Towing Tank I.N.S.E.A.N. C.N.R. of Rome (2000/2004):
October 2000 Towing Tank INSEAN ROME Hull C2414 (Figure 1)
October 2004 Towing Tank INSEAN Lake Bolsena Hull C2479

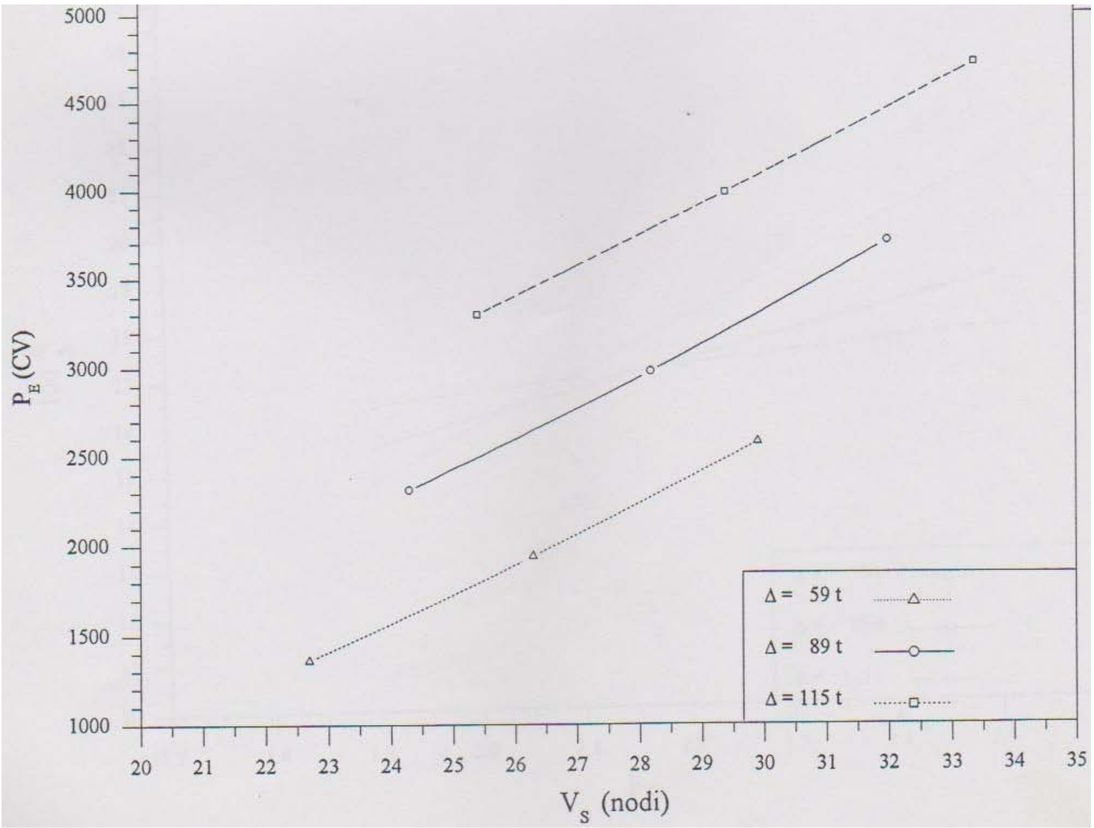

Figure 1. Resistance curve Towing Tank INSEAN CNR, Rome, 2000.

- Department of Naval Engineering of the University of Trieste (2008) directed by Prof. Igor Zotti, who personally tested the hull and has exhibited in the report to Congress Sea-Med 2012 "Evolutions and trends in the development of modern hydrodynamic fast hulls " (Zotti and Agrusta, 2012):

December 2008 Department naval UNITS Hull C412-08 (Figure 2)

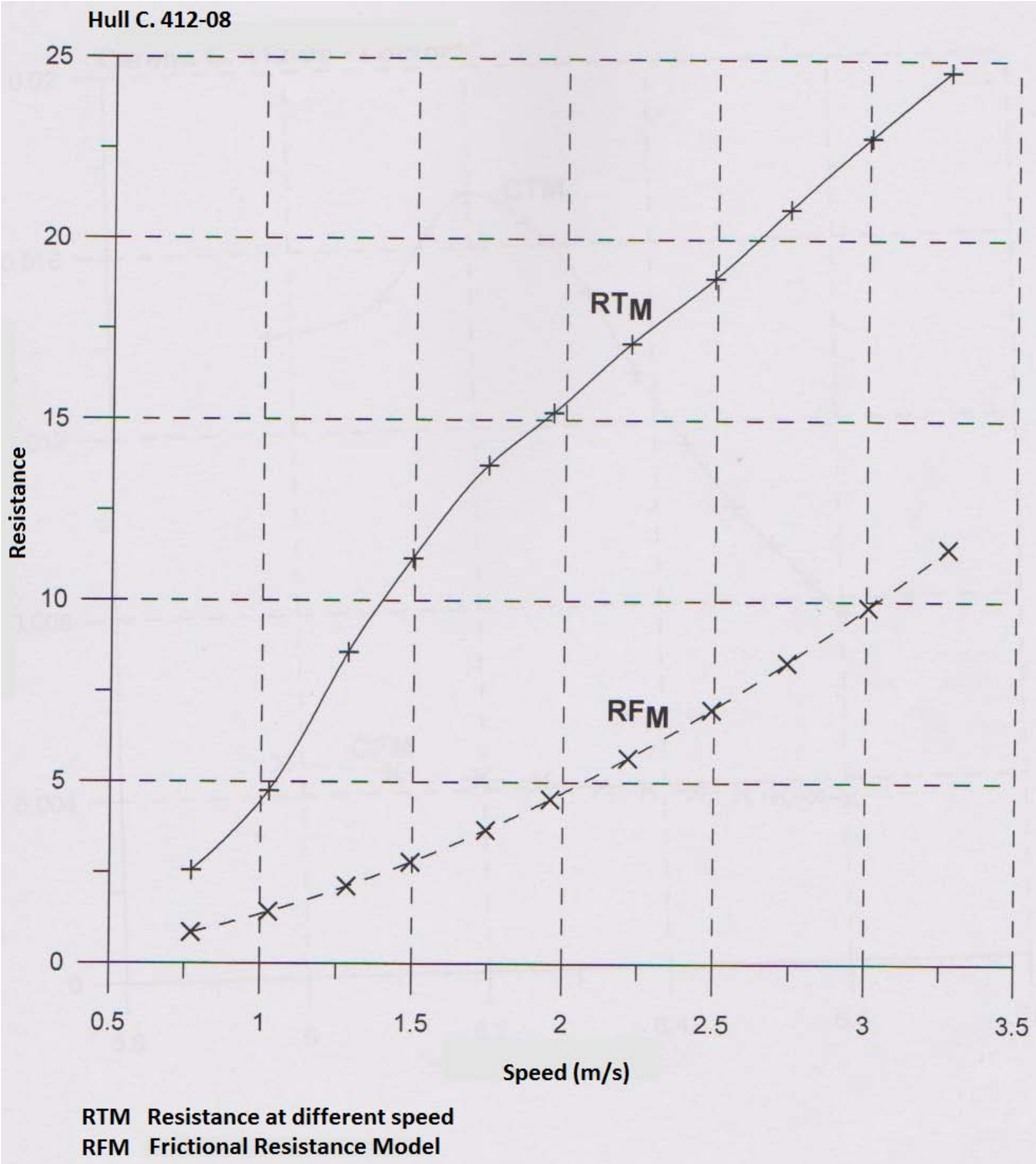

Figure 2. Resistance curve Towing Tank University of Trieste, 2008.

In Figure 2 is highlighted in the hull C 412-08 the resistance curve resulting by tests in Towing Tank at the University of Trieste, which show along the abscissa axis the speed of the tested model (meters per second) and along the ordinate axis the resistance in Newton, where RTM is the total scale resistance model and RFM model is the frictional resistance.
- Institute Towing Tank I.N.S.E.A.N. C.N.R. of Rome (2010, 2011):
August 2010-2011 Hull 2565 (where it was certified that a hull of 24 meters 70 tons displacing is able to reach 20 knots with a maximum of 1600 Cv), while for the same vessel at 60 tonnes must be a power of 1,450 Cv on a performance engine estimated at 50%.
- Tests on open water with self-propelled vessel at Bolsena Lake by Studio of Engineering and Consulting Naval Boghi & Partners, 2005 (“figure 5”), and other tests at sea an rivers (Fiumicino, Sabaudia)(2002-2009).
b) C.F.D. Studies:
- University of Stockholm (Sweden) (2014) as part of the European program PRACE SHAPE for innovation with the aim of promote cooperation and technology transfer between research and industry, where the MONOTRICAT SMEs, holder of the international patent Monotricat®,

participated with other 9 innovative European SMEs. The hull Monotricat was studied with simulation software Open FOAM (system open source CFD). The results obtained with the CFD OpenFOAM are substantially superimposable to those obtained with the tests in Towing Tank.
- Simulation in C.F.D. carried out in an Italian research center (2015) with the aim to optimize the hull, simulating speeds up to 42 knots for a hull of 24 meters and 70 tons displacing (model Towing Tank INSEAN CNR 2010), obtaining a resistance curve almost rectilinear (Figures 3, 4). Tests performed: Change in weight distribution; test very high speed.
In the last test in CFD (Italy) has been performed a simulation of variation of trim. In particular, tests have been carried out specifically for moving the center of gravity and precisely: simulation with the hull at bow up of + 0.5 ° and simulation with the hull at bow down of -0.5 °, without a significant difference in performance.
From the results of the simulations in C.F.D. at the Italian research center on optimized model obtained by varying the initial static trim, it is interesting to observe how the curves of dynamic trim absolutely not affected the change the center of gravity because the measured values are always roughly the same with the only addition of the initial static trim. Often, in fact, on traditional hulls, a small variation of the initial static trim can result in a large and amplified variation of dynamic trim, sometimes such as to significantly alter the conditions of motion of the hull. (Figures 3).

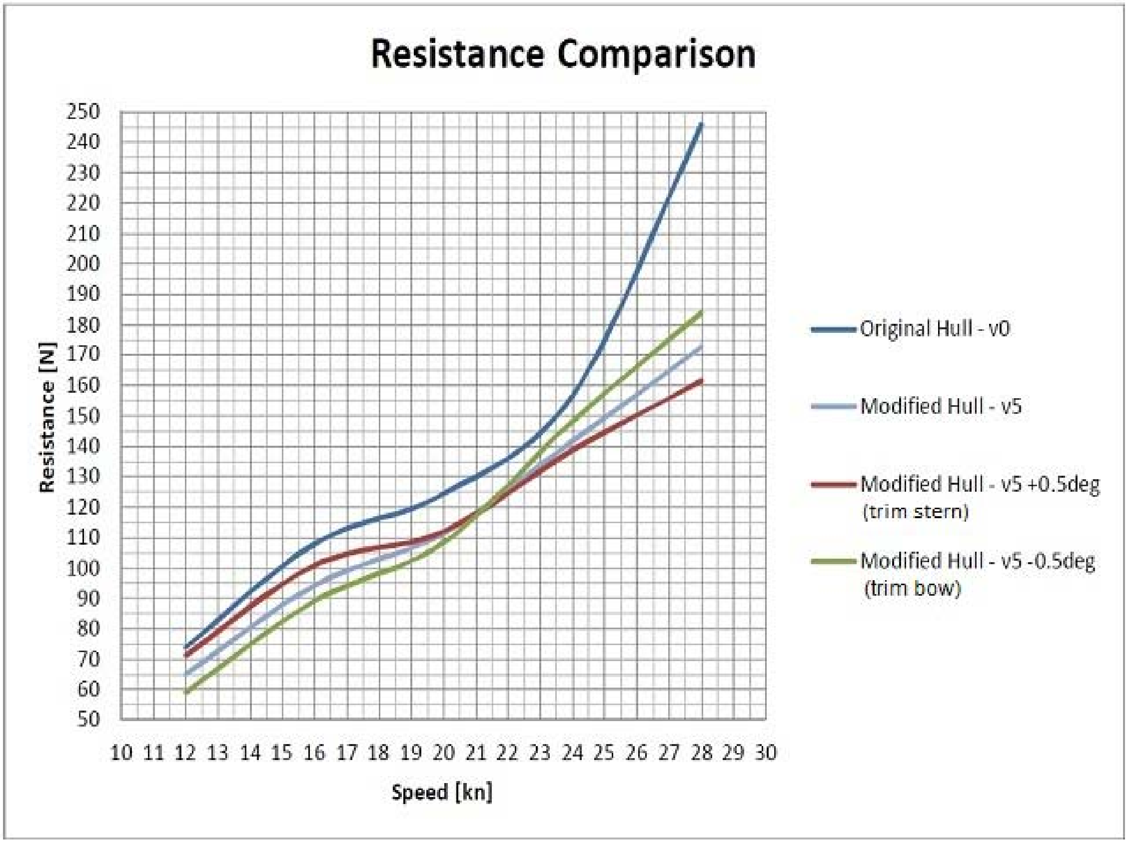

Figure 3. Variations in trim, 2015.

"Original Hull - v0" comes from tests conducted in Towing Tank INSEAN CNR in Rome in 2010.
"Modified Hull - v5" it is a modification done in CFD (test in Italy by NavalHead).
"Modified Hull - v5 + 0.5 degrees (trim stern)", "Modified Hull - v5 - 0.5 degrees (trim bow)". This is CFD simulations starting from different trims of the hull.
It was also performed with excellent results, a simulation at high speed up to a Fn of 1.38. (Figures 4).

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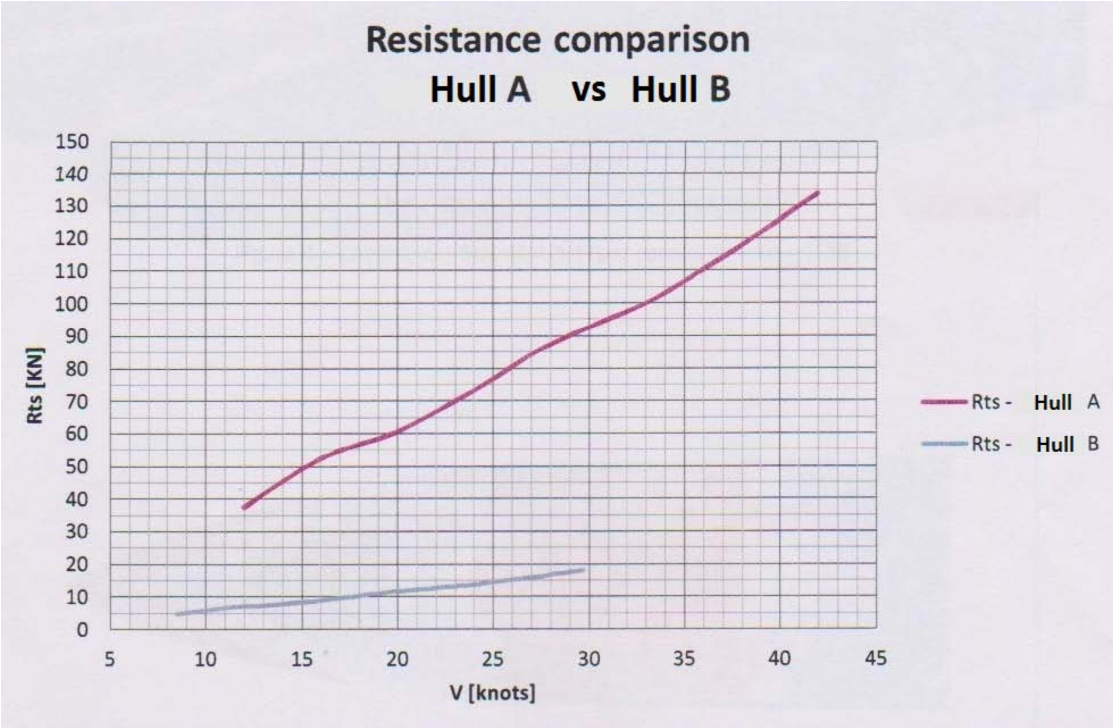

Figure 4. Resistance curve C.F.D., 2015: Comparison Resistance at different speed between Hull A length 24 meters and Hull B length 12 meters.

Figure 5. Self-propelled model hull navigating on Bolsena Lake (speed 22-24 knots)

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4. RESULTS

The hull patented Monotricat®, was then tested at leading research institutes and university Italian and foreign, to verify its peculiarity of being a displacement hull that navigates at speeds typical for planing hulls, thanks to the reduction of the viscous resistance between the water and the bottom of the hull which is obtained by exploiting the foam associated with the wave formation engendered from the bow and conveying it below the hull breaking the boundary layer on part of the surface of the hull with the result of significantly reduce the frictional resistance. For this reason it is comparable to a hull ASV without the need to "pump" air under it.
All experiments performed in Towing Tank have embraced a speed range up to a Fn equal to 1, while the so-called resistance curve results to be almost a straight line. Has been found in tests that actually the kinetic energy of the bow wave captured under the hull is transformed into pressure energy, causing the lifting of the aft section which is compensated with the hydrodynamic lift the bow of the hull allowing to maintain a trim that varies between 1 and a maximum of about 2 degrees, thanks to these forces which support the hull, whereby the hull Monotricat was also found to be not very sensitive to the displacement of the load. (mono-stab).
A demonstration of the distribution of the "spray" we present photos taken in Towing Tank INSEAN CNR of Rome showing their distribution at different speed (Figures 6, 7).

Figure 6. Spray hull Test towing Δ 70t - speed 18 knots, Towing Tank INSEAN CNR Rome, 2010.

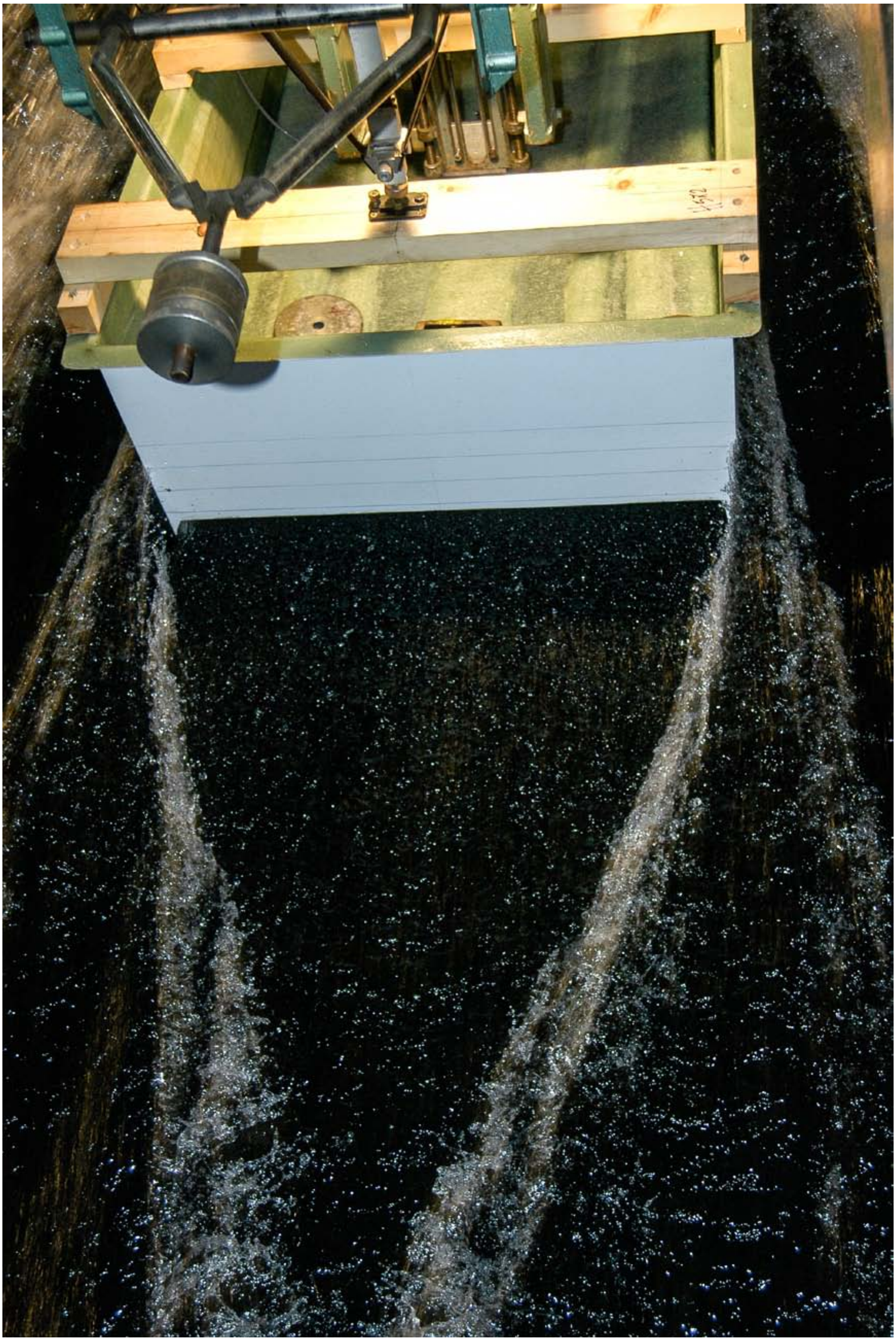

Figure 7. Spray hull Test towing Δ 70t - speed 24 knots, Towing Tank INSEAN CNR Rome, 2010.

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The summation of these prerogatives Hull Monotricat make a hull suitable to navigate with unusual efficiency at all operating speeds that are required; Also important the little influence the movements of the provision of cargoes on board, such that one can define a hull "mono-stab".
These experiences demonstrated that the hull Monotricat while navigating in displacement, is able to reach speeds typical of planing boats, while the so-called resistance curve is actually represents as a straight line.
Prof. Igor Zotti Director of the Department of Naval Engineering, University of Trieste, having been tested hull Monotricat in Towing Tank in Trieste, has counted it among the modern fast hulls mentioning it in the report to Congress Sea-Med of Messina in 2012. (Agrusta, Zotti, 2012).

Table 1. Geometric characteristics of the tested hull Monotricat

MONOTRICAT Hull				Displacement: 70t	
$L_{OS}/\nabla^{1/3}$	5.59	L_{OS}/B_{WL}	3.14	C_B	0.227
$B_{WL}/\nabla^{1/3}$	1.78	B_{WL}/T_M	4.02	C_P	--
$T_M/\nabla^{1/3}$	0.443	$S_S/\nabla^{2/3}$	9.78	C_M	--

Figure 8. Monotricat hull shape

5. CONCLUSIONS

The new architecture of the naval hull Monotricat encloses in a single hull the fundamental characteristics that have always required a great naval unit, namely:
- Ability to navigate in a wide speed range (from displacement speed to planing speed);
- Poor sensitivity to the displacement of the load;
- Security: as it results to be much wider than the traditional hulls, thus able to offer a "platform stability";
- Comfort navigation: the bow thin can be define a hull Wave Piercing;
- Cost management: the Towing Tank tests have shown that just a power of 1600 Cv to reach a speed of 20 knots for a vessel of 24 meters and displacement of 70 tons; or a power of 1,450 Cv for a displacement of 60 tonnes
- Regularity of movements: the bow wave-piercing and an unusual width allow deal more easily weather conditions adverse sea, unlike equal naval units.

ISBN 978-88-940557-1-9

ACKNOWLEDGMENTS

I thank the Association ATENA Associazione Italiana Tecnica Navale, especially in the persons of National President Dr. Bruno Della Loggia, President of the Roman Section Massimo De Domenico and Honorary President Adm. Albert Gauzolino.
I also thank Prof. Igor Zotti Director of the Naval Department of the University of Trieste and Andrea Agrusta of the University of Trieste.
I thank finally Dr. Lilit Axner SNIC Centers Coordinator PRACE Infrastructure Researcher Project manager at PDC of Stockholm University and Eng. Jing Gong of Stockholm University.
The work CFD OpenFoam in Swedish e-Science Center (SeRC) KTH Royal Institute of Technology - Stockholm (Sweden) was financially supported by the PRACE project funded in part by the EUs 7th Framework Programme (FP7/2007-2013) under grant agreement no. RI-312763.

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ISBN 978-88-940557-1-9