Automatic Optimization Computational Method for Unconventional S.W.A.T.H. Ships Resistance

Stefano Brizzolara and Giuliano Vernengo

***Abstract*—**The paper illustrates the main theoretical and computational aspects of an automatic computer based procedure for the parametric shape optimization of a particular unconventional hull typology: that for a catamaran S.W.A.T.H. ship. The goal of the integrated computational procedure is to find the best shape of the submerged hulls of a new U.S.V. (Unmanned Surface Vehicle) S.W.A.T.H. (Small Waterplane Area Twin Hull) vessel, in terms of minimum wave pattern resistance.

After dealing with the theoretical aspects the papers presents the numerical aspects of the main software module of the automatic procedure, which integrates a parametric generation routine for innovative and unconventional S.W.A.T.H. (Small Waterplane Area Twin Hull) vessel geometry, a multi-objective, globally convergent and constrained, optimization algorithm and a Computational Fluid Dynamic (C.F.D.) solver. The integrated process is able to find the best shape of the submerged hull of the vessel, subject to the total displaced volume constraint. The hydrodynamic computation is carried out by means of a free surface potential flow method and it is addressed to find the value of wave resistance of each hull variant. Results of the application of the described computational procedure are presented for two optimization cases and the obtained best shapes are compared with a conventional one, featuring a typical torpedo-shaped body, proving the effectiveness of the method in reducing the resistance by a considerable extent, in the order of 40 percent.

***Keywords*—**S.W.A.T.H., B.E.M., Wave Resistance, Parametric Modeling, Optimization, Genetic Algorithms

I. Introduction

Computer Assisted Optimization has become a very interesting numerical engineering discipline which allows to explore and obtain innovative solutions in many different fields of application [1] [2]. Its implementation in naval architecture (i.e. the design discipline that study the shape of a ship hull with respect to stability, strength, resistance and propulsion) becomes very effective especially when it is coupled with a parametric approach for the mathematical definition of the hull surfaces, in order to control their shape with a limited number of variables.

Naval architects, by tradition, are used to optimize ship hull forms by mean of model tests in towing tank, on scaled geosym models. Nowadays the model scale experiments can be substituted by modern Computational Fluid Dynamic (C.F.D.) codes that are able to solve with a good accuracy [3] the turbulent viscous flow around a hull advancing at a given speed in calm water. Numerical models can considerably speed up the optimization time, but the mode of selecting the variation of the hull form is still based on a trial and error scheme, highly reliant on an expert evaluation and interpretation of C.F.D. results, which does not facilitate the convergence on the optimal solution.

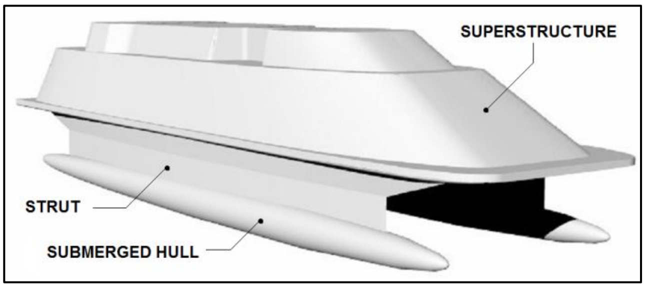

Fig. 1: Main elements of a standard S.W.A.T.H. vessel

Small Waterplane Area Twin Hull (S.W.A.T.H.) ships are a special concept of hull typology and configuration (see Fig. 1) featuring two or more slender struts that are actually piercing the free surface, while the major part of the displaced volume is concentrated well below the free surface in torpedo-like underwater bodies. The major advantage of this hull typology is its superior seakeeping ability. Another benefit of this type of vessel is a high deck area compared to their displacement. A typical drawback, though, is the higher resistance in calm water with respect to equivalent mono-hulls or catamarans.

The work presented in this paper is part of a project in collaboration with N.U.R.C. (N.A.T.O. Undersea Research Center, in La Spezia), whose aim has been to design a new small size (about 6m long) Unmanned Surface Vehicle (U.S.V.) with extended operability in rough sea conditions with respect to the existing solutions. For all the above, S.W.A.T.H. type of hull was considered as the best solution, but in order reduce the typical high powering requirement at relatively high speed, a dedicated optimization study of the underwater hull form has been performed.

To this scope an integrated, computer assisted, optimization procedure has been implemented, interfacing together a state of the art optimization algorithm, a 3D B-surface parametric geometry modeler and a free surface potential flow C.F.D. solver.

The idea derives from a previous successful attempt [4] of integrated hydrodynamic optimization of S.W.A.T.H. hull forms, that used a fully analytical description of the hull surface, a differential evolution algorithm and the same C.F.D. solver. This new study has introduced and experimented a more general multi-objective and

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S. Brizzolara is with the University of Genova, responsible of the Marine C.F.D. Group, via Montallegro, 1, 16145 Genova. Italy. (phone: +39-010-353.2386; fax: +39-010-353.2127; e-mail: Stefano.Brizzolara@unige.it).

G.Vernengo, is with the University of Genova, PhD Student of the Marine C.F.D. Group via Montallegro, 1, 16145 Genova. Italy. (phone: +39-010-353.2435; e-mail: Giuliano.Vernengo@dinav.unige.it).

constrained optimization algorithm and a new parametric B-surfaces definition of the hull geometry.

Each element of the optimization procedure will be better described in the next section.

II. Problem Formulation: Set-up of the Optimization Chain

This section would be described the definition of the problem. In order to give more clearness three different formulations will be showed: first of all, how the parametric model works and what are form parameters by which modify the shape of the hull; then a description of what method has been used to evaluate hydrodynamics performances of the vessel; finally, a brief explanation of the optimization algorithm and a more detailed description of the complete procedure.

A. *Parametric model*

The parametric model has been created in a dedicated environment using the software Friendship-Framework: its valuable feature concerns with the possibility to have a connection between some user-defined parameters and the mathematical description of surfaces as [4],[5],[6].

The basic design activity brought to the definition of two longitudinally separated and outward canted struts for each submerged hull, as in the example represented Fig. 4.

Because of the symmetry of the geometry, only a half of the entire S.W.A.T.H. has been modeled, also in the C.F.D. code, assigning proper boundary conditions on the symmetry plane. Moreover, because the purpose of this work is to optimize the shape with respect to hydrodynamics performance, only the model of the submerged hull and its struts have been defined, without modeling the deck and other elements of the deadworks or the hull appendages.

In this respect, the submerged part of the hull has been generated as an ellipsoid defined by two geometrically similar (with a scaling factor) B-Spline curves which represents its profile shape in the horizontal and vertical meridian planes, as in the example of Fig. 2. Each coordinate of the five internal control points (out of 7 used to actually define the B-spline) of the basic B-spline curve is a free form parameter which will be changed during the evolution of the optimization process.

Fig. 2 shows the layout of the control points: the first and the last one defines the maximum length of the hull; the second and the sixth can move only in vertical direction, to regulate the curvature radius at leading and trailing edge of the curve, respectively; the remaining inner three points are responsible for the unconventional shape variation, with an intermediate hollow and two humps.

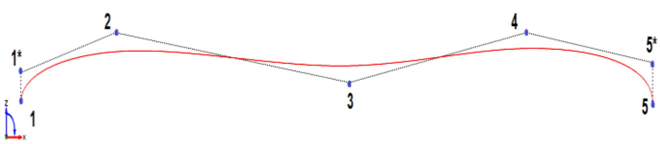

Fig. 2: Control points of the B-Spline curve type used for the horizontal and vertical profiles of the S.W.A.T.H. underwater body

The struts, instead, are defined as a wing surface, on the basis of a 2D transverse section defined, as for airfoils, with the entrance and exit angles, the value of the maximum camber and its relative position along the chord, as in the schematic drawing of Fig. 3. This is the set of free form parameters assumed for the struts shape modifications.

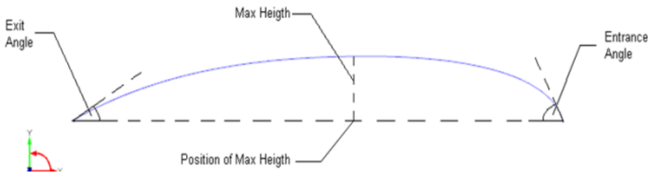

Fig. 3: Profile parameters for strut sections

Fig. 4 shows the final hull obtained by intersecting the struts with the underwater body: the generation and intersection in 3D is performed for each alternative shape that the optimization algorithm explore, which corresponds to a given set of the above defined free form parameters.

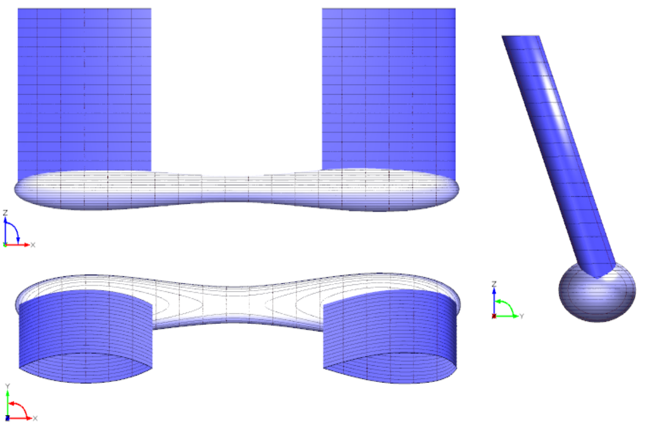
Fig. 4: Orthogonal views of the parametric model of the S.W.A.T.H.

B. *Optimization procedure*

As a main difference from the first cited cases of S.W.A.T.H. hull optimization, a different algorithm has been used to drive the optimization process, instead of the previously used differential evolution algorithm, also used with success by other authors in different applications [11] [12]. The new optimization strategy features a N.S.G.A.-II algorithm, first proposed by Deb K. [13]; this algorithm is based on different level of classification: before the selection phase, the population is distinguished, following the principle of non-dominance, several times in order to create sub-groups which would be useful for the evolution strategy. As well as common genetic operators, N.S.G.A.-II make use of some techniques like niching by which a parameter, called crowding distance, is assigned to each member to drive the exploration of the free variables space.

The optimization algorithm lead the process showed, as a high level flowchart, in Fig. 5. It is possible to sub-divide it in five steps:

1. Selection of the value of input parameters
2. Creation of the parametric model
3. Check of volume constrain
4. Wave resistance computation (evaluation of the objective function)
5. Evaluation of the objective function

A particular choice has been done on how to handle the problem constraints: since each evaluation of the cost function requires about four minutes, in order to reduce computational time, once the geometry of the has been generated, hydrostatic calculations are performed and the volume of the underwater part of the vessel is determined; the check of its given value is done at this stage: if the deviation from the expected value is out of a small tolerance, the computational process is stopped and the design alternative is discarded as unfeasible; otherwise if the given displacement is respected, the hydrodynamic computation is continued and the objective function is evaluated. This could affect in some way the converge capability of the algorithm, because will create unfeasible areas in the free variable space, although no particular problems have been manifested, as will be clear from in the next section.

In the presented example, it was decided to use eight free parameters, and hence an initial population of one hundred individuals, whose free parameters vectors were initially generated by means of a Sobol algorithm: this allow a random distribution in the first generation, while ensuring a quite uniform distribution of them over the design space and hence a good basis for the successive exploration.

C. BEM method for hydrodynamics analysis

In the following we present the basic theoretical details of the boundary element method used to solve the potential flow with free surface around the hull and predict the free wave pattern formation, and eventually estimate the wave resistance, which is the most variable and unknown component of resistance at relatively high speeds, as the design speed assumed in this study, corresponding to a Froude number Fn=0,66.

An incompressible irrotational potential flow is assumed by enforcement of the Laplace equation to the total velocity potential in the fluid domain bounded by the hull surface SB and the free surface. An indirect boundary element method, linearized with respect to the double model flow as developed in [8] is used as further adapted and successfully validated in the case of high speed mono- and multi- hull vessels [3], including the prediction of the dynamic attitude [8].

In a Cartesian reference frame travelling with the ship at U_∞ constant speed is centered at an arbitrary point on the intersection of the longitudinal symmetry plane with the undisturbed free surface (z axis oriented upwards), the total velocity potential can be written as

$$\Phi = U_\infty x + \phi \tag{1}$$

where ϕ is the perturbation potential with respect to the uniform incident flow. Both velocity potential functions must satisfy the Laplace equation in the whole domain:

$$\Delta\Phi = 0 \ , \ \ \Delta\phi = 0 \tag{2}$$

together with the following boundary conditions:

$$\vec{n}\cdot\nabla\Phi = 0 \qquad \text{on the hulls} \tag{3}$$

$$\nabla\Phi\cdot\nabla\zeta = 0 \qquad \text{on the free surface} \tag{4}$$

$$g\zeta + \frac{1}{2}\nabla\Phi\cdot\nabla\Phi = \frac{1}{2}U_\infty^2 \qquad \text{on the free surface} \tag{5}$$

$$\Phi \to U_\infty x \ , \ \phi \to 0 \quad \text{for} \quad x \to -\infty \tag{6}$$

namely, the Neumann condition on hulls surfaces (3), the kinematic and dynamic condition on the free surface (4) and (5) and the radiation condition for the disturbance upstream (6); $z=\zeta(x,y)$ represents the explicit unknown equation the define the shape of the wavy free surface.

In our method the free surface boundary conditions (4) and (5) are linearized using a small perturbation theory, by which the total velocity potential Φ is considered as the sum of a main contribution represented by the potential ΦD of the flow around a double model symmetrical with respect to the undisturbed free surface, considered as deeply immersed in the fluid, and the contribution of the new perturbation potential, due to presence of the wavy free surface.

The double model and the linear free surface potential flow problems are both numerically solved by a boundary element method which is based on the discretization of the boundary surface , namely the hull surface (SH) and the undisturbed free surface (SF), with a structured set of quadrilateral planar panels each having constant distribution of Rankine sources on it.

Defining the influence coefficient vector as the velocity vector induced at the centroid of panel i by a panel j having a uniform distribution of sources with constant strength σj:

$$\int_{quad\,j} \nabla\left(\frac{1}{r_{ij}}\right) dS_j \equiv (X_{ij}, Y_{ij}, Z_{ij}) \tag{7}$$

we discretized the boundary conditions (4) and (5), imposing them on each panel centroid taking into account for the contribution of any panel on the hull (NH in number) and on the free surface (NF in number). As a result after mathematical manipulation of the discretized boundary conditions written in terms of the double model and perturbation potential, the following linear system of equations, in the unknown sources intensities, is obtained:

$$\sum_{j=1}^{N_H+N_F} X_{ij}n_{xi} + Y_{ij}n_{yi} + Z_{ij}n_{zi} = Ux \qquad i = 1, N_H \tag{8}$$

$$\begin{aligned}
&\sum_{j=1}^{N_H+N_F}[2a_i X_{ij} + 2b_i Y_{ij} + (\frac{\partial\Phi_D}{\partial x})_i^2 \frac{\partial X_{ij}}{\partial x} + \\
&+ (\frac{\partial\Phi_D}{\partial y})_i^2 \frac{\partial Y_{ij}}{\partial y} + 2(\frac{\partial\Phi_D}{\partial x})(\frac{\partial\Phi_D}{\partial x})\frac{\partial Y_{ij}}{\partial x}]\sigma_j + \\
&+ 2\pi g\sigma_i = 2a_i(\frac{\partial\Phi_D}{\partial x} - U_\infty) + 2b_i \frac{\partial\Phi_D}{\partial y} \qquad i = 1, NF
\end{aligned} \tag{9}$$

To compute the derivatives of the potential, a four points differential operator is used, everywhere on the free surface in both longitudinal and transversal directions. As known this operator gives an implicit property of numerical damping of the disturbance which is used to numerically enforced the radiation condition (6). The free surface waves are found by substituting the total velocities calculated over the free surface panels in the linearized Bernoulli condition (5).

The wave resistance is found, in this study, by the integration of the dynamic pressure calculated on each panel. Other studies [3] used a (numerical) transverse cut method, to calculate the wave resistance from the energy content of the generated wave pattern. No attempt were made in this study to use this second method that requires a preliminary sensitivity study to identify the proper location of the transverse cut. The S.W.A.T.H. hull attitude was kept fixed in the computations of this study corresponding to static one, assuming that the ride control system, with active fins, would maintain this attitude at the design speed. Moreover it is believed that the influence of the stabilizer fins on the resistance might be of secondary effect, and hence neglected.

D. Validation of the C.F.D. method

The inviscid method outlined in previous section, has been applied in the case of a S.W.A.T.H. like mono-hull which was tested in towing tank for the validation study of C.F.D. methods on similar hulls. In order to compare the total resistance which follow from towing tank tests, it has been coupled with a thin boundary layer solver, which hasn't been used in the present study. The test case is a mono-hull of the S.W.A.T.H. type having elliptic cross sections and a symmetric strut having a circular arc section. The horizontal and longitudinal profiles of the hull are represented in Fig. 5, while the main characteristics of the model are reported in Table 1.

Table 1: Main Characteristics of the S.W.A.T.H. demi-hull model tested in towing tank for validation of C.F.D. methods

L_{OS} [m]	B_{max} [m]	H_{max} [m]	T [m]	S [m^2]	∇ [m^3]
Underwater Hull					
3.625	0.463	0.350	0.475	3.06	0.258
Strut					
1.72	0.12	0.125	-	0.542	0.021

Free surface inviscid calculations were performed in the complete range of Fn tested and the thin boundary layer, based on the inviscid pressure distribution, was calculated for the corresponding Reynolds number in model scale. A number of about 700 panels was used with about 30 streamlines to describe the (half of the) body. The free surface was discretized with about 3000-4000 panels depending on the Froude number, for an extension of about 3 hull length by one hull length aside.

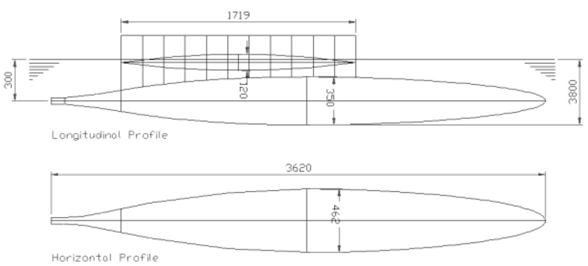

Fig. 5: Longitudinal and horizontal profile of the S.W.A.T.H. demi-hull model tested in towing tank for resistance measurements.

Bare hull resistance tests were conducted without the use of any turbulence stimulator, so also in the numerical calculations the natural transition criteria of Granville was used.

Fig. 6 presents the comparison between the numerically predicted and experimentally measured total resistance. Evidently, the agreement is excellent in the whole speed range, also near the peak due to wave resistance; poorer, on the contrary, for Fn<0.28, where probably the interactions between viscous-inviscid flows are more pronounced and highly non linear (large separated regions also in the laminar flow). Probably in this regime, direct viscous-inviscid interaction method, with a proper description of the separated flow regions and those with laminar bubbles, would lead to better correlations.

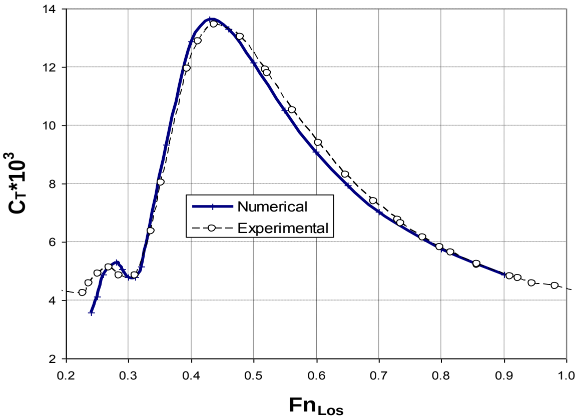

Fig. 6: Comparison of predicted and measured total resistrance for the test S.W.A.T.H. demihull

Anyhow, the thin boundary layer method used did not predict any flow separation up to the body truncated end, so frictional resistance were the only component of viscous resistance. The numerical frictional resistance coefficient is compared in Fig. 7 with the reference value obtained for the whole body using the correlation curves of the turbulent flat plate of Schoenherr and of the I.T.T.C.'57.

These reference curves are named 'composed' since the total friction resistance coefficient is obtained by summation of the two partial coefficients of the strut and of the hull, each at its characteristic (length) Reynolds number, and weighted by the correspond-ding wetted surface, i.e.:

$$C_F^{TOT} = C_F\left(Rn_{L_{STRUT}}\right)\frac{S^{STRUT}}{S^{TOT}} + C_F\left(Rn_{L_{HULL}}\right)\frac{S^{HULL}}{S^{TOT}} \qquad (26)$$

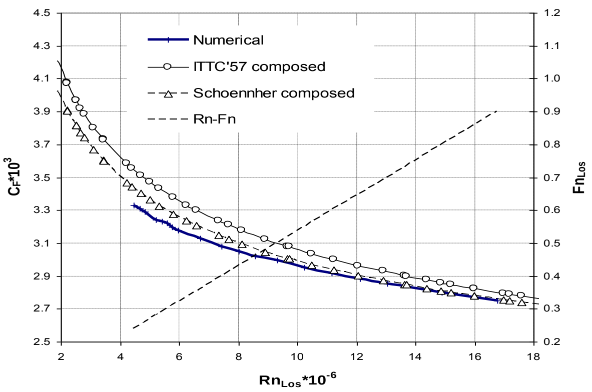

Fig. 7: Comparison of numerical total frictional resistance predicted for the test case at model scale Reynolds numbers, with total frictional resistance calculated on the basis of classical correlation curves.

For highest Reynolds number the numerical curve is practically identical to the turbulent flat plate curve of Schoenherr, while for *Rn* < 12*10e06, it results even lower, in spite of any form factor. In fact at these low Rn, a considerable portion of the hull and of the strut are interested by laminar flow, according to the transition criteria used. This large laminar portion of flow, clearly visible from Fig. 9 which presents the plot of the local friction coefficient at a typical model scale Rn, is also due to the very fine entrance body of the underwater hull. Laminar flow region on the streamlines extend up to the magenta color.

When numerical calculations for the full scale Reynolds number (100:1200*10e06) are compared (Fig. 8), then a certain form factor re-appears in the numerical calculations with respect to considered friction lines. In this respect the results obtained for full scale were judge realistic, keeping in mind that the scope of the optimization, for our optimization scope, has a comparative more than absolute meaning.

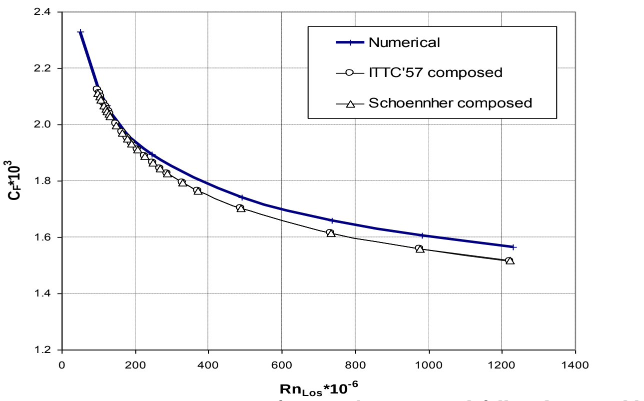

Fig. 8: Same comparison as in figure 6, but at typical full scale Reynolds numbers.

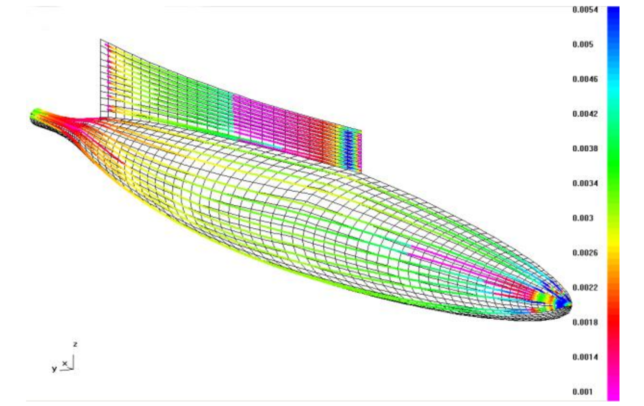

Fig. 9: Plot of streamlines coloured in relation to the local friction coefficient (colour scale on the right); one of the lowest model scale numbers RnLos=4.84·106.

E. Setup configuration for wave resistance computation

As mentioned in the previous section, the BEM works on a discretized mesh, constructed with quadrilateral elements, both on the hull body and the free surface; hence the choice of control parameters of this computational grid affects the quality of the analysis itself. Once this choice have been done, these parameters remain fixed during the whole optimization process: the reason is that otherwise there could be the undesirable possibility to confuse the optimization of hull shape with the one of the panel mesh parameters.

In order to have an excellent fitting between the hull surface modeled inside the C.A.D. software and the discretized one for the computation, it has been divided into 9 different zones, as shown in Fig. 10: one for each side of the two struts and five for the submerged body.

As regards free surface it has been divided in two zones, as shown in Fig. 11: the first one from the symmetry plane to the waterline of the hull and the other one from the end of the first to the end of the computational domain.

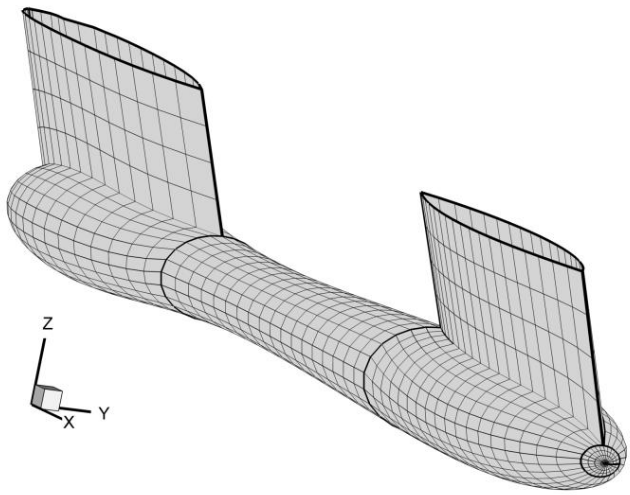

Fig.10: Panel mesh used for the hull (1824 quadrilaterals)

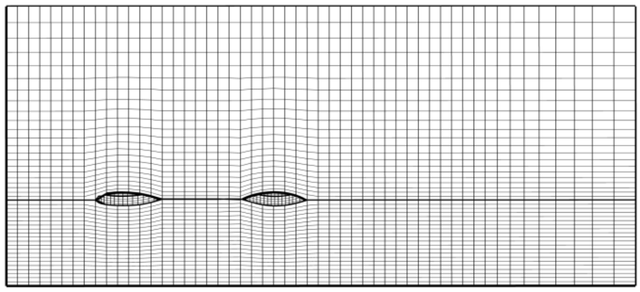

Fig.11: Panel mesh used for free surface (2236 quadrilaterals)

It have been used 4000 total panels for the computation: 1824 have been shared over the hull while 2236 over the free surface.

III. PROBLEM SOLUTION: OPTIMIZATION RESULTS

As previously mentioned the aim of the presented optimization procedure is to reduce the numerically predicted wave resistance for the S.W.A.T.H. hull, at the given Froude number of 0.6, with a constraint on the design displacement volume. Several run of this process have been carried out with the purpose of a careful exploration of the design space. In particular, two optimization cases are presented. They differ from three main items: the amplitude of the range assigned to the free variables; the number of free variables, which in the first case is limited to the six coordinates of the inner B-spline control points defining the underwater body geometry, while in the second case also the two other points controlling the leading edge and trailing edge radii are released; finally, on the set up of the genetic algorithm, whose governing parameters are listed in Table 2.

Table 3, instead, shows the selected ranges of variation for the free form parameters for both optimization cases: the value of the x-coordinate is expressed in percentage of the length of the submerged hull, while the z-coordinate is given in percentage of the reference (initial) height; coordinates indexes 1 to 3 are indicative of the inner control points, while Z_LE and Z_TE are the two parameters which are used to control curvature radii. It is to notice that the shape of both struts was kept unvaried in the presented cases, due to their delicate influence on the metacentric height of the vessel. In fact their area and position are directly proportional to the inertial of the waterline and hence directly related to the metacentric height.

Table 1: Parameters of N.S.G.A.-II

	1st Run	2nd Run
Crossover probability	0.7	0.9
Mutation probability	0.8	1.0

A minimum initial metacentric height is, in fact, necessary in order to grant an adequate static stability to the vessel and maintain lower values of the transversal and longitudinal angles of static equilibrium under an external inclining moment.

Particularly in the case of S.W.A.T.H. vessel both the transversal and longitudinal type of inclinations are to be considered and verified, on the contrary to a conventional hull in which the longitudinal inclination can be neglected. The geometry of the struts, then, was decided and fixed in the preliminary design phase [10] in order to grant sufficient static stability to the vessel.

Fig. 12 and Fig. 13 present the history of the objective function calculated for each design individual during the optimization procedure: on the y-axis of the graph the scale is for the non-dimensional wave resistance coefficient, CW; on the x-axis the integer scale refers to the I.D. (Identification Design) progressive number of each alternative design evaluated during the evolution (only successful or feasible designs are plotted).

Table 2: Ranges of variation of free variables

Free parameter	1st Run		2nd Run	
	Lower	Upper	Lower	Upper
X_1	0.05	0.3	0.03	0.5
X_2	0.3	0.65	0.3	0.7
X_3	0.6	0.95	0.5	0.975
Z_L.E.	0.3	0.3	0.2	0.4
Z_1	0.5	0.9	0.4	0.11
Z_2	0.11	0.4	0.11	1.1
Z_3	0.5	0.95	0.3	1.1
Z_T.E.	0.4	0.4	0.3	0.5

As it may be noticed from these graphs, a good convergence is reached in both cases after about one thousand calculation cases (unfeasible individuals excluded).

Special care has to be paid on the selection of valid points: in fact, as particularly evident from Fig. 12, there are few dozen of points which fall well below the mean trend line traced by the others: these points correspond to fake calculations, in which the C.F.D. solver has predicted an unrealistically low value of the objective function, generally due to a mis-generated panel mesh discretization of the hull geometry. The check of these miscalculated points and their related exclusion from the procedure have not yet been implemented in the integrated procedure.

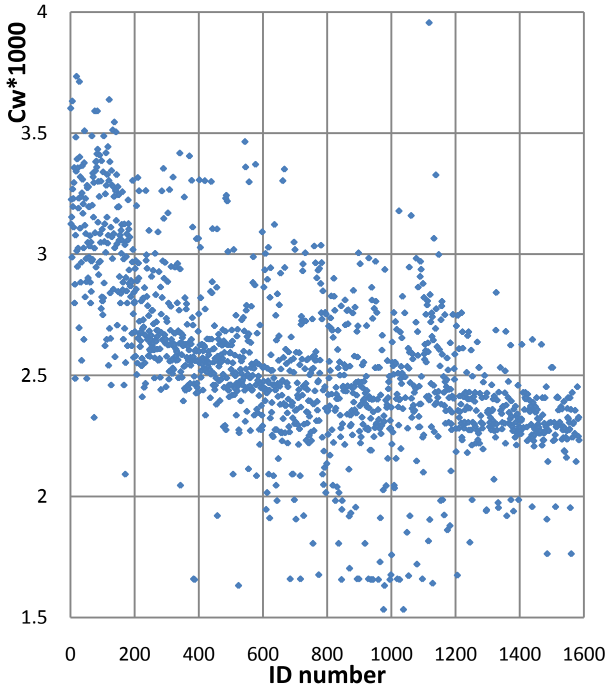

Fig. 12: Optimization history – 1st Run

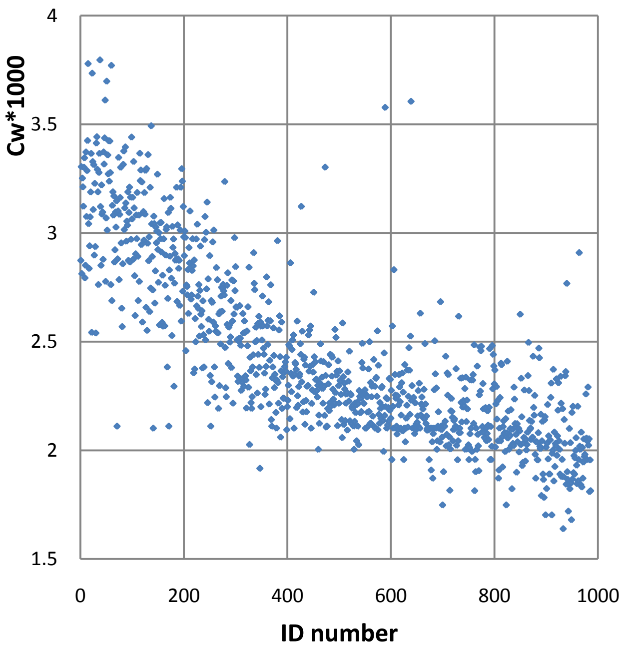

Fig. 13: Optimization history - 2nd Run

The second optimization case was able to reach lower values of the objective function: this is primarily due to the wider bounds assigned to the free parameters and, to a lesser extent, to the addition of the two additional parameters which control the curvature radii at the leading and trailing edge of the underwater body; indeed, at the beginning of the evolution of the second run, the optimization algorithm seems to follow a steeper gradient during the convergence on the minimum value of the objective function for the first few hundreds of I.D. cases.

The panel method used to solve the potential free surface flow around the hulls and calculate the wave resistance, is also solving the free wave pattern generated by the hull advancing at the given speed. Following the simplistic concept that to a higher deformations corresponds a higher energy content and hence a higher wave resistance, the predicted wavy free surface elevation can be compared from one case to another. With this simple criteria often used by designers in trial and error procedures it is possible to visually guess which solution could be better than others on the basis of the free wave pattern colored contours as those presented in Fig. 15 to Fig.17. Differences in the generated wave pattern by two different hull shapes, at a given speed, are justified by the interference effects that each wave train generated along the hull has with the other.

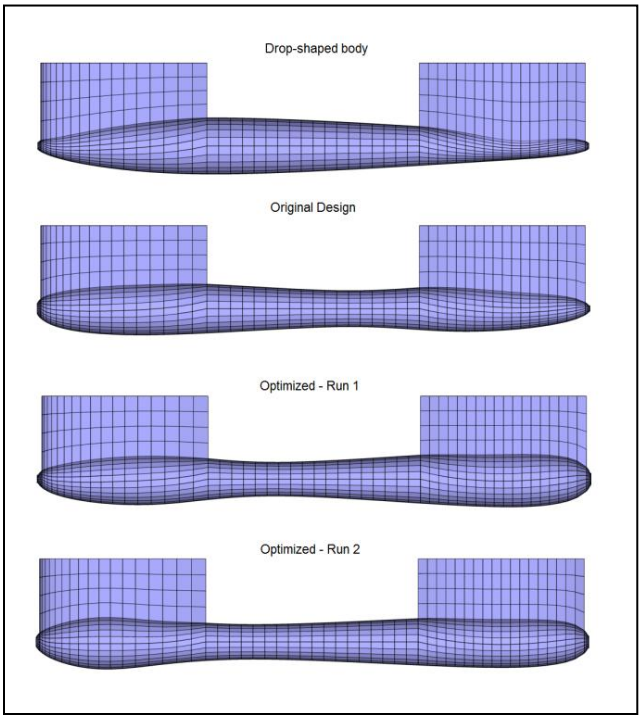

Fig. 14: Panel mesh of the four compared hulls

In order to realize the effectiveness of the optimization procedure, both initial (first point created by Sobol D.o.E.) and optimized hull variants are compared against a conventional (drop-shaped) underwater hull form, whose profile resembles the shape of a N.A.C.A. four digits symmetric airfoil, with maximum thickness at about 30% of chord length from the leading edge. Fig. 14 presents the 3D panel mesh generated for the compared hull shapes. Their wave patterns are compared from Fig. 15 to Fig. 17. Table 4 resumes the main features of the four design alternatives.

The qualitative comparison of wave pattern with the previously mentioned criteria also confirm the optimum solutions.

By comparison of the 3D shapes of the optimum hulls it can be inferred that the optimization procedure tend to create unconventional shapes, with enhanced intermediate hollow, properly positioned, to increase the positive interference effect between crests and hollows of the generated wave trains, which is responsible of the computed lower resistance.

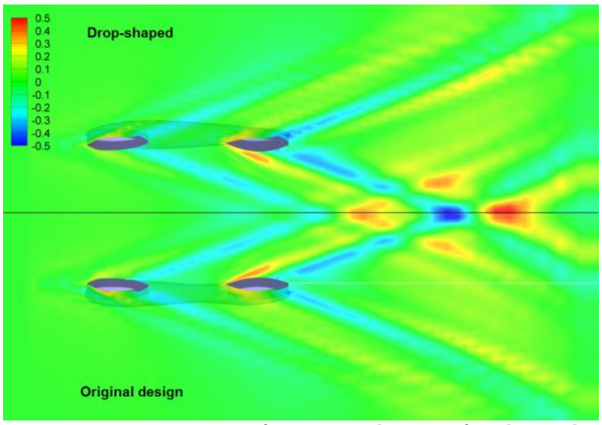

Fig. 15: Free Wave patterns of conventional (up) vs. first design alternative (bottom)

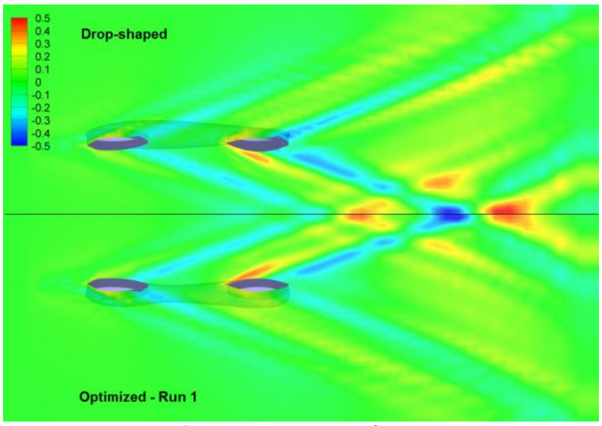

Fig. 16: Conventional (top) vs. Optimum of Run 1

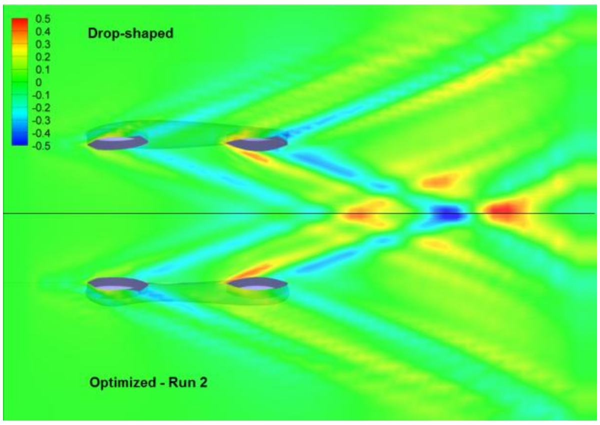

Fig. 17: Conventional (top) vs. Optimum of Run 2

Table 3: Features of optimum designs

Design	Run 1	Run 2	Initial	Conv.
X_1	0.053	0.0518	0.24	0.15
X_2	0.621	0.675	0.40	0.60
X_3	0.779	0.876	0.85	0.85
Z_L.E.	0.3	0.297	0.30	0.20
Z_1	0.862	0.746	0.65	0.30
Z_2	0.152	0.126	0.24	0.65
Z_3	0.745	0.838	0.74	0.60
Z_T.E.	0.4	0.399	0.40	0.20
Vol. [m^3]	4.288	4.049	4.080	4.268
Cw*10^3	***2.232***	***1.915***	***3.336***	***3.533***
ΔCw %	***- 36.8***	***- 45.8***	***- 5.6***	***0.0***

IV. Conclusions

A completely automatic, computer based, parametric optimization procedure by which is possible to find the best configuration of a S.W.A.T.H. hull form vessel has been described and applied in a practical case. Its effectiveness has been proved in different run cases: depending on which bounds the user impose to the variation of free parameters, this process has been able to automatically converge on optimum solution which can grant a considerable reduction of wave resistance: more than 45% reduction for the best case of run 2 with respect to a conventional shape. These values are in line, actually better, than those already found in a first attempt of optimization with a different procedure [4]. With respect to that initial case, present procedure is able to grant a robust and well defined convergence on the final global best solution.

From the analysis of the numerically predicted wave pattern it is verified the effect which causes this improvement is the favorable interference between the wave trains generated along the hull in correspondence of marked variation in shape.

It is known and has been demonstrated already by author [4] that viscous effect would be relevant in the optimization of the hull form, and in fact this will be the next step for future development of the new devised optimization procedure. The optimization for wave resistance only, though, has been proven to be effective also when the total resistance of the vessel is concerned as verified in [10] by comparison of R.A.N.S.E. predicted total resistance for the optimum and the original hull shapes.

Interesting and definitive results and indications will come from a new updated optimization chain which could include also viscous effect, for instance solved by means of a thin boundary layer solver, as proposed in [4].

References

[1] Zak B., Optimization of Control of Unmanned Underwater Vehicle in Collision Situation. 6th WSEAS Int. Conference on Computational Intelligence, Man-Machine Systems and Cybernetics, Tenerife, Spain, December 14-16, 2007.

[2] H. Wong ,S. Hsie, C. Wang, Optimizing Containership Size and Speed: Model Formulation and Implementation. WSEAS TRANSACTIONS on BUSINESS and ECONOMICS, Issue 7, Volume 4, July 2007. ISSN: 1109-9526

[3] Brizzolara S., Bruzzone D., Cassella P., Scamardella I., Zotti I., Wave Resistance and Wave Pattern for High Speed Crafts; Validation of Numerical Results by Model Tests, Proc. 22nd Symposium on Naval Hydrodynamics, Washington D.C., 1998, 69-83.

[4] Brizzolara S., Parametric Optimization of SWAT-Hull Forms by a Viscous-Inviscid Free Surface Method Driven by a Differential Evolution Algorithm, 25th Symposium on Naval Hydrodynamics, St. John's, Newfoundland, Canada, 2004, Vol V, pp. 47-64.

[5] Brizzolara S., Vernengo G., Biliotti I., et al., Automatic Parametric Hull Form Optimization of Fast Naval Vessels, 7th Int. Conf. on High Performance Marine Vessel, HIPER2010, Melbourne, Florida.

[6] Biliotti I., Vernengo G., Brizzolara S., Parametrization and Optimization of Round Bilge and Deep-V Frigate Hull Types for Resistance and Seakeeping, 1st Friendshhip European User Meeting and Conference, 2010 Potsdam, Germany.

[7] Vernengo G., Biliotti I., Brizzolara S., Viviani M., et al., Influence of Form Parameters Selection on the Hull Surface Shape Control for Hydrodynamic Design, Int.Conference on Ships and Shipping Research, NAV 2009, Messina, Italy.

[8] Bruzzone, D., Numerical Evaluation of the Steady Free Surface Waves, Proc. C.F.D. Workshop Tokyo, Ship Res. Inst. Tokyo, Vol.I, 1994, pp. 126-134.

[9] Brizzolara S., Bruzzone D. , Numerical Wave Resistance and Dynamic Trim for High Speed Crafts, Proc. NAV 2000 Int. Conf., Venice, Vol.I, 4.2.1-4.2.13.

[10] Brizzolara S., Curtin T., Bovio M., Vernengo G., Concept Design and Hydrodynamic Optimization of an Innovative S.W.A.T.H. USV by C.F.D. methods, to be published Ocean Dynamics Journal, Springer.

[11] S. Rahnamayan, G. G. Wang, Solving Large Scale Optimization Problems by Opposition-Based Differential Evolution (ODE), WSEAS TRANSACTIONS on COMPUTERS, Issue 10, Volume 7, October 2008. ISSN: 1109-2750.

[12] J. A. Ramırez-Ruız, L. M. Fernandez-Carrasco, M. Valenzuela-Rend´on, E. Uresti-Charre, A Simple, Non-Generational Genetic Algorithm based on Moving Averages for Multiobjective Optimization. Proceedings of the 10th WSEAS International Conference on EVOLUTIONARY COMPUTING, ISBN: 978-960-474-067-3

[13] Deb K. et Al., A fast and elitist multi-objective genetic algorithm: N.S.G.A.-II, Indian Institute of Technology, KanGAL Report No. 200001, Kampur, India.

Stefano Brizzolara is Aggregate Professor at the University of Genova, where he teaches computational hydrodynamics for ship design in the MSc course in naval architecture and in the MSc course of yacht design. As head of the Marine C.F.D. Group, he drives several research projects related to the intelligent integration of C.F.D. codes in the design of innovative hull forms for fast marine vehicles and propulsion systems. His previous experience includes senior hydrodynamic designer in Fincantieri Naval Business Unit and experimental research at the cavitation tunnel in Rome as officer of the Italian Navy.

Giuliano Vernengo is PhD student at the Department of Naval Architecture of the University of Genova (Italy) and works within the Marine C.F.D. Group. His work deals with numerical methods for parametric description of hull shapes and numerical optimization with respect to hydrodynamics performances.