,, Caius Iacob" **Conference on**
Fluid Mechanics&Technical Applications
Bucharest, Romania, November 2005

New Radial Crenellated-Corrugated Stern Sections (Tanasescu's Stern Shape) Obtained by Progressive Numerical Carving, coupled with an Inverse Problem for Optimizing the Expected Wake

by
Horatiu TANASESC [1]

Abstract

Present-day tendency in maritime transportation domain is represented by designing and building of bigger, faster and more energy-saving ships but at the same time having a required level for stern hull structure noise and vibration more stricter. A ship hull lines design shape, for reaching (obtaining) high hydrodynamic qualities imposes aiming towards following three main objectives: - to minimize forward resistance; - to improve propulsion performance; - to increase the global hydrodynamic stability. A fine wake distribution from an immediately upstream propeller parallel plane disk can leads to: increasing the propulsion efficiency (output), reducing the formation of propeller cavitation (having as an indirect consequence decreasing of noise and vibration level induced in the stern structure). Moreover, the global hull hydrodynamic stability improving by using of a special kind of stern having certain **architecture (more appropriate)**, can not but favourable. Evidently, the dynamics of a cavitating propeller depends on system environment in which it is operating: in this sense the flow field in the case of a propeller mounted behind of a ship hull is very different from that one in an open water test or in a section of a cavitation tunnel. Thus, a propeller that is very efficient in open water can not be suited for a certain kind of stern shape. Due to this reason the wake distribution in the propeller disk plane represents a key factor for designing of a ship hull surface. With a view to fulfilling of the desiderata mentioned above the authors of this project propose a new stern shape concept: with crenellated-corrugated sections (Tanasescu's stern shape). Using the stern shape new concept could imposed lead to improving of water particles axial velocities distribution in propeller disk with a view of a propitious dynamical coupling between propeller upstream flow and propeller through flow. Much more, a stern shape having crenellated-corrugated stern sections can combine the high speed with seakeeping upper characteristics. As supplementary background for justification of our new stern concept having crenellated-corrugated sections we may mention: - stream tube theory (the water particles axial velocities distribution at entrance in the propeller disk can be configured favourably – homogenized – by comprising the radial crenellated-corrugated stern sections in a stream tube that includes also the propeller disk), - Bernoulli effect (increasing of fluid (water) particles flow velocities of fluid (water) particles in the regions within which the fluid pressure is decreased).

[1] Univ. *DUNAREA DE JOS* of Galati
E-mail: `tanasescuhoratiu@yahoo.com`

1 CONDITION ON NATIONAL AND INTERNATIONAL SCALE AT DOMAIN LEVEL AND PAPER PROPOSED

Unfortunately, in Romania and even abroad the state of the art of the proposed theme is very feeble due to its huge complexity. The project represents an absolute novelty (innovation) in the naval domain (field). There are no significant results obtained at present. R&D units with concerns in this direction are especially in Japan, Netherlands, United States, Sweden, Italy, Spain, France, Germany, Great Britain, Russia, etc. The great majority of actual scientific papers in naval hydrodynamics are primarily dedicated to ship forward resistance and stability. Potential users can be all ship designers and builders.

2 OBJECTIVES

By reference to condition on national and international scale and in connection with actual state of paper domain and theme :
problems proposed to be solved
propulsion efficiency (output) improving(minimum energetic consumptions) ;
propeller cavitation reduction, level of noise and vibration induced in stern structure decreasing;
seakeeping global hydrodynamic stability increasing;
measurable objectives
velocity and pressure fields in stern-propeller region (LDV, PIV/PTV);
axial velocities in propeller disk distribution (wake maps);
Problems and objectives proposed to be solved will contribute to the top new knowledge accumulation in a very actual and complex scientific field, namely as contemporary naval hydrodynamic is.

3 SCIENTIFIC AND TECHNICAL PAPER DESCRIPTION

Always, but especially in contemporary conditions (circumstances) of apparition (emerging) of some modern stern shapes (more and more complex), improving propusion and stability performances represented and represent an important distinct problem for researchers from naval hydrodynamics field and not only. The cause of this remarkable interest is owed to the fact that a good distribution of the wake from an upstream plane, parallel with the propeller, can lead both to propulsion efficiency (output) increasing and propeller cavitation decreasing. In its turn propeller cavitation decreasing has as an extreme positive consequence noise and vibration level in stern structure reducing. Obtaining of a good wake distribution is an important objective of all naval architects. Moreover, hull global stability improving by using of a special kind of stern having certain architecture (more appropriate), can not be but favourable. Before apparition of powerfull modern digital computers, the ship designers pre-establish the hulls shapes, then perform tests on models, in experimental model basins, for wake characteristics examination. If the wake properties cannot meet the expectation, they then modify the hull form and perform another test, repeating the process until satisfactory results are

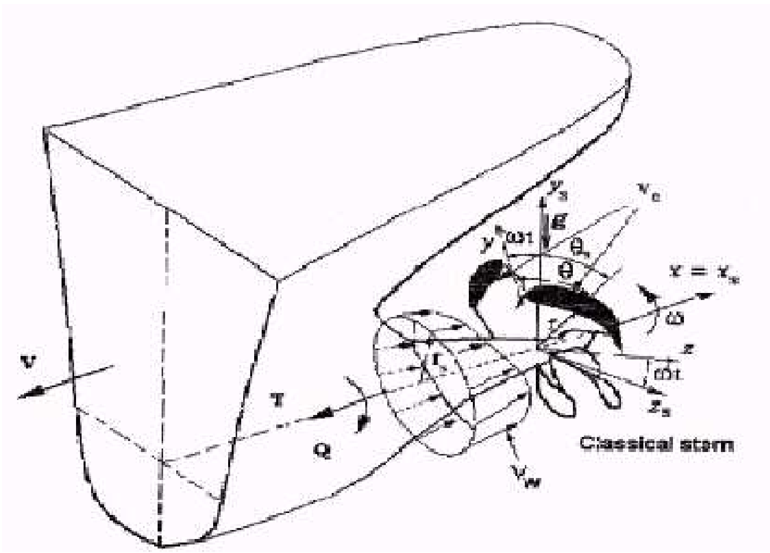

Figure 1: Classical stern

obtained. This methodology repeated cyclicly is a high time and cost consumer. As a consequence, in recent years theoretical models (physical-mathematical) and new numerical techniques were applied for in march performances study (forward resistance, required power at propeller blade) and attitude (global hydrodynamic stability) of hulls. Of course the final target (a little far-off) is represented by devising of some computational instruments able to simulate numerically, as precise as possible, both performances and dynamical attitude of full scale ships, in real working conditions. As a contribution in this direction the present paper is proposing the introduction of the direct and inverse problem, physical-mathematical modelling and numerical implementation (inclusive numerical treatment accuracy) of flow phenomena which can emerge in the case of hulls incuding a new stern shape concept having crenellated-corrugated sections (Tanasescu's stern shape).

In the case of naval propellers the fluctuating cavity volume (due to the interaction between wake generated by flow around ship hull and propeller) represents the most significant source for noise and vibration induced in stern structure.

Authors consider as an interesting idea building of a new mathematical model, one-dimensional flow tube, which includes the new stern effects (having practiced radial crenellated-corrugated stern sections – Tanasescu's stern shape) on (about) propeller. With this end in view, we propose imgining of a streamline tube, having cvasi-cylindrical increasing sections, which starts from front propeller disk and stretches until hull cylindrical region, including the whole stern region of a classical hull with practiced crenellated-corrugated stern sections.

Of course the dynamics of a cavitating propeller is dependent of environment system in which it works. The flow field around a propeller mounted behind a stern hull is very different of that which is developed when a propeller is tested in open water or a section of a cavitation tunnel. A propeller that is very performant in open water can not be suited for a given stern shape. Due to this reason wake distribution in a propeller disk plane represents a key factor for a ship design.

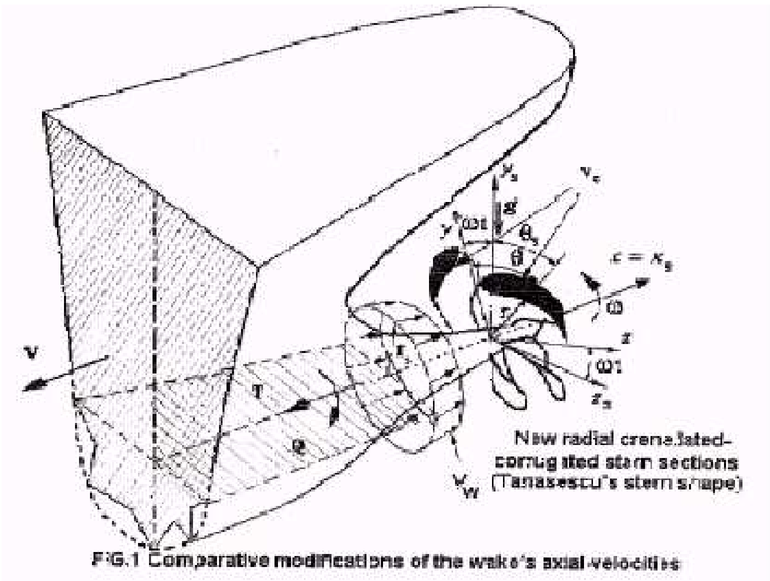

Figure 2: New oncept of stern shape

Taking into account the streamline tube theory and the Bernoulli effect, we can esteem (consider) that the 3D spectrum of flow generated around and outside of a classical stern hull having practiced transversal crenellated-corrugated stern sections can be substantially improved (modified, redistributed) by architectural optimization in the sense of axial velocities from a propulsion propeller immediate front plane uniformization (equalization) (see figs. 1 and 2). The number of crenellated-corrugated teeth and their heights will be optimized by direct numerical experiments. For each section the teeth step size (the distance between two consecutive crests or troughs) decreases on girth, from the centerline plane towards the boards. The maximum heights (amplitudes) of the crenellated-corrugated teeth will be progressively reached longitudinally in front of the propeller and transversally in the centerline plane, respectively. The directions of the crenellated-corrugated sections teeth crests and troughs longitudinal lines, which start immediately after the cylindrical zone, will be those of the stern natural streamlines (which can be established experimentally in a paint flow test) for vortices turning up avoiding and for a minimum forward resistance obtaining.

new stern shape concept foundation.

The one-dimensional flow will be considered and analysed from four different sections of a stream tube (see Fig.2) which includes :

1 – radial crenellated-corrugated stern (far upstream) ;

2 – the disk situated immediately (upstream) in front of the propeller ;

3 - the disk immediately behind (downstream) the propeller;

4 - a disk downstream (far downstream) ;

The relation between far upstream and far downstream will be obtained by Bernolli's equation application (the Bernoulli effect). p_1 represents ship's service velocity stern depression.

The geometry numerical optimization for the new stern proposed with the view of axial velocities

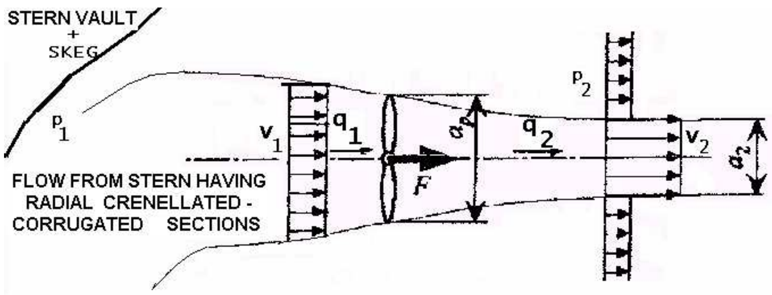

Figure 3: Stream tube theory and Bernoulli effect application as a supplementary background for

uniformization will be performed in two stages :
I – first a coarse one – numerical carving (direct problem) ;
II – second a fine one (direct problem coupled with inverse problem) ;
Both problems (direct and inverse) will be solved recurrently in two succesive cycles.

3.1 Direct problem presentation (analytical and numerical formulations)

Direct flow problem belongs to the class of Boundary Value Problems (BVP). It is founded on potential disturbance theory Neumann-Kelvin and uses Rankine source method. The problem is formulated in a Cartesian coordinate system (X-Y-Z) fixed to the hull (time-independent flow) with the X-Y plane in the undisturbed water free-surface, the X-axis chosen to be positive in the upstream direction and the vertical axis Z is positive downward. Assumptions: - the fluid (water) is considered incompressible (ρ=ct.); - the flow is irrotational; - we neglect viscous effects (boundary layers, turbulence, separation), surface tension, breaking waves. The physical model will be converted in analytical equations. By virtue of these assumptions it is convenient to introduce a function ϕ (X,Y,Z) called the velocity potential function, whose partial derivative in any direction gives the velocity's component in that direction.

Laplace's equation:

$$\nabla^2\phi\,(x,y,z)=0 \tag{1}$$

The boundary condition **on the wetted surface** of the hull:

$$\nabla\phi\cdot\boldsymbol{n}=0 \tag{2}$$

The dynamic boundary condition on water free-surface:

$$-g\varsigma+\frac{1}{2}\left(\phi_x^2+\phi_y^2+\phi_z^2-U^2\right)=0 \tag{3}$$

The kinematic boundary condition on water free-surface:

$$\phi_x\varsigma_x+\phi_y\varsigma_y-\phi_z=0 \tag{4}$$

The non-linear boundary condition for water free-surface:

$$\frac{1}{2}\left[\phi_x\left(\phi_x^2+\phi_y^2+\phi_z^2\right)_x+\phi_y\left(\phi_x^2+\phi_y^2+\phi_z^2\right)_y\right]-g\phi_z=0 \tag{5}$$

The total potential:

$$\phi=\Phi+\varphi' \tag{6}$$

The linearised boundary condition for water free-surface:

$$\begin{aligned}&\frac{1}{2}[\ \Phi_x\left(\Phi_x^2+\Phi_y^2\right)_x+\Phi_y\left(\Phi_x^2+\Phi_y^2\right)_y+2\Phi_x\left(\Phi_x\varphi_x^{'}+\Phi_y\varphi_y^{'}\right)_x+\\&+2\Phi_y\left(\Phi_x\varphi_x^{'}+\Phi_y\varphi_y^{'}\right)_y\\&+\varphi_x^{'}\left(\Phi_x^2+\Phi_y^2\right)_x+\varphi_y^{'}\left(\Phi_x^2+\Phi_y^2\right)_y\ ]-g\varphi_z^{'}=0\end{aligned} \tag{7}$$

The relation proposed by **DAWSON**:

$$\Phi_xF_x+\Phi_yF_y=\Phi_LF_L \tag{8}$$

$$\Phi_L^2\Phi_{LL}+\left(\Phi_L^2\Phi_L^{'}\right)_L-g\varphi_z^{'}=0 \tag{9}$$

$$\left(\Phi_L^2\phi_L\right)_L-g\phi_z=2\Phi_L^2\Phi_{LL} \tag{10}$$

Wave elevation:

$$\varsigma=-\frac{1}{2g}\left(U^2+\Phi_L^2-2\Phi_L\phi_L\right) \tag{11}$$

The DAWSON's boundary condition corrected by **RAVEN(MARIN)**:

$$\nabla\phi\cdot\nabla\left(\Phi_L^2\right)+\Phi_L\frac{\partial}{\partial L}\left(\Phi_L^2+2\varphi_L^{'}\Phi_L\right)+2g\varphi_z^{'}=0 \tag{12}$$

$$\frac{1}{2}\nabla\Phi\cdot\nabla\left(\Phi_L^2\right)+\Phi_L\frac{\partial}{\partial L}\left(\Phi_L\phi_L-\Phi_L^2\right)+g\phi_z=0 \tag{13}$$

Radiation condition for free-surface perturbation:

$$\phi=\Phi+\begin{cases}O\left(\dfrac{1}{\left|\vec{x}\right|}\right),\left|\vec{x}\right|\to\infty\\O\left(1\right)\end{cases} \tag{14}$$

The forces:

$$\vec{F}=\iint_S P\,\vec{n}\,dS \tag{15}$$

The moments:

$$\vec{M} = \iint\limits_{S} P\left(\vec{r}\ x\ \vec{n}\right) dS \tag{16}$$

The pressure calculated from **Bernoulli:**

$$P = \rho g z + \frac{1}{2}\left[U^2 - |\nabla\phi|^2\right] \tag{17}$$

The numerical solution algorithm can be separated into four distinct operations: -pre-processing, - the double-body calculation (with two-symmetry planes); - free-surface grid generation; - the full free-surface calculation. The curvi-linear hull surface is decomposed into flat quadrilateral panels (in conformity with Hess and Smith's original method): **control point** (lies in the plane of each panel; represents the origin of the local co-ordinate system); **collocation point** (at which the panel boundary conditions are applied); both the control point and the collocation point can coincide with **the centroid** of panel, which for improved accuracy can be projected onto the actual hull surface. The velocity potential is determined by integration of the appropriate **Green's function** for **Rankine** source:

$$\phi\left(x, y, z\right) = \iint\limits_{S} \frac{\sigma\left(q\right)}{r\left(p, q\right)} dS \tag{18}$$

The discrete form of the velocity components:

$\phi_{xi} = \sum\limits_{j=1}^{M} \sigma_j X_{ij} + U$

$$\phi_{yi} = \sum_{j=1}^{M} \sigma_j Y_{ij} \tag{19}$$

$\phi_{zi} = \sum\limits_{j=1}^{M} \sigma_j Z_{ij}$

The equation (2) can be written in discrete form in the following way:

$$\sum_{i=1}^{M} (X_{ij}N_{xi} + Y_{ij}N_{yi} + Z_{ij}N_{zi})\sigma_j = -UN_{xi} \tag{20}$$

The discrete form of equation (2) in the case of panels which lie above the undisturbed water plane is given by:

$\sum\limits_{j=1}^{M} \delta_{ij}\sigma_j = 0$where $\delta_{ij} = \left\{ \begin{array}{l} 1\,(i = j) \\ 0\,(i \neq j) \end{array} \right.$ (21)

The derivative of potential function along a transom stern streamline:

$$\phi_L = \frac{U^2 + \Phi_L^2 + 2g\varsigma'}{2\Phi_L} \tag{21}$$

The pressure at the hull **collocation** points is evaluated from Bernoulli's equation:

$$P_i = \sum_{i=1}^{M} \left[\rho g z_{Pi} + \frac{1}{2}\rho \left(U^2 - \left(\phi_{xi}^2 + \phi_{yi}^2 + \phi_{zi}^2 \right) \right) \right] \tag{22}$$

The necessary relations for wave resistance, sinkage force and trim moment:

$$R_w = -\sum_{i=1}^{M} P_i N_{xi} \Delta S_i \tag{23}$$

$$S_f = -\sum_{i=1}^{M} P_i N_{zi} \Delta S_i \tag{24}$$

$$T_m = -\sum_{i=1}^{M} P_i \left(N_{xi} z_{pi} - N_{zi} x_{pi} \right) \Delta S_i \tag{25}$$

The total area of integration and the corresponding displacement volume:

$$A = \sum_{i=1}^{M} \Delta S_i \tag{26}$$

$$V = -\sum_{i=1}^{M} \Delta S_i z_{pi} N_{zi} \tag{27}$$

In the case of radial crenellated-corrugated stern sections, a supplementary physical, mathematical and numerical modelling will be necessary due to special flow phenomena which appear presenting some different properties.

3.2 Inverse problem presentation

In accordance with professor O. M. ALIFANOV : *Solution of an inverse problem entails determining unknown* **causes** *based on observation of their* **effects**. *This is in contrast to the corresponding direct problem, whose solution involves finding effects based on a complete description of their causes.*

Numerical description of stern shapes by B-spline method

In naval domain, usually, there are two methods used for 3D surfaces definition: Bézier's method and B-spline method. B-spline curves represent a generalisation of Bézier's curves.

The main drawbacks of Bézier's method are :

numerical instability for a great number of control points;

global change of curve's form by moving of a single control point.

Due to this reason, the B-spline technique will be used in this paper, as a method for numerical definition and manipulation of stern surfaces.

The surface is generated by a net of parametric curves that are intersecting. The method will be implemented on a computer with interactive graphical facilities, for surface design and fairing. Using

a small number of fix (control) points, the definition will be realised using the monitor's screen interactively. An exact connection between these fix (control) points and surface definition is established by restricting of longitudinal parametric curves to waterlines, so making possible the surface manipulation under form of plane projections on screen. The surface definition by B-spline method does not imposes any kind of specific geometrical constraints, knuckle lines, transom sterns, discontinuities, or propeller hubs, these being modellable elements.
Let us consider a parametric B-spline surface given by

$$\begin{array}{l} Q(u,w) = \sum\limits_{i=1}^{n+1} \sum\limits_{j=1}^{m+1} B_{i,j} N_{i,k}(u) M_{j,l}(w) \\ 2 \le k \le n+1; 2 \le \ell \le m+1 \end{array} \tag{28}$$

where:

$$\begin{aligned} N_{i,1} &= \begin{cases} 1 & \text{if} x_i \le u \le x_{i+1} \\ 0 & \text{otherwise} \end{cases} \\ N_{i,k}(u) &= \frac{(u-x_i)N_{i,k-1}(u)}{x_{i+k-1}-x_i} + \frac{(x_{i+k}-u)N_{i+1,k-1}(u)}{x_{i+k}-x_{i+1}} \end{aligned} \tag{29}$$

and

$$\begin{aligned} M_{j,1} &= \begin{cases} 1 & \text{if} y_j \le w \le y_{j+1} \\ 0 & \text{otherwise} \end{cases} \\ M_{j,l}(w) &= \frac{(w-y_j)M_{j,l-1}(w)}{y_{j+l-1}-y_j} + \frac{(y_{j+l}-w)M_{j+1,l-1}(w)}{y_{j+l}-x_{j+1}} \end{aligned} \tag{30}$$

where:
x_i, y_j $-$the elements of a uniform knot vector;
k,ℓ $-$: $w$the order of the B-spline surface in the u and w directions;
n, m - are one less than the number of polygon net points in the u and w directions;
$Q(u, w)$ - are the surface data points;
N, M - B-spline basis functions (can be determined from the knot vector and the parameter values u and w);
$B_{i,j}$ $-$are the required polygon net points (control points); if $B_{i,j}$ are given, the surface data points $Q(u, w)$ can be calculated from equation (1);
B-spline surface obtaining:
- for each known surface data point, equation (1) provides a linear equation in the unknown B$_{I,j}$ ' s and similarly for all the surface data points. In matrix notation :

$$[Q] = [C][B] \tag{31}$$

- since for any arbitrary rxs topologically rectangular surface point data, [C] is not normally square, a solution can be obtained only on some mean sense :

$$[B] = \left[[C]^T [C]\right]^{-1} [C]^T [Q] \tag{32}$$

Inverse problem (stern shape geometry re-design)

For the inverse hull design problem, the after main hull is regarded as unknown and dominated by a set of control points. In addition, the desired distributions of dimensionless axial component Ux_i on the propeller disk plane are considered available. The axial velocity component Ux_i is calculated by interpolating potential results on the propeller plane along the circumferential (θ) and specified radial (r) directions so that it can be expressed as $Ux(r_i\ ,\ \theta_i)$.

Let the desired axial wake in the propeller disk plane be denoted by $Ux(r_i\ ,\ \theta_i) \equiv$ Ux$_i$, i=1,n where n represents the number of sampling points on the propeller disk plane. Then the inverse problem can be stated as follows:

By utilizing the above mentioned desired axial wake coefficients Ux_i, design the new hull shape for the after main hull. The solution of the inverse problem is obtained in such a way that the following function is minimized:

$$f\left[\overset{\wedge}{\Omega}\left(\hat{B}\right)\right] = \sum_{i=1}^{I}\left[\hat{U}\left(\underset{j}{\hat{B}}\right) - U_{xi}\right]^2 = \Delta^T\Delta; j = 1,\cdots,J \tag{33}$$

where;

$\hat{U}_{xi}$ −are the estimated or computed axial velocity coefficients on the propeller disk's locations (r$_i$, θ_i). These quantities are determined from the solution of the direct problem given previously by using an estimated hull form $\overset{\wedge}{\Omega}\left(\hat{B}\right)$;

I - the number of points in which the wake is measured;

J - the number of control points that govern the stern geometry, J=(n+1)x(m+1);

 - the estimated quantities.

The Levenberg-Marquardt Algorithm

From those mentioned above we conclude that equation (5) can be minimised with respect to the estimated parameters B$_j$, to obtain :

$$\frac{f\left[\overset{\wedge}{\Omega}\left(\hat{B}\right)\right]}{\partial B_j} = \sum_{i=1}^{I}\left[\frac{\partial \underset{xi}{\hat{U}}}{\partial B_j}\right]\left[\underset{xi}{\hat{U}} - U_{xi}\right] = 0; j = 1,\cdots,J; I \geq J \tag{34}$$

If I $\leq$ J the inverse problem solutions are impossible to be calculated because equations system will be undetermined.

Equation (6) is linearized by expanding the function $\underset{xi}{\hat{U}}(B_j)$ **i**n Taylor series and retaining the first-order terms. Then a damping parameter λ is added to the resulting expression to improve convergence, leading to the Levenberg-Marquardt method given by :

$$(F + \lambda^n \cdot I) \cdot \Delta B = D \tag{35}$$

where

$$F = \Psi^T\Psi \tag{36}$$

$$D = \Psi^T \Delta \tag{37}$$

$$\Delta B = B^{n+1} - B^n \tag{38}$$

n – iteration index;
T – transpose of matrix
I – identity matrix;
ψ −Jacobian matrix

$$\Psi \equiv \frac{\partial U_x}{\partial B^T} \tag{39}$$

The Jacobian matrix defined by equation (8) is determined by perturbing each unknown parameter B_j at one time and computing the resulting change in axial velocity coefficients from the solution of the direct problem.
Equation (35) is now written in a form suitable for iterative calculation as :

$$B^{n+1} = B^n + \left(\Psi^T \Psi + \lambda^n I\right)^{-1} \Psi^T \left(\underset{x}{\hat{U}} - U_x\right) \tag{40}$$

Numerical method
Being given an arbitrary initial solution (pre-estimated) for set of requested parameters – the control points B (obtained by using stern shape geometry and B-spline surface approximation), the numerical method (the algorithm) Marquardt can be summarized as follows :
•Solve the direct problem to obtain the estimated (or computed) axial wake ....
•Construct the Jacobian matrix in accordance with equation (8);
•Update B from equation (9);
•Check the stopping criterion; if not satisfied, then go and start procedure from beginning.
Note that due to the fact that the target function Ux_I is not located on the hull surface, the correlation between target function and control points is not very sensitive. In order to avoid the possibility of numerical divergence during the viscous flow simulation process, it is better to select slight loosing stopping criteria at the preliminary stage.

3.3 Experimental validation (on model and full scale)

Of course, as great **LEONARDO DA VINCI** was saying : *FIRST I SHALL TEST BY EXPERIMENT BEFORE I PROCEED FARTHER, BECAUSE MY INTENTION IS TO CONSULT EXPERIENCE FIRST AND THEN WITH REASONING SHOW WHY SUCH EXPERIENCE IS BOUND TO OPERATE IN SUCH A WAY. AND THIS IS THE TRUE RULE BY WHICH THOSE WHO ANALYZE THE EFFECTS OF NATURE MUST PROCEED; AND ALTHOUGH NATURE BEGINS WITH THE CAUSE AND ENDS WITH EXPERIENCE, WE MUST FOLLOW THE OPPOSITE COURSE NAMELY, BEGIN WITH EXPERIENCE, AND BY MEANS OF IT INVESTIGATE THE CAUSE*
and in our case the experimental validation both on model and **especially on some full scale ships** is decisive.

4 CONCLUSIONS

In case the paper proves to be feasible from a practical point of view it will mean a radical turning point in shipbuilding domain field, the results/advantages being enormous:
propulsion efficiency (output) improving(minimum energetic consumptions) ;
propeller cavitation reduction, level of noise and vibration induced in stern structure decreasing;
seakeeping global hydrodynamic stability increasing;
The radical turning point can be comparable with in Japan bulb invention by **Professor Takao INUI**, for which the author has received the highest distinction from Japan's Emperor. Thus if the bulb acts on bow divergent waves (decreasing the forward resistance), in same way the new stern concept with crenellated-corrugated radial stern sections can redirect favourable the emergent stern waves (improving the generated wake distribution, with all train of positive consequences).
The new kind of stern shape proposed can be made even from a plastic material without affecting at all main steel stern structure, only its role being to change favourably the water flow axial velocity spectrum for a better upstream coupling with the flow through propeller.