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# NEW METHODS TO IMPROVE THE PROPULSION PERFORMANCE OF SHIPS

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***Abstract:*** *The project tries to draw attention and briefly focuses on ships hull's stern flows in the light of two absolutely strict original ideas (concepts) in ship hydrodynamics, belonging to the author: 1. a new stern hydrodynamic concept (NSHC), with radial crenellated-corrugated sections; 2. using of an inverse piezoelectric effect [(electric current→high-frequency power generator→piezoelectric driver made of certain ceramic material, which induces an elliptical vibratory movement (high frequency over 20 kHz), into the elastic side plates (15 mm thickness) in the streamlines direction (of the external flowing water)], able to reduce the total forward resistance.*
***Keyword:*** *stern form, wake distribution, hydroframe system, propulsion system, design sensitivity*

## 1. INTRODUCTION

No one, whether he be a naval architect, a ship owner, or a simple passenger, can look over the stern of a ship and view the turbulent tossing above the propeller race without an instinctive realization that most of this upheaval is wasted effort. When he takes time to visualize the irregular nature of the currents which flow into the propeller disc he must certainly feel great admiration for a propulsion device which can take such confused water and make so much out of it in the way of useful thrust. By the same token, he must have confidence that some day, somehow, the turmoil surging out of the propeller disc can be converted into useful power that will speed him faster on his way. How, he asks, is this to be done? The answer is simple: by a greater knowledge of the basic phenomena and a better understanding of the fundamental principles governing the flow and motion of water and the reasons for the particular behaviour of a ship and its propulsion devices.

## 2. TECHNICAL REQUIREMENTS

**Theoretical aspects** In real conditions, a propeller is fitted behind the ships (models) hull's stern, working in a non-uniform water stream, which has been disturbed by the ship's hull during its forward motion. The ship's moving hull carries with it a certain mass of the surrounding water forming a region in which there is a rapid change in velocity well-known under the name of **boundary layer**. The propeller being placed behind the ship's hull stern, there is in the ship's body trail. As a consequence (even considering the average velocity), the velocity of water particles relative to the propeller disk is no longer (both neither in magnitude and nor in direction), equal to the velocity of advance of the propeller relative to still water. This trail, in which there is a difference between the ship speed and the speed of the water particles relative to the ship is also termed **wake**. Generally speaking, the wake is a zone not investigable theoretically (analytically), due to very complex, aleatory flow character within it. In ship's propeller theory, a distinctive importance is having only the incipient part of the trail (wake), located immediately in the front of the propeller disk plane. The movement from this zone is called wake movement or simply wake. The wake movement can be investigated or in the presence or in the absence of the propeller, when is taking the attribute of the effective wake or the nominal wake, respectively. However, the wake movement of interest is only that from the plane where the propeller follows to be situated. The flow's average velocity from that plane is termed wake speed $V_W$, and is in general smaller then ship's speed $V_S$, relative to infinite upstream water. If the water is moving in the same direction as the ship, the wake is said to be positive then:

$$\text{Wake} = V_S - V_W$$

For adimensionalization, the precedent relation can be divided by either $V_W$ or $V_S$ leading to two wake factors

- Froude wake factor = $w_F = (V_S – V_W) / V_W$;
- Taylor wake factor = $w = (V_S – V_W) / V_S$;

Besides, this general effect of the ship's hull, there will be local perturbations due to the shaft, shaft bossings or shaft brackets and other appendages. These effects combined lead to the so called relative rotative efficiency (RRE), defined by:

RRE = $\eta_R$ = efficiency of propeller behind the ship hull / efficiency of propeller in open water (at speed $V_W$);

Always, but especially in present circumstances, propeller cavitation reducing, overall propulsive efficiency and stability improving, represent important challenges for researchers from ship hydrodynamics field and not only. As already mentioned previously, the dynamics of a cavitating propeller depends on the system environment in which it is operating: such as, the flow field within 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 architecture. For this reason, <u>the wake distribution in the propeller disk plane represents a key element for designing of a ship hull stern form.</u> A uniform wake distribution from an immediately upstream propeller parallel plane disk can lead to the formation of propeller cavitation decreasing (having as indirect consequence on the noise and vibration level induced on board and in the hull stern structure, lowering), the propulsive efficiency increasing (for minimum energetic consumptions obtaining). Therefore, obtaining of a good nominal wake distribution is an important objective of all naval architects. In addition, the global – directional hydrodynamic stability improving by using a special kind of stern having certain architecture (more appropriate), can not be but favourable.

**Up-to-date level in the field** Present-day tendency in maritime transportation industry is represented by designing and building of bigger, faster, more energy-efficient and stable ships but simultaneously having stricter noise and vibration levels for stern hull structure. A modern ships hull lines are designed to minimize forward resistance, to reduce propeller cavitation, to improve propulsion performance and to increase global hydrodynamic stability. Since the apparition of the first ships, the naval architects ceaselessly were racking their brains how to improve the existing hull forms. As a general recently accepted opinion, the ships of the future will be designed and built only on the basis of some **new devised concepts.** It is well known that the stern flow problem is rich in complexity and poses many challenges. Ships hull's stern flows have received much attention these last years, in particular with regard to their modelling and design principles. As **a state of the art** in the field, the most recently known industrial achievements, focused on flows improvement in the stern region, which consist in symmetrically flattening of the stern lateral surfaces towards the central plane. This concept has resulted in a huge amount of inconveniences almost in all practical applications to real ships (unsuitable placing of equipments, lack of necessary spaces for inspections, repairs, etc.). For a long time, the present project's author thought how to redesign the two systems - hydroframe system and propulsion system – very important (critical) for a ship, so that the hydroframe may meet the propulsion and the propulsion may meet the hydroframe in an optimal way.

**Scientific research's objectives**

- total forward resistance reduction, propulsive efficiency increasing (for minimum energetic consumptions obtaining);
- propeller cavitation reduction (for level of noise and vibration induced on board and in the stern structure decreasing);
- development of a numerical parameterized model;
- design sensitivity analysis of fields generated;
- optimizations;
- original concepts and ideas validation;
- new methodologies establishing.

It is hoped that the successful solving of the above mentioned objectives will contribute to the top new knowledge accumulation and progress, in a very important, actual and complex scientific field as contemporary ship hydrodynamics is.

**Project description, results obtained, future prospects** Considering the presented ideas, I have proposed (intuitively, based on experience), a new stern hydrodynamic concept of streamline tube type, (having quasi-cylindrical increasing sections), which starts from front propeller disk and stretches until hull cylindrical region (Fig. 1). In devising of this new design concept, the author referred (as a supplementary basic background) to two very well known and simple existing theories: - <u>the streamline tube theory</u> (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 also comprises the propeller disk); - <u>the Bernoulli Effect</u> (increasing of water particles axial velocities in the regions within which the water pressure is decreased).

Taking into account the streamline tube theory and the Bernoulli effect, we can estimate 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 by an architectural optimization in the sense of axial velocities from a propulsion propeller immediate front plane uniformization (Figure.2).

**Figure 1:** The new stern hydrodynamic concept

The directions of the crenellated-corrugated sections teeth crests and troughs longitudinal curved lines, will be those of the stern natural streamlines (which can be established experimentally in a flow visualization test) for vortices turning up avoiding and for a minimum forward resistance obtaining.

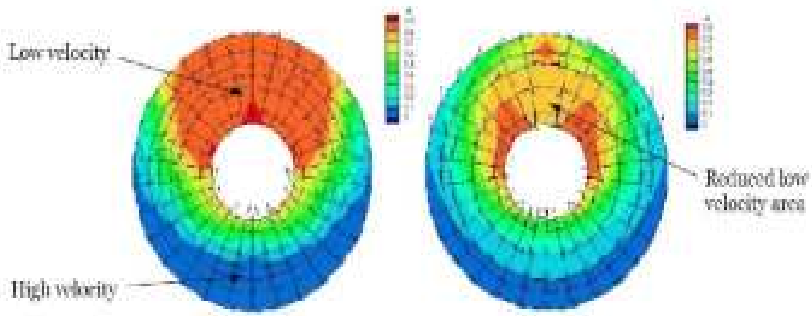


**Figure 2**: Comparison between experimental wake obtained for the model with initial stern shape design (left) and for the model with modified stern shape in conformity with the new concept design (right).

**<u>Finally, the most important, until now, proved result, is the reducing of propeller cavitation (working in the simulated nominal wake of the hull using the new stern hydrodynamic concept with radial crenellated - corrugated sections), practically to zero (Figure 3).</u>**

**Figure 3:** Simulated nominal wake testing, in 850x850 mm section of the cavitation tunnel at 25 rps rotative speed (it can be remarked lack of cavitation)

Unfortunately, this cavitation decreasing (lack of cavitation) is associated with a total forward resistance (of the ship) increasing (approximately 4-5%) due to initiation and movement of some multiple increased vortices (Fig. 4), resulted from the separation (although a low one – Figure. 5) of the boundary layer (destruction of an important part of fluid mechanical energy, pressure decreasing on the down stream part of the ship stern body, etc…).

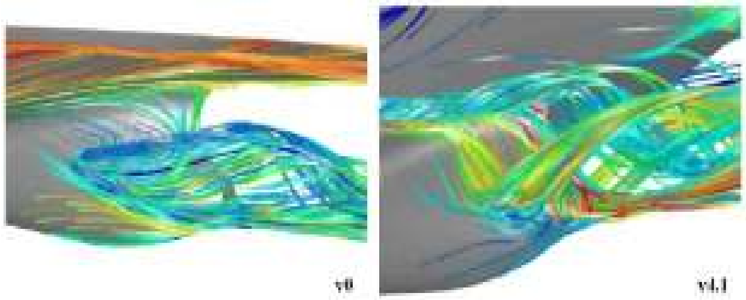

**Figure 4**: Vortex initiation and separation – FLUENT 6.3
( left - the model with initial stern shape design - simple vortex; right- the model with modified stern shape in conformity with the new concept design- multiple vortices)

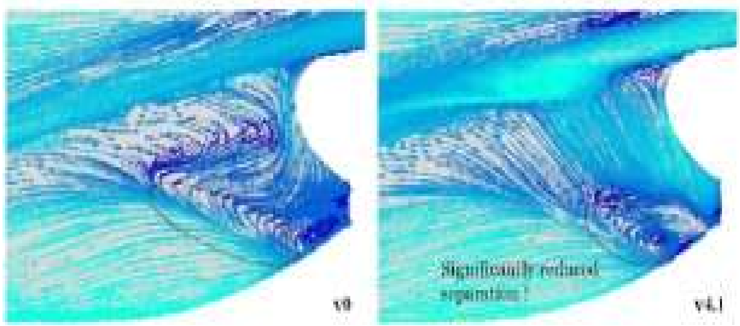

**Figure 5**: Limit streamlines on stern surface- FLUENT 6.3
( left - the model with initial stern shape design; right - the model with modified stern shape in conformity with the new concept design)

Therefore, it would be necessary (a much more) reducing or even complete separation and multiple vortices phenomena (within the turbulent boundary layer) avoiding. In this direction I thought that I should try to use the inverse piezoelectric effect (electric current→high-frequency generator→piezoelectric driver made of certain ceramic material – Figure. 6), which induces an elliptical vibratory movement (high frequency over 20 kHz), into the elastic side plates (15 mm thickness) in the streamlines direction (of the external flowing water).

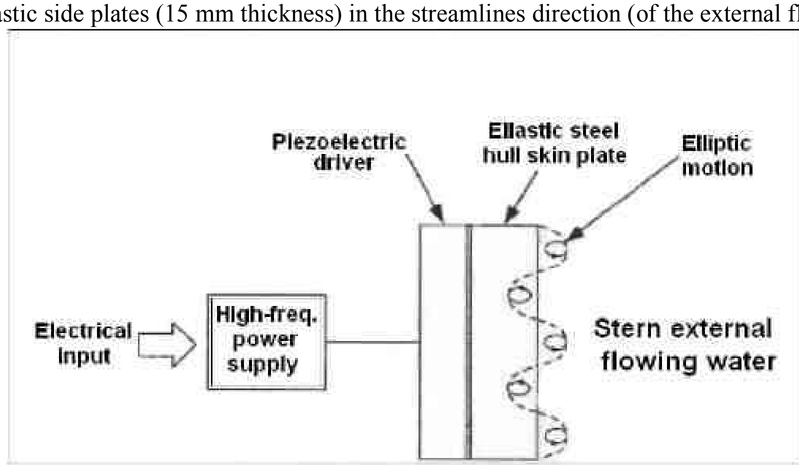


**Figure 6** : Principle scheme of an ultrasonic vibrator

Piezoelectricity is the ability of crystals and certain ceramic materials to generate a voltage in response

to an applied mechanical stress. Piezoelectric effect was discovered by Pierre and Jacques Curie in 1880.
The basic principle would be the following: certain piezoelectric ceramic materials can be used to convert electrical energy into mechanical energy in the form of vibrations of an elastic body (ship hull stern plates), whose surface points perform an linear elliptic motion (in the streamlines direction of the external flowing water), with an ultrasonic frequency over 20 kHz.

Water particles (from within the ship hull stern turbulent boundary layer – Figure.7), are pressed against vibrating steel plates reducing the interface (hull - water), skin friction drag.
It is hoped that such a combination of devices can reduce ship forward resistance due to hull skin-water friction reduction by controlling the inside turbulent boundary layer flow characteristics.

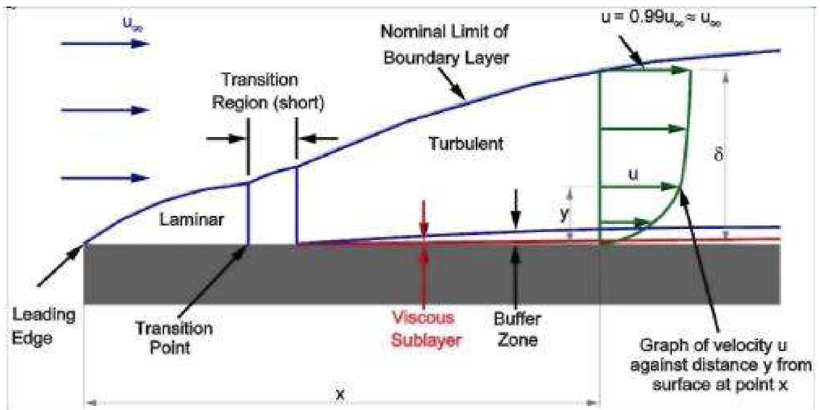

**Figure 7**: Boundary-layer flow regions

In addition, as a continuation and a completion of the researches accomplished in this contract, author considers as interesting the realization of a:

- **parameterized geometrical model** streamline tube type, (including the effects of new stern design having quasi-cylindrical increasing radial crenellated-corrugated sections on inside propeller flow);
- **design sensitivity analysis** of the new stern fields generated.

$$\nabla f = \frac{df}{dx_i} = \underbrace{\frac{\partial f}{\partial x_i} + \frac{\partial f}{\partial \gamma}\left[\frac{\partial \gamma}{\partial x_i}\right]}_{\text{grid sensitivity}} + \underbrace{\frac{\partial f}{\partial \phi}\left[\frac{\partial \phi}{\partial x_i}\right]}_{\text{flow sensitivity}}$$

## 3. CONCLUSION

In these cases different geometries (as necessary form, width and depth, along hull distances, for flow separation avoiding), should be studied theoretically, numerically and experimentally. Design sensitivity analysis consists in determining derivatives of a system's response with respect to its design parameters $x_i$. In the context of design optimization (of the new hydrodynamic stern concept proposed), the response is expressed in terms of objective and constraint functions, and accordingly the overall aim of design sensitivity analysis is to find the gradients of these functions. However, since any such problem function depends explicitly on the dependent variables Ø of the considered problem, sensitivity formulations in essence aim at the calculation of the derivatives $\delta Ø / \delta x_i$. In other words, the changes in flowfield Ø resulting from a given change in design must be predicted. After the determination of these flowfield sensitivities, it is a matter of straightforward calculus to compute the design sensitivities of any problem function.

$i = 1 \ldots n_{dv} \rightarrow$ where: dv – design variables;
$f(x_i)$ – problem function (typically identical with objective and constraints function); $x_i$ – design parameters; $\gamma(x_i)$– geometrical quantities;
$Ø(x_i)$ – vector containing unknown flow variables (velocities, static pressure, possibly turbulence modeling quantities), determined by the governing equations). Obviously, both geometry and flow are implicitly controlled by the design parameters through hull stern surface parameterization, mesh generation and flow analysis.
**Interdisciplinarity degree** The main disciplines from which the present project is taking its sap are:

- mathematical-physics (partial differential and integral equations);
- physics applications; technical physics;

- materials physics;
- modeling and simulation;
- hydraulics and fluid mechanics;
- naval hydrodynamics.

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