THE CONCEPT OF HYDRO LIFE SHIP PROPULSION

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ABSTRACT
This paper suggests a new system of propeller in order to achieve a fuel consumption reduction by means a variation of the geometry. Named HyLife, is introduced as a revision of the current Littoral Combat Ship (LCS) class Independence propulsion system. The results achieved are an outline based on mathematical approximations. More accurate data requires shop test, sea trials and CFD analysis.

KEYWORDS: *Ship Propulsion Efficiency, Fuel Consumption, HyLife propulsion, Littoral Combat Ship*

I. INTRODUCTION

To move a vessel over the sea will always mean problems and complications to solve. Solid versus liquid, vibrations versus cavitation, speed versus stability and managing the water flow effectively is an interesting point in which there is still a lot to do. Providing variable geometry to a ship propeller has clear advantages speaking in terms of consumption, speed and autonomy [1, 2]. It also lets enter common solutions from turbo machinery such as nozzles and anticavitation valves. Hydro Life (HyLife), the codename of the project, pretends to be a step forward to a better future. HyLife is a naval propulsion system to drive along high speeds. The idea for the development of HyLife, as a system for ship propulsion, originates from Kaplan turbine [3]. The Kaplan turbine nowadays is used as a hydraulic machine to produce electricity from the waterfall of a dam [4]. Each of the blades rotates relative to the hub to accommodate different rates of water. Managing in that way, the water flow operates at peak efficiency for a wide range of situations. It results in a system able to provide an energy exchange conversion of about 98%. [5],[11],[12], which means that almost all the water which enters the Kaplan turbine is transformed into electricity. The success of Kaplan turbine is mostly result of the variable geometry of its design. It is able to vary the inclination of every blade (or pitch angle) and that allows the accommodation of each different water flow. It evolves to adapt to adversity and in that versatility lays its success.

HyLife pretends to achieve similar results but from another point of view. It is a pump, a propeller and not an impeller so in any case it will be possible to reach energy exchanges conversions of about 90%. However, the point is the same: to channel the water flow through a pipe to control it and push it as well as possible in order to move the ship efficiently.

The greatest enemy of a turbine, as well as a ship propeller, is cavitation. Overall, cavitation occurs when the total pressure of the fluid equals the pressure of steam at any point of the propulsion system. Particularly concerning a propeller, the total pressure of the fluid is the sum of the atmospheric and hydrostatic in a position and an instant given. When the hydrostatic pressure decreases until it becomes equal to the atmospheric and as it keeps decreasing the flow tends to experience negative pressures. And, because that is impossible, air bubbles appear. When they collapse and explode produce the phenomenon known as microjet: implosions a 1000 m/s and 10000 Pa. This microjet destroys the propeller and causes the leaks of energy. As the blades start to erode, the occurrence of cavitation increases because the surface is not smooth anymore. The super cavitation, being the most destructive, was treated here. If the blades are fixed there is one and only one flow that allows the maximum performance. Out of this, the triangle of speeds cannot sustain an optimum incidence vector of water and air appears at the inlet or at the outlet of the blades depending on how it is moving away from the optimum flow or design flow. The basic strategy to prevent the occurrence of cavitation is to equal static pressure to atmospheric pressure and operate at all times in the design flow.

Summarizing, moving the blades prevents flow suctions that generate cavitation. In the Kaplan turbine the water moves the blade, in HyLife the blade moves the water. As a propulsion system, HyLife pumps the inlet flow converting its kinetic energy in pressure energy. The vanes of a nozzle that direct the flow through the outlet of the system assist this pressure energy. Consequently, not only the cavitation inception speed is controlled but also it alleviates noise of the assembly. It also controls the phenomenon of propeller singing or phenomenon of Von Karman vortex. The latter are vortices generated at the outlet of the propeller and they cause percussions on the blades of a certain frequency.

II. HYLIFE DESIGN BASICS

This pipe or loading chamber conducts a certain amount of water to the propeller of HyLife. Thus a water mass flow achieved is predictable, uniform and it is easier to control flow conditions (Fig. 1 and Fig. 2).

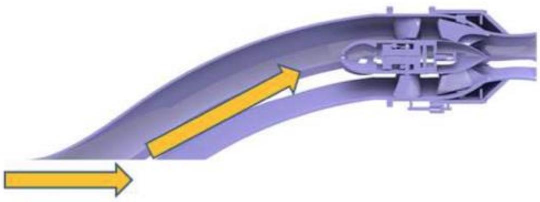

Figure 1. The loading chamber and the position of HyLife propeller

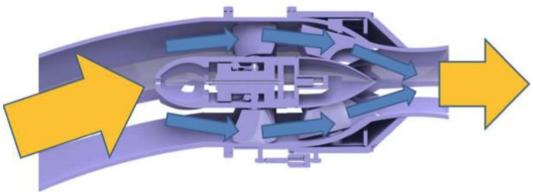

Figure 2. Flow management

HyLife is a controllable pitch propeller (CPP) mounted with a variable geometry nozzle and two rings of anticavitation valves (Fig. 3 and Fig. 4). The nozzle directs the flow after the propeller. The pitch movement of propeller and nozzle are conjugated. CPP already exists in marine propulsion while the rest of the solution is more commonly used in turbo machinery.

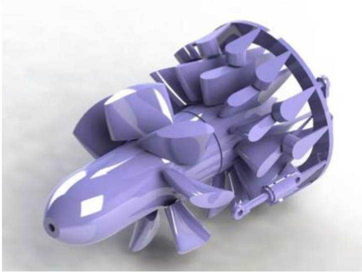

Figure 3. Isometric view of a propeller and a nozzle

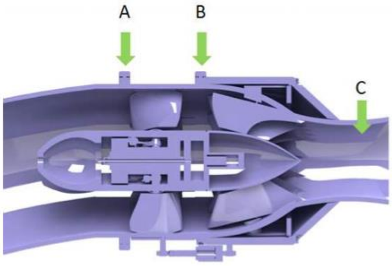

Figure 4. Position of anticavitation valves

The propeller blades are moved by an oil hydraulic piston coaxially mounted inside the drive shaft. This drive shaft is hollow inside and feeds oil at the end where the rotary joint is housed. This joint injects oil in two ways needed to move the piston (Fig. 5 and 6).

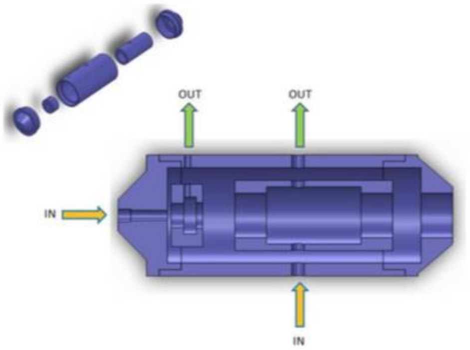

Figure 5. Rotary joint with inlets and outlets of oil

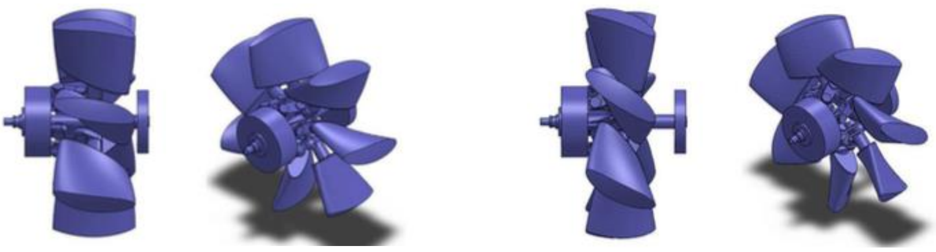

Figure 6. Closing and opening phase respectively of the propeller

Steering gates serve to deflect the flow of water from the chamber and move the ship in the right direction (Fig. 7). Every gate deflects the flow differently in order to steer the ship.

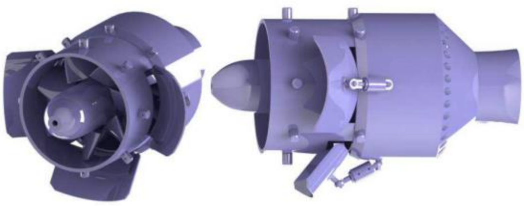

Figure 7. Steering gates

The CPP converts the kinetic energy of the shaft into pressure energy to move the water. This is expelled through the nozzle, which deflects the fluid to obtain the maximum thrust possible. Propeller and nozzle vary their geometry to operate at different speed triangles. The anticavitation valves sustain certain pressure level in the inlet and outlet of the propeller. Therefore they iron out cavitation phenomena increasing the thrusting efficiency of the propulsion system. The main components of the HyLife system are presented on Fig. 8.

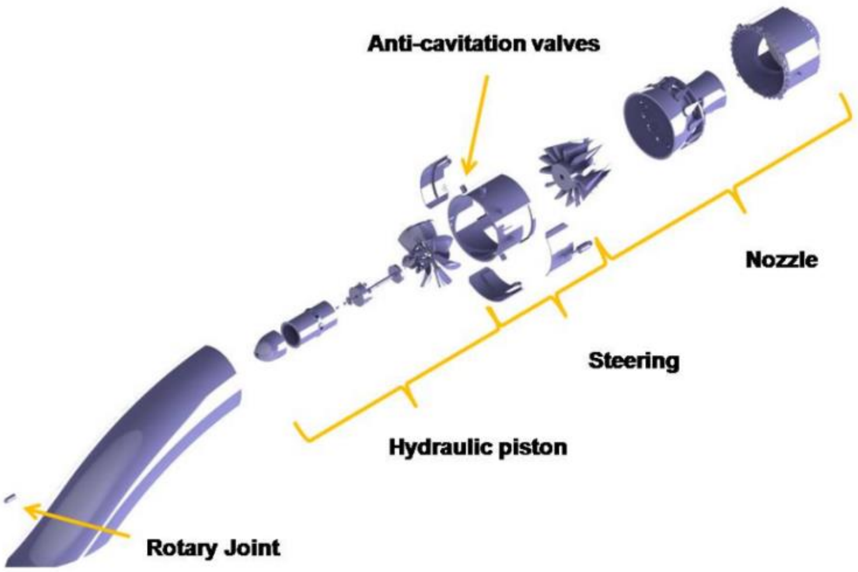

Figure 8. HyLife assembly

III. THE ADAPTATION TO LCS

The point of HyLife is to manage the water flow as efficient as possible. The main problems to deal with here are high speed and cavitation. In terms of benefits higher efficiency means less cost because of fuel consumption savings, as well as possible increase of autonomy for the ship and reduction in emissions.

To have an approach for the best use of HyLife in ship propulsion, a ship benchmarking was done taking in consideration 120 ships of all kind: merchant, passenger, military, etc. A number of data graphics were obtained concerning displacement, ratio length/breadth and ratio breadth/draught versus water mass flow, Q, such as one on Fig. 9.

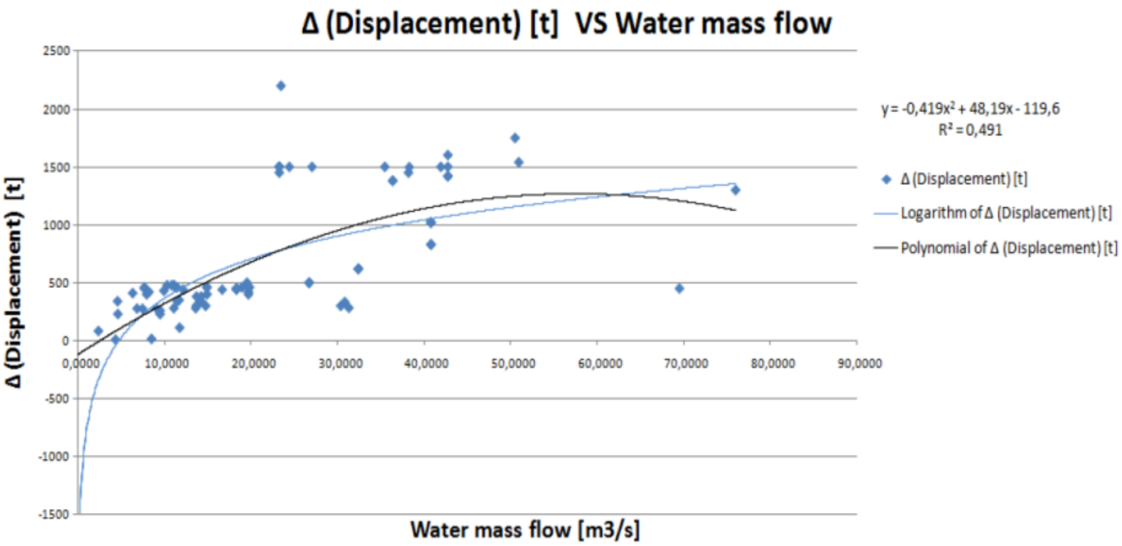

Figure 9. Vessel displacement vs. water mass flow

Based on the benchmarking study the Littoral Class, which represents an example of the effort to reach high efficiency, reliability and operational endurance (low fuel consumption), was chosen to test the performance of the new system. It is a trimaran made in duraluminium designed to navigate at the highest speeds in shallow seas (Fig. 10), with displacement 3000 t, breadth 31,6 m, draught 4,27 m and design maximum speed 50 kn.

Figure 10. CAD 3D LCS [6]

The available data of LCS was used to make a comparison in terms of real numbers. The current propulsion system of LCS belongs to Wärtsilä and all the technical specifications, necessary for comparison with HyLife, are available. The mathematical model that describes the fuel consumption is also available [7]. The HyLife was designed to accomplish the technical requirements like size, weight and break power, known from the LCS. The initial design properties are given in table 1.

Table 1. HyLife main data - initial values

Water mass flow, Q [m^3/s] - nominal	120
Water mass flow, Q [m^3/s] - maximum	150
Nominal shaft speed at maximum Q [rpm]	1500
Number of blades of the helix	4 to 8
Number of vanes of the nozzle	7 to 13
Number of impellers per ship	2
Output power available per impeller [MW]	30
Maximum output power per impeller [MW]	45

The prime movers of the LCS are a combination of gas turbines and diesel engines known as CODAG (COmbined Diesel And Gas engineering plant). The diesel engines are more efficient and therefore have lower fuel consumption, operate at low and cruising speeds. From 18 kn turbines are lit to drive the ship at high speeds (up to 50 kn).
It is possible to adapt this CODAG system to fit HyLife, which means to add variable/controllable propeller geometry to the propulsion system. The current lay-out is made with 2 impellers instead the 4 ones of the former design (Fig. 11).

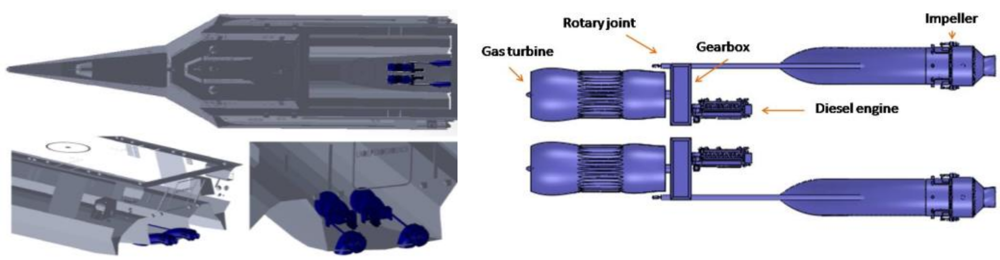

Figure 11. Adaptation of HyLife in the LCS (left) and propulsion plant lay-out (right)

By controlling the pitch of the blades and cavitation inception, the pressure of the flow is more homogeneous and there is less turbulence in the inlet and outlet.

IV. THE PERFORMANCE OF THE HYLIFE

Two points have been considered regarding HyLife performance: propulsion efficiency and fuel consumption.

4.1. Propulsion efficiency

For the calculation of the efficiency the model for waterjet system was used [8]:

$$\eta_H = \frac{\left(\frac{V_f}{V}\right) - (1-\tilde{\omega}_f)}{\left(\frac{V_f}{V}\right)^2 (1+\xi_{ex}) + \frac{2gh_j}{V^2} - (1-\tilde{\omega}_f{}^2 - \xi_{in})} \quad (1)$$

where:

V_f = speed at which the jet is ejected through the propeller [m/s],

V = speed of the vessel [m/s],

$\tilde{\omega}_f$ =effects on fluid potential energy due to agents external to the boundary layer,

ξ_{ex} = losses due to the flow at the outlet of the nozzle,

ξ_{in} = losses due to the flow at the inlet of the impeller,

g = acceleration of gravity, [9,81 m/s],

h_j = vertical distance to which the water rises after the impeller outlet above the waterline, [m].

ξ_{ex} and ξ_{in} are the most important parameters where the variable geometry enables a decrease of the losses at the inlet and outlet of the propeller. The calculations had started with the data in table 1. Through several iterations, by changing the number of blades, number of vanes of the nozzle and variable geometry it was possible to estimate the efficiency of the HyLife propulsion system between 0,70 and 0,80. Compared to the estimated efficiency of the current LCS propulsion system (between 0,60 and 0,65) and using the same approach, it was concluded that HyLife could improve the efficiency about 8 to 14%. The assessed improvement in efficiency is mostly thanks to the impeller with controllable pitch blades but also the nozzle with controllable pitch vanes and the anticavitation valves play an important role in achieving (increasing) the overall efficiency. The final data for the HyLife are given in table 2.

Table 2. HyLife data for the LCS

Q [m^3/s] - nominal	120
Q [m^3/s] - maximum	160
Shaft speed - maximum Q [rpm]	1400
Helix diameter [m]	2,28
Number of blades of the helix	7
Number of vanes of the nozzle	13
Number of impellers per ship	2
Output power available per impeller [MW]	31,1
Maximum output power per impeller [MW]	44,2
Maximum weight [t]	3000
Maximum speed of the vessel [kn]	50+
Life cycles [years]	30
Overall efficiency	0,70 - 0,80

4.2. Fuel consumption

The data about fuel consumption is available by Program Executive Office (PEO) and Commander Logistics Group Western Pacific (COMLOGWESTPAC) [7].

This ship class responds to the Exponential Model of fuel usage [9, 10]. The consumptions of HyLife are calculated by using Eq. 2 and the results are presented in table 3:

$$F = p_0 + p_1 e^{p_2 V^3} \quad (2)$$

where:

F = consumption of F76 Military Diesel fuel oil [l/h],

V = ship speed, [kn],

p_0, p_1, p_2 = dimensionless variables.

Table 3. Summary table with the consumption of different models available

Speed	COMLOGWESTPAC [l/h]	HyLife [l/h]	PEO [l/h]
5			314
7	261	218	
10			832
15			1820

18	931	777	
18,5			5413
20			6245
25			7392
30	7767	6483	12855
35			14937
40	14055	11731	17019
45			19101
47	18378	15329	
50			21183

For all speeds the fuel consumption of HyLife is lower and calculated average fuel saving is 16,5% as presented on fig. 12.

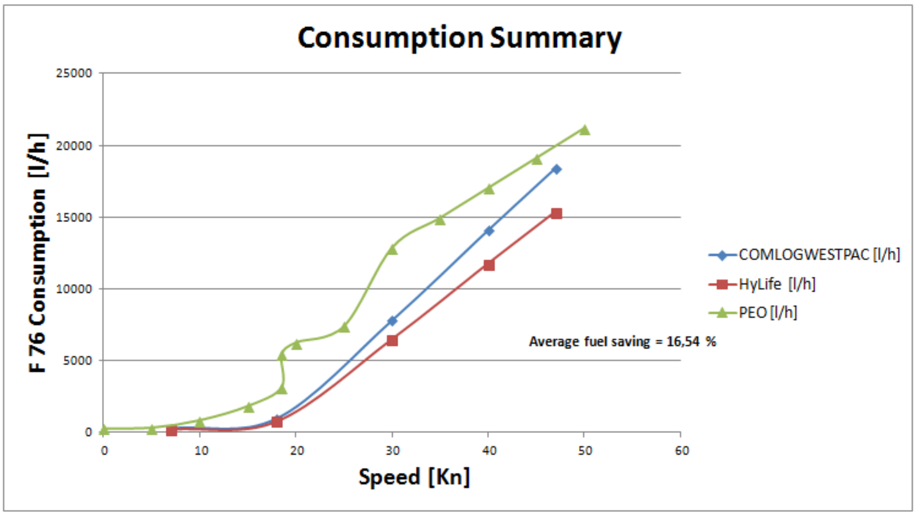

Figure 12. Summary of fuel consumption

V. Conclusion

Presented HyLife propulsion system has shown a better overall efficiency, 8% to 14%, and lower fuel consumption, on average about 16% if mounted on LCS class ship and compared to the existing propulsion system. In addition, this reduction of consumption directly means a notorious reduction in emissions, namely NOx, SOx and CO and also a potential increase of operational endurance. The level of detail of the system in this preliminary investigation includes a number of auxiliary devices such as rotary joints, anticavitation valves, hydraulic pistons and other essential to ensure the proper functioning of the whole.

Following recommendations to this work should be:

- CFD model testing
- Material selection
- Definition of Light Running/Heavy Running (LR/HR) propeller curve
- Definition of engine/movers load diagram
- Axial resistance of the shaft
- Torsional lay-out of shaft line
- Palmgren-Miner durability analysis
- Operational/Experimental Modal Analysis (OMA) of the shaft
- Build and test scaled prototypes in sea trials

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