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PROPULSION PERFORMANCES STUDY FOR A CHEMICAL TANK

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ABSTRACT

The design of a propulsion system for each ship must take into consideration a large number of factors. Some important factors that will lead to an efficient propulsion system are: the selection of suitable components (main engine, transmission, propulsion device) and their integration in a limited but functional space, to achieve maximum propulsion efficiency, to meeting the criteria of safe operation and comfort conditions on board. Considering the factors listed above, the paper presents a study regarding the propulsive performances and propulsion system design for a chemical tanker. To choose the optimal components, the analysis has been performed for 4 different combinations: engine- propeller. The operation of the propeller behind the ship induces unsteady forces which can initiate vibrations of the ship's hull. Therefore, in the last part of the paper, the effect of the operation of the propeller designed for the chemical tank has been analysed. In this sense, the surface forces induced by the propeller that appear in the stern vault are also a centre of interest in this work.

Keywords: chemical tank, propulsion performances, pressure/surface forces

1. INTRODUCTION

A chemical tank is a high-capacity ship whose propulsive performance is a main feature; therefore, the design of an efficient propulsion system is a point of interest. The present study related to propulsive performances [7], has been performed for a chemical tank (Figure 1) with an overall length of 101.49 meters and 16.6 meters breadth, the main characteristics of which are presented in Table 1.

First, starting from the shapes and the geometrical characteristics of the hull, the ship resistance has been theoretically computed and for tanker's propulsion, the power requirements has been established using an in-house code developed by the first author. Two diesel engines were chosen, and two propellers were redesigned for each prime mover, resulting in four study cases. The ship propulsive performances have been analysed and the case that offers the optimal combination engine power, propeller's efficiency and shipowner desired speed has been selected. The effect of designed propeller operation behind the chemical tank hull and the surface forces induced by it on stern vault have been a centre of interest in the last part of the present work.

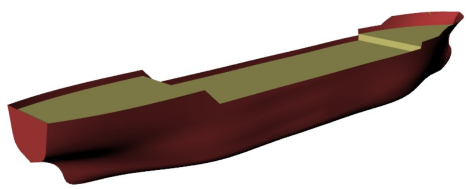

Fig.1 Chemical tank hull

Table 1. Ship main characteristics

Name	U.M.	Value
Length overall	L_{ovl} [m] =	101.49
Length waterline	L_{wl}[m] =	97.4
Breadth	B [m] =	16.6
Draught	T [m] =	7.00
Depth	H [m] =	9.40
Volume	V [m] =	8616
Displacement	Δ [t] =	8840
Block coefficient	C_B =	0.76
Velocity	v [Kn]=	14

For ship resistance calculation, the theoretical method developed by Holtrop-Mennen has been used [1]. Based on this method, the total ship resistance may be computed by summing the following components: frictional resistance (based on ITTC-1957 formula) R_F multiplied with the form factor $(1+k_1)$, appendages resistance R_{APP}, wave resistance R_W, resistance due to bulb R_B, additional resistance of immersed transom R_{TR} and the model-ship correlation resistance R_A:

$$R_T = R_F(1+k_1) + R_{APP} + R_W + R_B + R_{TR} + R_A \quad (1)$$

Using this theoretical method, the computation has been performed for a range of speed between 12-16 knots, and a value of 250 kN has been obtained for the total ship resistance at 14 knots speed.

2. PRELIMINARY PROPELLER CHARACTERISTICS AND NECESSARY PROPULSIVE POWER CALCULATION

Due to lower acquisition costs and operating performance, the naval propeller propulsion system is most common in chemical tankers. In a preliminary phase, it is necessary to estimate the propulsive power taking into account the ship resistance previously determined. Thus, the first stage consists in calculation of the engine brake power based on preliminary propeller efficiency. For this reason, in the initial design stage, for propulsive performance investigations, the B Wageningen series propellers diagrams are used and the torque and thrust coefficients K_T, K_Q are computed for different values of the advance ratio J, using polynomial formulas:

$$K_T = \sum_{K=0}^{38} A_{KT}\,(z)^{Q_k}(J)^{x_k}(P/D)^{y_k}(A_e/A_0)^{z_k} \quad (2)$$

$$K_Q = \sum_{K=0}^{46} A_{KQ}\,(z)^{Q_k}(J)^{x_k}(P/D)^{y_k}(A_e/A_0)^{z_k} \quad (3)$$

In the above formulas, in addition to the regression coefficients A_{KT}, A_{KQ} and the calculation exponents Q_k, x_k, y_k, z_k , geometrical parameters of the propeller such as: blade area ratio Ae/A_0 , pitch ratio P/D and number of blades z are found.

Using these polynomial equations, the open water hydrodynamic characteristics of the B Wageningen screw series can be computed for a given propeller and usually they are plotted as KT (J) and K_Q (J) curves.

For the chemical tanker studied in the present work, the input data used for necessary propulsive power calculation are presented in Table 2.

Table 2. Input data

Number of blades of propeller, z	4
Propeller diameter, D [m]	4.90
Propeller blade area ratio, Ae/A0	0.55
Thrust force, T [kN]	324.89
Velocity, v [Kn]	14
Wake coefficient, w	0.331
Thrust deduction fraction, t	0.2
Water density, ρ [t/m^3]	1.025

In the first step of the used method, the thrust coefficients K_T have been computed and plotted on the same diagram, for different values of the pitch ratio (P/D = 0.6; 0.8; 1; 1.2) and for a range of the advance ratio between 0 and 1 (Figure 2) [7] .

On the same diagram, the ship curve has been plotted: the non-dimensional thrust coefficient as required by the ship's resistance: $K_{T,ship} = const \times J^2$ (Figure 2).

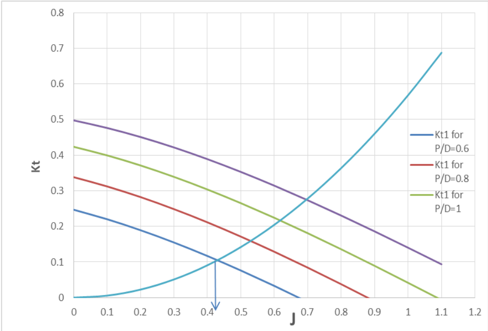

Fig. 2 Propeller thrust curves intersecting with ship curve

To achieve the thrust balance (ship speed versus shaft revolution) the intersection points between ship curve ($Kt_{ship}=ct\cdot J^2$) and propeller thrust coefficient curves $K_T(J)$ are found [2], finally resulting the optimal advance coefficient corresponding to the maximum propeller efficiency (Figure 3).

The calculation is an iterative one and the final results will be the optimal values for propeller efficiency in free water (Figure 3), optimal propeller pitch (Figure 4), the revolution rate and the delivered power. Using the delivered power value and taking into account the power losses and design margin, the brake power may be computed in order to select the main engine.

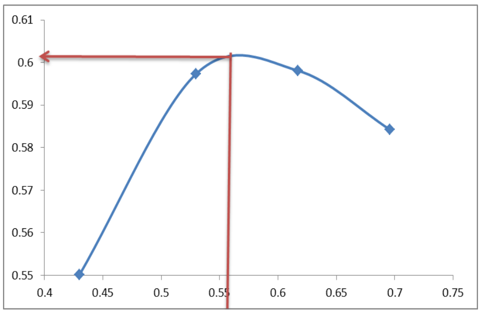

Fig. 3 Propeller efficiency versus advance coefficient

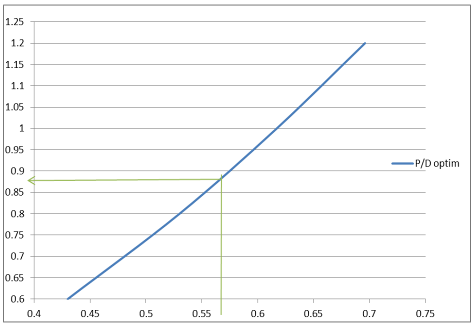

Fig. 4 Optimal pitch ratio versus advance coefficient

For the present study, the results related to the necessary propulsive powers are given in Table. 3.

Table 3. Results related propulsive power calculation

Delivered power Pd [kW]	2538.75
Effective power Pe [kW]	1980.44
Thrust power PT [kW]	1515.62
Hull efficiency η_h	1.19
Propeller efficiency ηb	0.60
Relative rotative efficiency ηr	0.99
Shaft efficiency η_{shaft}	0.97
Reduction gear efficiency η_{gear}	1
Design margin Md	0.1
Sea margin Ms	0.15
Necessary brake power Pb [kW]	3622.51
Necessary brake power Pb [hp]	4857.79

Based on the presented theoretical method, the first author has developed during master degree studies at the Naval Architecture Faculty [7] a JAWA software for necessary propulsive power calculation. Such a program allows the elimination of errors that may occur from an inaccurate reading of diagrams and the results are as close as possible to physical reality and they can be obtained in a short time. The program input interface and output data are presented in Figure 5.

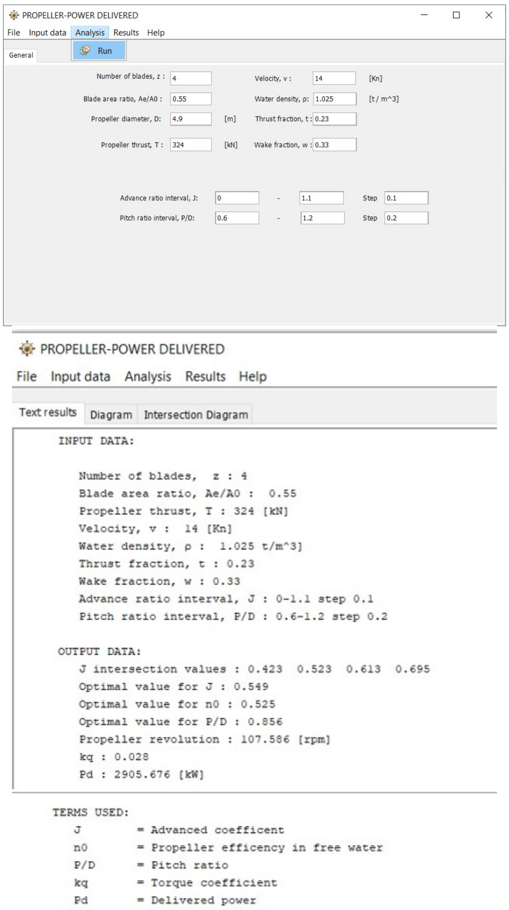

Fig. 5 Input software interface and output data

3. DIFFERENT TYPES OF MOTORIZATION STUDY

For the tanker propulsive performances investigation, four motorisation cases have been analysed. The ship's propulsion system design is usually an iterative process and after the necessary power calculation and main engine selection from catalogue, the optimal propeller geometry and its performances have to be recalculated.

Considering this, one Wartsilla engine with power of 4350 kW and one MAN engine, with a power of 3840 kW, were chosen. For each engine two propeller have been redesigned at two different design points (for a power using coefficient cu=0.75 including Sea Margin SM=15, Engine Margin EM=10% and cu=0.85 including only Sea Margin SM=15%).

Once the engine has been chosen, the optimal propeller diameter has been computed by finding the optimal combination of power, revolution rate, advance ratio to ensure maximum efficiency. The intersection points between non-dimensional torque coefficient as delivered by the shaft (Kq=const x J^5) and propeller torque coefficient curves $K_Q(J)$ are found, finally resulting the advance coefficient corresponding to the maximum efficiency and optimal propeller diameter (Figures 6,7).

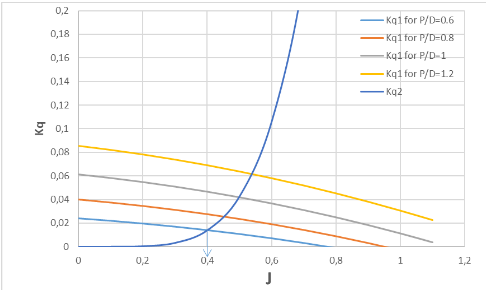

Fig.6 Propeller thrust curves intersecting with ship curve

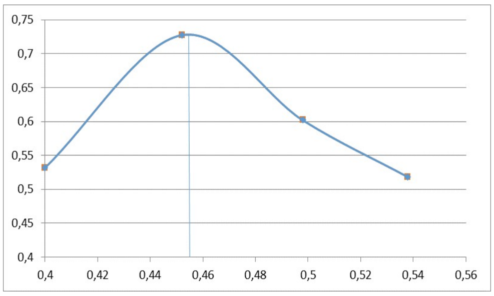

Fig. 7 Propeller efficiency versus advance coefficient

The propeller has been designed for each motorisation case and the ship-engine-propeller performances have been computed and analysed. During the calculations, the interdependence between the characteristics of the propulsion machine and the performances of the propeller can be observed.

Table 4. Ship/propeller characteristics
Case 1

Engine 1 WARTSILA RT-flex35	
Brake Horsepower [kW]	4350
Revolution rate [rpm]	167
Number of cylinders	5
Sea margin SM [%]	15
Engine margin EM [%]	10
Propeller	
Diameter [m]	3.95
Number of blades z	4
Pitch ratio P/D	0.79
Ship	
Speed [knots]	14.4

Table 5. Ship/propeller characteristics
Case 2

Engine 1 WARTSILA RT-flex35	
Brake Horsepower [kW]	4350
Revolution rate [rpm]	167
Number of cylinders	5
Sea margin SM [%]	15
Engine margin EM [%]	0
Propeller	
Diameter [m]	3.96
Number of blades z	4
Pitch ratio P/D	0.79
Ship	
Speed [knots]	14.81

Table 6. Ship/propeller characteristics
Case 3

Engine 2 MAN B&W S30ME-B9.5	
Brake Horsepower [kW]	3840
Revolution rate [rpm]	195
Number of cylinders	6
Sea margin SM [%]	15
Engine margin EM [%]	10
Propeller	
Diameter [m]	3.49
Number of blades z	4
Pitch ratio P/D	0.79
Ship	
Speed [knots]	13.72

Table 7. Ship/propeller characteristics
Case 4

Engine 2 MAN B&W S30ME-B9.5	
Brake Horsepower [kW]	3840
Revolution rate [rpm]	195
Number of cylinders	6
Sea margin SM [%]	15
Engine margin EM [%]	0
Propeller	
Diameter [m]	3.51
Number of blades z	4
Pitch ratio P/D	0.79
Ship	
Speed [knots]	14.03

The results obtained for each motorization case are presented in the Tables 4-7. It can be observed that even if the same engine is used, by choosing different propeller design point, the propeller characteristics and ship speed performances will be modified.

After applying the method in all four cases, it is found that the optimal propulsion system will be obtained in case 4, by using the Man engine, at a power utilization coefficient of 0.85. In this case, a propeller will be obtained with 3.51 m diameter, resulting a ship speed of 14.03 Knots, the closest value to the shipownwer desired speed.

4. SURFACE FORCES (PRESSURE PULSSES) CALCULATION

The analysis of the complex system: ship hull, prime mover and propulsion device play an important role in the design of a new ship. The location of the propeller behind the ship hull involves the propeller's working in a non-uniform fluid field, which leads to the appearance of unsteady hydrodynamic forces induced by the propeller and transmitted to the ship hull via the shaft line (bearing forces) and through the water (surface/pressure forces) (Figure 8). Possible errors made in the design of the propulsion system may have consequences on both the propeller and the hull.

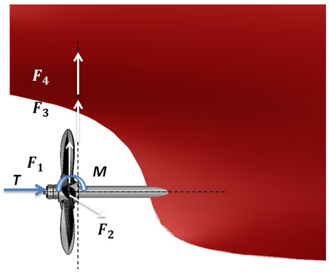

Fig. 8 Forces resulted from propeller operation in unsteady flow

The analysis of the vibrations induced by the propeller operating in non-uniform flow behind ship involves two problems:
- firstly, a hydrodynamic problem represented by the assessment of the propeller unsteady hydrodynamic forces which may constitute excitations for the ship hull;
- secondly, a structural analysis problem, to analyse the dynamics response of the structure (shaft line, ship hull structure).

In this chapter, the first stage was approached, following the calculation of the surface forces. The surface forces are defined as unsteady forces induced by the propeller acting in non-uniform flow behind the ship and transmitted to the ship hull through seawater in form of pressure pulses. They result by summing the pressure fluctuation on the ship aft extremity surface and their amplitude is determined on the one hand by the propeller operating condition (propeller blade shape and loading, presence of cavitation) and on the other hand by the geometric configuration of the propeller location behind the ship [5].

The DNV [6] method was used to determine the surface forces. It is a theoretical method that has as input data characteristics of ship hull and the geometry of the propeller (Table 8). The method was applied for 3 points located on 3 different sections of the stern of the ship: one located exactly in the plane of the propeller, the second one arranged at 3 m from the axis, and the last one at a distance equal to 1.5 times the diameter of the propeller [7] (Figures 9,10,11,12). The results related to the force per unit in the analysed sections are given in Tables 9-11. Observing the resulted values, it can be seen the decrease of the force exerted on the body with the increase of the distance from the propeller axis. The final value for surface forces will be of 9650 kgf.

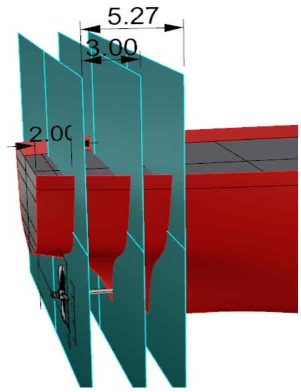

Fig. 9 Sections studied

Table 8. Input data

Main data	
Propeller diameter, D [m]	3.51
Revolution rate [rpm]	195.00
Ship velocity, v [Kn]	14.03
Thrust force,T [tf]	33.11
Blade area ratio, Ae/A0	0.55
Blades number, z	4.00
Shaft immersion, ha, [m]	4.74
Ship draught, Ta [m]	7.00
Wake/clearance	9.40
Effective wake, we	0.33
Propeller geometry data	
c0.8	0.95
c0.9	0.76
c0.95	0.40
(f/c0.8)	0.01
(f/c0.95)	0.01
(P/D0.8)	0.79
(P/D0.95)	0.79
(t/D0.7)	0.33

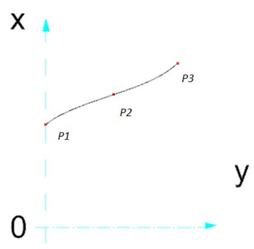

Fig. 10 Section 1

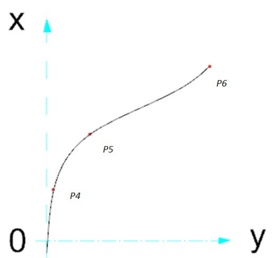

Fig. 11 Section 2

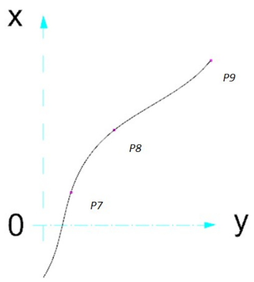

Fig. 12 Section 3

Table 9. Section 1 – obtained results

Point number	d/R	Po [kgf/m2]	Pc [kgf/m2]
1	0.73	85.88	474.81
2	1.859	9.18	175.57
3	3.119	1.84	104.65
Point number	d/R	Pz [kgf/m2]	Pc2 [kgf/m2]
1	0.73	467.61	317.49
2	1.859	174.57	117.40
3	3.119	104.44	69.98
Force per unit length in section [kgf/m]			2128.88

Table 10. Section 2 – obtained results

Point number	d/R	Po [kgf/m2]	Pc [kgf/m2]
4	1.725	11.42	189.17
5	2.033	6.09	160.55
6	3.79	1.06	86.11
Point number	d/R	Pz [kgf/m2]	Pc2 [kgf/m2]
4	1.725	187.53	126.49
5	2.033	159.82	107.36
6	3.79	85.99	57.58
Force per unit length in section [kgf/m]			1389.97

Table 11. Section 3 – obtained results

Point number	d/R	Po [kgf/m2]	Pc [kgf/m2]
7	3.112	85.88	104.86
8	3.371	9.18	96.81
9	4.697	1.84	69.49
Point number	d/R	Pz [kgf/m2]	Pc2 [kgf/m2]
7	3.112	104.69	70.12
8	3.371	96.64	64.73
9	4.697	69.43	46.47
Force per unit length in section [kgf/m]			888.96

The total value for the surface forces must be considered as input data in the structural analysis for the dynamics response of the ship hull's structure as a result of the propeller operation in non-uniform flow.

5. CONCLUDING REMARKS

The present study was focused on the propulsive performance investigation and on the design of an optimal and efficient propulsion system for a high-capacity chemical tank. In this sense, within this work, a preliminary propeller was initially designed to determine the necessary power. During master degree studies at the Naval Architecture Faculty, the first author has developed a

JAWA software for necessary propulsive power calculation.

For the design of the optimal propulsion system, four motorisation cases have been analysed. The propeller has been designed for each case and the ship-engine-propeller performances have been computed and analysed. By comparing the results, the interdependence between the characteristics of the propulsion machine, the performances of the propeller and ship speed have been analysed.

In the second part of the study, the surface forces acting on the hull, as a result of the functioning of the propeller behind the ship have been determined. The value obtained is an entry date for the structural analysis, to determine dynamics response of the hull´s structure as result of the propeller operation in non-uniform flow behind the ship.

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