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FUEL CONSUMPTION CALCULATION FOR OFFSHORE SUPPORT VESSELS

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Abstract. *The growing rise in fuel prices combined with new pollutant emission requirements justifies the importance of urgent measures to reduce consumption. Fortunately, the reduction of Greenhouse Gases is almost always associated with the reduction of consumption. Such reductions can be seen as an increase in energy efficiency. To achieve these goals, it is of great importance to use frameworks capable of estimating engine consumption with a high degree of accuracy under different ship loading conditions. In these cases, the total resistance of the ship is calculated, considering the effects of waves, wind and current. In this article a Platform Supply Vessel is used as a case study. The vessel operates in the Campos Basin region of Rio de Janeiro/Brazil. The operating company is responsible for fuel oil costs. Therefore, measures to reduce consumption assume great importance. Fuel consumption data of the ship were used, and the calculated values presented good accuracy in relation to real data.*

Keywords: *fuel consumption, fuel saving, Platform Supply Vessels*

1. INTRODUCTION

For offshore support vessels in charter contracts, the cost of fuel is covered by the contracting companies, in most cases. However, in some short-term contracts, this cost is the responsibility of the ship's operating company. For this reason, these companies are improving their fuel consumption monitoring tools, frequently installing fuel flow meters, and thus enabling the use of conventional and machine learning approach.

Although machine learning models have high accuracy and relatively low processing time (Chen et al, 2023), it is a technique real fuel consumption data dependent. On the other hand, traditional methods, although based on different formulations and their associated errors, can be applied to ships that do not have a fuel consumption database.

According to Gkerekos et al. (2019) when the cost of HFO (heavy oil) is at 500 U\$/ton, the fuel cost represents about 75% of the operating costs, in large container ships. Worldwide maritime transport consumes about 300 million tons of fuel per year (Barbosa, 2022). Therefore, concerns about the type of fuel to be used in marine engines in the coming decades are justified, both in terms of consumption and emissions.

2. METHODOLOGY

For ships in operation whose propulsive system has already been chosen, the consumption estimation process initially consists of adjusting a model developed in the framework in such a way that the engine-propeller set of the model is the same, or very similar, to that of the real ship. This process begins with the calculation of the ship's resistance in still water, at its service speed.

In this approach, the start point is the calculation of Effective Horse Power (EHP). Through the coefficients of the ship's hull, the THP (Thrust Horse Power) value is obtained. Next, it is necessary to choose the propeller. In this step, the Kt-Kq-J diagrams of the respective propeller series are used and the DHP (Delivery Horse Power) can be obtained. The figure 1 illustrates this sequence.

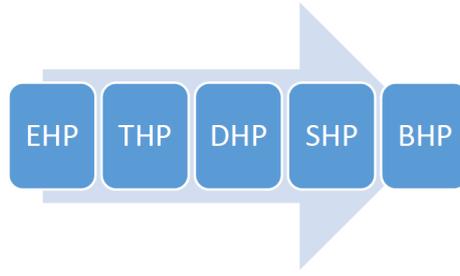


Figure 1: Effective Power to Engine Power

Firstly, the ship particulars were used in a framework named DSP, obtaining as a result the total resistance in still water and the wake coefficient, reduction propulsive factor and relative rotational efficiency, as illustrated in the Figure 2.

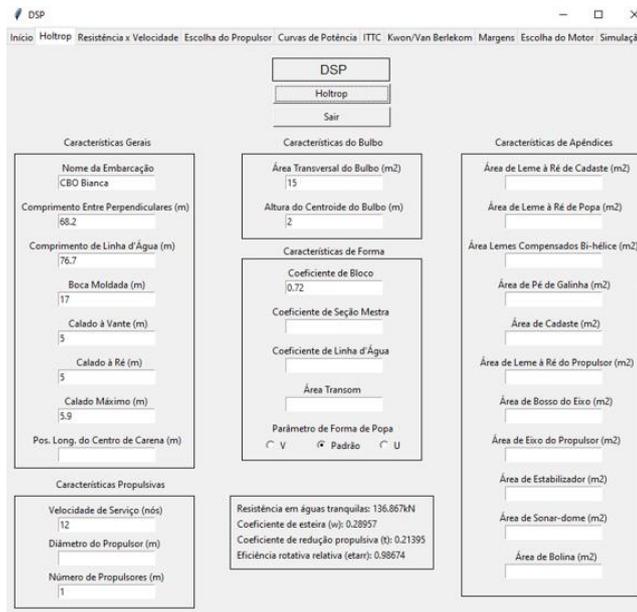


Figure 2. DSP Framework

The next step is the choice of the propeller, performed using polynomials that represent the dimensionless values of thrust, torque and speed, respectively named K_T , K_Q and J . Such polynomials were developed and presented in Bernitsas et al. (1981). These coefficients are defined as:

$$K_t = \frac{T}{\rho \cdot n^2 \cdot D^4} \quad (1)$$

$$K_q = \frac{Q}{\rho \cdot n^2 \cdot D^5} \quad (2)$$

$$J = \frac{V_a}{n \cdot D} \quad (3)$$

Where:

K_T is the Thrust Coefficient

K_q is the Torque Coefficient

T is the propeller Thrust in N

Q is the propeller Torque in N.m

V_a is the advance velocity in m/s

J is the Advance Coefficient

n is the rotational speed in Hz

ρ is the specific mass in kg/m^3

D is the propeller diameter in m

This stage consists of optimizing the propeller based on the characteristics of the ship. In this stage, the parameter to be optimized is the open water efficiency. DSP software then creates a "loop" of iterations and obtains a family of a few tens of thousands of propellers.

After choosing the propeller, the power curves can be plotted as a function of the proposed propeller operating speed. Such curves are calculated from the different ways as presented below.

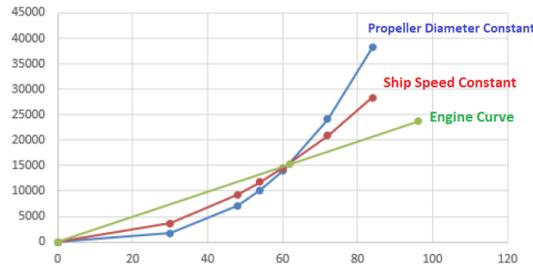


Figure 3. Power Curves

The Thrust Horse Power (THP) is expressed as:

$$THP = T \cdot V_a \quad (4)$$

$$BHP = \frac{THP}{\eta_s \eta_o \eta_{rr}} \quad (5)$$

By replace Eq. (5) in Eq. (4) we have:

$$BHP \cdot \eta_s \eta_o \eta_{rr} = T \cdot V_a \quad (6)$$

Making explicit T in Eq. (1) and substituting in Eq. (6), we have:

$$BHP \cdot \eta_s \eta_o \eta_{rr} = K_T \cdot \rho \cdot n^2 \cdot D^4 \cdot V_s \cdot (1 - \omega) \quad (7)$$

Where:

THP is the Thrust Horse Power

BHP is the Break Horse Power

η_s is the shaft efficiency

η_o is the open water propeller efficiency

η_{rr} is the rotative relative propeller efficiency

ω is the wake coefficient

Equation (7) denotes that the power (BHP) varies in quadratic form in relation to rotational speed (n) if ship speed (V_s) is constant. By other side, the power (BHP) varies in cubic form in relation to rotational speed, if propeller diameter is constant as follow.

$$BHP = Q \cdot 2\pi n \quad (8)$$

$$BHP = K_q \cdot \rho \cdot n^2 \cdot D^5 \cdot 2\pi n = K_q \cdot 2\pi \cdot D^5 \cdot \rho \cdot n^3 \quad (9)$$

The initially calculated still water must be added to the ship's additional resistance due to wind and waves. Additional Resistance is divided in three parts, showed in Eq. (10).

$$\Delta R = R_{AA} + R_{AW} + R_{AS} \quad (10)$$

Where:

R_{AA} is the wind resistance

R_{AW} is the wave resistance

R_{AS} is the resistance due salinity

Wind resistance can be obtained in accordance with ITTC (International Towing Tank Conference) formulation. The wind resistance parameters are showed in Figure 4.

$$R_{AA} = \frac{1}{2} \rho_A C_{DA} (\psi_{wref}) A_{XV} V_{wref}^2 - \frac{1}{2} \rho_A C_{DA}(0) A_{XV} V_G^2 \quad (11)$$

Where:

- ρ_A is the air density
- C_{DA} is the wind coefficient
- Ψ_{wref} is the wind direction
- V_{wref} is the wind speed
- V_G is the ship speed
- A_{XV} is frontal ship area

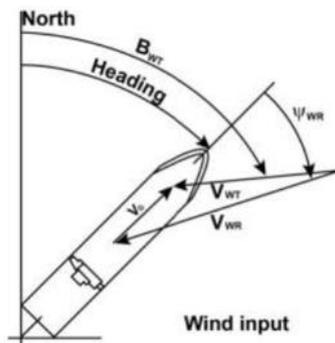


Figure 4. Wind Resistance Parameters

This calculation can be performed in three formulations:

- Application of Margins: sea, rotation and engine
- Kwon/Van Berlekon (2008)
- ITTC (2021)

Then, the power to move the ship forward at service speed can be calculated. The DSP framework performs the calculations based on formulations presented in Van Berlekon (1978) and Kwon (2008), as well as ITTC (2021). Through the analysis, it was observed that the ITTC formulations presented the most assertive results, therefore, this methodology was chosen to continue the case study.

3. CASE STUDY

In order to validate the methodology presented above, a case study was carried out on an offshore support vessel. Platform support vessels (Figure 5) are basically classified into:

- PSV (Platform Supply Vessel);
- AHTS (Anchor Handling Tug Supply);
- OSV (Offshore Support Vessel);
- PLSV (Pipeline Supply Vessel).

These vessels operate in 4 typical situations:

- Laden;
- Dynamic Positioning;
- Port;
- Stand-by.

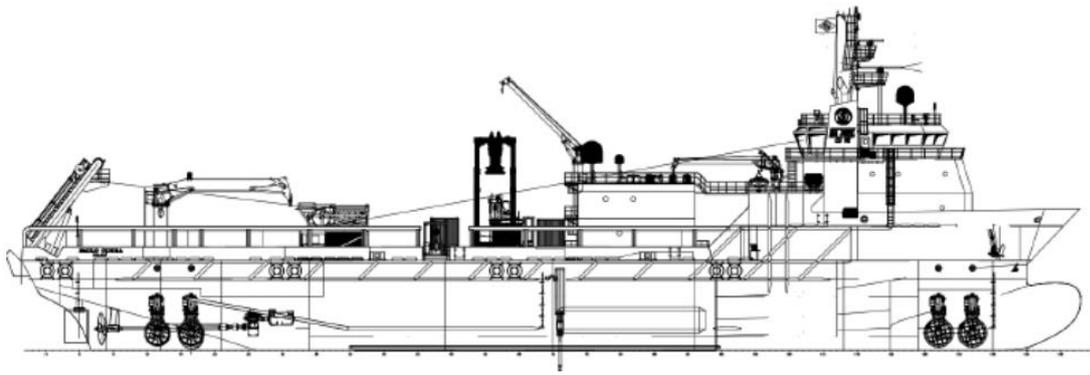


Figure 5. Platform Supply Vessel

The case study was a PSV vessel, with a route in the Campos Basin. To carry out this study, it was used a database of approximately 1 year of records (between January 2022 and January 2023) of wind and wave conditions, as well as ship speed and consumption of the vessel's propulsion engines. The records were performed with a time interval of 10 minutes. From the data obtained, it was possible to assemble a graph to establish the operational profile of this vessel based on its speed, as can be seen in the Figure 6.

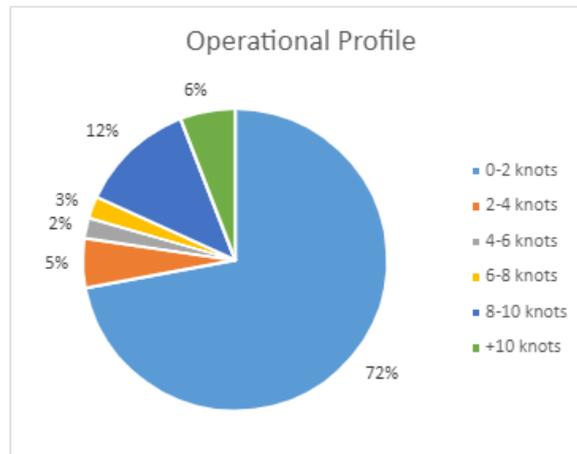


Figure 6. PSV Operational Conditions

This vessel spends most of its time at low speeds, that is, stopped in port, maneuvering, or dynamically positioning. Only 18% of the time, it operates in route, around its service speed (10 knots).

The objective of the developed framework is to design the propulsive system so that the proposed system approximates the real one as much as possible and simulate wind and wave conditions faced by the vessel to, finally, estimate the fuel consumption. It is possible to obtain real environmental conditions through free software, and then use these data as input for the developed framework. The Figure 7 illustrates one of the positions of the PSV vessel studied here.

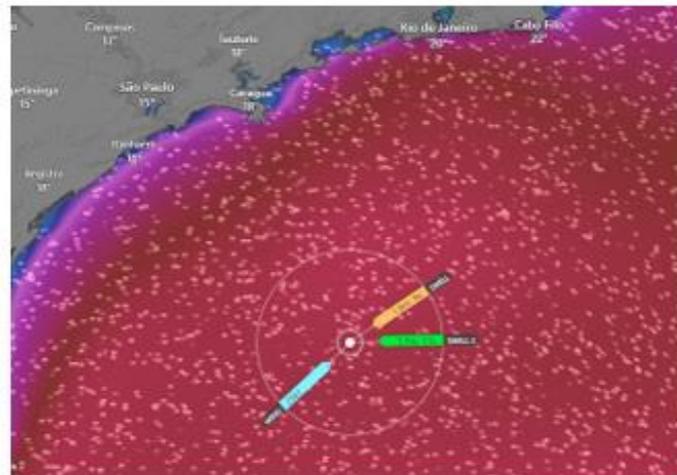


Figure 7. Weather Conditions

At this point, the power (BHP) and rotational speed (n) are already calculated, and the next step is the engine selection. Offshore support vessels use medium-speed engines, basically for reasons of volume and weight in the engine room. The case study is equipped with two medium-speed engines, each with a power of 2320 kW. By the datasheet of the actual engine used on the vessel, as well as data from bench tests. In this way, the fuel consumption for different loads of this engine was obtained. Therefore, it was possible to establish a relationship between the vessel's power and fuel consumption, this relationship can be quantified through the Eq. (11) and the curve is presented in Figure 8.

$$BHP = 10^{-9}FOC^2 + 0,0058.FOC - 119,5 \quad (11)$$

Where:

FOC is the Fuel Consumption in g/h

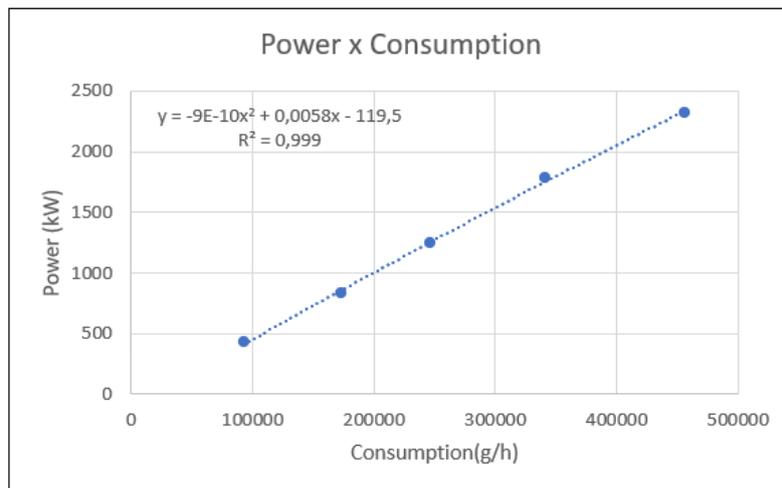


Figure 8. PSV: Power versus Consumption Curve

Then, it was also possible to establish an opposite relationship to the previous one, that is, an equation of (real) consumption as a function of power.

$$FOC = 0,0062.BHP^2 + 171,63.BHP + 21679 \quad (12)$$

Before carrying out data validation, it was necessary to treat the records, that is, remove data that contributed, in some way, to an incorrect analysis. For example, records were removed that showed a very low engine load, since, in this type of situation, the engine tends to have a very high consumption, making it difficult to model. Another situation that was discarded from the analysis concerns points of very large power transients, for example, when there is a sudden increase or reduction in the engine load, as these abrupt changes cause consumption that is difficult to be modeled. Due to the high number of records, it was not possible to analyze all the data, so attention was paid to records where the ship was operating

between 8 and 11 knots. 200 records were analyzed, obtaining a maximum deviation of 10% from estimated consumption to actual consumption.

In order to have greater visibility of the results obtained, the 200 records were divided into 5 periods (each with 40 records) and the consumption in each of the periods was added up. Finally, a table was set up with the sum of consumption per period and then the graph shown below was generated. The Figure 9 shows this comparison.

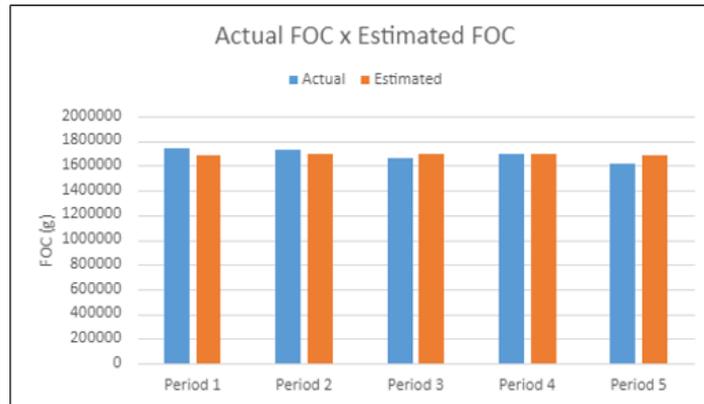


Figure 9. Real versus Estimated FOC

From the graph above, it is possible to identify good adherence between the estimated consumption values in relation to the actual one, with an average error of 5.2% in the 5 periods.

4. CONCLUSION

A robust methodology was developed, based on traditional approaches, to carry out a correct dimensioning of the propulsive system of medium and large vessels, as well as to carry out an accurate estimate of the fuel consumption in these vessels. Through the data that authors had access, it was possible to elaborate, through polynomial regression, an equation that governs the behavior of the fuel consumption of the medium rotation engine studied in function of the power, that is, it is possible to predict the consumption of this engine at any load percentage, accurately.

The case study was successful, obtaining a average discrepancy of 5 % between the estimated consumption value and the actual value, taking into account 200 consumption records. It is pointed out that the greater assertiveness of the consumption estimate occurred at high engine loads, obtaining, in many cases, the exact value.

5. FUTURE RESEARCH

Machine Learning models were already created for the Platform Supply used as study case in this paper. It were applied the algorithms: Decision Tree, Support Vector Machine and Linear Regression presenting maximum R-squared respectively of 0.93, 0.96 and 0.78. These results will be re-analyzed for presentation in the next Congress.

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