TECHNICAL NOTE

VIRTUAL ARRIVAL: A REAL OPTION FOR ENERGY SAVING?

V Capurso, M Ferrando, P Gualeni and **M Viviani** , University of Genoa, Italy

SUMMARY

The maritime traffic is the real backbone of the international transport of goods in the world and it is driven by a severe observance of time scheduling. Nevertheless, mainly in relation with the most traveled routes, frequently it might happen that port facilities are congested, and the time schedule for ship load/unload operations is accordingly delayed. In this circumstance the choice is between meeting the original ETA (estimated time of arrival) and then let the ship riding at anchor or slowing down the ship in order to adjust the arrival to the actually needed time window.

The latter option is called "Virtual Arrival"[1] because it consists of applying a speed reduction that fits the new time for port operations instead of arriving at the original ETA. The purpose of this paper is to investigate to what extent the Virtual Arrival policy could be a valuable option providing a reasonable energy saving for ships. The potential benefits are considerable and they result in direct saving in fuel consumption, reduction of CO_2 emissions and less congested port areas.

NOMENCLATURE

ρ	Water density (kg m^{-3})
V	Ship speed (Kn)
D	Propeller diameter (m)
N	Propeller number of revolution (RPM)
P_B	Brake power (kW)
J	Advance coefficient
K_T	Thrust coefficient
K_Q	Torque coefficient
T	Thrust required to propel the ship (kN)
R_T	Resistance of the ship (kN)
T	Thrust deduction fraction
w	Wake fraction
η_H	Hull efficiency
η_O	Open water efficiency
η_R	Relative-rotative efficiency
η_S	Shaft efficiency
SFOC	Specific Fuel Oil Consumption (g kW^{-1} h^{-1})
BN	Beaufort number
FOC	Fuel Oil Consumption
MCR	Maximum continuous rating
VAD	Virtual Arrival Decision

1. INTRODUCTION

There are around 70,000 ships engaged in international operations and this unique industry carries 90% of world trade [2]. Sea transport has justifiable image of conducting its activity in a manner that creates remarkably little impact on the global environment.

The problem of exhaust emissions from marine traffic has been recognized from the International Maritime Organization [10] and solutions to model it have been widely discussed as in Jalkanen et al., 2009 [11] where a specific example is presented for the Baltic Sea area.

It is nevertheless the case that enhancement of efficiency can reduce fuel consumption, save money and decrease environmental impacts for ships.

This challenge was met by the IMO in 2009 when the Marine Environment Protection Committee (MEPC) issued a package of guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP) [2].

There are several measures that can be adopted in order to save fuel and one of these consists in adopting a reduction of the operational speed, especially when delays are identified at the discharge port [1].

The heavy fuel oil consumption is defined by three main factors (1): the specific fuel oil consumption, the power and the time on route.

$$HFO\ consumption = SFOC \cdot P_B \cdot Time \qquad (1)$$

On the one hand, if the speed decreases, as a direct consequence, time increases and the SFOC presumably rises as well because the engine runs at a different load than the optimum one indentified in terms of the minimum specific consumption. On the other hand, the power decreases with a cubic trend and this is the reason why the global effect is generally a reduction in fuel consumption.

Even if not promptly visible, equation (1) takes into account the influence of the propeller working point on the open water efficiency η_o.

This parameter is the lowest efficiency term in the propulsion efficiency chain, hence, even a small variation of η_o can produce a significant variation on the brake power. Not only does the propeller working point influence the brake power values but it also has effect on the SFOC through the specific fuel oil consumption map, therefore is not easy to evaluate its global effect at first sight.

All in all, it is generally possible to say that the Virtual Arrival policy of speed reduction is a good option for fuel-efficient operations when delays due to a lack of receptivity of the port of arrival are the issue.

Moreover, it is important to point out that this policy needs to be supported by all the parts involved in the shipping chain and a special clause has to be enforced in the Charter Party to avoid claims. The attention to the actual ship performances is so sharp sometimes that a weather analysis service defined as "Weather Analysis Service Provider" (WASP) [1] is also needed.

The aim of this paper is to discuss the following topic: in case the port of arrival is not ready to receive the ship, to what extent is it advisable to slow down? Answer is in the conclusions of the paper and the evaluation is performed in terms of fuel saving and the relevant CO_2 reduction by means of an application case.

2. APPLICATION CASE

2.1 CASE STUDY

The study has been applied to a 50,000 DWT Chemical Tanker. The main characteristics are reported in Table 1.

Length between perpendiculars	173.9	m
Breadth moulded	32.2	m
Depth moulded	18	m
Draft Design (MLD)	11	m
Full load displacement	56100	t

Table 1: Main characteristics

Obviously, beside what above mentioned data, all the proper technical data have been supplied to the authors in order to perform the application case developed in this paper.

2.2 VIRTUAL ARRIVAL HYPOTHESIS

The route considered is “Bilbao – New York”, 3150 nautical miles (Figure 1).

To perform this exercise, i.e. to estimate how much fuel can be saved, some assumptions have to be made. First of all, delay time windows have to be defined: intervals of 3, 6, 12, 24 and 48 hours are considered.

Another variable to consider is the time when the decision of speed reduction is taken. It has been simulated to reduce the speed from three points defined as VAD (Virtual Arrival Decision) points:

- from the beginning of the course (0 nm from Bilbao)
- at half the distance of the course (1574 nm from Bilbao)
- one fourth of the course from the arrival (2360 nm from Bilbao)

Figure 1: Virtual Arrival Decision Points on the route Bilbao-New York

3. METHODOLOGY

3.1 POWER PREDICTION

An automated tool able to quantify the ship brake power has been developed. In particular, this computational tool carries out calculations in terms of ship calm water resistance and brake power, depending on the ship draft and trim for a given speed range.

The power prediction is based on the semi-analytical and statistical method developed by Holtrop [3, 4] for two main reasons: the possibility of an automated implementation and the capability to introduce, the effect of trim on ship resistance, by a proper methodology based on the LCB (longitudinal centre of buoyancy) position.

Firstly, the geometrical model of the ship has been created in order to carry out hydrostatic calculations and derive the necessary geometrical properties for the ship resistance evaluation. To this aim, an “Integrated Hydrostatic Table” (IHT) containing all the geometric data required by the Holtrop Method has been linked to the spreadsheet built according to the Holtrop methodology.

Starting from the input data (aft and forward drafts), the tool can evaluate all the parameters, basically geometric information, that can be used to draw the curves of vessel resistance for different trims and displacements.

Moreover, in Holtrop approach is possible to find statistical formulae to evaluate the propulsion factors t, w and η_R. These values, in addition to the calm water total resistance [2, 3], are used to calculate the open water efficiency according to the Wageningen Propeller B Series [5].

$$T = \frac{R_T}{(1-t)} \quad (2)$$

$$V_A = V \cdot (1-w) \quad (3)$$

A constant value can be therefore calculated (4).

$$\frac{K_T}{J^2} = \frac{T}{\rho N^2 D^4} \cdot \frac{(\mathrm{N} \cdot \mathrm{D})^2}{\mathrm{V_A}} = \frac{\mathrm{T}}{\rho D^2 V_A} \quad (4)$$

Afterwards, a function with a parabolic trend (5) may be defined.

$$f(J) = \left(\frac{K_T}{J^2}\right) \cdot J^2 \quad (5)$$

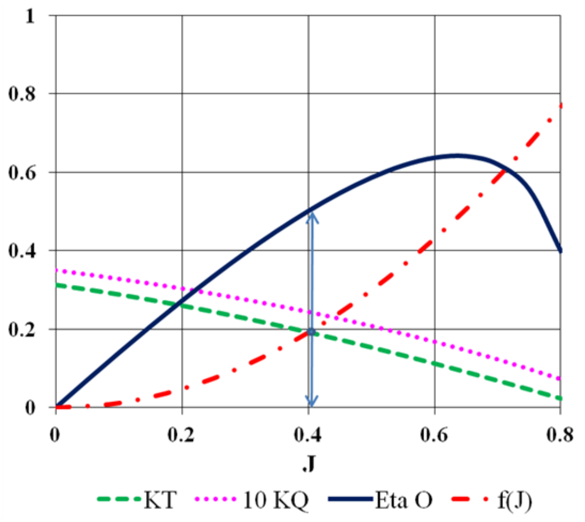

Figure 2: Open water curves

This function (5) combined with the open water curves (Figure 2), makes it viable to find the value of equilibrium J and of the main propeller features; it is so possible to calculate the effective value of η_o in order to accurately define the brake power.

3.2 ADDED RESISTANCE

The required power and propeller characteristics are usually estimated for a still water condition but during its operational life, the ship encounters different sea conditions and on many occasions the seaway has a great influence on ship resistance and propulsion features.

The term added resistance is used to describe the increase in ship resistance induced by the generation of waves as a consequence of ship motions. To this purpose the ship resistance in calm water is increased by a percentage, usually 15%, in order to take into account the effect of seaway.

In this study, calculation of the added resistance has been carried out using the Townsin & Kwon methodology [6, 7, 8] based on equation (6).

$$\frac{\Delta V}{V} = \left[1 + \frac{\Delta R}{R}\right]^{1/2} - 1 \quad (6)$$

$$\Delta R = R \cdot \left[\left(\frac{\Delta V}{V} + 1\right)^2 - 1\right] \quad (7)$$

$$\mu \frac{\Delta V}{V} \cdot 100\% = a \cdot BN + \frac{BN^b}{d \cdot \nabla^{\frac{2}{3}}} \quad (8)$$

The Townsin method identifies the added resistance (7) as due to an involuntary speed loss (8) for head weather which depends on the following parameters:

- ∇ (ship volume of displacement in m^3)
- *BN* identifies wind and sea state
- μ represents the weather direction reduction factor
- *a* and *d* depend on ship type and load condition

After some applications and comparisons, this method was considered reliable for Sea State less or equal 5 (BN≤6) in order to evaluate a more realistic percentage of added resistance.

3.3 SPECIFIC FUEL OIL CONSUMPTION MAP

The main engine of the considered vessel is a two-stroke MAN-B&W diesel engine, customized by Samsung, model 6S50MC (MK6).

From the MCR, the engine load diagram may be obtained, according to the procedure indicated in the "MAN Project Guide".

Once the engine load diagram is defined, it is possible to plot the power curve obtained according to what previously exposed. This step is called "matching" as it actually matches the available engine power with the one required by the propulsion chain through the propeller.

At this stage of the discussion, it is important to create a SFOC map that could be able to identify the SFOC for every point of the load diagram.

Specific fuel oil consumptions are provided by the manufacturer over the notional propeller curve.

This curve is given in the technical manual of the engine and it is different from the actual propeller power absorption curve since it approximates the propeller working points by means of a theoretical cubic curve passing through the MCR point.

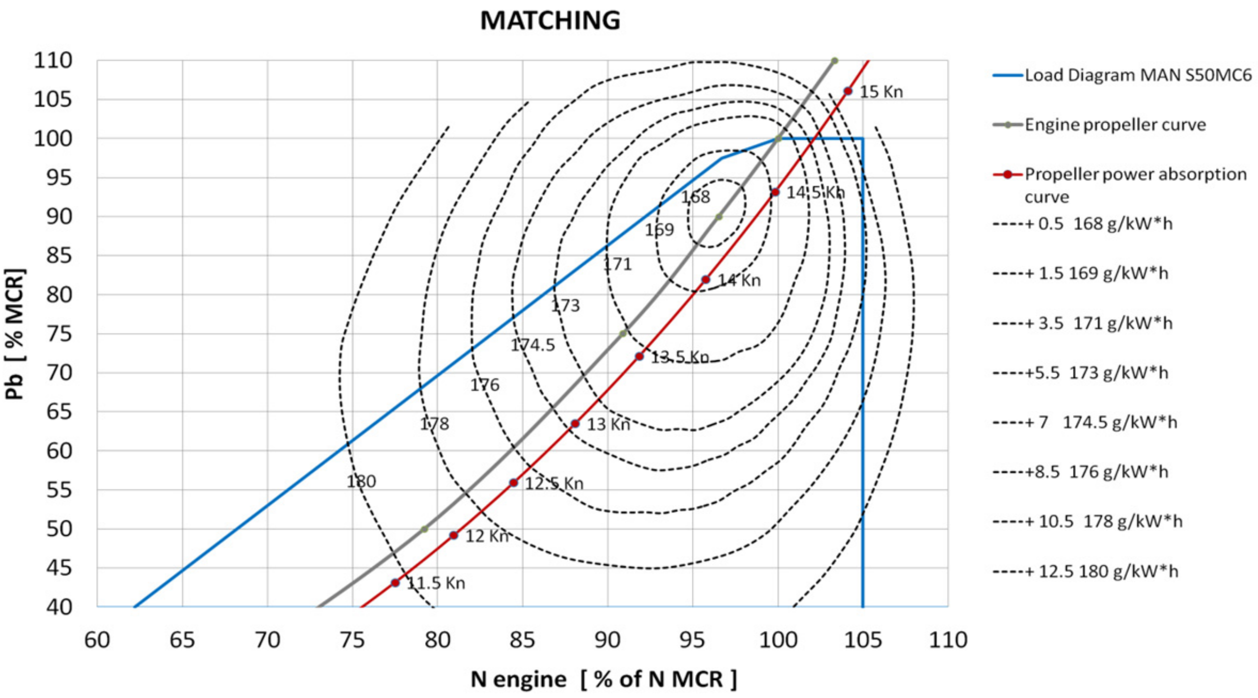

Figure 3: Specific Fuel Oil Consumption Map (derived by authors)

To proceed with the creation of a consumption map not available for the considered vessel, references have been made from a generic two stroke diesel engine SFOC map [9] in order to intercept its contour lines with the SFOC values given over the layout propeller curve of the MAN engine.

Once the contour lines and the point of minimum specific consumption are correctly positioned, the map is ready to be the background where to plot the propeller power absorption curve (Figure 3): in this way it is possible to read the specific fuel oil consumption for each speed, in any trim condition. This procedure has been linked to the above mentioned methodology for ship resistance evaluation at different conditions.

3.4 AIR POLLUTANT EMISSIONS

In the general context of sustainable development for the world economy, the shipping industry contributes to the global trade in order to have a relatively minimal impact on the environment. Despite the fact that shipping represents 90% of global trade, this is statistically the most efficient and least polluting way to transport goods.

For example, speaking about carbon dioxide, ships are responsible for about 3% of global CO_2 emissions [10].

Moreover, for each type of fuel there is a direct relationship between carbon content and the amount of CO_2 produced according to ISO 8217 Fuel Standard.

In this case, the fuel considered is a Heavy Fuel Oil with a carbon content of 0.85%: the coefficient provided to convert one kilo Newton of fuel burned to CO_2 kilo Newton of emissions is 3,1144. This approach is going to be applied later in the calculations.

3.5 VERIFICATION

A sensitivity check was carried out comparing the shaft power as predicted from the Holtrop method, with no added resistance, and the Sea Trial powering curve for a twin ship as provided from the ship owner (Figure 4).

The two curves are comparable especially in the range of practical interest, i.e. low speeds up to 14 Knots.

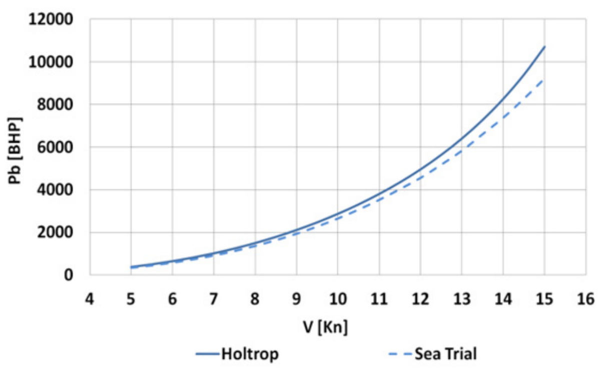

Figure 4: Shaft power comparison between Holtrop prediction and Sea Trials curve for a twin ship

A specific SFOC map for the given engine is not available, therefore it is difficult to compare the influence of the engine load on the specific fuel oil consumption, although the map well represents the trend for a generic two strokes engine.

However, the predictions of fuel consumption were compared with the actual values obtained from the ship owner as from the Voyage Audit Report.

For the given voyage at Loaded condition, the average Fuel Oil consumption is 31.60mT/day at 13.40 Knots. Different curves of daily Fuel Oil Consumption (FOC) were computed depending on the Sea State (Figure 5).

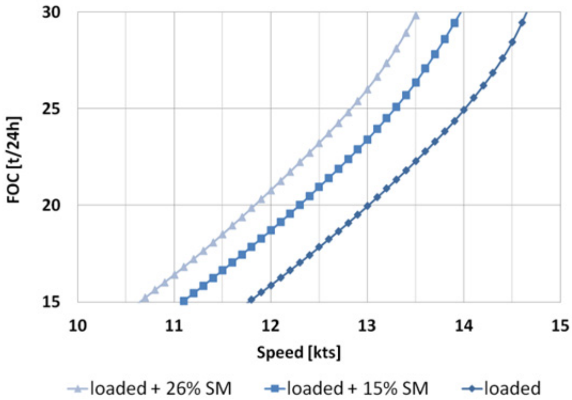

Figure 5: Daily Fuel Oil Consumption predicted for different Sea States

The lower curve do not consider added resistance, while the middle one represents the standard 15% Sea Margin and the upper one stands for 26% Sea Margin which is a more realistic prevision of the sea state encountered by the ship during this voyage, corresponding to Sea State 4 or BN 5. Entering in the graph with the same speed as in the report, is it possible to notice that the predicted and reported values agrees with an accuracy of 10%.

The underestimation in the fuel consumption is due to the effect of waves which is complex to evaluate, as well as the intrinsic approximations in the model.

4. RESULTS

Results are presented for a full loaded condition with 26% Sea Margin representative of the sea condition encountered on the route Bilbao–New York.

In the following graphs (Figure 6) the percentage of fuel consumption is presented in comparison to the nominal (no delay) on the vertical axis, while delays in hours are given on the horizontal axis.

In the first graph, is it possible to observe that, in case of announced 30 hours delay, reducing the speed since the departure, , up to 10% fuel can be saved. In the second graph, the theoretical curve for 0 VAD has been compared with other two curves, the middle one represents a reduction of speed from half course while the upper one from one quarter distance to the arrival port. The horizontal axis is limited to 12hours because for larger delay and low speed, is not possible to read the correct SFOC on the consumption map.

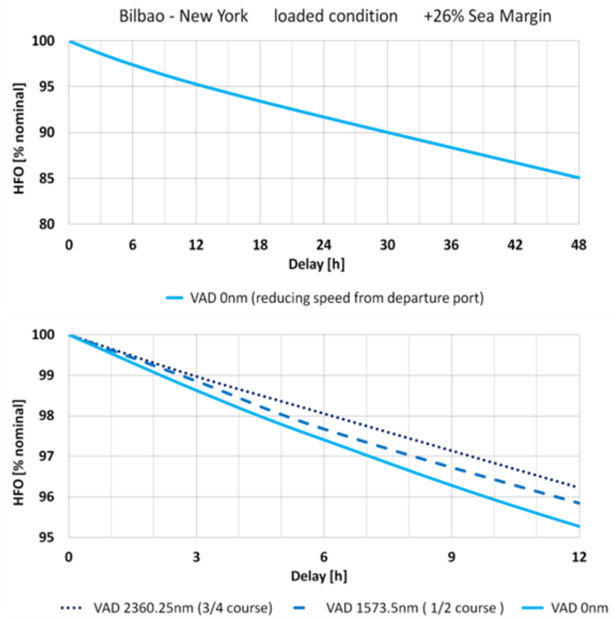

Figure 6: Percentages of fuel consumption over delay

The point of Virtual Arrival Decision (VAD) is a variable of the problem and it influences the fuel consumption, even if only by a few percentage points, as it is possible to note from the narrow distance among the three curves.

In particular, the bigger the delay is, the more saved tons of fuel there are: this is a general trend independent of the load condition and the propeller working point.

The next step is to compute the tons of CO2 emitted during this voyage, knowing tons and type of fuel burnt.

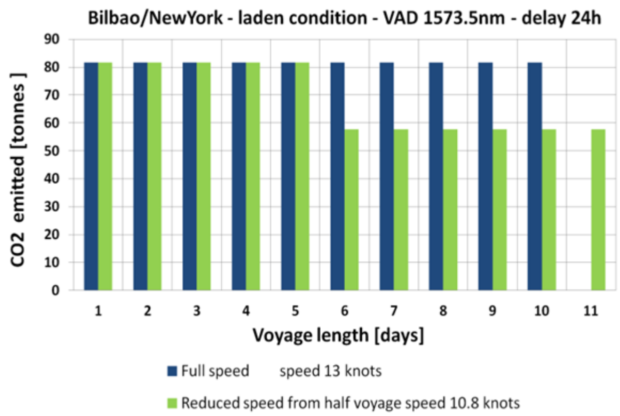

Figure 7: Impact of Virtual Arriving on CO2 emissions

The diagram above (Figure 7) presents the result of the virtual arrival procedure: the first bars report CO2 emissions in 10 days of sailing fully loaded at nominal speed, whereas the other bars show a speed reduction from half a course and then, one day more of navigation.

The figures reported in Table 2 show that up to 10% can be saved on bunker and CO2 emissions by means of a ship speed reduction in order to meet the new ETA when delays are identified at the discharge port.

CO_2 emissions at full speed	816.6	t
CO_2 emissions at reduced speed	754.9	t
reduction in CO2 emissions	61.7	t
reduction in SOx emissions	1.2	t
reduction in NOx emissions	1.5	t

bunker at full speed	262.2	t
bunker at reduced speed	242.4	t
bunked saved	19.8	t

Table 2: Benefits of Virtual Arrival

Talking specifically about the propeller working point, it is important to observe that the ship considered has a low Froude number (Fn < 0.2), hence the ship resistance is nicely approximated by the parabolic trend (9), therefore considering equation (10), it is possible to obtain the thrust as in equation (11).

$$R_T = \alpha \cdot V^2 \quad (9)$$

$$R_T = T \cdot (1 - t) \quad (10)$$

$$T = \frac{\alpha}{(1-t)} \cdot \left(\frac{V_a}{1-w}\right)^2 \quad (11)$$

It is now possible to evaluate k_T/J^2 (12) using the previous equation.

$$\frac{k_T}{J^2} = \frac{\alpha V_a{}^2}{(1-t)(1-w)^2 \rho n^2 D^4} \cdot \frac{n^2 D^2}{V_a{}^2} =$$

$$= \frac{\alpha}{(1-t)(1-w)^2 \rho D^2} \quad (12)$$

D, α, ρ are constant while *t* and *w* are weakly variable, for this reason the parameter k_T/J^2 is almost constant at any speed, hence it is possible to note that the advance coefficient *J* of equilibrium is contained into a narrow range of variation as for the open water efficiency η_O (Figure 8).

This permits to conclude that the possible shortcoming on η_O due to a working point at a lower ship speed, is generally not significantly jeopardizing the advantages on fuel consumption expected by a reduction in ship speed.

5. CONCLUSIONS

Since a global economic development is expected over the next few years, solutions to improve the energy efficiency of ships need to be considered: in case of port of call congestion, a ship speed reduction policy could be an initial strategy to cut fuel consumption and emissions.

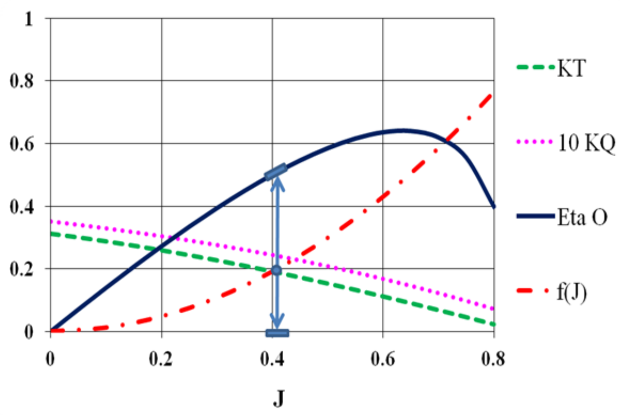

Figure 8: Propeller working point

In this paper a practical application of the Virtual Arrival policy has been investigated. Beyond the discussion on the governing parameters, the possibility to achieve an appreciable fuel consumption reduction has been demonstrated.

The result is of course mainly dependant on the power reduction but the timing of the decision of speed reduction has a not negligible influence as well. The influence of the engine SFOC and propeller η_O being different from the optimum design condition is nearly negligible. It is however fundamental to redefine the Charter Party contract and to improve collaboration between all the parties involved in the shipping industry.

6. ACKNOWLEDGEMENTS

The authors would like to thank d'Amico Tankers Navigation Company for all the material and the support given.

7. REFERENCES

1. Intertanko, OCIMF, "Virtual Arrival- Optimising Voyage Management and Reducing Vessel Emissions", *November 2010*
2. International Maritime Organization, "Guidance for the development of a ship energy efficiency management plan (SEEMP)", *MEPC.1/Circ.683, 17 August 2009, pp. 2 – 6*

3. International Maritime Organization, "Prevention of Air Pollution from Ships", *Second IMO GHG Study 2009 - Update of the 2000 IMO GHG Study*
4. J.-P. JALKANEN, A. BRINK, J. KALLI, H. PETERSSON, J. KUKKONEN, and T. STIPA, *"A modelling system for the exhaust emissions of marine traffic and its application in the Baltic Sea area",* Atmos. Chem. Phys., 9 9209-9223, 2009
5. HOLTROP J. and MENNEN G.G.J., "An Approximate Power Prediction Method", *International Shipbuilding Progress, Vol.29, July 1982*
6. HOLTROP J., "A Statistical Re-Analysis of Resistance and Propulsion Data"
7. OOSTERVELD M.W.C. and OOSSANEN P. VAN, "Further computer-analysed data of the Wageningen B-screw Series", *International Shipbuilding Progress, July 1975, pp. 251 - 262*
8. PRPIĆ-ORŠIĆ J. (University of Rijeka), NABERGOJ R. , TRINCAS G. (University of Trieste), "The methods of added resistance estimation for ship in a seaway"
9. SCHNEEKLUTH H and BERTRAM V., "Ship Design for Efficiency and Economy", *1998*
10. TOWNSIN R.L. , KWON Y.J., "Approximate Formulae for the Speed Loss Due to Added Resistance in Wind and Waves", *The Royal Institution of Naval Architects 1982*
11. PALTRINIERI S., "Ottimizzazione dell'accoppiamento motore-elica sulla base del minimo consumo orario", *Master Degree in Naval Architecture and Marine Engineering, University of Genoa, 2006*