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Report on WP 2.1 Potential Flow Methods for Seakeeping and Loss of Stability in Extreme Seas

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Document History

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SHOPERA-D2.1-ver.1	15-12-2014	*Potential Flow Methods for Seakeeping and Loss of Stability in Extreme Seas*
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Document Control Sheet

Title: Potential Flow Methods for Seakeeping and Loss of Stability in Extreme Seas

Abstract
The report provides information about the developments performed on the existing codes. IST and the University of Rijeka have further developed a code to determine the added resistance in waves and the specific fuel consumption associated with the operation of ships in various conditions. Calculations have been made over various routes of the Atlantic. NTUA have performed calculations to validate their parametric roll code and did further developments in the code.

Summary Report:

Progress report of the work performed under the Task 2.1 by the partners IST, NTUA and University of Rijeka as subcontractor of Ulianik Shipyard.

Introduction
One of the objectives of the project is to consider how ships will perform in adverse sea states. Task 2.1 deals with nonlinear codes of ship motions that can determine the various ways in which the ships can lose stability in these sea states and to determine the added resistance in waves.

Value added to SHOPERA
In Task 2.1 NTUA-SDL is working on the refinement and further development of the 3D seakeeping code HYBRID for simulating the 6 DoF nonlinear ship motions in adverse sea states and for studying the parametric rolling problem.
IST is working on the estimation of the effects of heading, sea-state, initial speed, ship draft and route on the attainable speed and the fuel consumption. The influence of wind is also being studied.

Achievements
1. Validation of numerical schemes for the convolution integral calculation.

2. 6-DoF motion simulation of S-175 containership at zero speed and nonzero speed.

3. Extension of the added resistance code, which was previously capable of treating only head seas, also to the oblique-sea cases. Preliminary validation has been done with the S-175 ship.

Input from other Deliverables
none

Exploitation of results
Developed method on the added resistance in short waves will/may be exploited in WP4/5/6 and in the new guidelines.

This executive summary may be published outside the SHOPERA consortium. *NO*

Work carried out by	**Approved by**
IST – C. Guedes Soares NTUA - Shukui Liu	*Name of internal reviewer and date of acceptance:*
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1 Introduction

The partners involved in this task are IST, NTUA and University of Rijeka as subcontractor to Ulianik Shipyard.

2 Report of activities

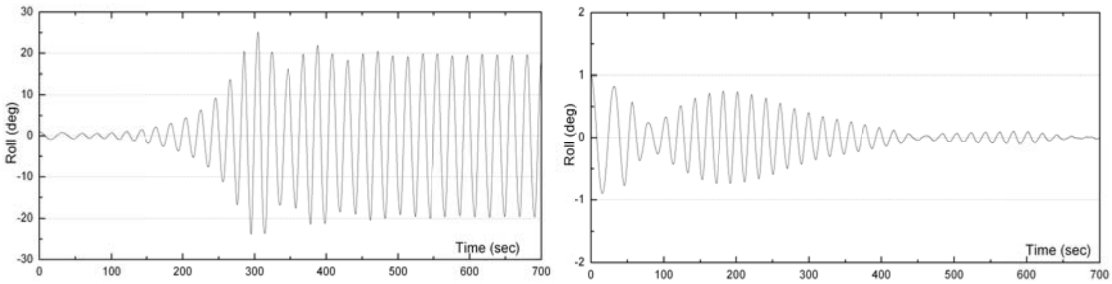
2.1 NTUA

2.1.1 Potential flow methods for seakeeping and loss of stability in extreme seas

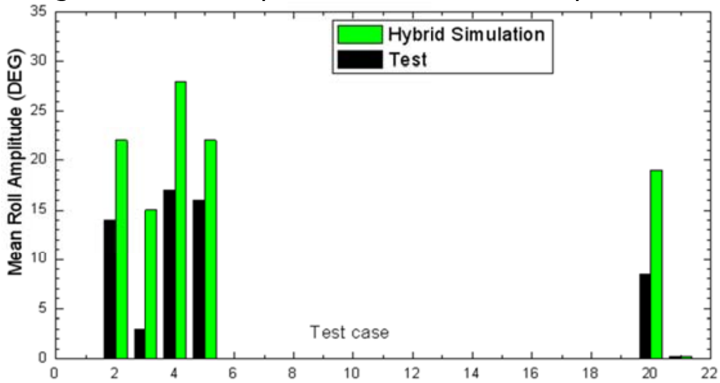
NTUA-SDL is working in Task 2.1 on the refinement and further development of the 3D seakeeping code HYBRID for simulating the 6 DoF nonlinear ship motions in adverse sea states and for studying the parametric rolling problem. The HYBRID code has been applied to the study of parametric rolling problem of the ITTC-A1 ship and the calculation of drift forces and added resistances of RoPAX, KVLCC2, and DTC ships. The HYBRID code is essentially a nonlinear time domain method based on the impulse response function concept and incorporates the nonlinear Froude-Krylov force and hydrostatic force to simulate the six DoF ship motions (Liu et al, 2014). For the calculation of drift forces and added resistances, the far-field method together with proper semi-empirical formula for short wave region correction is used (Liu et al , 2011 and Liu & Papanikolau, 2013).

Typical results are shown as follows:

Parametric Roll simulation- Comparison with model tests for ITTC-A1 ship (see, SAFEDOR benchmark study by Spanos-Papanikolaou, 2009):

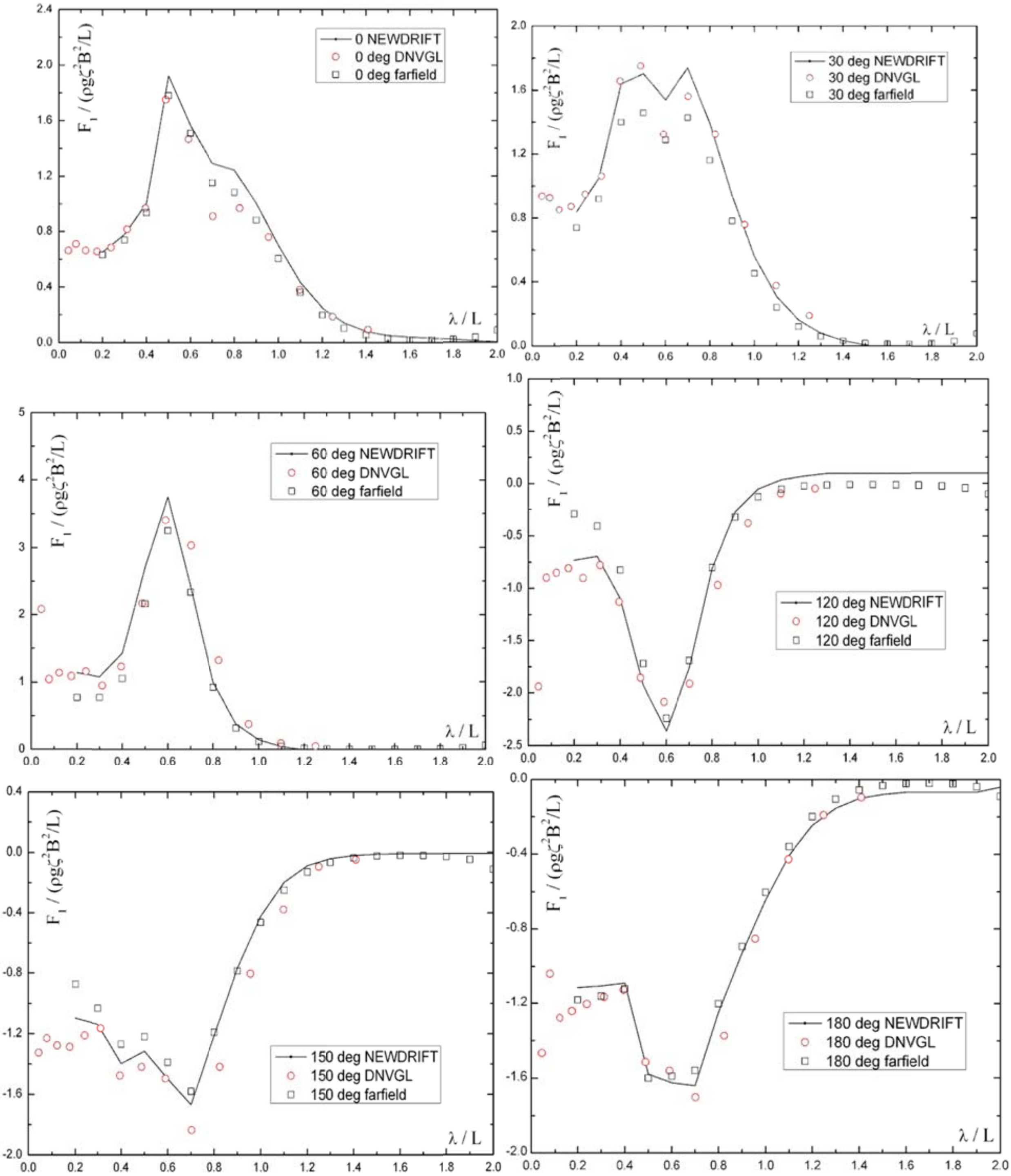


Time history of roll angle simulation of test case T20 and T21of ITTC-A1 ship in head waves



Comparison of simulation with tank test results

Drift and Added resistance calculations



Drift force results for KVLCC2 tanker in sea conditions of different headings
Near field method vs Far field method vs DNVGL

2.2 IST

A reliable estimation the attainable ship speed, fuel consumption and greenhouse gases (GHG) emission in different conditions of initial speed and loading and under the effect of various environmental factors is essential for an efficient maritime transportation. In a design phase these factors are often computed only for the calm water condition, however, during its exploitation, the ship encounters different sea conditions and in many occasions, the seaway influences the resistance and propulsion features.

In this work the effects of heading, sea-state (in terms of significant wave height and wave period), initial speed, ship draft (that is loading condition) and route on the attainable speed and the fuel consumption are estimated. The influence of wind is being currently studied.

The speed loss is calculated through a methodology proposed by Prpić-Oršić and Faltinsen (2012) by taking into account the engine and propeller performance in actual seas (including ventilation) as well as the mass inertia of the ship. The attainable ship speed is obtained as a mean of the actual speed computed in the time domain. The instantaneous ship speed is calculated according to the method proposed by Journee (Journee 1976, Journee & Meijers 1980) by taking into account propeller in-and-out-of-water effect on ship propulsion. The still water resistance is calculated according to Holtrop & Mannen method (Holtrop & Mannen 1982, Holtrop 1984), an approximate procedure which is widely used at the initial design stage of a ship. The calculation of added resistance in waves is partly carried out according to the direct pressure integration procedure developed by Faltinsen et al. (1980) integrated for the case of short waves by the asymptotic theory developed by the same authors give reliable results for moderate Froude numbers and common hull forms.

The main propulsion engine is modelled with a zero-dimensional model assuming constant torque (Medica & Mrakovčić, 2002). It ensure a precise determination of the engine fuel consumption in many conditions.

The open water propeller characteristics are obtained by Oosterveld & Oossanen method (1975), while the relation between the thrust required by the propeller and the number of revolution is obtained by using the torque characteristics of an assumed B-series propeller behind the ship and a wake fraction. The thrust loss coefficient is estimated from a simplified ventilation thrust loss model, which is obtained by utilizing known experimental data (Smogeli, 2006).

A ship slows down either involuntarily due to increased resistance from the wind and waves, or voluntarily due to navigation hazards or fear of heavy weather damage from excessive ship motions and accelerations, propeller racing, slamming or boarding seas. At lower sea states, decrease of ship speed is related to additional resistance due to waves and wind, while at higher sea states the safety of ship operation depends significantly on weather conditions and the full range of adverse dynamic effects must be taken into account. Both the causes of speed reductions are considered into account in this work. Slamming probability, green water probability, vertical acceleration and propeller emergence probability are taken into account for voluntary speed reduction with limits recommended in the literature (0.01, 0.05, rsm 0.215g and 0.1, respectively). This allows a reliable estimation of the voluntary speed loss especially in head, quartering and following seas, while the influence of roll, that is currently under study but still not included in the method, limits its use in beam seas.

A very important factor in assessing the cost of travel is the ship route planning. For this reason the results have been used to predict speed loss and fuel consumption in the main routes of the North Atlantic (see figure 1) considering the specific weather that the ship will experience in each path described by mean of wave scatter diagram and relative wave heading probabilities (Vettor and Guedes Soares, 2015).

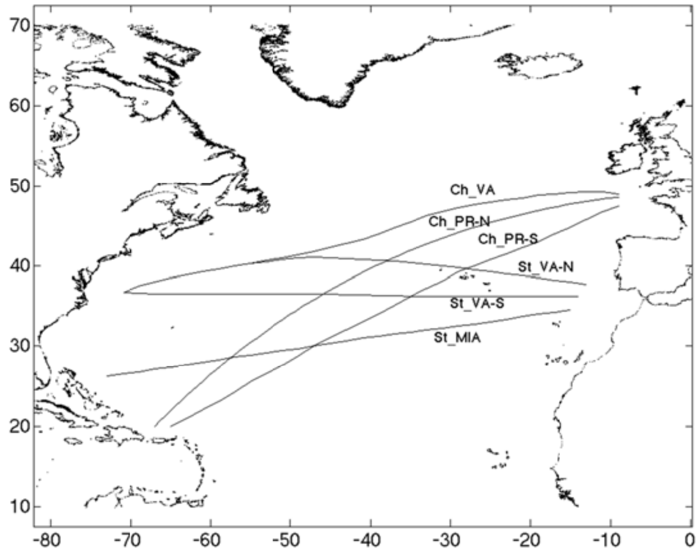


Figure 1. Main North Atlantic trans-oceanic routes (from Vettor and Guedes Soares, 2015)

The calculations of attainable ship speed, fuel consumption and related CO2 emission have been performed for the S-175 containership. The main particulars of the ship are given in Table 1 (ITTC, 1978). A fixed pitch propeller of 5.6 meter diameter with 6 blades is used. For main engine dynamic simulation a two-stroke low speed marine engine is used.

Table 1. Main particulars of the S-175 container ship

Length between perpendiculars	175.0 m
Breadth moulded	25.4 m
Design draft	9.5 m
Freeboard	7.0 m
Displacement	24272 tonnes

The attainable speed and the respective fuel consumption calculated for head and following waves, obtained for the most probable zero crossing periods related to specific sea states using ITTC spectrum, are shown in figure 2, figure 3, figure 4 and figure 5. The curves refer to the case of involuntary (full line) and voluntary speed reduction (dashed line).

The Fig. 2 shows that the attainable ship speed estimated for sea states with significant wave height from 8 to 12 m is nearly constant (even slightly higher for significant wave height of 12 m), while for following seas the value of speed drop will continue to grow as expected. This trend could be explained by the fact that the one-parameter wave spectrum is used. So, for very high significant wave height it probably gives back a sea-state characterized by very long waves (high zero crossing period), thus there are almost no relative motions. It can also be assumed that is impossible to obtain reliable values of ship speed for such adverse weather conditions where the ship dynamics is affected by many highly nonlinear effects. However, the inaccuracy of those results will not significantly affect the results of mean ship speed for the whole voyage because such extremely high sea states are very rare, and even if the ship is going toward such storm, the master will certainly try to avoid it (Prpić-Oršić et al. 2014).

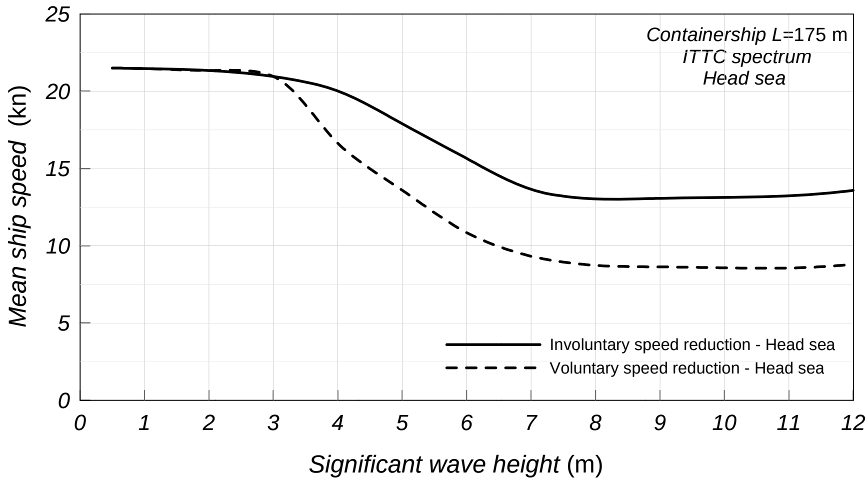


Figure 2. Ship speed loss for head sea

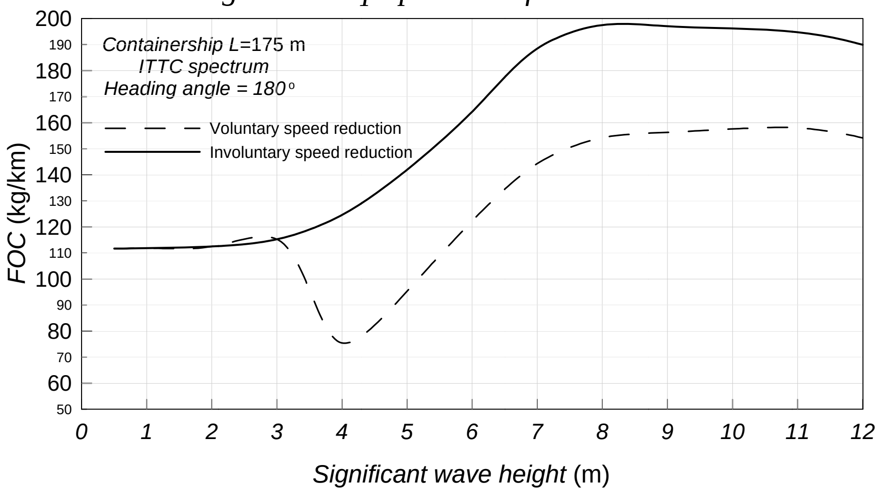


Figure 3. Fuel consumption for head sea

As expected, the trends of fuel consumption and CO_2 emissions follow the speed loss trend. It can be noticed that for sea states with significant wave height higher than 4 m, the speed loss significantly increase as well as the fuel consumption.

Furthermore the analysis showed that the small change of draft could significantly affect the speed loss under real weather conditions. The analysis of the speed loss percentage for different initial ship speed (full ahead and lower engine loads) shows that lowering the ship speed does not always mean economic voyage, especially considering various loading conditions. This has been found for instance comparing the cases of 12 kn and 24 kn at ship draft of 9.5 m where, in percentage, speed loss was be doubled (voluntary) or tripled (involuntary) for lower speed values.

The mean results for the six main North Atlantic routes have been analyzed for the cases of involuntary and voluntary speed reduction. As an example, table 2 provides the results relative to the fuel consumption and the CO_2 emissions for the case of voluntary speed reduction. The percentage of voyage time increase compared to still water is approximately doubled when considering voluntary speed reduction. For the selected ship the northernmost route (Ch_VA in figure 1) seems to be the most demanding from that point of view and at this route "real-weather" voyage duration increased by almost 14% compared to time needed in "calm-weather" conditions. At the same time, due to the lowering of the power, the fuel consumption decreases by 10% as well as CO_2 emission.

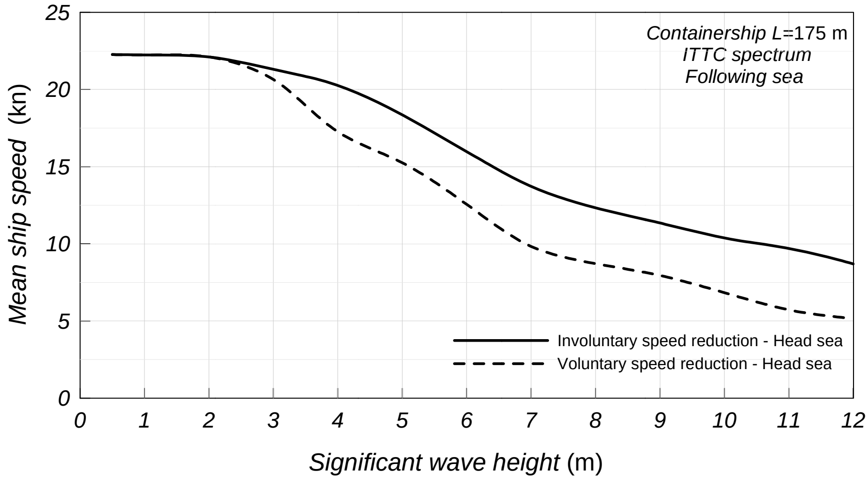


Figure 4. Ship speed loss for following sea

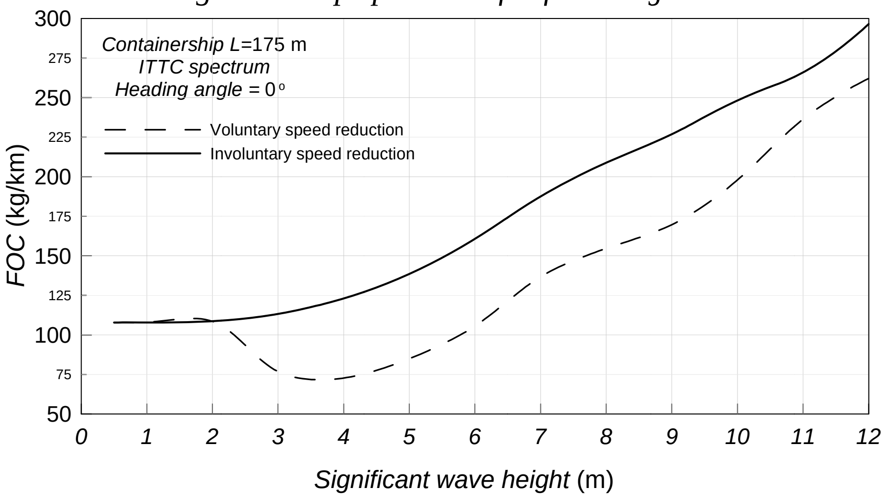


Figure 5. Fuel consumption and CO_2 emissions for following sea

The results of proposed strategy will improve a very important segment of maritime transport technology, i.e. green ship design and shipping which assumes decreasing of fuel consumption and GHG emissions and at the same time much safer navigation for crew, passengers and the ship herself.

Table 2. Fuel consumption and CO_2 emissions (real weather conditions – voluntary speed reduction).

		Route 1	Route 2	Route 3	Route 4	Route 5	Route 6
Speed	[kn]	20.3	19.9	19.3	20.8	19.8	20.2
Time	[h]	158.4	163.1	145.8	146.7	138.4	136.8
	% increase	7.6%	9.3%	13.1%	4.9%	10.1%	8.0%
FOC	[kg/km]	103.2	102.2	99.5	104.6	100.8	102.2
	% increase	-6.3%	-7.2%	-9.7%	-5.0%	-8.4%	-7.2%
CO_2	[kg/km]	327.5	324.4	315.6	332.0	320.0	324.1

3 Major achievements within the scope of the project

1. Validation of numerical schemes for the convolution integral calculation.
2. 6-DoF motion simulation of S-175 containership at zero speed and nonzero speed.
3. Extension of the added resistance code, which was previously capable of treating only head seas, also to the oblique-sea cases. Preliminary validation has been done with the S-175 ship.

4 Dissemination activities

A paper entitled "Time domain simulation of nonlinear ship motions using an impulse response function method" was published on ICMT2014.

A paper entitled "Practical approach to the added resistance of a ship in short waves" is officially accepted by ISOPE2015.

The full paper entitled "Prediction of Parametric Rolling of Ships in Single Frequency Regular and Group Waves" has been submitted to STAB2015.

Journal papers:

Vettor, R., Guedes Soares, C. (2015). Detection and analysis of the main routes of voluntary observing ships in the North Atlantic, Journal of Navigation, *68 (2015) 397*

Vettor, R., Guedes Soares, C. (2015). Assessment of the storm avoidance effect on the wave climate along the main North Atlantic routes. (submitted to Journal of Navigation).

5 Exploitation of results

Developed method on the added resistance in short waves will/may be exploited in WP4/5/6 and in the new guidelines.

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