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Executive Summary

This document reports about an update of the database of ferry performance and emissions from the ship simulator hosted at Unizd, which first version was provided along with D.3.2.2. The current deliverable includes propulsion and performance data of a specific Ro-Pax ship and her CO2 emissions in terms of environmental state variables. Resulting data were fitted by a multi-dimensional models developed and implemented by CMCC. The response model is used by the ship routing model VISIR for the computation of eco-routes for ferries in the Adriatic Sea.

1. Introduction

This report corresponds to GUTTA project deliverable D 4.1.1, and documents its execution and the results achieved.

From the ship simulator hosted at UniZd, parameters such as speed through water, engine rpm, propeller rpm, main engine power output, emission measurements and more were measured, recorded and then analyzed. 17 different parameters across 287 different simulations and simulated conditions are recorded for the purposes of determining the relation between external conditions and energy consumption and flue gas component emissions.

The raw data were then fitted for extracting a functional dependence of vessel performance and emissions on the wind and sea state. Such response is used by the latest version of the ship routing model VISIR for computing least-CO2 routes in the Adriatic Sea. For this, we refer to the companion deliverable D. 4.1.2 and to the journal paper [1].

The report is organized into a description of the methodology (simulators and data processing), in Sect.2, and presentation of the results, in Sect.3. The conclusions are drawn in Sect.4.

2. Methodology

The University of Zadar, at its premises, owns a coupled command-bridge engine-room simulator. For the purpose of GUTTA project, the software data package for a specific ferry was acquired.
As described in D.3.2.2 the simulator consists of the "Wärtsilä-Transas Marine NTPro 5000 Navigation Simulator" with a "Full mission" command-bridge simulator and a realistic console coupled to the "Wärtsilä ERS-LCHS 5000 TechSim" engine-room and cargo-handling simulator.

The simulated vessel type used for GUTTA project is a Ro-Pax ferry with a twin, four-stroke engine (MAN Diesel 32/40 Twin Medium Speed Engines) with controllable pitch propellers (cpp). The vessel also includes cpp bow thrusters (hydraulic system not modelled) with a power of 1,000 kW and two fin stabilizers which may or may not be active. The simulated vessel and its specific characteristics are shown in Figure 1 and Table 1 [2].

- Length, overall – 125 m
- Breadth, molded – 23.4 m
- Designed draft, molded – 5.3 m
- Service speed – approx. 19 knots

Propulsion:

- 2 x MAN 8L32/40 Four stroke, medium speed, turbocharged, non-reversible main diesel engine, MCR 4,000 kW at 750 RPM
- 2 x Controllable Pitch Propeller (CPP)
- CPP Bow Thruster 1000 kW
- 2 x Fin Stabilizers

Electric Plant:

- 3 x Diesel Generator 600 kW, 450V AC, 60 Hz, 3 ph (diesel engine – CAT 3508B)
- 1 x Shaft Generator (PTO) 1160 kW, 450V AC, 60 Hz
- Emergency Diesel Generator 260 kW, 450V AC, 60 Hz

Figure 1 Wartsila ROPAX simulator specifications [2]

Table 1 Additional specific characteristics of the simulated vessel model
(starred quantities are not reported by the manufacturer but correspond to values for similar vessels)

	Name	*Symbol*	*Value*	*Units*
Hull	Length overall	LOA	125	m
	Length at waterline	L_{WL}	114	m
	Breadth	B	23,4	m
	Draft middle	T	5,3	m

	Hull coefficient	C_B	0,54	-
	Deadweight	DWT	4050	t
	Gross tonnage*	GT	14000	t
	Number of passengers*	n_{PAX}	400	-
	Lane meters*	L_m	1250	m
Propulsion	Main engine power	P_{ME}	4000	kW
	Main engine rated speed	R_S	750	rpm
	Service speed	v_S	19	kts
	Auxiliary engine power	P_{AE}	3 x 600	kW

The simulator was used to simulate different conditions in order to determine the relation between external (wind/wave) conditions and energy consumption and flue gas component emissions. The configuration of the wind and wave variables is based on the relation from [3]. Swell and sea-currents were not used as part of the configuration. The wind/wave to ship heading true direction was variable in the range 0° to 180°, while the engine load (MCR) varied between 70% to 100% MCR.

The following is a list of the main recorded parameters:

- speed through water (STW)
- Shaft power (P)
- Specific fuel oil consumption (SFOC)

The shaft power and specific fuel oil consumption resulted from averaging of the values for the twin main engines. For each simulator setup (i.e., values of wind magnitude and direction plus telegraph lever/engine load), a time dependent signal was recorded for about 25 minutes long. Its initial transient dynamics (about 2 minutes) were not used, and the remaining signal (which was quite constant) averaged. Stabilizer fins of the ferry hull were not active.

The multi-dimensional dependence of each output variable (STW, P, SFOC) was fitted by means of a cascade of 1D least-square fits, each using elementary functions only (polynomial, trigonometric, or exponential functions). The final fit function was evaluated vs. the observed data (i.e., the simulator data) in terms of standard statistical metrics (bias, rmse, correlation coefficient) presenter later in Table 2.

The final calculation of CO_2 emission rate (tons CO_2/hour) is done as shown in the following relation:

$$\frac{dCO_2}{dt} = SFOC \times P \times C_f \qquad (1)$$

where C_f represents a conversion factor of 3,206 g/g accounting for marine diesel oil fuel [4].

Emissions from the auxiliary engine were not considered, as during the simulation load on each diesel generator was constant and at only about one quarter of the power reported in Table 1. The total CO_2 emission were obtained by integrating the rate of Equation (1) along the ship path.

3. Results

The multidimensional information collected at the ship simulator along with the fit results is presented in Figure 2.

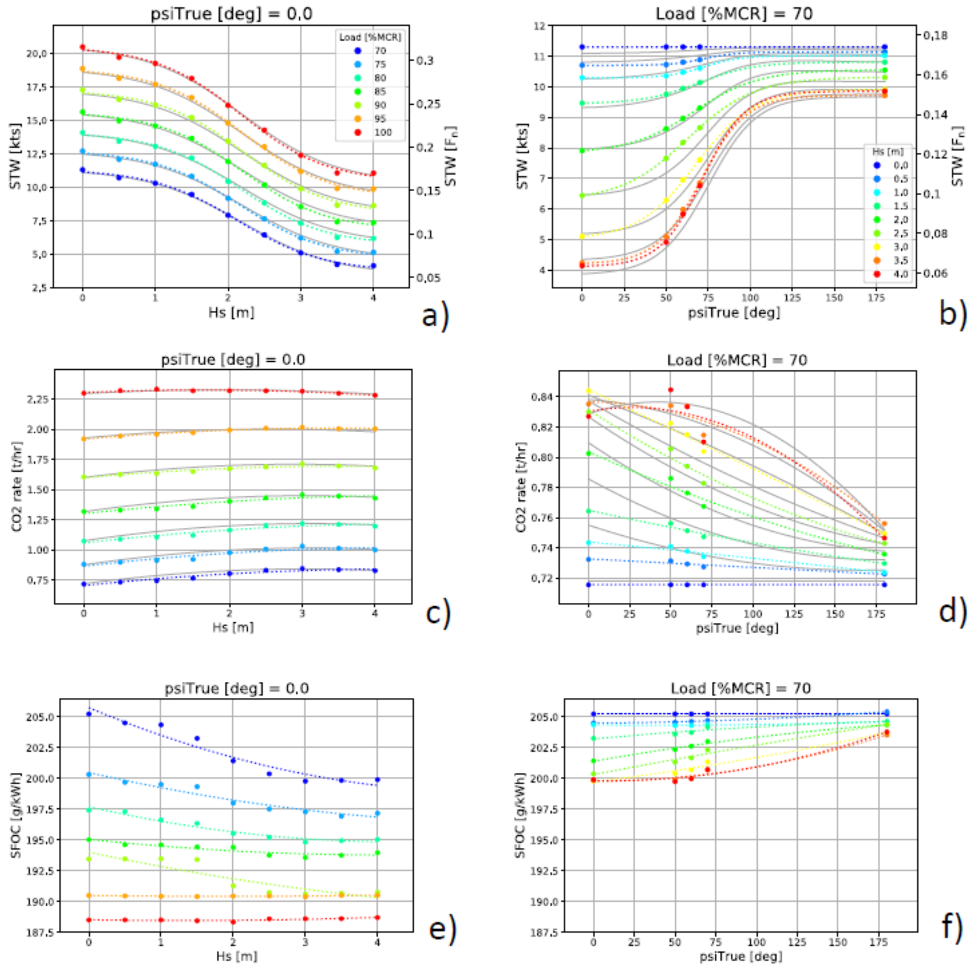

Figure 2 Slices of the multidimensional response function of the vessel of Figure 1 collected at the simulator (dots) compared to 1D fits (colored dotted lines) and to multi-dimensional fits (grey lines)

The left column panels represent dependences on maximum significant wave height (Hs) at various main engine loads (%MCR) for head seas (Ψ=0°) while the right column represents dependences on angle of attack of wind Ψ at various wave heights (Hs), for MCR = 70%.

The ferry speed loss as a function of significant wave height is presented in Figure 2a. For a given Hs, the spacing between STW values relative to fractional engine load values is, in the range explored, nearly constant. As it can be seen, the spacing decreases from 1.5 to 1.2 kts as Hs increases from 0 to 4 m.

The dependence of STW on wind angle Ψ, can be fitted by a hyperbolic tangent, Figure 2b. Maximum speed loss occurs for head seas, with a sharp reduction from head to following winds occurring at 50° < Ψ < 70°. This could be possibly related to the asymmetry of the vessel's superboard.

The CO2 emission rate is calculated using Equation (1) and displayed in Figure 2c,d. For a given sea state, it increases threefold as % MCR raises from 70% to 100%. However, for a given angle of attack of wind and engine load, dCO2/dt still varies with Hs by more than 10% at the lowest load (Figure 2c). For a given load and significant wave height, it also changes with the angle of attack in an appreciable way, especially at large Hs, where it reduces by about 10% as one goes from head to following sea (Figure 2d).

It should be noted that combinator mode was used for simulated vessel propulsion system. During combinator mode the engine revolutions are proportional to fractional engine load (i.e. position of telegraph lever). Main engine load accounts for most of the variability of both STW and emission rate while the residual variability is ascribed to the running conditions of the propeller. As propellers run in heavier conditions, power delivered at the propeller shaft increases, while SFOC decreases (Figure 2e,f). Power was not shown on afore mentioned figures, but can be obtained from Equation 1.

Overall quality of the multidimensional fits with respect to the original datapoints gathered from the ship simulator was assessed through standard metrics and presented in Table 2. Presented metrics for the entire set of datapoints (315 values) and for a specific engine fractional load value (45 values) show quite satisfactory results.

Table 2 Quality assessment of the multi-dimensional model of the vessel response function with respect to the simulator datapoints

Variable	Engine load	Bias	RMSE	Pearson's R
STW	all	-0.66%	0.19 kts	0.9987
dCO_2/dt	all	+0.49%	0.014 t/hr	0.9997
STW	70%	-1.40%	0.22 kts	0.9968
dCO_2/dt	70%	+1.16%	0.014 t/hr	0.9644

4. Conclusions

The results documented in this report show the promising features of using advanced simulators to research and model various dependencies between weather and sea loads and their effect on fuel efficiency and greenhouse gas emissions.

By using the data base of collected simulated Ro-Pax vessel parameters at different conditions the functional dependence between external (wind/wave) conditions and energy consumption, power and CO2 emissions was created.

The results and their metrics show quite satisfactory results which will be used for the development of next phase of new VISIR-2 model. Also, the results gathered during this research period of the GUTTA project will be used/compared to data collected aboard actual ships, described in report D3.1.3., for validation of the response model derived from the ship simulator.

References

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