Influence of Lightweight Change on Ship Performance

Matija Vasilev
University of Belgrade
Faculty of Mechanical Engineering
Ocean Pro Marine Engineers LTD

Milan Kalajdžić
University of Belgrade
Faculty of Mechanical Engineering
Associate professor

An influence assessment of lightweight change on Energy Efficiency Existing Ship Index/Energy Efficiency Design Index performance for two supramax bulk carriers is presented in this paper. The study covers a variation of lightweight from 100% to 85% with the step of 5% reduction. The influence on ship performance is determined through deadweight, reference speed, and engine load. In one part of the work, deadweight is considered to be constant, so the study covers the impact of displacement change on ship speed and power, while in the other one, displacement was kept the same so that the direct influence of deadweight on performance indices was considered. Due to displacement change, a new power curve should be derived, and for this purpose, the Holtrop-Mennen method has been used to predict total resistance. Estimated results show that an increase in speed can be up to 0,7% for the same power and a reduction in power up to 2,6% for the same speed. An increase of a deadweight affects the performance indices up to 3,2%.

Keywords: *energy efficiency, EEDI, EEXI, lightweight*

1. INTRODUCTION

Displacement of the ship consists of lightweight (*LWT)* and deadweight (*DWT)*. Lightweight is a term that represents the total weight of an empty ship (mass without cargo, fuel, lubricating oil, water (ballast, fresh, potable, stores, people (passengers and crew)). Deadweight is defined as a variable load that a ship can carry. One of the most important things in the initial design stages is to estimate the LWT as precisely as possible. Lightweight can be roughly separated into the weight of the hull (steel weight), the weight of the machinery (equipment weight), and the weight margin. There are a lot of approximate formulas for determining the weight of the hull and machinery. Some of the empirical formulas for direct calculation of previously mentioned groups of weight have been in use for decades and can be found in [1-3]. Weight margin or tolerance of uncertainty in the initial design stage is 3% of the deadweight according to [2], 1-2% for simple structures (tankers and bulk carriers), and 2-3% for more complex ships [3]. Nevertheless, the initial *LWT* assessment can be based on a non-dimensional coefficient [3], such as ratios between certain weight groups, including *the DWT- Δ* ratio for a particular type of ship. As the most common and precise procedure nowadays, it can be considered as the conversion of weights from the parent ship to the designed ship [4]. It is interesting that in the last 50 years, the *LWT* has had a decreasing trend of roughly 20% for some ship types [5], and according to [6], the average efficiency has improved by 22-28% within a decade. Also, according to [7], the *LWT-LBD* ratio (where *L* – length, *B* – breadth, *H* – depth) is decreasing for larger *DWT*, which means that smaller ships are usually heavier, which is one of the reasons why larger ships are being built.

On the other hand, over the decades, supply and demand have increased globally due to society's development and civilization's progress. Consequently, there was a need for a greater and more frequent exchange of goods between more distant countries. This led to the design and construction of larger ships [7,8]. Larger ships also required the installation of larger engines, while larger engines required a larger amount of fuel, and combustion of a larger amount of fuel leads to greater pollution from greenhouse gases. Even though in 2011 Marine Environment Protection Committee released a resolution [9] in order to prevent pollution from newbuilt ships falling under the MARPOL Annex VI and over 400 GT through *EEDI* that set-in use from 2013, the global trend of CO_2 is still rising [10]. Also, International Maritime Organization (IMO) has introduced an energy efficiency parameter [11] for existing ships through *EEXI* that will enter into force in 2023. and it is based on *EEDI*. This regulation covers only seagoing ships, while some of the first evaluations of inland waterways cargo ships' efficiency indices are described in [12].

The overtaken work has to give an answer how extensive can be the benefit in energy efficiency if the *LWT* is reduced and whether it could be compared with other energy-saving measures such as the installation of Energy Saving Devices (ESD), optimized operational strategies, fuel changes, hull cleaning, and anti-fouling paint application, propeller polishing, etc. The ESD can improve the overall efficiency by 6-14% with pre-swirl ducts [13] or 2-5% with post-swirl devices [14]. Optimized operational strategies such as optimum trim, speed, and routing can save up to 5% in power [14]. The effect of different fuel types on the environment can be found in [15,16], while the anti-fouling application and polishing could have a significant influence [17, 18].

Received: June 2022, Accepted: September 2022

Correspondence to: Matija Vasilev
Ocean Pro Marine Engineers LTD,
Takovska 45, 11000 Belgrade, Serbia
E-mail: matija@oceanpro.eu

doi: 10.5937/fme2204615V

2. METHODOLOGY

Two ships are considered in this paper: bulk carrier 1 and bulk carrier 2. The main particulars are shown in Table 1:

Table 1. Main particulars

	Bulk Carrier 1		Bulk Carrier 2	
	Scantling	Design	Scantling	Design
year	2011		2010	
Loa [m]	197		189.9	
Lpp [m]	194		182.7	
B [m]	32.26		30.5	
H [m]	18		17.5	
T [m]	12.65	11.3	12.8	11
WS [m^2]	10084	9508	9054	8305
AT [m^2]	25.6	5.2	6.05	0
LCB [%]	1.14	1.54	1.93	2.38
KB [m]	6.571	5.861	6.637	5.686
Cb [-]	0.853	0.844	0.831	0.819
Cp [-]	0.855	0.847	0.835	0.823
Cw [-]	0.929	0.925	0.915	0.891
Δ [t]	69179	61150	60796	51498
DWT [t]	58675	50646	50136	40838
LWT [t]	10504		10660	
MCR [kW]	8630		9480	
V_{des} [kn]	14.5		14.5	

They have different bow types: bulk carrier 1 has an unusual bow with a vertical stem, while bulk carrier 2 has a bulbous bow. Their non-dimensional resistance $Rt/(\Delta \cdot g)$ in the function of Froude number (based on length) is shown in the following figure:

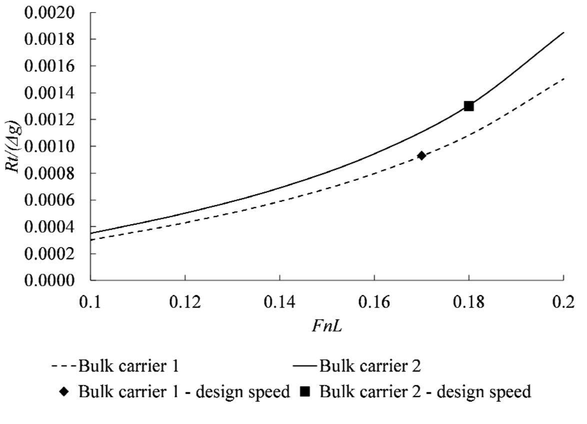

Figure 1. Non-dimensional total resistance vs. speed comparison

Bulk carrier 1 has approximately 19% (average) better performance for the same speed (Figure 1). Also, bulk carrier 1 has approximately 10% larger wetted surface, which is a dominant part of viscous resistance at low speeds. This means that pressure resistance is significantly less because the total resistance of this ship is less. Both ships were completed (built) within a year, but the keel of bulk carrier 2 was laid in 2004. while the keel of bulk carrier 1 was laid in 2010. It seems that in a period of 6 years, design in the shipping industry has significantly progressed. Ships have become lighter, could carry more cargo, and go faster even with a less powerful engine.

Both ships are made from the same steel grade (mild steel); although bulk carrier 1 is longer and wider, she is also lighter. The capacity of bulk carrier 1 is greater by approximately 10000t at the design draft. So, it was interesting to find out, could bulk carrier 2 be faster if she had been made lighter.

Figure 2 are shown 3D models of both considered bulk carriers, while characteristic sections are shown at the end of this topic.

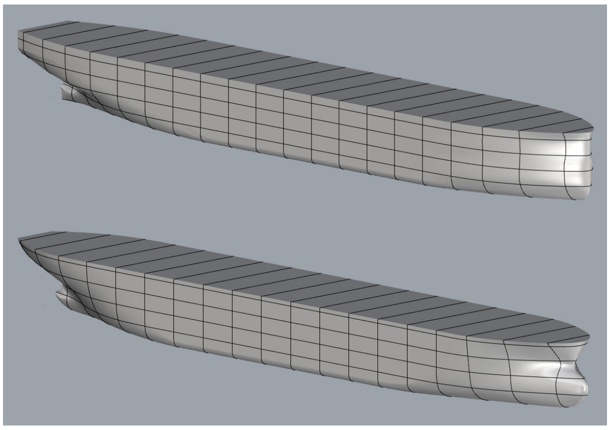

Figure 2. Hull shape - bulk carrier 1 (up), bulk carrier 2 (down)

The reduction of *LWT* in this paper refers to the reduction of steel weight, but this information is not given in the ship's documentation. So, the steel weight and machinery weight for both ships are approximated as an average value derived from the following formulas also given in [3]:

$$m_1 = 0,1 \cdot X \cdot e^{-5,7310^{-7} \cdot X}, X = \frac{1}{12} \cdot L^2 \cdot B \cdot \sqrt[3]{C_B} \quad (1)$$

$$m_2 = \frac{1}{6} \cdot C_B^{2/3} \cdot L \cdot B \cdot H^{0,72} \cdot \left[0,002 \cdot \left(\frac{L}{H} \right)^2 + 1 \right] \quad (2)$$

$$m_3 = 0,03325 \cdot L^{1,65} \cdot \left(B + H + 0,5 \cdot T \right) \cdot (0,5 \cdot C_B + 0,4) \quad (3)$$

$$m_4 = 0,032 \cdot E^{1,36}, E = L \cdot \left(B + T \right) + 0,85 \cdot L \cdot \left(H - T \right) \quad (4)$$

$$m_5 = \left[0,07 + 0,064 \cdot e^{-\left(0,5 \cdot u + 0,1 \cdot u^{2,45}\right)} \right] \cdot L \cdot B \cdot H ,$$

$$u = \log \left(\frac{\Delta}{100} \right) \quad (5)$$

$$m_6 = 0,78 \cdot LWT . \quad (6)$$

Average approximated data are given in Table 2:

Table 2. Estimation of group weights

	Bulk carrier 1	Bulk carrier 2
W_{steel} [t]	9130	8251
$W_{\mathrm{machinery}}$ [t]	1292	1305
LWT_{app} [t]	10422	9555
LWT [t]	10504	10660
Δ*LWT*	-1%	-10%

Approximated LWT_{app} of bulk carrier 1 is within the proposed margin, while *the* LWT_{app} of bulk carrier 2 is underestimated by 10%. The proposed reduction rate for steel weight is 5, 10, and 15% in accordance with previous observations and achieved possible reductions described in [19]. After applying reduction rates, total *LWT* is decreased for 4, 9, and 13% (bulk carrier 1) and 4, 8, and 12% (bulk carrier 2). In order to simplify the procedure and further calculation, the estimated new *LWT* equals to original reduced by 5, 10, and 15%. This means that reduction is not directed to steel weight only but to total *LWT*.

The influence of *LWT* reduction was determined through three parameters, and the estimation procedure is summarized in Table 3:

Table 3. Overall calculation procedure

	LWT	*DWT*	*Δ*	V_{ref}	*Engine Load*
Case 1	100%	original	original	original	original
	95%	const.	reduced	to estimate	const.
	90%				
	85%				
Case 2	100%	original	original	original	original
	95%	const.	reduced	const.	to estimate
	90%				
	85%				
Case 3	100%	original	original	original	original
	95%	increased	const.	/	/
	90%				
	85%				

The term 'original' in the previous table means that *DWT* and *Δ* are taken from the ship's Stability Booklet.[1] For scantling and design draughts, while original speed represents reference speed, and the original engine load is engine power load which corresponds to reference speed. Reference speed is needed for attained *EEXI* and attained *EEDI* calculation. Full form of attained *EEXI* and attained *EEDI* formulas are given in [19] and [20], respectively, but here, these parameters are evaluated according to simplified form:

$$att.EEXI = \frac{P_{ME} \cdot C_{FME} \cdot SFC_{ME,app} + P_{AE} \cdot C_{FAE} \cdot SFC_{AE,app}}{f \cdot Capacity \cdot V_{ref,EEXI}} \quad (7)$$

$$att.EEDI = \frac{P_{ME} \cdot C_{FME} \cdot SFC_{ME,app} + P_{AE} \cdot C_{FAE} \cdot SFC_{AE,app}}{f \cdot Capacity \cdot V_{ref,EEDI}} \quad (8)$$

All parameters from (10) and (11) are described in [11,18,19]. The required *EEXI* and *EEDI* are calculated in accordance with [11]:

$$req.EEXI = req.EEDI = a \cdot DWT^{-c} \cdot \left(1 - \frac{Y}{100}\right) \quad (9)$$

where for bulk carriers a = 961,79; c = -0,477 and Y = 20 [11]. Attained *EEXI* and *EEDI* have to be below their required *EEXI* and *EEDI*. $V_{ref,EEDI}$ is defined as the speed at 75% of Maximum Continuous Rating (*MCR*), while $V_{ref,EEXI}$ is calculated in accordance with the following equation given in [19]:

$$V_{ref,EEXI} = k^{\frac{1}{3}} \cdot \left(\frac{DWT_{S,service}}{Capacity}\right)^{\frac{2}{9}} \cdot V_{S,service} \cdot \left(\frac{P_{ME}}{P_{S,service}}\right)^{\frac{1}{3}} \quad (10)$$

Service power ($P_{S,\ service}$) is equal to 85% of *MCR* and with no sea margin included. $DWT_{S,\ service,}$ corresponds to design deadweight, while $V_{S,\ service}$ is the sea-trial service speed under the design draught corresponds to $P_{S,\ service}$. k is scale coefficient and equals 0,97 [20]. Reference speed for *EEDI* is evaluated in accordance with the [21] and it is a speed that corresponds to 75% of maximum installed power (*MCR*).

In cases 1 and 2, *DWT* was kept constant, so the *Δ* is reduced because of a reduced *LWT*. The effect of the lighter ship is determined via the expected speed increase for the same power for case 1 and vice versa for case 2. In case 3, *DWT* is increased to compensate for the *LWT* reduction in order to keep the *Δ* constant. The power curve stayed the same in this case, so the effect of this change on *EEXI*/*EEDI* can be directly estimated.

A change in *Δ* is manifested by a change in a draught, so the ship has different *LCB*, *Cb*, *Cp*, *Cw*, *WS*, etc. Previously mentioned parameters are given in Stability Booklets for different draughts. For each new *Δ*, these parameters have been linearly interpolated. Due to variations in main particulars, the total resistance is different and, therefore, power curves. To estimate new total resistance, Holtrop-Mennen (HM) method has been used where resistance due to bulb presence is separated from total resistance. In order to verify results, they are compared with available data from Model Test[2] Reports for considered ships. If there is an average deviation greater than 5% in total resistance between calculated and Model Test data, a residual resistance coefficient in the HM method is calibrated until average differences become less than 5% in the area where the model test had been performed. The residual resistance coefficient is derived as the difference between the total resistance coefficient and the frictional resistance coefficient (with roughness allowance included). All formulas for HM method can be found in [22], [23], [24], [25] and [26]. The calibration coefficient is evaluated for scantling and design draughts. For other draughts, calibration coefficients are linearly interpolated for draughts between design and scantling and linearly extrapolated for less-than-design draughts. After total resistance assessment, the engine load is evaluated in accordance with the following equation:

$$P_b = \frac{V \cdot 0,5144 \cdot R_T}{\eta_D \cdot \eta_S} \quad (11)$$

where η_D is the quasi-propulsive coefficient and η_s is shaft efficiency. These coefficients are usually given in Model Test reports, but for bulk carrier 1 are not available and therefore they are assumed to be 0,7 as per [27] for each speed. For shaft efficiency, 0,985 is applied for both ships.

After evaluation of power curves, speeds at 75% (usual reference speed) and 85% (the usual speed at Nominal Continuous Rating (*NCR*)) of *MCR* can be

---

[1] Each ship should be provided with a stability booklet, approved by the Administration, which contains sufficient information to enable the master to operate the ship in compliance with the applicable requirements.

[2] Ship model testing can protect shipowners and shipbuilders from costly and preventable mistakes. It's used to check systems and specs on a new design, assess midlife upgrades or renovations, determine the outside limits of a vessel's capabilities, or troubleshoot problems.

determined, and thereafter reference speed. As the attained *EEDI* and attained *EEXI* formulas are practically the same (7) and (8) where reference speed is stated in denominators like *DWT* (i.e., *Capacity*); direct influence on these energy efficiency parameters can be assessed in cases 1 and 3. In case 2, an engine power load reduction for initial reference speed is evaluated.

3. RESULTS

Compared obtained and calibrated results (total resistance) from the HM method for scantling and design draught (100% *LWT*) together with model test data, are shown in the following figures (bulk carrier 1 – Figure 3, bulk carrier 2 – Figure 4):

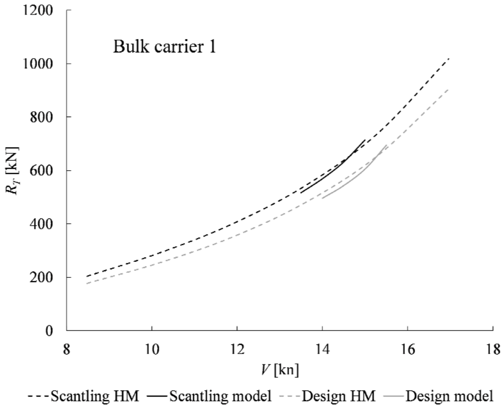

Figure 3. Estimated total resistance and model test results for scantling and design draught (bulk carrier 1)

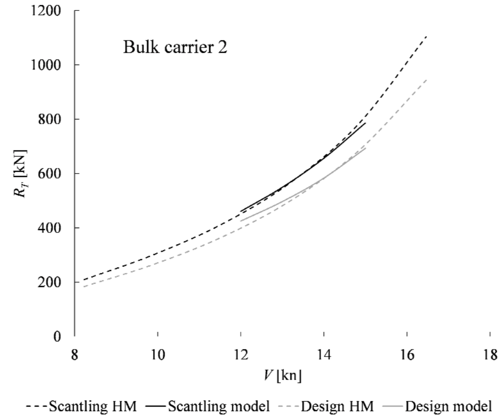

Figure 4. Estimated total resistance and model test results for scantling and design draught (bulk carrier 2)

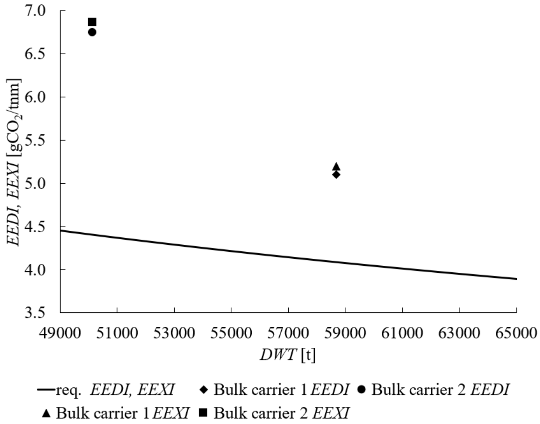

Figure 5. Attained and required *EEDI*/*EEXI*

Input parameters for the HM method, together with estimated total resistance and engine load for all cases, are summarized in tables at the end of the paper. Table 4 are presented input data for attained and required *EEDI* and *EEXI* with calculated relative differences between them for scantling and design draught with 100% of *LWT*.

Table 4. Initial energy efficiency parameters

Parameter	Bulk carrier 1	Bulk carrier 2
P_{ME} [kW]	6472,5	7110
P_{AE} [kW]	431,5	474
C_{FME} [tCO$_2$/tFuel]	3.206	3,206
C_{FAE} [tCO$_2$/tFuel]	3.206	3,206
SFC_{ME} [g/kWh]	190	190
SFC_{AE} [g/kWh]	215	215
f [-]	1	1
Capacity [t]	58675	50136
$V_{ref\ EEDI}$ [kn]	14,16	13,77
$V_{ref\ EEXI}$ [kn]	13,90	13,53
(Attained) *EEDI* [gCO$_2$/tnm]	5,105	6,746
(Attained) *EEXI* [gCO$_2$/tnm]	5,200	6,864
req. *EEDI* [gCO$_2$/tnm]	4,089	4,408
req. *EEXI* [gCO$_2$/tnm]	4,089	4,408
Δ*EEDI* [%]	24,8%	53,1%
Δ*EEXI* [%]	27,2%	55,7%

Attained *EEDI* and *EEXI* are also presented graphically in the following figure:

From the standpoint of energy efficiency, bulk carrier 1 is approximately 25% better than bulk carrier 2, but both are very far from the required indices. The influence of *LWT* change is checked for both energy efficiency parameters for the following reasons:

- *LWT* can only be changed in the initial design phase; therefore *EEDI* has been calculated;
- To assess how far these ships would be today from required (*EEXI*) values if they had been built lighter.

Case 1: $DWT = const.$, Δ is reduced due to a reduction in *LWT*; hence new reference speeds (V_{ref_EEDI} and V_{ref_EEXI}) are evaluated. Results are shown in Table 5.

If the *LWT* is reduced by 5-15%, a possible speed increase of 0,2-0,5% for scantling draught and 0,2-0,6% for design draught could be expected. In the following table, direct influence on *EEXI* and *EEDI* is calculated, where in the *EEXI* improvement column, V_{ref} for different percentages of *LWT* is compared against V_{ref} for full *LWT*. In *EEDI* improvement column, *V* at 75% MCR (Table 6) for scantling (95%, 90%, 85% *LWT*) draught are compared against original *LWT* (100% *LWT*).

Table 5. Speed assessment at 75% and 85% of *MCR*

		Bulk carrier 1		Bulk carrier 2	
	% *LWT*	*V* @75% *MCR*	*V* @85% *MCR*	*V* @75% *MCR*	*V* @85% *MCR*
Design	100%	14,63	15,12	14,44	14,92
	95%	14,64	15,14	14,47	14,96
	90%	14,67	15,16	14,50	14,98
	85%	14,68	15,18	14,53	15,02
Scant.	100%	14,16	14,64	13,77	14,21
	95%	14,20	14,69	13,80	14,24
	90%	14,22	14,71	13,83	14,28
	85%	14,26	14,74	13,84	14,29

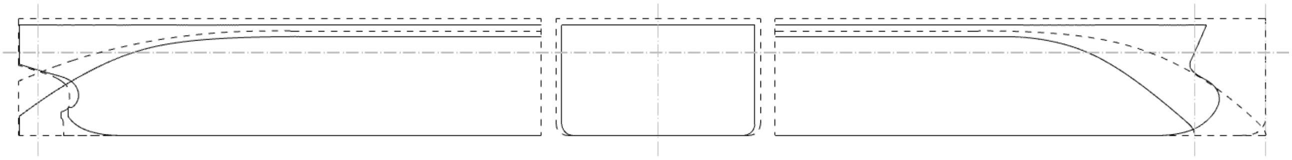

Figure 6. characteristic sections at midship, center line, and water line (dashed line – bulk carrier 1, solid line – bulk carrier 2)

Table 6. *EEXI/EEDI* improvement assessment

	Bulk carrier 1			Bulk carrier 2		
% *LWT*	V_{ref}	*EEXI* improve.	*EEDI* improve.	V_{ref}	*EEXI* improve.	*EEDI* improve.
100%	13,90	-	-	13,53	-	-
95%	13,91	0,1%	0,3%	13,57	0,2%	0,2%
90%	13,93	0,3%	0,5%	13,59	0,4%	0,4%
85%	13,95	0,4%	0,7%	13,62	0,6%	0,5%

Case 2: $DWT = const.$, Δ is reduced due to a reduction in *LWT*; hence new power for the same reference and design speed is evaluated for design and scantling draught when 5, 10, and 15% of *LWT* decrease is applied. Results for bulk carrier 1 are shown in Table 7, and for bulk carrier 2 in Table 8.

Table 7. Brake power reduction – bulk carrier 1

	V_{ref} = 13,9 kn		V_{des} = 14,5 kn	
% *LWT*	ΔPb [%] Scantling	ΔPb [%] Design	ΔPb [%] Scantling	ΔPb [%] Design
95%	-1,0%	-0,4%	-1,1%	-0,4%
90%	-1,8%	-1,0%	-1,8%	-1,0%
85%	-2,6%	-1,4%	-2,6%	-1,4%

Table 8. Brake power reduction – bulk carrier 2

	V_{ref} = 13,53 kn		V_{des} = 14,5 kn	
% *LWT*	ΔPb [%] Scantling	ΔPb [%] Design	ΔPb [%] Scantling	ΔPb [%] Design
95%	-0,9%	-0,8%	-0,9%	-0,9%
90%	-1,7%	-1,4%	-1,8%	-1,5%
85%	-2,1%	-2,2%	-2,1%	-2,4%

Case 3: In the previous two cases, Δ was reduced due to the reduction of *LWT*, while *DWT* was kept the same. In this case, when the *LWT* is being decreased, *DWT* is increased to keep the Δ constant (original). Consequently, the original power curves are the same because the draught has not been changed. However, the effect on *EEDI/EEXI* is present. As it is stated earlier that *DWT* (*Capacity=DWT*) is in the denominator in *EEDI/EEXI* formula (7), (8) direct influence of *DWT* change can be obtained just by comparing new *DWT* with the original. Results are shown in Table 9:

Table 9. Influence of *DWT* change on *EEDI/EEXI*

	Bulk carrier 1		Bulk carrier 2	
% *LWT*	New *DWT* [t]	ΔDWT [%]	New *DWT* [t]	ΔDWT [%]
95%	59085	0,9%	50669	1,1%
90%	59610	1,8%	51202	2,1%
85%	60135	2,7%	51735	3,2%

Table 10. Input parameters for HM method (bulk carrier 1)

	Bulk carrier 1							
	100% *LWT*		95% *LWT*		90% *LWT*		85% *LWT*	
	Design	Scantling	Design	Scantling	Design	Scantling	Design	Scantling
DWT [t]	50550	58560	50550	58560	50550	58560	50550	58560
LWT [t]	10504	10504	9979	9979	9454	9454	8928	8928
Δ [t]	61054	69064	60529	68539	60003	68013	59478	67488
T [m]	11.30	12.65	11.21	12.59	11.12	12.48	11.03	12.37
LCB [%]	1.57%	1.16%	1.60%	1.18%	1.63%	1.18%	1.65%	1.24%
WS [m^2]	9495	10084	9457	10047	9418	10000	9380	9952
Cb [-]	0.842	0.851	0.842	0.849	0.841	0.850	0.840	0.851
Cp [-]	0.845	0.854	0.845	0.852	0.844	0.853	0.844	0.853
Cw [-]	0.922	0.927	0.922	0.927	0.922	0.926	0.921	0.926
AT [m^2]	5.2	25.7	4.1	24.7	3.0	22.8	2.0	21.0

Table 11. Input parameters for HM method (bulk carrier 2)

	Bulk carrier 2							
	100% *LWT*		95% *LWT*		90% *LWT*		85% *LWT*	
	Design	Scantling	Design	Scantling	Design	Scantling	Design	Scantling
DWT [t]	40838	50136	40838	50136	40838	50136	40838	50136
LWT [t]	10660	10660	10127	10127	9594	9594	9061	9061
Δ [t]	51498	60796	50965	60263	50432	59730	49899	59197
T [m]	11.00	12.80	10.90	12.70	10.79	12.60	10.69	12.46
LCB [%]	2.38%	1.93%	2.41%	1.95%	2.44%	1.98%	2.46%	2.01%
WS [m^2]	8305	9054	8263	9012	8216	8971	8173	8913
Cb [-]	0.820	0.832	0.819	0.831	0.818	0.831	0.818	0.832
Cp [-]	0.823	0.835	0.822	0.834	0.822	0.833	0.821	0.835
Cw [-]	0.892	0.916	0.890	0.915	0.889	0.913	0.887	0.912
AT [m^2]	0.0	6.1	0.0	5.5	0.0	4.9	0.0	4.2

Table 12. Total resistance and brake power – design and scantling draught – bulk carrier 1

Design	100% *LWT*	95% *LWT*	90% *LWT*	85% *LWT*	100% *LWT*	95% *LWT*	90% *LWT*	85% *LWT*
V [kn]	*Rt* [kN]	*Rt* [kN]	*Rt* [kN]	*Rt* [kN]	*Pb* [kW]	*Pb* [kW]	*Pb* [kW]	*Pb* [kW]
14.00	526	523	520	518	5489	5468	5436	5414
14.50	579	577	573	571	6259	6237	6199	6174
15.00	635	633	629	627	7111	7087	7043	7015
15.50	696	694	689	687	8049	8023	7972	7939
16.00	760	758	753	750	9076	9048	8989	8952
16.50	828	826	820	817	10196	10167	10099	10057
Scantling	100% *LWT*	95% *LWT*	90% *LWT*	85% *LWT*	100% *LWT*	95% *LWT*	90% *LWT*	85% *LWT*
V [kn]	*Rt* [kN]	*Rt* [kN]	*Rt* [kN]	*Rt* [kN]	*Pb* [kW]	*Pb* [kW]	*Pb* [kW]	*Pb* [kW]
13.50	539	534	530	525	5432	5378	5337	5288
14.00	594	588	584	579	6209	6145	6100	6047
14.50	654	647	642	637	7072	6995	6948	6890
15.00	717	709	705	699	8025	7934	7885	7822

Table 13. Total resistance and brake power – design and scantling draught – bulk carrier 2

Design	100% *LWT*	95% *LWT*	90% *LWT*	85% *LWT*	100% *LWT*	95% *LWT*	90% *LWT*	85% *LWT*
V [kn]	*Rt* [kN]	*Rt* [kN]	*Rt* [kN]	*Rt* [kN]	*Pb* [kW]	*Pb* [kW]	*Pb* [kW]	*Pb* [kW]
12.00	393	391	388	385	3552	3527	3505	3480
13.00	486	482	479	475	4738	4702	4673	4636
14.00	595	590	586	581	6255	6203	6164	6112
15.00	720	713	709	702	8161	8087	8037	7963
16.00	862	853	848	840	10650	10547	10481	10379
Scantling	100% *LWT*	95% *LWT*	90% *LWT*	85% *LWT*	100% *LWT*	95% *LWT*	90% *LWT*	85% *LWT*
V [kn]	*Rt* [kN]	*Rt* [kN]	*Rt* [kN]	*Rt* [kN]	*Pb* [kW]	*Pb* [kW]	*Pb* [kW]	*Pb* [kW]
12.00	443	439	436	433	4150	4114	4084	4059
13.00	551	547	542	540	5638	5588	5543	5518
14.00	681	674	669	667	7517	7448	7384	7362
15.00	831	823	815	814	9921	9826	9736	9718
16.00	1002	992	982	981	13058	12930	12804	12794

Compared to case 1, the effect of *DWT* change (Case 3) has a greater influence on *EEDI*/*EEXI* than speed increase due to Δ reduction. That was to be expected due to the higher order of magnitude of *DWT* than V_{ref}.

4. CONCLUSIONS

The influence of possible *LWT* reduction on ship performance has been carried out in this paper. Reduction rates were assessed to be 5, 10, and 15% based on *LWT* (original and approximated) comparison of two bulk carriers. If one ship is larger than the other in terms of *L*, *B*, *T*, or Δ it doesn't necessarily mean that she is heavier. The structural design dates from different, but again, very close periods and the improvement is significant – 19% better performance in terms of total resistance. It turned out that an unusual bow with a vertical stem is more efficient for current Froude numbers. In addition, *the LWT* of compared ships are similar, so it was interesting to point out whether the bulk carrier 2 had had better performance, in case less steel was used.

Results are based on *EEDI*/*EEXI* (case 1 and case 3) performance check and possible reduction in brake power for design and reference speed (case 2). Study shows that *DWT* change has a greater influence (depending on *LWT* reduction rate) on *EEDI*/*EEXI* performance (up to 3,2%) than a change in reference speed (up to 0,7%), while brake power reduction can be 0,4-2,6% for the same speed. This reduction is equivalent to the pollution of 1000 cars per year. The reduction is negligible in terms of *EEDI/EEXI* because there are 1.4 billion motor vehicles worldwide. However, from the ship owner's point of view, every percentage of reduction that will imply money-saving is significant. Nevertheless, *LWT* change is only one step in the initial design phase of how we can improve ship performance, and some of the additional ways are described in [28].

The benefit of lighter ships could be achieved by paying attention in the design construction stage. Savings that can be accomplished during the initial design process are equal to the savings that are very difficult to achieve by installing some of the ESD. However, there is still space for possible further improvement with ESDs.

ACKNOWLEDGMENT

This work was partially supported by the Ministry of Education, Science and Technological Development (Project no. 451-03-68/2022-14/200105) of Serbia.

REFERENCES

[1] Watson, D.: Practical Ship Design, Elsevier Ocean Engineering Book Series, Vol. 1, 2002.

[2] Schneekluth, H., Bertram, V.: Ship Design for Efficiency and Economy, Butterworth Heinemann, Second edition, 1998.

[3] Papanikolaou, A.: Ship Design – Methodologies of Preliminary Design, Springer, 2014.

[4] Roh, M. I., Lee, K. Y.: Computational Ship Design, Springer, 2018.

[5] Chen, S., Frouws, K., Van de Voorde, E.: Technical changes and impacts on economic performance of dry bulk vessels, Maritime Policy & Management: The flagship journal of international shipping and port research, 2010.

[6] Faber, J., Hoen, M.: Historical trends in ship design efficiency, CE Delft, Delft, 2015.

[7] Kristensen, H., Lutzen, M.: Existing Design Trends for Tankers and Bulk Carriers – *Design changes for Improvement of the EEDI in the Future*, Technical Information Center of Denmark, IMDC2012, Glasgow, 2012.

[8] Kalajdžić, M., Vasilev, M., Momčilović, N.: Power reduction consideration for bulk carriers with respect to novel energy efficiency regulations, Brodogradnja, Vol. 73 No. 2, 2022.

[9] IMO MEPC, Resolution MEPC.203(62): Amendments to the Annex of the Protocol of 1997 to amend the International Convention for the prevention of pollution from ships, 1973, as modified by the protocol of 1978 relating thereto.: IMO, 2011/07/15, 2011.

[10] IMO, Fourth IMO Greenhouse gas study, International Maritime Organization, 2021.

[11] IMO MEPC, Resolution MEPC.328(76): Amendments to the Annex of the Protocol of 1997 to amend the International Convention for the prevention of pollution from ships, 1973, as modified by the protocol of 1978 relating thereto.: IMO, 2021.

[12] Simić, A., Radojčić, D.: On Energy Efficiency of Inland Waterway Self-Propelled Cargo Vessels, FME Transactions, Vol. 41 No. 2, 2013.

[13] Mancini, S., Vitiello, L., Bilandi, R. N., De Carlini, M.: Shipping Decarbonization: An Overview of the Different Stern Hydrodynamic Energy Saving Devices, Journal of Marine Science and Engineering, 2022.

[14] Molland, A.F., Turnock, S. R., Hudson, D. A., Utama, I. K. A. A.: Reducing Ship Emissions: A Review of Potential Practical Improvements in the Propulsive Efficiency of Future Ships, Transition of the Royal Institution of Naval Architects Part A: International Journal of Marine Engineering, 2014.

[15] Brynolf, S., Baldi, F., Johnson, H.: Energy Efficiency and Fuel Changes to Reduce Environmental Impacts, Shipping and the Environment, Springer, 2016.

[16] Jafarzadeh, S., Schjolberg, I.: Emission Reduction in Shipping Using Hydrogen and Fuel Cells, *Proceedings of the ASME 2017 36th International Conference on Ocean*, Offshore and Arctic Engineering, OMAE2017, 25-30.06.2017, Trondheim, 2017.

[17] Townsin, R. L.: The Ship Hull Fouling Penalty, Biofouling: The Journal of Bioadhesion and Biofilm Research, Taylor & Francis, 2003.

[18] Khor, Y. S., Xiao, Q.: CFD simulations of the effects of fouling and antifouling, Ocean Engineering, Vol. 38, Issue 10, 2011.

[19] Momčilović, N., Motok, M.: Estimation of Ship Lightweight Reduction by Means of Application of Sandwich Plate System, FME Transactions, Vol. 37 No. 3, 2009.

[20] Intersessional Working Group. Draft report of the eight meeting of he Intersessional Working Group on Reduction of GHG Emissions from Ships (ISWG-GHG 8). Norway: IMO, 2021/05/28

[21] IMO MEPC, Resolution MEPC.308(73): Guidelines on the Method of Calculation of the attained Energy Efficiency Design Index (EEDI) for new ships: IMO, 2018/10/26, 2018.

[22] Holtrop, J.: A statistical analysis of performance test results, International Shipbuilding Progress, Vol. 24, No. 270, 1977.

[23] Holtrop, J. Mennen, G.G.J.: A statistical power prediction method, International Shipbuilding Progress, Vol. 25, No. 290, 1978.

[24] Holtrop, J. Mennen, G.G.J.: An approximate power prediction method, International Shipbuilding Progress, Vol. 29, No. 335, 1982.

[25] Holtrop, J.: A statistical re-analysis of resistance and propulsion data, International Shipbuilding Progress, Vol. 31, 1984.

[26] Molland A. F., Turnock S. R., Hudosn D. A.: Ship resistance and propulsion: Practical Estimation of Ship Propulsive Power, Cambridge University Press, 2011.

[27] International Standard, ISO 15016-2015: Ships and marine technology – Guidelines for the assessment of speed and power performance by analysis of speed trial data, ISO 2015, 2015.

[28] Kalajdžić, M., Vasilev, M., Momčilović, N.: Assessment of Energy Efficiency for the Existing Cargo Ships, Journal of Maritime Sciences, Vol. 1 No. 1, 2022.

NOMENCLATURE

AT [m^2]	wetted transom area
B [m]	breadth
Capacity [t]	*DWT* at scantling draught
Cb [-]	block coefficient
C_{FAE} [tCO_2/tFuel]	Conversion factor between fuel consumption and CO_2 emission for auxiliary engine
C_{FME} [tCO_2/tFuel]	Conversion factor between fuel consumption and CO_2 emission for main engine
Cp [-]	prismatic coefficient
Cw [-]	water plane coefficient
DWT [t]	deadweight
$DWT_{S,service}$ [t]	design deadweight
EEDI [gCO2/tnm]	Energy Efficiency Design Index
EEXI [gCO2/tnm]	Energy Efficiency of Existing Ship Index
f [-]	correction factor
g [m/s^2]	gravitational constant, g=9.81
H [m]	depth
k [-]	scale coefficient
KB [m]	vertical center of buoyancy
LCB [%]	longitudinal center of buoyancy
Loa [m]	length overall
Lpp [m]	length between perpendiculars

LWT [t]	lightweight
LWT_{app} [t]	approximated lightweight
MCR [kW]	maximum continuos rating
NCR [kW]	nominal continuos rating
P_{AE} [kW]	Power of auxiliary engine
Pb [kW]	Brake power
P_{ME} [kW]	Main engine power (75% of *MCR*)
$P_{S,service}$ [t]	power of main engine corresponds to $V_{S,service}$
Rt [kN]	Total resistance
SFC_{AE} [g/kWh]	Specific fuel oil consumption for auxiliary engine
SFC_{ME} [g/kWh]	Specific fuel oil consumption for main engine
T [m]	draught
V [kn]	speed
V_{des} [kn]	design speed
V_{ref} [kn]	reference speed
V_{ref_EEDI} [kn]	Reference speed for *EEDI* calculation (speed at 75% of *MCR*)
$V_{ref\ EEXI}$ [kn]	Reference speed for *EEXI* calculation
$V_{S,service}$ [kn]	service speed under design draught
$W_{\text{machinery}}$ [t]	machinery weight
WS [m^2]	wetted surface
W_{steel} [t]	steel weight
Δ [t]	Displacement
ΔDWT [%]	relative deadweight difference
$\Delta EEDI$ [%]	Relative *EEDI* difference
$\Delta EEXI$ [%]	Relative EEXI difference
ΔLWT [%]	relative lightweight difference
ΔPb [%]	relative brake power difference
η_D [-]	quasi-propulsive coefficient
η_S [-]	shaft efficiency

УТИЦАЈ ПРОМЕНЕ МАСЕ ПРАЗНОГ БРОДА НА СОПСТВЕНЕ ПЕРФОРМАНСЕ

М. Василев, М. Калајџић

Утицај промене масе празног брода на Индекс енертетске ефикасности постојећих и нових бродова за два „supramax“ брода за превоз расутог терета је приказан у овом раду. Рад обухвата редукцију масе празног брода од 100% до 85%, са кораком од 5%. Утицај на перформансе брода је одређен кроз преосталу масу, референтну брзину и оптерећење мотора. У једном делу рада, преостала маса је сматрана константном, те је разматран утицај промене депласмана на брзину брода и потребну ангажовану снагу, док је у другом делу, депласман сматран константним, па је размотрен директан утицај преостале масе на индексе енергетске ефикасности. Услед промене депласмана, било је потребно одредити нову криву снаге, па је за потребе процене тоталног отпора коришћена метода Холтроп-Менен. Добијени резултати показују да је могуће остварити повећање брзине до 0,7% за исту снагу, док редукција снаге за исту брзину може достићи до 2,6%. Повећање преостале масе побољшава индексе енергетске ефикасности до 3,2%.