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INFLUENCE OF THE SERVICE MARGIN OF SERVICE PARAMETERS OF TRANSPORT SHIP PROPULSION SYSTEM

Part I

Propulsion engine service parameters of transport ship sailing on a given shipping route

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Abstract

During ship sailing on a given shipping route in real weather conditions all propulsion system performance parameters of the ship change along with changes of instantaneous total resistance and speed of the ship. In this paper results of calculations are presented of distribution function and mean statistical values of screw propeller thrust, rotational speed and efficiency as well as propulsion engine power output and specific fuel oil consumption occurring on selected shipping routes at different SM values. On this basis new guidelines for ship propulsion system design procedure are formulated.

Keywords*: thrust, efficiency and rotational speed of screw propeller, long-term prediction, shipping route, design working point of screw propeller, service margin*

1. Introduction

A crucial element of a design process of a transport ship propulsion system is the selection of its design parameters, i.e. determination of a speed value for which screw propeller should be designed and determination of a thrust value which should be developed by this propeller at the assumed speed. Correct selection of the design speed is specially important for ships fitted with fixed pitch propellers (most often applied to transport ships) as only at that design speed such propeller is able to use full engine power output.

The service speed at which the designed ship has to operate in real weather conditions on a given shipping route, should be assumed as the design speed.

The way of calculation of the mean long-term service speed and the mean long-term resistance of the ship is presented in [1,2,3]

The design working point of screw propeller is associated with the following design parameters: ship speed and propeller thrust. Selection of such point is very important with a view of correct operation of propulsion system. In this point screw propeller efficiency should reach as - high - as possible value. For screw propellers interacting with piston combustion engines the design point is usually placed half way between the points *A* and *B* (Fig. 1), that generally ensures correct operation of the propulsion system in the point *B*, i.e. in service conditions (real weather conditions). The characteristic crossing point *A* (Fig 1) is determined on the basis of the ship resistance on still water, while characteristic crossing point *B* is determined while taking into account additional resistance values of wind and waves. As a standard characteristic 1 results from the addition of 15% *SM* to characteristic 2. As demonstrated in publications [1], [2], [3] such SM value is offen to small to establish a mean statistical service speed of ship on numerous sailing routes with adequate probability (i.e. eg. 95%) Instantaneous service speed of a ship and its total resistance depend on instantaneous weather conditions occurring on a given shipping route. Hence working parameters of the screw propeller designed and applied to propel the ship will be changeable depending on weather parameters and assumed criteria of propulsion system control [4]. Knowing statistical data on wind and waves occurring on a given shipping route as well as long-term distribution function of ship speed [3] on the route, one can determine long-term distribution functions of working parameters of the screw propeller and hence mean statistical location of its working point on a given shipping route.

The working parameters of the propeller and the overall propulsion system depend also on the adopted *SM* value

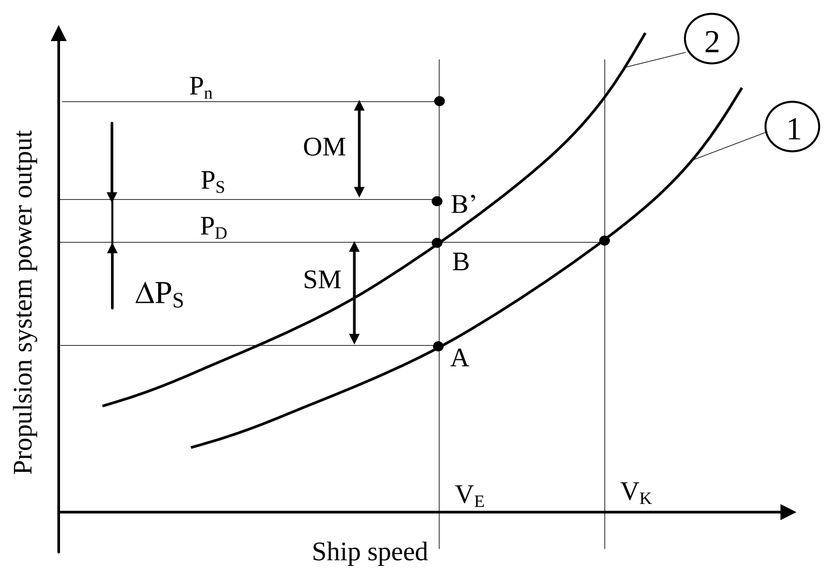


Fig. 1. Predicted service speed of ship
P_n – nominal power output of engine, P_S – shaft-line power, P_D – power delivered to propeller cone, V_K – contractual speed of ship, V_E – predicted service speed of ship, 1 – still-water propeller curve for clean ship hull, 2 – predicted propeller curve with service margin, in real conditions, OM – operational margin, SM – service margin, ΔP_S – power loss at shaft-line (and possibly… if used)

Therefore this paper presents calculations - performed for a designed ship – of long-term service parameters of screw propeller and mean service location of its working point as well as a discussion on how these would influence the ship's design working point at different values of service margin

2. Service parameters of screw propeller

The service parameters of screw propeller to be calculated for a ship sailing on a given shipping route are the following:

⇒ the propeller thrust T,

⇒ the propeller rotational speed n_p,

⇒ the free-propeller efficiency η_0 .

The propeller thrust T with the propeller situated behind a ship's hull is calculated for the total resistance R_C of a ship sailing through waves at assumed service speed V_E with a given geometry of a screw propeller (mathematical model adopted to calculate the propeller thrust is presented in [1], [2], [3]). In calculations of thrust, its fall resulting from sailing on waves was taken into account [5].

The engine speed n_p transmitted on the screw cone and its torque Q while sailing through waves on a given shipping route [1], [2], [3], and open water propeller efficiency η_0, is presented by the equation:

$$\eta_0 = \frac{K_T}{K_Q} \cdot \frac{J}{2\pi} \tag{1}$$

where:

K_T – propeller thrust ratio,

K_Q – propeller torque ratio,

J – advance ratio.

3. Mean statistical values of screw propeller service parameters of ship sailing on a given route

The calculation of mean statistical values of screw propeller service parameters were performed according to the algorithm shown in [2], [3] or [5], for ship *M2* (whose parameters are given in [3]), for different sailing routes [3] and propelling engines whose nominal power was determined at 15% *SM* (a standard value adopted during the *M2* design procedure) and then *SM* = 20% and 25%.

Results of the calculations for the selected ship and its shipping routes are presented in the form of :

- histogram of propeller thrust and its mean statistical value
- histogram of propeller speed and its mean statistical value
- histogram of propeller efficiency and its mean statistical value
- mean statistical propeller working point,
- probability distribution function of long-term occurrence of given values of propeller rotational speed and ship service speed.

All the calculations were performed under the assumption that engine's power output reaches at most 0.9 P_n.

In the below attached figures the calculation results are presented for K_1 containership [3] on two very different shipping routes: 5b - "easy" one and 2b - „difficult" one – in the sense of occurrence of long-term weather parameters.

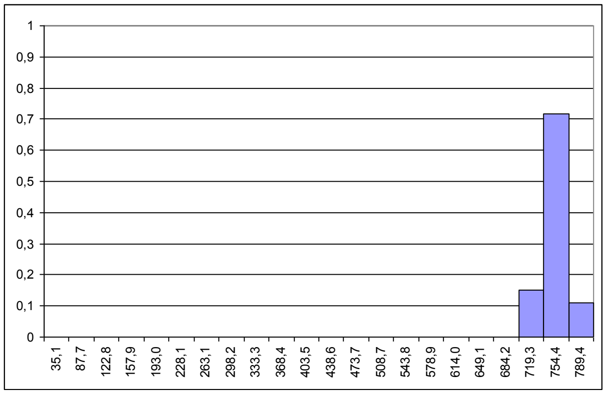
The results of the calculations are presented in Fig. 2 ÷ 6 and a summary table 1.

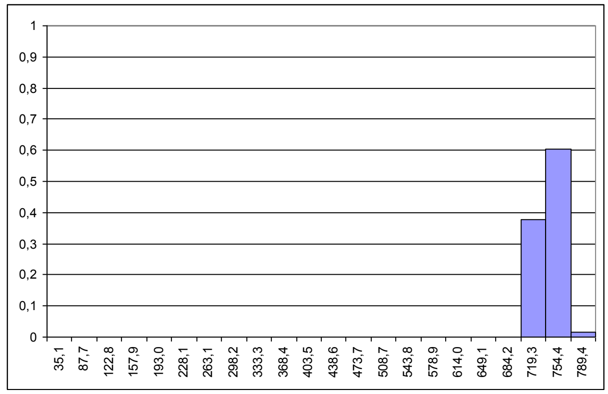
Ship: M2 - assumed service speed = 7,72 [m/s] SM=15%
- probability of maintaining the assumed speed P_{VE}

Route no. 2b - $P_{VE} = 0{,}55$ Route no. 5b - $P_{VE} = 0{,}86$

Thrust histograms

P_{TT}



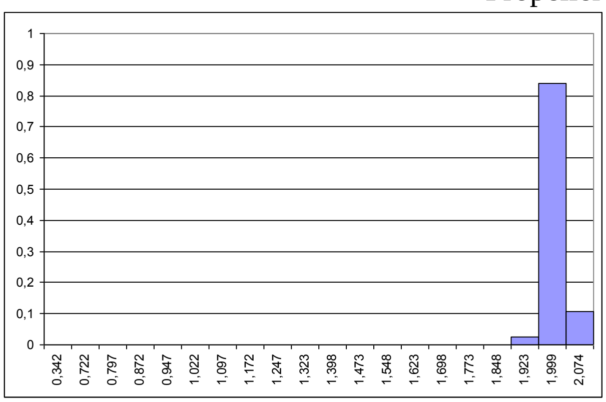


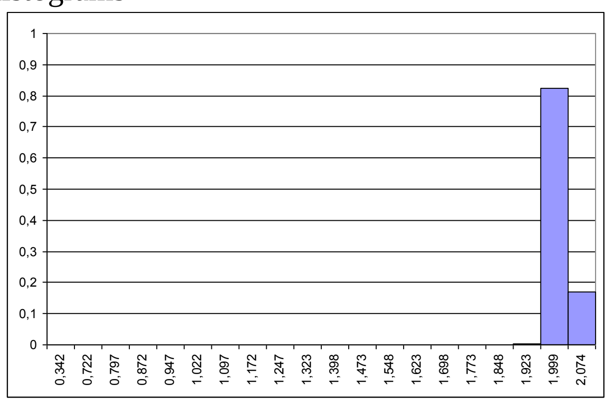
Thrust on still water T= 737 [kN] T [kN]

Mean thrust $\overline{T}$ = 752 [kN] Mean thrust $\overline{T}$ = 741 [kN]

Propeller histograms

P_{Tn}



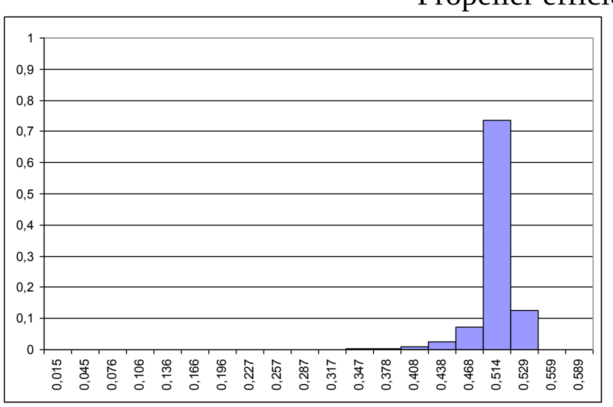


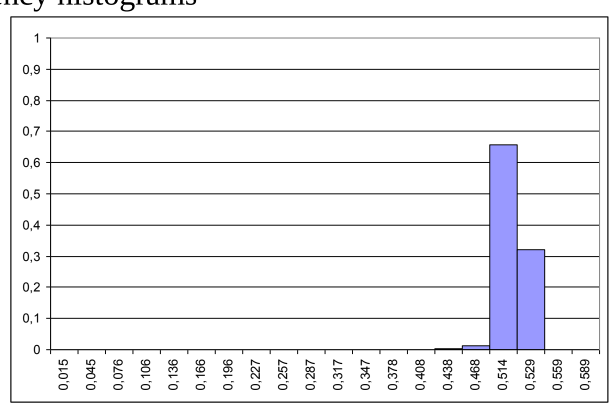
Nominal propeller speed n_n= 2,030 [1/s] n[1/s]

Mean propeller speed $\overline{n}$ = 2,021 [1/s] Mean propeller speed $\overline{n}$ = 2,031 [1/s]

Propeller efficiency histograms

$P_{T\eta}$





Propeller efficiency in still water η_0= 0,513 η_0 [-]

Mean propeller efficiency $\overline{\eta}_0$= 0,499 Mean propeller efficiency $\overline{\eta}_0$= 0,510

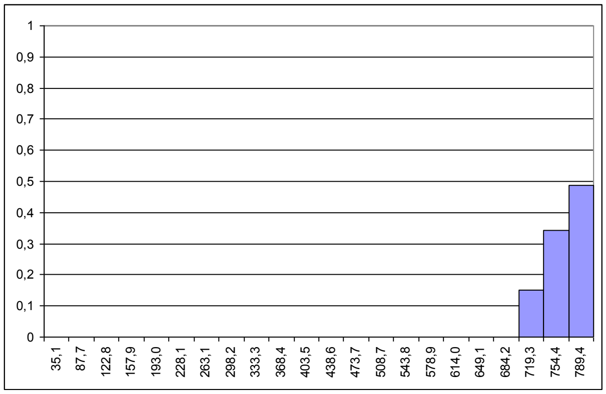
Fig. 2. Histograms and mean statistical values of thrust, propeller speed and efficiency of an M2 ship on sailing routes 2b and 5b (SM = 15%)

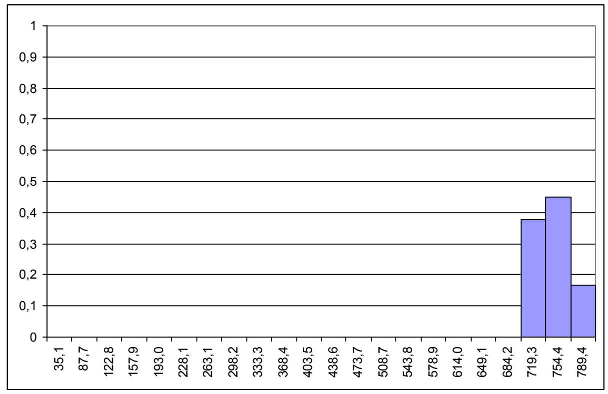
Ship: M2 - assumed service speed = 7,72 [m/s] SM=20%
- probability of maintaining the assumed speed P_{VE}

Route no. 2b - P_{VE} = 0,79 Route no. 5b - P_{VE} = 0,96

Thrust histograms

P_{TT}



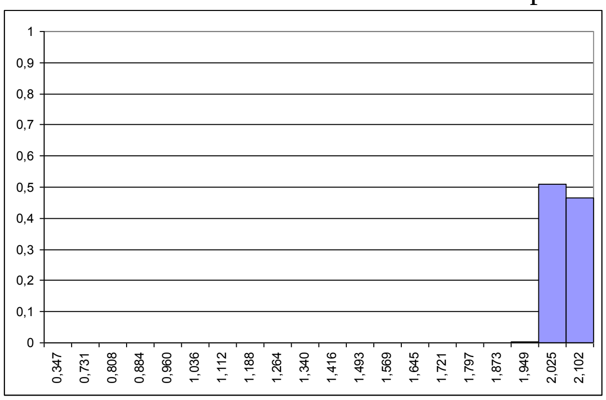


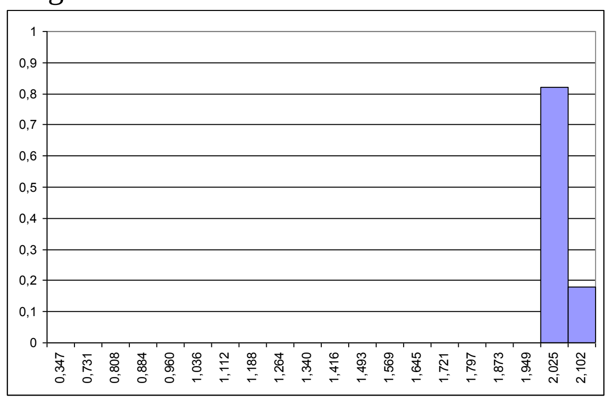
Thrust on still water T= 737 [kN] T [kN]

Mean thrust $\overline{T}$ = 785 [kN] Mean thrust $\overline{T}$ = 752 [kN]

Propeller histograms

P_{Tn}



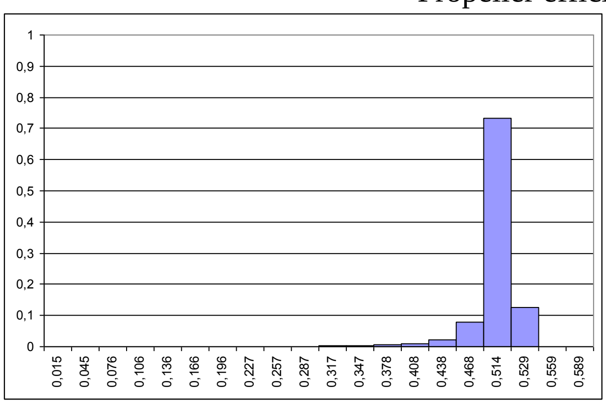


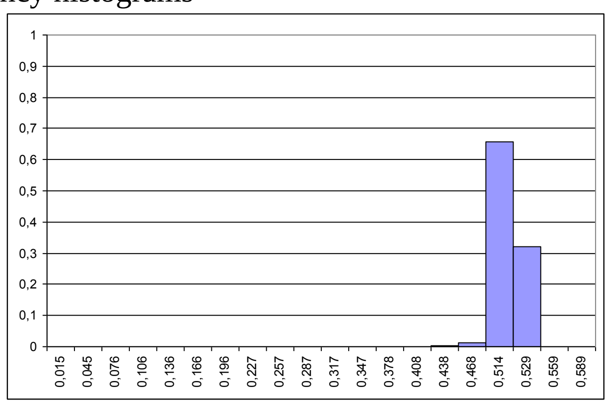
Nominal propeller speed n_n= 2,057 [1/s] n[1/s]

Mean propeller speed $\overline{n}$ = 2,063 [1/s] Mean propeller speed $\overline{n}$ = 2,045 [1/s]

Propeller efficiency histograms

$P_{T\eta}$





Propeller efficiency in still water η_0= 0,513 η_0 [-]

Mean propeller efficiency $\overline{\eta}_0$= 0,499 Mean propeller efficiency $\overline{\eta}_0$= 0,510

Fig. 3. Histograms and mean statistical values of thrust, propeller speed and efficiency of an M2 ship on sailing routes 2b and 5b (SM = 20%)

Ship: M2 - assumed service speed = 7,72 [m/s] SM=25%

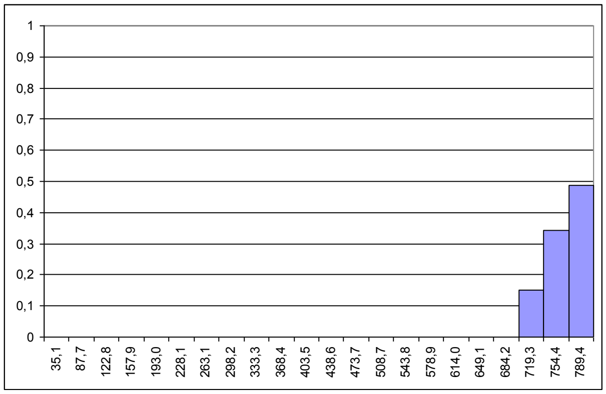
- probability of maintaining the assumed speed P_{VE}

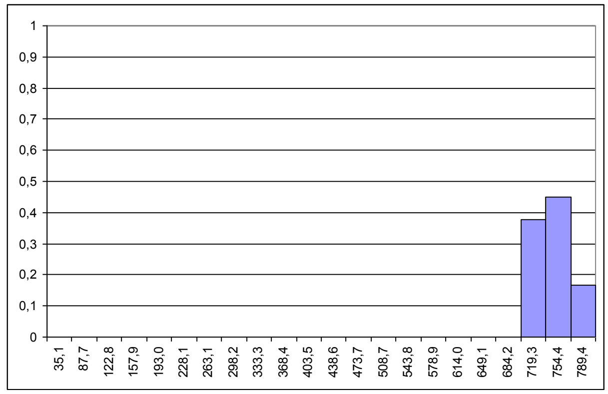
Route no. 2b - P_{VE} = 0,82

Route no. 5b - P_{VE} = 0,97

Thrust histograms

P_{TT}





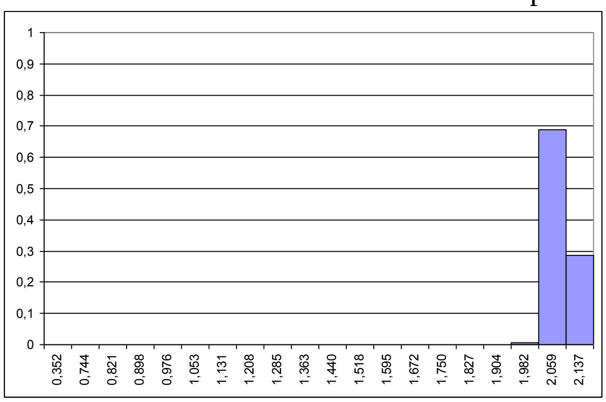
Thrust on still water T= 737 [kN] T [kN]

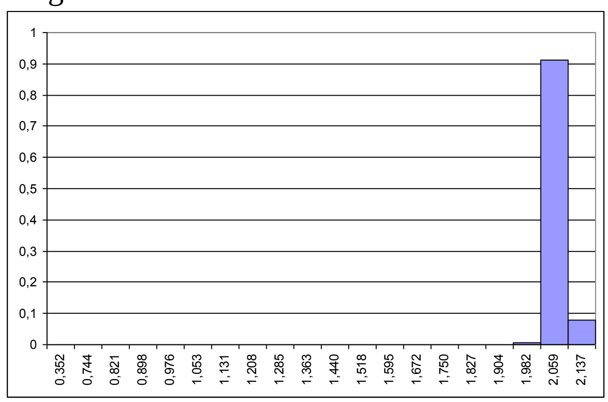
Mean thrust $\overline{T}$ = 790 [kN]

Mean thrust $\overline{T}$ = 753 [kN]

Propeller histograms

P_{Tn}





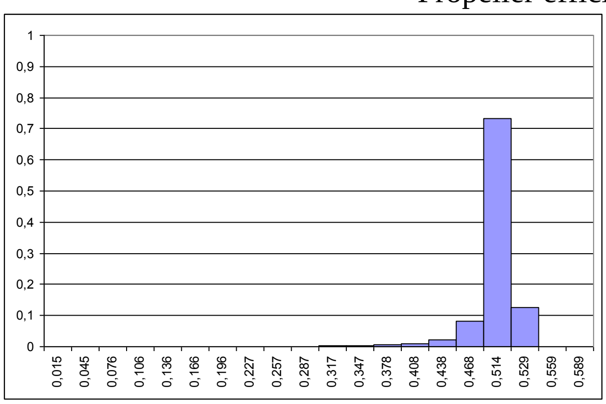
Nominal propeller speed n_n= 2,092 [1/s] n[1/s]

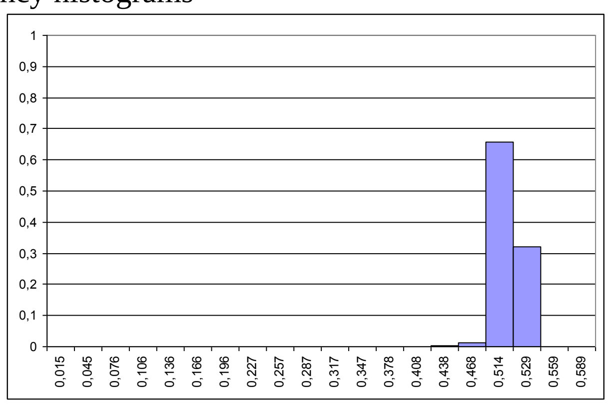
Mean propeller speed $\overline{n}$ = 2,070 [1/s]

Mean propeller speed $\overline{n}$ = 2,047 [1/s]

Propeller efficiency histograms

$P_{T\eta}$





Propeller efficiency in still water η_0= 0,513 η_0 [-]

Mean propeller efficiency $\overline{\eta}_0$= 0,499

Mean propeller efficiency $\overline{\eta}_0$= 0,510

Fig. 4. Histograms and mean statistical values of thrust, propeller speed and efficiency of an M2 ship on sailing routes 2b and 5b (SM = 25%)

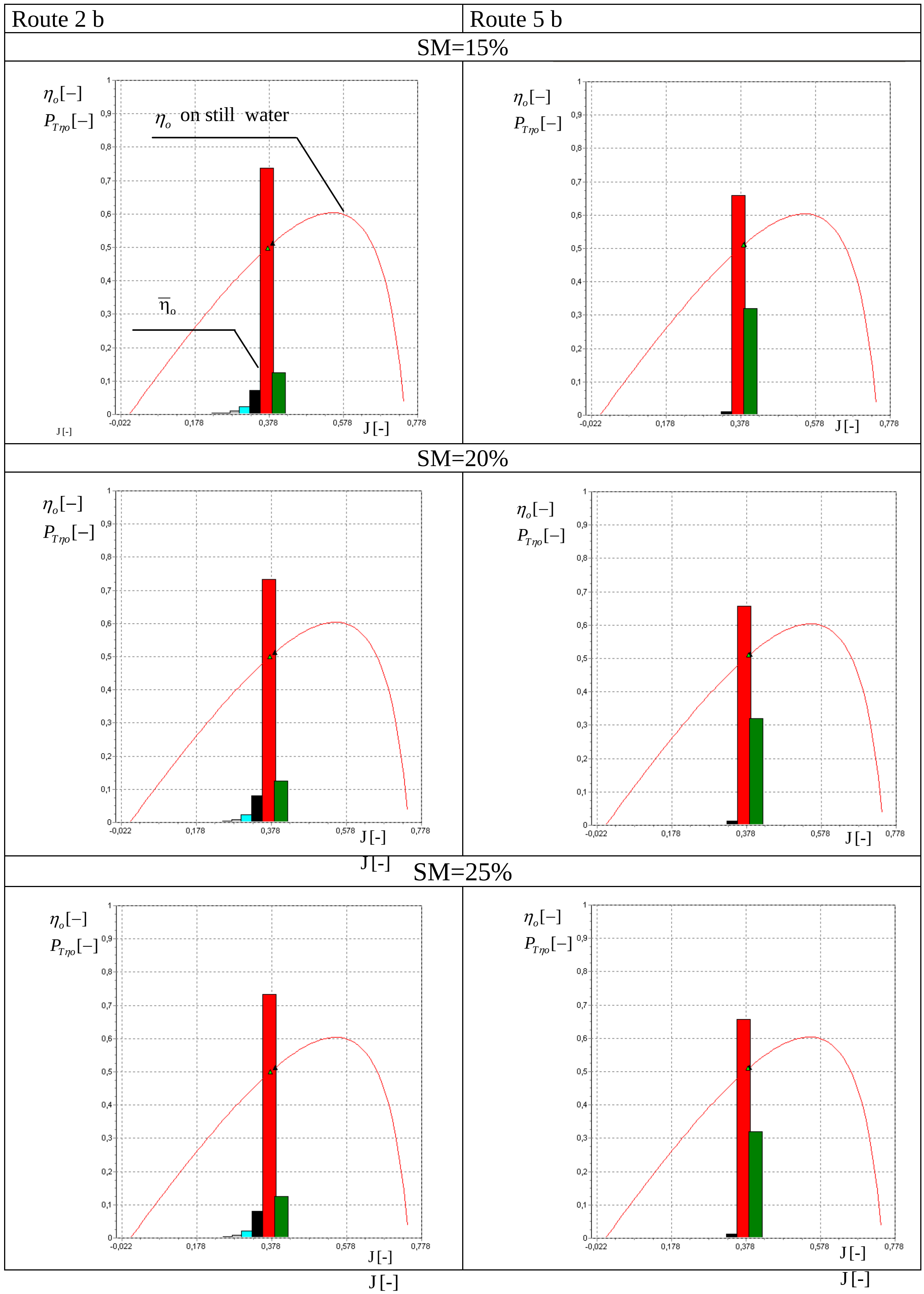
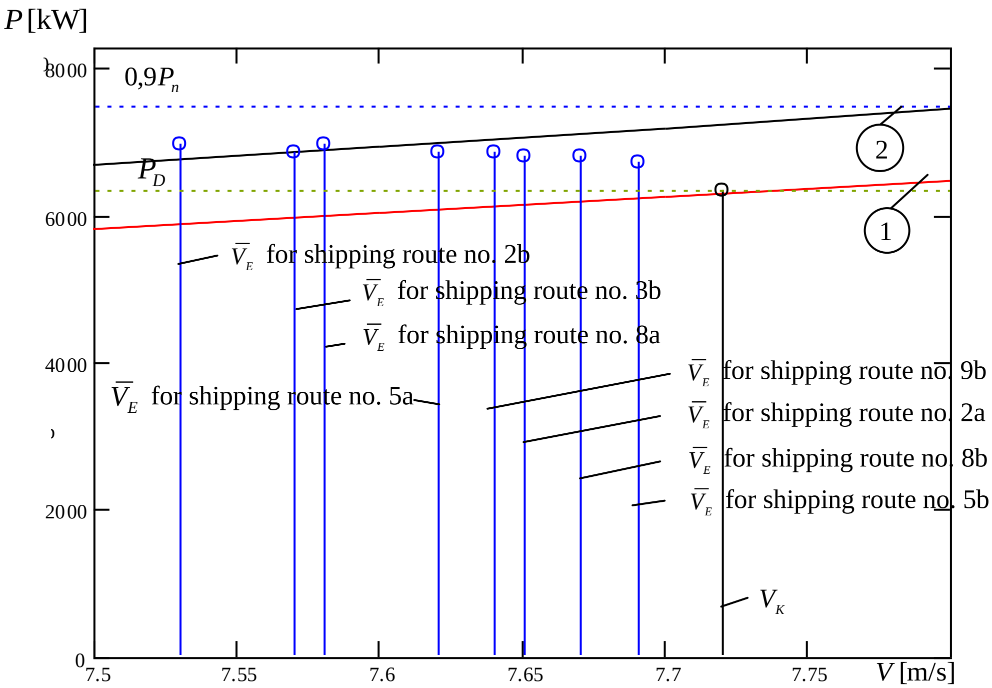
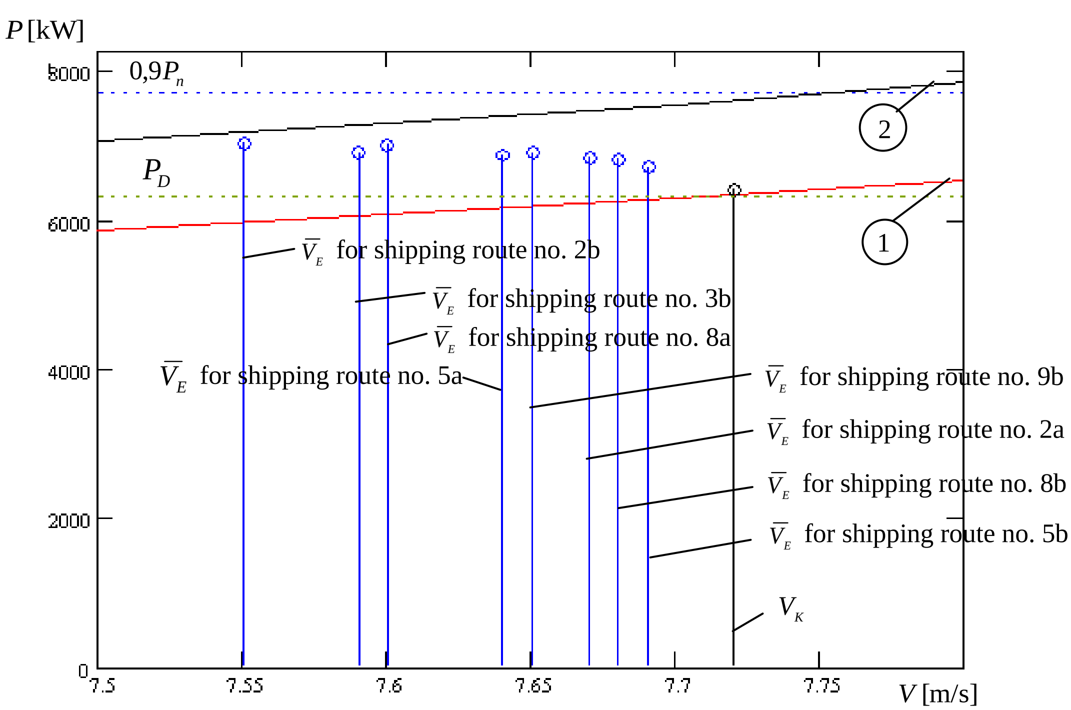


Fig. 5. Histogram, mean statistical propeller efficiency on sailing route and still water of the M2 ship

service margin 15%



service margin 20%



service margin 25%

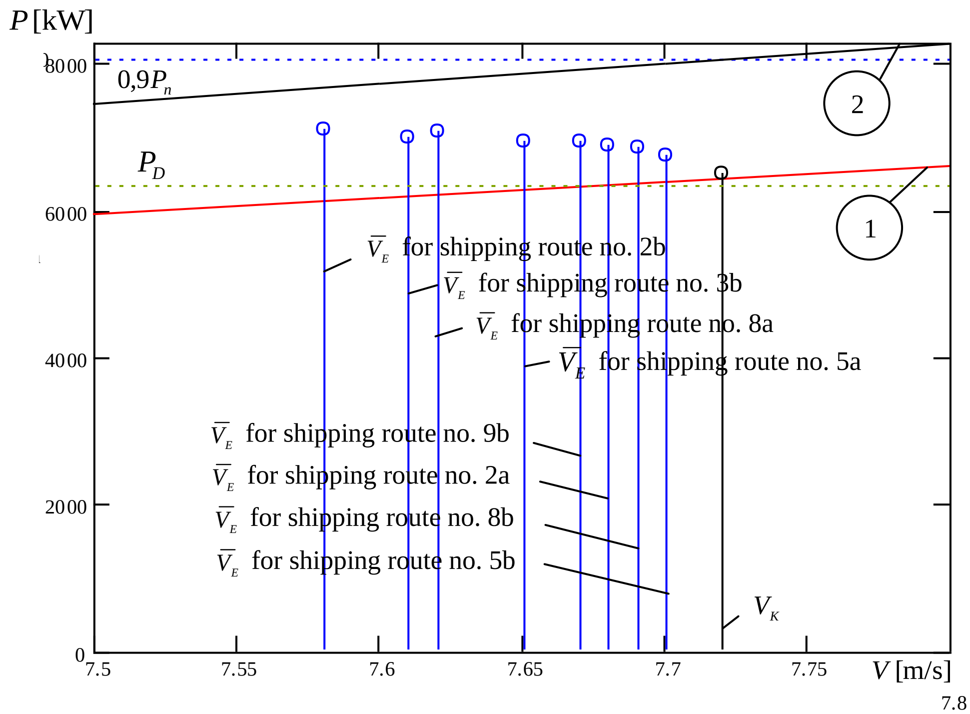


Fig. 6. Mean statistical working point of a screw propeller of K1 ship depending on a mean statistical long-term service speed $\bar{V}_E$ on various sailing routes

1 – still-water propeller curve, 2 – propeller curve containing the service margin SM = 15%, 20%, 25%, P_D – power delivered to propeller cone at ship's contractual speed in still water conditions, N_n – nominal power output of propulsion engine,

$\bar{V}_E$ – mean statistical long-term value of ship service speed on given shipping route, V_K – contractual speed of ship

Table 1. Mean statistical of service parameters M2 ship for route 2b and 5b

Shipping route	Route no. 2b			Route no. 5b		
Service margin	15%	20%	25%	15%	20%	25%
Probability of maintaining the assumed speed V = 7,72 [m/s]	0,55	0,79	0,82	0,86	0,96	0,97
Mean statistical service speed $\bar{V}_E$ [m/s]	7,53	7,55	7,58	7,68	7,69	7,70
Mean statistical propeller thrust $\bar{T}$ [kN]	752	785	790	741	752	753
Mean statistical propeller speed $\bar{n}_p$ [1/s]	2,021	2,063	2,070	2,031	2,045	2,047
Mean statistical propeller efficiency $\bar{\eta}_0$ [-]	0,499	0,499	0,499	0,510	0,510	0,510

4. Mean statistical working point of propeller

Histograms of thrust, propeller speed and efficiency (Fig. 2 – 5) show, that working parameters of a propeller are largely dependent on weather conditions on a given sailing route. Mean statistical parameters of a propeller were calculated at different service margin values (*SM* = 15, 20 i 25%). In this case the main aim was to maintain the assumed speed without overloading the propelling engine. With such criterion in mind, it shows that the bigger the *SM* value the higher mean statistical service speed of a ship, while the exact value of SM did not have any major effect on propeller efficiency on a given sailing route (Table 1)

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