

# Calculation of the mean long-term service speed of transport ship

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## Part III Influence of shipping route and ship parameters on its service speed

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### ABSTRACT

*Service speed obtainable by a ship in real weather conditions when sailing on a given shipping route, is one of the major parameters which have great impact on ship operation costs. The so far used, very approximate method of service speed prediction based on "service margin", is very little exact. In this paper a new method based on additional ship resistance dependent on mean statistical parameters of wave and wind occurring on a given shipping route, is presented. The mean long-term service speed is calculated on the basis of the calculated additional resistance and the screw propeller and propulsion engine parameters. Also, a new definition of service margin and a way of its calculation is presented apart from the results of the mean service speed calculation depending on ship's type and size and shipping route.*

**Keywords :** ship service speed, wind, waving, shipping route, service margin, long-term prediction.

### PARAMETERS OF THE SHIPS FOR WHICH CALCULATIONS WERE PERFORMED

Calculations of the mean additional resistance and mean long-term service speed were performed for 7 existing ships of determined propulsion systems and 15% service margin. They represented two types of ships : bulk carriers and containerships of different size. The main parameters of the ships are given in Tab.4.

All calculations for each ship were performed for constant ship's draught and constant state of hull and propeller surface, that made it possible to more accurately compare the ships sailing on a given shipping route, by taking into account ship's type and size. The used computer software has been

so designed as to make it possible to perform calculations at variable draught (considered as a random variable of a given occurrence probability) and for changeable state of hull and propeller surface.

### SHIPPING ROUTES

For the calculations of the mean additional resistance and mean long-term service speed the most representative shipping routes were selected on the basis of [1]. They are specified in Tab.5 and shown in Fig.16.

All additional data which describe ship's voyage on a given shipping route (i. e. specification of sea areas crossed by the route, probability of ship's staying in a given sea area,  $f_A$ , ship's course angle  $\psi$  and probabilities of ship's courses in a given sea area,  $f_\psi$ ) can be found in [4].

Tab. 4. Ship main parameters .

Ship Data	Symbols	Container-ship K1	Container-ship K2	Container-ship K3	Bulk carrier M1	Bulk carrier M2	Bulk carrier M3	Bulk carrier M4
Length b.p.	L [m]	140.14	171.94	210.20	138.0	185.0	175.6	240.0
Breadth	B [m]	22.30	25.30	32.24	23.0	25.3	32.2	32.2
Draught	T [m]	8.25	9.85	10.50	8.55	10.65	12.05	11.6
Displacement at T	$\nabla$ [m <sup>3</sup> ]	17300	29900	47250	21441	40831	56396	73910

<b>Contract speed</b>	$V_k$ [m/s]	8.44	9.62	10.80	7.15	7.72	8.2	8.28
<b>Propeller diameter</b>	$D_p$ [m]	5.2	6.15	7.42	5.0	5.8	6.2	6.5
<b>Propeller pitch</b>	$P$ [m]	3.9	5.8	6.8	4.2	3.9	5.7	4.5
<b>Engine rated power</b>	$N_n$ [kW]	6930	13750	26270	4710	7500	12000	12720
<b>Driving engine rated speed</b>	$n_n$ [1/s]	2.33	1.82	1.72	1.85	2.03	1.64	1.93
<b>Still - water resistance of ship for T and <math>V_k</math></b>	$R$ [kN]	461.3	858.8	1477.5	405.9	600.4	865.6	947.6
<b>Service margin assumed in propulsion system design</b>	$k_z$ [%]	15	15	15	15	15	15	15

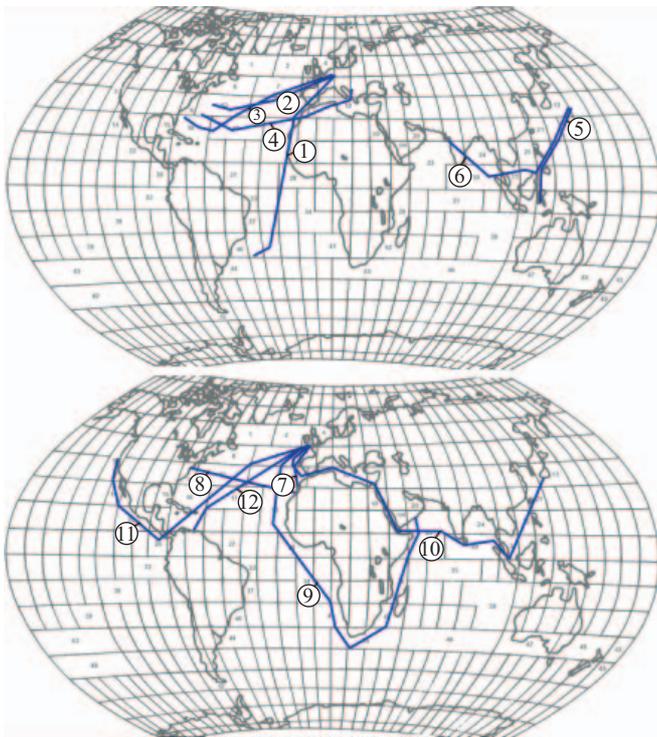


Fig. 16. Runs of the shipping routes for which calculations were performed.

In each case the calculations were performed for both legs of voyage (there and back) hence every shipping route has two indices : a and b (e.g. shipping route no. 2 → 2a and 2b).

Tab. 5. Specification of the shipping routes used for calculation of additional resistance and service speed of ship.

No.	Name
1	South America – West Europe
2	US East coast – West Europe
3	US East coast – Gulf of Mexico – West Europe
4	US East coast – Mediterranean – West Europe
5	Indonesia – Japan
6	Persian Gulf – Japan
7	North Africa – West Europe
8	North Africa – US East coast
9	Persian Gulf – Africa – West Europe
10	West Europe – Mediterranean – Persian Gulf – Japan
11	West Europe – Panama Canal – US West coast
12	West Europe – South and Central America

## CALCULATION RESULTS

The calculation results for every ship and shipping route are presented in the form of bar charts for the additional resistance  $\Delta R$  and service speed  $V_E$ . The speed the ship is able to achieve, was calculated under the assumption that its set value has to be maintained or its maximum value achievable in a given weather conditions at simultaneous keeping the set ship course, has to be determined. The obtained bar charts were also approximated by using the distribution functions : that of the additional resistance  $f(\Delta R)$ , and that of service speed  $f(V_E)$ , with the determined  $R^2$  (share of the “resolved” variance), [2].

Under the bar charts for a given ship and shipping route the following data are tabularized :

- the maximum value of additional resistance,  $\Delta R_{max}$ , which occurred for a given ship on a given shipping route
- the mean value of additional resistance,  $\Delta \bar{R}$ , calculated from the formula :

$$\Delta \bar{R} = \frac{\sum_{i=1}^{n_R} P_{TR_i} \cdot (\Delta R_i = \text{const})}{\sum_{i=1}^{n_R} P_{TR_i}} \quad (45)$$

- the relative resistance increase, PR, calculated from the formula :

$$PR = \frac{\Delta \bar{R}}{R} \cdot 100\% \quad (46)$$

- the set value of ship service speed,  $V_{ZE}$
- the minimum value of ship speed,  $V_{min}$ , which occurred on a given shipping route at keeping a set course
- the mean long-term value of ship speed,  $\bar{V}_E$ , on a given shipping route, calculated from the formula :

$$\bar{V}_E = \frac{\sum_{i=1}^{n_V} P_{TV_i} V_i (\Delta R_i = \text{const})}{\sum_{i=1}^{n_V} P_{TV_i}} \quad (47)$$

- the probability,  $P_{V_E}$ , of maintaining the service speed,  $V_{ZE}$ , on a given shipping route at keeping a set course
- percentage of the events in which ship speed has been reduced for the reason of exceeded ship’s sea-keeping criteria
- percentage of the events in which no result of calculations, i.e. no value of ship speed, has been found. The lack of solu-

tion resulted from the fact that it was assumed to keep a set course, that was not possible in very high and oblique waves - the ship course should be changed in such situations.

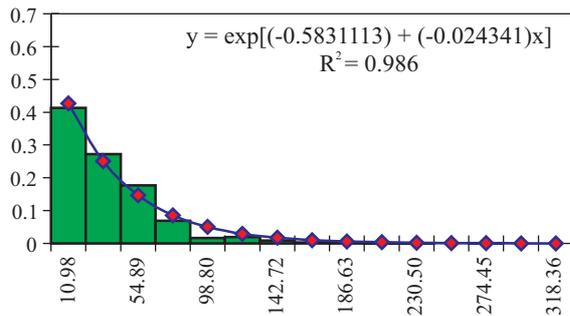
The calculated bar charts for all the ships (Tab.4) and all the shipping routes (Tab.5) together with the remaining results can be found in [4]. The example bar charts for **K1** ship (Tab.4) sailing there and back on the chosen route (South America – West Europe), are presented in Fig.17.

In Fig.19 are showed the values of additional resistance index for the same ship, defined by means of the formula (46) depending on a shipping route. The index should not be identified, as for its value, with the service margin because it constitutes a definite long-term statistical quantity tightly connected with parameters of weather conditions occurring on a given shipping route, hence value of the index is changeable whereas value of the service margin assumed in design process is of a constant value. However, value of the index may suggest

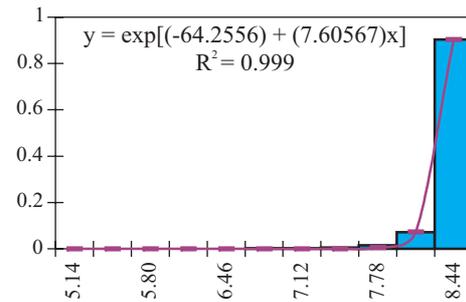
**Ship : K1**

**Shipping route no. 1a**

*Histogram and distribution function of additional resistance*



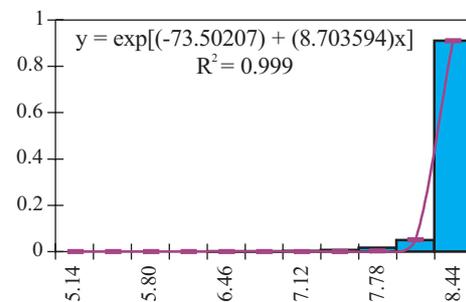
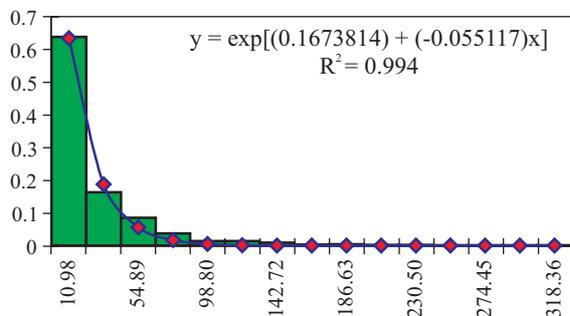
*Histogram and distribution function of service speed*



Still-water resistance at the speed $V_K$ [kN]	R	461.26
Max. additional resistance [kN]	$\Delta R_{max}$	367.70
Mean additional resistance [kN]	$\Delta \bar{R}$	35.77
Resistance increase [%]		7.8
Percentage of no-solution events [%]		0.11

Set service speed [m/s]	$V_{ZE}$	8.44
Minimum speed [m/s]	$V_{min}$	1.88
Mean speed [m/s]	$\bar{V}_E$	8.38
Probability of $V_{ZE}$	$P_{V_E}$	0.90
Percentage of speed-reduction events [%]		0.11

**Shipping route no. 1b**



Still-water resistance at the speed $V_K$ [kN]	R	461.26
Max. additional resistance [kN]	$\Delta R_{max}$	365.74
Mean additional resistance [kN]	$\Delta \bar{R}$	28.02
Resistance increase [%]		6.1
Percentage of no-solution events [%]		0.22

Set service speed [m/s]	$V_{ZE}$	8.44
Minimum speed [m/s]	$V_{min}$	1.88
Mean speed [m/s]	$\bar{V}_E$	8.37
Probability of $V_{ZE}$	$P_{V_E}$	0.92
Percentage of speed-reduction events [%]		0.07

*Fig. 17. Bar charts and distribution functions of additional resistance and service speed for K1 ship.*

**ANALYSIS OF THE ACHIEVED RESULTS**

The presented calculation results clearly show which value of the mean long-term service speed can be achieved by the ship or which value of probability of maintaining a given service speed on a given shipping route can be achieved at a service margin value assumed in design process of ship propulsion system (e.g. 15 %). Both the quantities for **K1** ship on different shipping routes are shown in Fig.18.

how large service margin for a given shipping route should be to maintain the set service speed at a given probability of its exceeding; it can be clearly observed when comparing the diagrams in Fig.18a and Fig.19. It means that in the case of applying the traditional method of determining the propulsion engine output power, with the use of service margin, percentage value of service margin for a given ship should be tightly correlated with statistical parameters of weather conditions on a given shipping route, and with an assumed probability of maintaining an assumed long-term service speed of ship.

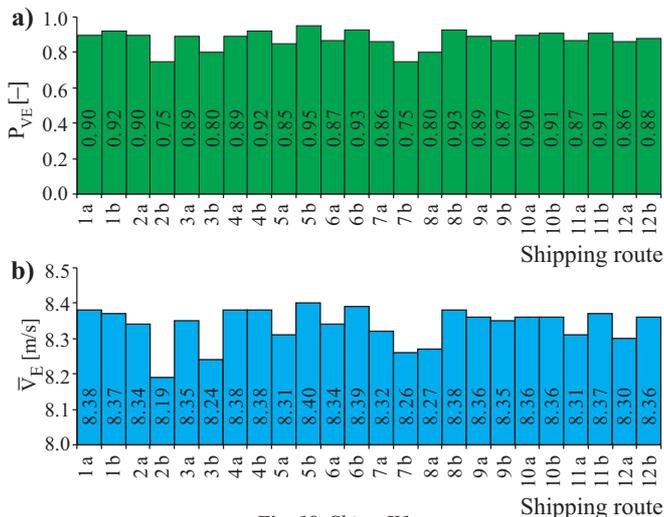


Fig. 18. Ship : K1.  
a) probability of maintaining the set service speed  $V_{ZE}$   
b) mean long-term service speed.

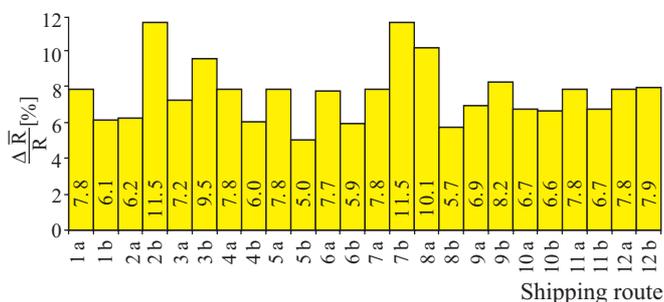


Fig. 19. Index of additional resistance increase for K1 ship, depending on shipping route.

In Fig. 18 and 19 is presented an influence of shipping routes on the parameters associated with speed of K1 ship. The same relations for the remaining ships can be found in [4].

In the next figures an influence of type and size of ship on the parameters associated with its speed on a given shipping route, is presented. As the considered ships differed to each other with regard to the contract speed  $V_K$  the following index of maintaining the set speed was introduced :

$$WP = \frac{\bar{V}_E}{V_{ZE}} \cdot 100\% \quad (48)$$

The index makes it possible to more accurately compare performance of particular ships on a given shipping route. In Fig. 20 ÷ 25 are presented : the probability,  $P_{VE}$ , of maintaining the set service speed  $V_{ZE}$ , the index WP acc. (48), as well as the index of increase of additional resistance acc. (46), for bulk carriers and containerhips, respectively.

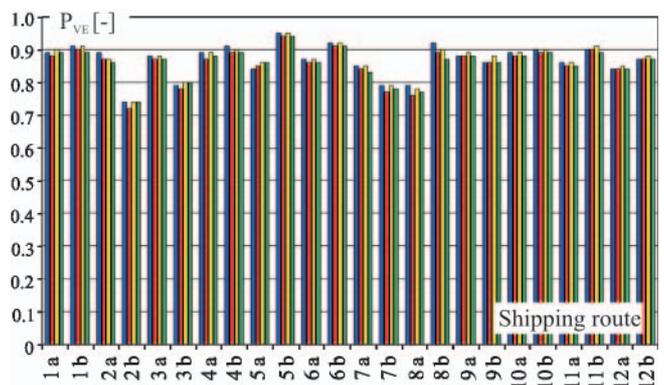


Fig. 20. Probability of maintaining the set service speed  $V_{ZE}$  of bulk carriers : blue - M1; red - M2; yellow - M3; green - M4.

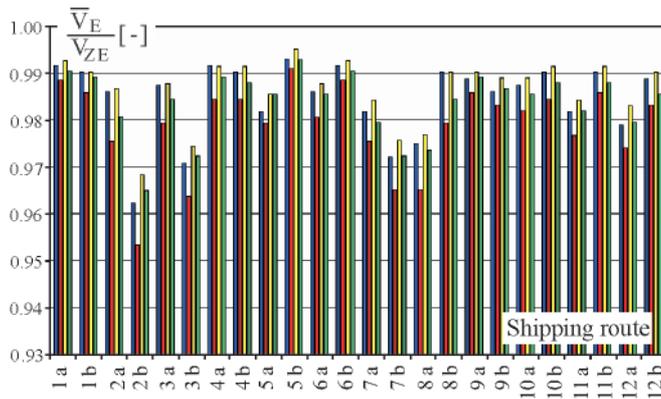


Fig. 21. Index of maintaining the set service speed  $V_{ZE}$  of bulk carriers : blue - M1; red - M2; yellow - M3; green - M4.

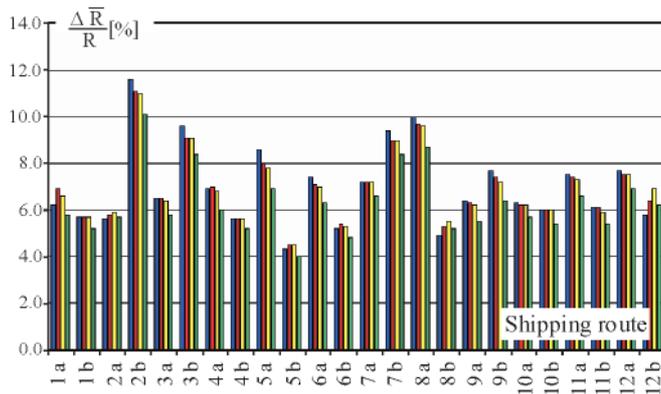


Fig. 22. Index of additional resistance increase for bulk carriers : blue - M1; red - M2; yellow - M3; green - M4.

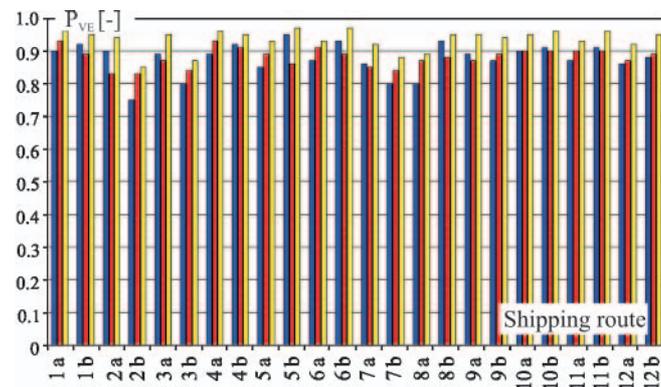


Fig. 23. Probability of maintaining the set service speed  $V_{ZE}$  of containerhips : blue - K1; red - K2; yellow - K3.

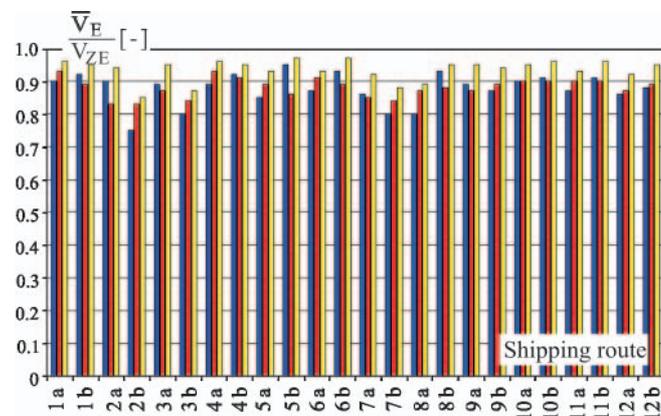


Fig. 24. Index of maintaining the set service speed  $V_{ZE}$  of containerhips : blue - K1; red - K2; yellow - K3.

From comparison of the diagrams it results that the performance of the ships on a considered shipping route differs to each other. Some ships show a greater value of the probability,  $P_{VE}$ ,

of maintaining the set service speed  $V_{ZE}$ , and a greater value of the index WP than those showed by other ships. It speaks for different effectiveness of their propulsion systems.

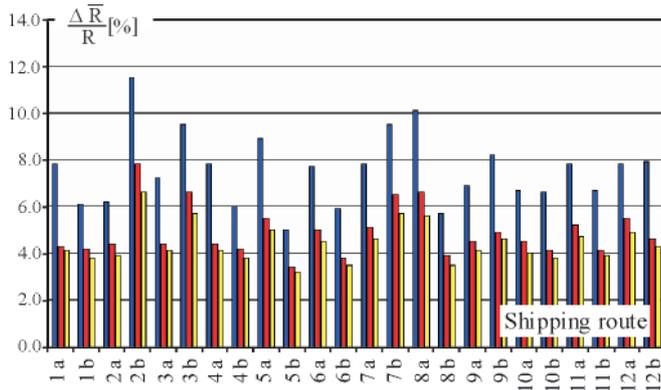


Fig. 25. Index of additional resistance increase for containerships : blue - K1; red - K2; yellow - K3 .

In the traditional designing of ship propulsion system and determining of service margin value (e.g. on the level of 15% [3,4]) the set service speed in real weather conditions is assumed lower than the contract speed by about 1 knot (for ships of the contract speed up to 20 knots). Hence for **K1** ship were performed calculations of the probability,  $P_{VE}$ , of maintaining a set service speed for its two values :

$$\Rightarrow V_{ZE} = V_K$$

$$\Rightarrow V_{ZE} = V_K - 1 \text{ [kn]}$$

and their results presented in Fig. 26.

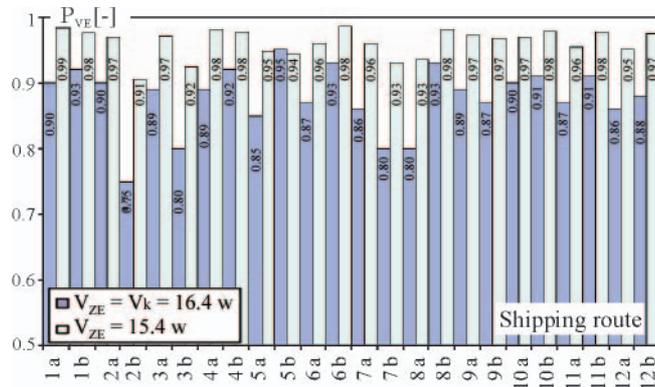


Fig. 26. Probability of maintaining the set service speed  $V_{ZE}$  of K1 ship .

In the second case (i.e.  $V_{ZE} = V_K - 1 \text{ [kn]}$ ) the probability  $P_{VE}$  for many shipping routes is close to 1, that is in compliance with the current designing practice and to a certain extent confirms (and verifies) accuracy of the performed calculations.

### A PROPOSAL OF DEFINITION OF SERVICE MARGIN

On the basis of the performed calculations and conclusions resulting from the diagrams in Fig. 18 ÷ 25 was elaborated a proposal of definition of the service margin which associates a set service speed with probability of its maintaining on a given shipping route during a long time period.

#### Proposed definition of the service margin $k_z$ (which determines surplus of engine output power)

*For a given ship sailing on a given shipping route, the service margin  $k_z$  should have such percentage value as the ship*

*in assumed loading conditions and assumed state of its hull and propeller surface, would be able to maintain the service speed,  $V_{ZE}$ , assumed in the frame of long-term prediction, at the assumed exceeding probability  $P_{VE}$ .*

The definition concerns a designed ship intended for sailing on a given shipping route, however it can be also generalized to cover an arbitrary sailing region.

It should be observed that :

- ❖ too large value of  $V_{ZE}$  relative to  $V_K$  (contract speed) or too large value of the probability  $P_{VE}$  may cause that  $k_z$  would take large values and such ship would appear operationally unprofitable for its owner
- ❖ a reasonable (smaller) value of  $V_{ZE}$  may cause that at a reasonable value of  $k_z$ , the probability  $P_{VE}$  would reach the value of one ( $P_{VE} = 1$ ).

The above given comments mean that ship owner, when ordering a ship, should be aware of :

- \* a value of the long-term service speed he expects to be reached and
- \* at which level of its maintaining probability the designed ship would appear operationally profitable for him.

For the so defined service margin were performed calculations aimed at determination of its percentage value depending on shipping route under assumption that the set service speed  $V_{ZE}$ , maintained during long time period, will be equal to  $V_K$  ( $V_{ZE} = V_K$ ) with the probability  $P_{VE} = 0.95$ .

The results of service margin calculations for **K1** ship in function of shipping route are presented in Fig.27.

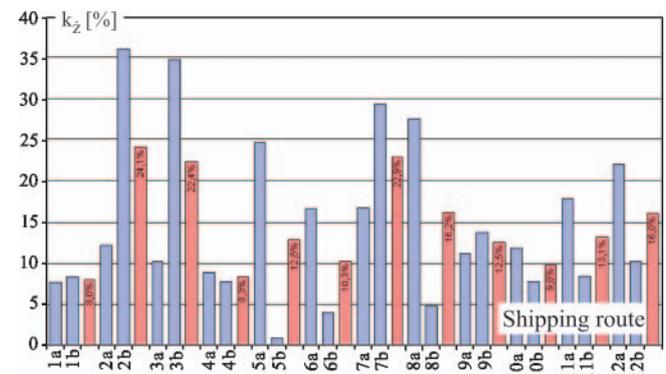


Fig. 27. The service margin  $k_z$  calculated for K1 ship in function of shipping route, for  $V_{ZE} = V_K$  and  $P_{VE} = 0.95$ ; blue - service margin for one-leg voyage of the ship; red - mean service margin for a shipping route .

### CONCLUSIONS

From the performed calculations the following conclusions can be drawn :

- Additional resistance of ship and its mean service speed depend on statistical weather parameters of shipping routes, hence ship service parameters depend on a kind of shipping route hence full utilization of statistical long-term parameters of waves and winds makes more accurate predicting ship service speed on a given route, possible.
- Influence of ship's type and size on its service parameters (resistance, speed) is observable but not so great as that of shipping route, but definite differences in effectiveness of the same ship on a given shipping route can be observed, that speaks for different quality (perfection) of designed propulsion systems.

- Service margin's value can be determined on the basis of ship service speed assumed by ship owner and probability of its maintaining on a given shipping route, hence it is not to have a constant value for a given shipping route, but it may result from targets and strategy which ship owner would apply to a given ship.

On the basis of the presented method was elaborated a computer software which may be also used for the following purposes :

- Comparison and assessment of ship designs as well as existing ships from the point of view of their service costs
- Optimization of a shipping route for a ship, especially in rough weather conditions
- Investigation of many other service parameters of ship and its equipment, e.g. frequency of using ship's steering gear on a given shipping route.

Calculation results obtained in the frame of long-term prediction of ship service parameters will be presented in separate papers.

#### NOMENCLATURE

- $f(V_i)$  – probability distribution function of occurrence of the instantaneous ship speed  $V_i$   
 $f(\Delta R_i)$  – probability distribution function of occurrence of the instantaneous additional resistance  $\Delta R_i$   
 $f_A$  – probability of ship's staying in a given sea area A  
 $f_\psi$  – probability of ship's sailing with the speed V and course angle  $\psi$   
 $k_z$  – service margin  
 $n_R$  – number of intervals for additional resistance  
 $n_V$  – number of intervals for ship speed  
 $PR$  – relative increase of resistance  
 $P_{TR}$  – total occurrence probability of the additional resistance  $\Delta R$  of a given value

- $P_{TV}$  – total probability of developing the speed V by a ship at occurrence of the additional resistance  $\Delta R$   
 $P_{VE}$  – probability of developing by a ship the set service speed  $V_E$   
 $R$  – still-water ship resistance  
 $R^2$  – share of the "resolved" variance  
 $V_E$  – service speed  
 $\overline{V_E}$  – average long-term service speed of a ship sailing on a given shipping route  
 $V_k$  – contract speed  
 $V_{ZE}$  – set service speed  
 $WP$  – index of maintaining the set service speed  
 $\Delta R$  – additional resistance resulting from rough weather conditions  
 $\overline{\Delta R}$  – statistical average value of additional resistance  
 $\psi$  – geographical angle of ship course.

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## Miscellanea

### The Foundation for Safety and Environment Protection

#### 25 years of training on manned ship models

In 1981 in Iława (Silm lake) on the basis of agreement between the then Maritime High School, Gdynia, and Gdańsk University of Technology was commenced regular education activity aiming at training ship masters, first officers and pilots in ship manoeuvring. The trainings were based on large manned floating ship models equipped with devices simulating operation of the ship systems engaged in manoeuvring. The first training model representing a tanker is one out of nine models used today for training courses. As the years go construction and outfitting of models as well as training water areas, at first simple and sparse, have been becoming more and more perfect and better adjusted to fulfilling their role. Also, organizational form of the training has been changed - in 1989 the Foundation for Safety and Environment Protection, Iława, was established by both the universities with

the aim of carrying out trainings and research in the area of safety at sea.

In spite of many difficulties due to objective external factors and sometimes a pessimism as to purposefulness of developing the methods based on models (in the times of proliferation of computer simulation) the Centre in Iława today ranks as one of the best worldwide, equipped with the most suitable training models and water areas providing the widest training possibilities. Also, an unique approach to realization training tasks has been elaborated. As a result the use of vacancies in training courses reaches 100%, and representatives of many countries and organizations are turning to the Centre for advise or directly for realization of a similar undertaking on their territory. So far, as many as 2600 ship masters, first officers and pilots from almost 40 countries and all continents have taken part in various training courses in Iława.