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Propulsion prognosis for a ship according to the zero version (0-JH) of the new power prediction method

SUMMARY

The ITTC-78 power prediction method can be divided into three groups of procedures: R_{TS} – procedures, T_{BS} – procedures and the Q_{BS} – procedures. Only the Q_{BS} - procedures were analyzed in the paper [7] where a new approach to the determination of Q_{BS} and n_S parameters was given. A new idea of the equivalent open propeller is the basic difference between the Q_{BS}-ITTC procedures and the new Q_{BS}- procedures called JH ones.

This paper presents the numerical results of power prediction for a selected ship, obtained with the use of the zero version (0-JH) of the new method (in its 0-JH3 variant) . A comparison between the ITTC-78 method, 0-JH3 method and sea trial results was also given.

INTRODUCTION

The essence of the new method for prediction of the propeller power P_{DS} and its revolutions n_S was presented in [7]. Two versions of the method were distinguished : the zero version called 0-JH method and the developed version called R-JH method. The calculation results presented in this paper illustrate application of the 0-JH method in its 0-JH3 variant.

The block diagram of the method is shown in Fig.1. The diagram differs from that given in Fig 4a of [7]. The difference consists in adding the block which, except the determination of V_{TQS0} according to ITTC transformation, introduces the parallel determination of V_{TQS} by means of the parameter G defined as follows :

$$G = \frac{\frac{V_{TQS}}{V_S}}{\frac{V_{TQM}}{V_M}} \tag{1}$$

According to (1) the ship - scale effective mean velocity V_{TQSG} is determined by :

$$V_{TQSG} = V_{TQM}\left(\frac{V_S}{V_M}\right)\cdot G \tag{2}$$

where G is an arbitrary value from the neighbourhood of

$$G_0 = \frac{\frac{V_{TQS0}}{V_S}}{\frac{V_{TQM}}{V_M}} \tag{3}$$

within the first step of the prognosis.

The final results of calculations of Q_{BS}, n_S, P_{DS} can be expressed as functions of the parameter G which makes it possible to analyze them by assuming the value V_{TQS} different from V_{TQS0} (possible correction of ITTC transformation formula).

The block diagram in Fig.1 emphasizes three essential features of the 0-JH method :

➲ The first one is the solution of the set of equations from the block {1, 2} regarding model conditions. The solution result is the pair of values (J_{TQM}, A_M).
The effective advance coefficient J_{TQM} guarantees that the thrust and torque coefficients K_T, K_Q for the behind propeller SB_M and equivalent free propeller $S0(A_M)$ are equal to each other.
The parameter A_M determines the specific propeller $S0(A_M)$ belonging to the single-parameter family of free propellers, S0(A), which is the equivalent free propeller.
It is necessary only to determine whether the single-parameter families of propellers are practically applicable. Two families of propellers can be distinguished.
The first one, $S0(V_0)$, used in the 0-JH2 variant of the 0-JH method is the family of propellers optimal in the stream of the velocity V_0. Thus the velocity V_0 is the parameter of the family.
The second one, $SB_{mod}(P/D)$, used in the 0-JH3 variant of the 0-JH method is the family of propellers of a given geometry compatible with that of the behind propeller (SB) except the radial distribution of pitch, which is replaced by a constant pitch different for each propeller belonging to the family. The pitch coefficient P/D is the family parameter.

1	$K_{TBM} = K_{TOM}(J, A_j)$
2	$K_{QBM} = K_{QOM}(J, A_j)$
3	J_{TOM}
4	A_M
5	$S0_M(A_M)$
6	$K_{TOM}(J)$
7	$K_{QOM}(J)$
8	ΔK_T
9	ΔK_Q
10	$K_{TOS}(J)$
11	$K_{QOS}(J)$
12	$\frac{K_{TOS}(J)}{J^2}$
13	$\frac{K_{QOS}(J)}{J^2}$
14	V_{TQM} → ITTC →
15	V_{TQS0}
16	$G_0 = \frac{\frac{V_{TQS0}}{V_S}}{\frac{V_{TQM}}{V_M}}; \; G = \frac{\frac{V_{TQS}}{V_S}}{\frac{V_{TQM}}{V_M}}$
17	$V_{TQSG} = G\sqrt{\alpha}\, V_{TQM}$
18	$B_{TSG} = \frac{T_{BS}}{\rho_S \cdot V_{TQSG}^2 \cdot D_S^2}$
19	$B_{QSG} = \frac{Q_{BSG}}{\rho_S \cdot V_{TQSG}^2 \cdot D_S^3}$
20	$B_{TSG} = \frac{K_{TOS}(J)}{J^2}$
21	J_{TQSG}
22	$n_{SG} = \frac{V_{TQSG}}{J_{TQSG} \cdot D_S}$
23	$K_{TQSG} = \frac{T_{BS}}{\rho_S \cdot n_{SG}^2 \cdot D_S^4}$
24	$B_{QSG} = \frac{K_{QOS}(J_{TQSG})}{J^2}$
25	B_{QSG}
26	$Q_{BSG} = B_{QSG} \cdot \rho_S \cdot V_{TQSG}^2 \cdot D_S^3$
27	$K_{QBSG} = \frac{Q_{BSG}}{\rho_S \cdot n_{SG}^2 \cdot D_S^5}$

Fig.1. *Block diagram of the zero version 0-JH. Procedure (Q_{BS}, n_S)*

Because the results obtained by application of both propeller families were practically the same it was decided to use, in this paper, the second, i.e. SB_{mod}(P/D) family. The advantage of this family is that the pitch coefficient of the equivalent propeller can be regarded as the mean effective pitch coefficient of the behind propeller.

- The second essential feature of the 0-JH method is the transformation of V_{TQM} into V_{TQS0} according to ITTC-78 standard as well as the transformation of the hydrodynamic characteristics $K_{TOM}(J)$, $K_{QOM}(J)$ of the equivalent free propeller $S0(A_M)$ into $K_{TOS}(J)$ and $K_{QOS}(J)$ characteristics and determination of

$$\frac{K_{TOS}}{J^2}(J) \text{ and } \frac{K_{QOS}}{J^2}(J) \text{ functions.}$$

- The third important element of the method in question consists in introducing equations arising from the demand of equality of the thrust as well as the torque loading coefficients of both propellers in ship scale (i.e. the behind and equivalent free propellers).

Both equations are shown in Fig.1(see block {20} and {24}). The effective advance coefficient J_{TQSG} and the propeller revolutions $n_{SG} = \frac{V_{TQSG}}{J_{TQSG} \cdot D_S}$ result from the block {20}.The value of B_{QSG} results from the block {24} and consequently Q_{BSG} from block {26}, and K_{QBSG} from block {27}.

INPUT DATA OF SELECTED SHIP

For the purpose of calculations it was decided to make use of the ship-propeller system whose geometrical data, results of resistance and propulsion tests, propulsion prognosis according to ITTC-78 method and measured mile ship test results are collected in Tab.1, 2 and 3.

Tab.1. *Results of model propulsion tests*

Scale $\alpha = 37$

Hull model	*M-4567*	*Propeller model diameter*	$D_M = 0.2216m$
Propeller model	*P-89*	*Propeller diameter*	$D_S = 8.2m$

V_S	V_M	n_M	T_M	Q_M	K_{TM}	K_{QM}	t_M	w_{TM}
[kn]	[m/s]	[1/s]	[N]	[Nm]	[-]	[-]	[-]	[-]
15.0	1.269	8.53	32.4	0.969	0.1847	0.02492	0.211	0.352
17.0	1.438	0.87	44.0	1.278	0.1873	0.02460	0.230	0.347
19.0	1.607	11.45	61.9	1.783	0.1958	0.02545	0.209	0.353

Tab.2. *Propulsion characteristics of the ship according to ITTC-78 method*

V_S	T_{BS}	Q_{BS}	K_{TBS}	K_{QBS}	$t_S=t_M$	w_{TS}	n_S
[kn]	[kN]	[kNm]	[-]	[-]	[-]	[-]	[1/s]
15.0	1374.0	1497.0	0.16268	0.021615	0.211	0.304	1.350
17.0	1891.0	1992.0	0.16832	0.021624	0.230	0.311	1.557
19.0	2717.0	2836.0	0.17642	0.022457	0.209	0.304	1.823

Tab.3. Measured mile propulsion test results

			Ship velocity					
			[kn]	[m/s]	[kn]	[m/s]	[kn]	[m/s]
			15.0	7.71	17.0	8.738	19.0	9.766
Power P	[HP]		17444.0		26766.0		44613.0	
	[kW]		12826.0		19687.0		32804.0	
Torque Q [kNm] $Q = Q^{*} \cdot 10^{6}$	Q^{*}		1.4831929		1.9741011		2.8098799	
Torque coefficient K_Q: $K_Q = 0.0263152 \frac{Q^{*}}{n_S^2}$			0.0205843		0.020598		0.021396	
Revolutions	n_S	[1/s]	1.377		1.588		1.859	
	n_S^2	$[1/s]^2$	1.89613		2.522		3.45588	

POWER PREDICTION RESULTS BY USING THE 0-JH METHOD

The results of calculation of Q_{BS} and n_S for three values of the ship velocity V_S (15, 17 and 19 kn) and seven values of G parameter within the range $0.9 \le G \le 1.2$ are graphically presented in the form of Q_{BS} function :

$$Q_{BS} = Q_{BS}(G, V_S) \tag{4}$$

in Fig.2 and of n_S function

$$n_S = n_S(G, V_S) \tag{5}$$

in Fig.3.

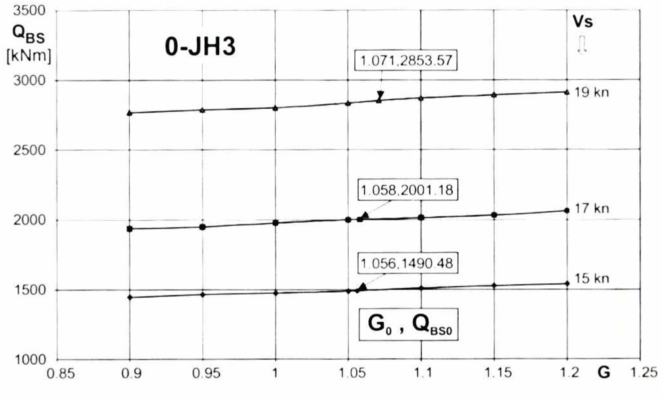

Fig.2. Graphical view of the function $Q_{BS} = f(G, V_S)$

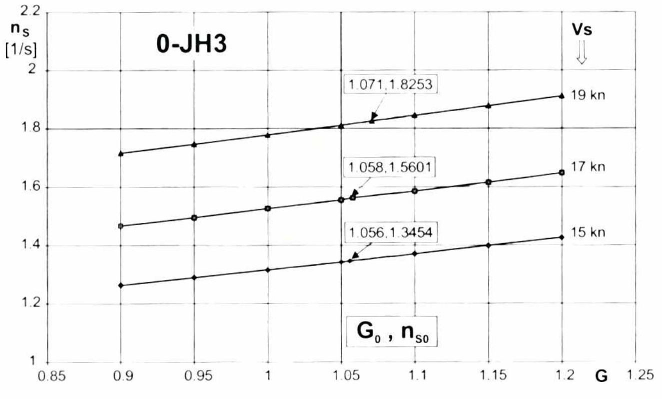

Fig.3. Graphical view of the function $n_S = f(G, V_S)$

Because of high compatibility of the calculation results obtained with the application of the equivalent free propeller from the single-parameter family $S0(V_0)$, and those with the use of the equivalent free propeller from the family $SB_{mod}(P/D)$, this paper presents the results of the latter calculation version only, further called the 0-JH3 method.

To compare results obtained from the 0-JH3 method and ITTC-78 one such values of G_0 were determined for which the methods became comparable. The way of choosing G_0 parameter :

$$G_0 = G_0(V_S) \tag{6}$$

is show in Tab.4.

Tab.4. Determination of the values $(V_{TQS}/V_S)_0$ according to the 0-JH3 method for values γ obtained from the ITTC-78 method

V_S [kn]	V_S [m/s]	V_M [m/s]	$\left(\frac{V_{TQS}}{V_S}\right)_0$	$\frac{V_{TQM}}{V_M}$	G_0	t	z	γ	.
15	7.710	1.2681	0.7074	0.6698	1.0560	0.211	0.749	0.5247	
17	8.738	1.4372	0.6866	0.6485	1.0580	0.230	0.730	0.5320	**0-JH3**
19	9.766	1.6063	0.6982	0.6512	1.0710	0.209	0.751	0.5290	
15	7.710	1.2681	0.6960	0.6480	1.0740	0.211	0.749	0.5247	
17	8.738	1.4372	0.6890	0.6530	1.0550	0.230	0.730	0.5320	**ITTC-78**
19	9.766	1.6063	0.6960	0.6470	1.0757	0.209	0.751	0.5290	

The formula of transformation from V_{TM} into V_{TS} within the ITTC-78 method has the following form :

$$\frac{z - \frac{V_{TS}}{V_S}}{z - \frac{V_{TM}}{V_M}} = \gamma \tag{7}$$

where

$$z = 1 - (t + 0.04) \tag{8}$$

$$\gamma = \frac{(1+k) \cdot C_{F0S} + \Delta C_F}{(1+k) \cdot C_{F0M}} \tag{9}$$

$$k = 0.25 \tag{10}$$

$$\Delta C_F = \left[105 \left(\frac{k_S}{L_{WLS}} \right)^{1/3} - 0.64 \right] \cdot 10^{-3} \tag{11}$$

$$k_S = 150 \cdot 10^{-6} [m] \tag{12}$$

$$C_{F0} = \frac{0.075}{(\log R_n - 2)^2} \tag{13}$$

$$R_{nM} = \frac{V_M \cdot L_{WLM}}{\nu_M} \tag{14}$$

$$R_{nS} = \frac{V_S \cdot L_{WLS}}{\nu_S} \tag{15}$$

ν - water kinematic viscosity dependent on temperature.

For the particular velocity V_S and selected ship the values of *z* and γ should be independent of the used recalculation method. The values of γ in the last column of Tab.4 were determined from the formula (7) for ITTC-78 method and the same values related to the velocity V_S are presumed within the 0-JH3 method.

For given values of γ the values of

$$\left(\frac{V_{TQS}}{V_S}\right)_0 \quad \text{and} \quad G_0 = \frac{\left(\frac{V_{TQS}}{V_S}\right)_0}{\frac{V_{TQM}}{V_M}}$$

within the 0-JH3 method, were determined from (7).

$$\text{For} \quad G_0 = f\,(V_S) \tag{16}$$

$Q_{BS}(G_0)$ and $n_S(G_0)$ were determined respectively. Their values are presented in Fig.2 and 3.

Tab.5. *The comparison of the measured mile results and propulsion prognoses according to ITTC-78 and 0-JH3 methods*

	V_S	n_S	P_{DS}	Q_{BS}
	[kn]	[1/s]	[kW]	[kNm]
Measured mile	15	1.377	12826.0	1483.19
	17	1.588	19687.0	1974.10
	19	1.859	32804.0	2809.88
ITTC-78	15	1.35	12699.0	1497.0
	17	1.557	19486.0	1992.0
	19	1.823	32479.0	2836.0
0-JH3	15	1.3454	12593.2	1490.48
	17	1.5601	19606.4	2001.18
	19	1.8253	32710.1	2853.57

Tab.5 contains the final results of prognosis according to the 0-JH3 and ITTC-78 methods. For purpose of verification the measurement results of the torque Q_{BS}, power P_{DS}, propeller revolutions n_S and ship velocity V_S obtained during the measured mile ship tests are also included. In Fig.4 the data of Tab.5 are additionally shown as diagrams of the following functions :

$$P_{DS} = P_{DS}(V_S) = 2\,\pi\, n_S\, Q_{BS} \quad [\text{kW}] \tag{17}$$

$$n_S = n_S(V_S) \quad [\text{sec}^{-1}] \tag{18}$$

$$Q_{BS} = Q_{BS}(V_S) \quad [\text{kNm}] \tag{19}$$

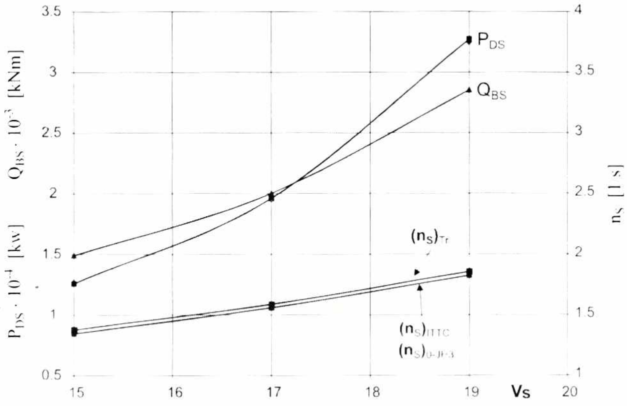

Fig.4. *Results of propulsion prognosis*

Tab.6 contains the relative deviations of revolutions, torque and power resulting from the ITTC-78 and 0-JH3 prognoses as well as the measured mile ship test results. Definitions of the deviations are given in Col.1, and the 2nd Col. contains their denotation. In the successive columns the values of deviations for three different velocities are included. Their negative value indicates that the bottom indexed method provides a greater value.

Tab.6. *The relative deviations for n_S, Q_S and P_{DS} according to three methods*

		V_S [kn]		
		15	17	19
$(\Delta n_S)_B^A = \frac{(n_S)_A-(n_S)_B}{(n_S)_A}\cdot 100\ [\%]$	$(\Delta n_S)_{ITTC}^{Tr}$	3.72	1.95	1.93
	$(\Delta n_S)_{0-JH3}^{Tr}$	2.29	1.75	1.81
	$(\Delta n_S)_{0-JH3}^{ITTC}$	0.36	-0.20	-0.13
$(\Delta Q_S)_B^A = \frac{(Q_S)_A-(Q_S)_B}{(Q_S)_A}\cdot 100\ [\%]$	$(\Delta Q_S)_{ITTC}^{Tr}$	-0.93	-0.91	-0.92
	$(\Delta Q_S)_{0-JH3}^{Tr}$	-0.49	-1.37	-1.56
	$(\Delta Q_S)_{0-JH3}^{ITTC}$	0.43	-0.46	-0.62
$(\Delta P_{DS})_B^A = \frac{(P_D)_A-(P_D)_B}{(P_D)_A}\cdot 100\ [\%]$	$(\Delta P_{DS})_{ITTC}^{Tr}$	0.99	1.02	0.99
	$(\Delta P_{DS})_{0-JH3}^{Tr}$	1.81	0.41	0.29
	$(\Delta P_{DS})_{0-JH3}^{ITTC}$	0.83	-0.62	-0.71

Indices used in Col. 2 :

Tr - *measured mile tests*
ITTC - *ITTC method*
0-JH3 - *0-JH3 method*

CONCLUSIONS

- The power prediction according to the ITTC-78 method is realized for a definite value of the parameter G_0 :

$$G_0 = \frac{\left(\frac{V_{TS}}{V_S}\right)_0}{\frac{V_{TM}}{V_M}}$$

where $\left(\frac{V_{TS}}{V_S}\right)_0$ results from the ITTC-78 full-scale transformation of $\left(\frac{V_{TM}}{V_M}\right)$.

- The 0-JH3 method gives P_{DS}, n_S, Q_{BS} being functions of the parameter G :

$$G = \frac{\frac{V_{TQS}}{V_S}}{\frac{V_{TQM}}{V_M}}$$

The relevant value of this parameter is to be determined.

- The comparison of these methods was performed for the same value of the parameters $G = G_0$. From Tab.6 it is evident that the relative deviations in prediction of the propeller revolutions n_S and propeller torque Q_{BS}, are smaller than 0.5%, and those of the propeller power P_{DS} - than 0.85%. Both methods, i.e. 0-JH3 and ITTC-78 one give practically the same prediction results when the same assumptions are made for scale effect determination of the effective mean velocity and of the open propeller characteristics.

- The 0-JH3 method can be regarded as an independent, first approximation method or as an integral part of the developed method R-JH3 giving the input data to the equation set in full-scale equalizing the thrust and torque coefficients of the behind - and the equivalent open screw propeller.

FINAL REMARKS

- The final results of the 0-JH3 method are employed in the developed version (R-JH3) of the new power prediction method outlined in [5] , in which the application of the univocal demand of equality of K_T and K_Q coefficients of the behind propeller and the equivalent free propeller, is extended to ship scale. In R-JH3 method the value of the parameter G ($G \neq G_0$) is determined.
  The R-JH3 method provides extremely convenient opportunities for verifying propulsion prognoses in the future when the thrust of screw propeller is also measured apart from the torque, revolutions and velocity.
- In both, 0-JH3 and R-JH3, methods the notion of rotational efficiency is abandoned because its value is always equal to unity. The univocal definitions of the effective mean velocities are introduced. The new univocal concept of the effective mean pitch coefficient is defined. New verification opportunities were developed for determination of scale effect on the basis of model test results.
- The 0–JH3 and R-JH3 methods substitute the experimental investigation of free-propeller hydrodynamic characteristics by numerical determination of characteristics of a single-parameter family of screw propellers.
- Calculation results obtained by means of R-JH3 method will be published in a short time.

Appraised by Jan A.Szantyr, Prof.,D.Sc.,N.A.

NOMENCLATURE

A - screw family parameter
B_Q - torque loading coefficient
C_F - resistance coefficient
D - screw propeller diameter
G, G_0 - parameters defined in equations (1) and (3), respectively
ITTC - International Towing Tank Conference
J - advance coefficient
K_T - thrust coefficient
K_Q - torque coefficient
L_{WL} - ship length (water line)
n - screw propeller revolutions
P - propeller pitch
P_{DS} - power
Q - propeller torque
R_n - Reynold's number
S - wet surface of the ship
SB - behind screw propeller
S0 - open water propeller
t - thrust deduction factor
T - propeller thrust
V - velocity
w_T - wake fraction according to thrust equality
ΔK_T - thrust coefficient scale effect correction
ΔK_Q - torque coefficient scale effect correction
ν - kinematic viscosity
ρ - water density

Indices & acronyms

A - average mean velocity (in general)
B - behind conditions
j - step number in j-iteration process
M - model ship
0 - open water conditions
S - full scale ship
T - thrust
Q - torque
TQ - thrust and torque simultaneously
ITTC - International Towing Tank Conference

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Conference

Shipbuilding Industry of 2002

On 10÷11 May this year 20th Scientific Session on Shipbuilding was held under this title in Gdańsk. The conference was organized by : Polish Society of Naval Architects and Marine Engineers – KORAB, Faculty of Ocean Engineering and Ship Technology of Technical University of Gdańsk, and Gdynia Shipyard Co.

The opening paper titled :

Shipbuilding industry of 2002
Its recent state and prospects

was presented by Prof. Jerzy Doeffer, a senior of Polish shipbuilding industry.

47 papers contained in the conference program were split into four topical groups within which the following themes were dealt with :

1st Group : **New types of ships and tools for their designing** (16 papers)

- Some design problems of recently built ships by Polish shipyards
- Analysis of hydromechanical features of floating units
- Strength prediction and assessment of ship structural joints
- Testing of sea-keeping qualities of ships in a model tank
- Numerical and simulation methods applied to research on ship motions in waves
- Logistic and hydrological research ships

2nd Group : **Ship propulsion and energy systems** (9 papers)

- Gas turbine propulsion systems for ships
- Modelling and optimizing methods of thermal processes in ship diesel engines
- Conventional ship propellers of higher efficiency
- A unique device for pitch control of small-power ship propellers
- Scheduling of technical maintenance of ship equipment and training of ship engineers by means of a ship power plant simulator

3rd Group : **Ship safety** (7 papers)

- New approach to safety at sea and its criteria
- Operational reliability and safety of ship power plants as an element of their designing
- Classification rules and risk assessment methods
- Influence of anti-fouling paints on safety of ships and marine environment
- Evacuation methods of people from passenger ships

4th Group : **Technology and organization of building ships** (15 papers)

- Technology and application of sandwich structural elements
- Modern working processes of ship hull elements
- Accuracy control of engineering processes
- Steel-aluminium structures
- Ship launching with application of innovative sliding materials – laboratory tests and practical experience
- Bearing arrangement of ship propulsion shafts
- Management of deliveries from contractors and organization of work of metrologists in shipyards

In the second day of the Conference their participants had an opportunity to visit Gdynia Shipyard, to be acquainted with its production processes and the history of reconstruction of 1000 t gantry crane.