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On the power prediction methods in the preliminary ship design stage

SUMMARY

The ITTC-78 power prediction method can by divided into three groups of procedures: R_{TS} – procedures, T_{BS} – procedures and the Q_{BS} – procedures. Only the Q_{BS} – procedures are analyzed in this paper. A new approach to the determination of Q_{BS} and n_s parameters is proposed. Outline of the new method is briefly presented.

The new idea of equivalent open propeller is the basic difference between the ITTC Q_{BS} – procedures and the Q_{BS}-JH – procedures. The aim of this approach is to reduce the number of parameters needed to be corrected due to the scale effect and to generate a situation where the Q_{BS}, n_s and V_{TS} parameters are of unique value independent of the subjective choice of averaging criteria.

INTRODUCTION

The power prediction methods, although different in details, are all tending towards the determination of the following parameters :

- the hull resistance $\boldsymbol{R_{TS}}$
- the propeller thrust $\boldsymbol{T_{BS}}$
- the propeller torque $\boldsymbol{Q_{BS}}$
- and the propeller revolution number $\boldsymbol{n_S}$.

The ITTC-78 method [6] needs two kinds of model tests and a standard treatment of scale effects on resistance to determine the R_{TS} and T_{BS} values :

- the hull resistance test (R_{TS} – procedures)

$$R_{TM} \xrightarrow{\text{scale effect}} R_{TS}$$

- the self-propulsion test (T_{BS} – procedures)

$$t_M \longrightarrow t_M = t_S = t \longrightarrow T_{BS} = \frac{R_{TS}}{1-t}$$

The third group of procedures refers to Q_{BS} and n_S determination and will by known in this paper as the Q_{BS} – procedures.

To calculate the last two parameters Q_{BS} and n_S in the ITTC-78 method introduces an idea of equivalent open propeller.

In general the following definition of the equivalent open propeller (*SO*) can be given :

The K_T and K_Q coefficients of the *SO* – screw propeller and the *SB* – behind propeller are equal when the *SO* propeller is working in a stream with V_A velocity. This V_A velocity, satisfying the set of equations :

$$K_{TB} = K_{TO}\,(J_A) \tag{1}$$

$$K_{QB} = K_{QO}\,(J_A) \tag{2}$$

is called the mean effective velocity (MEV). In consequence, three other coefficients of the *SB* and *SO* – propeller are also equal :

- thrust loading coefficients :

$$\frac{K_{TB}}{J_A^2} = \frac{K_{TO}}{J_A^2}(J_A) \tag{3}$$

- torque loading coefficients :

$$\frac{K_{QB}}{J_A^2} = \frac{K_{QO}}{J^2}(J_A) \tag{4}$$

- propeller efficiencies :

$$\eta_B^A = \eta_O\,(J_A) \tag{5}$$

The ITTC-78 method makes use of a deformed definition of the equivalent open propeller (*EOP*). The *EOP* has been selected a priori. The *SB* – behind propeller was decided to be *EOP*, when it is working in the uniform stream with the stream velocity $V_A = V_T$ if the thrust coefficients are equal, i.e. $K_{TB} = K_{TO}(J_T)$, or with the stream velocity $V_A = V_Q$ if the torque coefficients are equal, i.e. $K_{QB} = K_{QO}(J_Q)$. Such a deformation of the *EOP* definition is leading inevitably to two different results of the mean effective velocity ($V_T \neq V_Q$).

The ITTC-78 method decided to use the thrust equality to receive the J_{TM} and $V_{TM} (= J_M \cdot \eta_M \cdot D_M)$ parameters and to receive the wanted V_{TS} value after the scale - effect transformation of V_{TM}. After equalizing the thrust loading coefficients of the *SB* – propeller and the *EO* – propeller :

$$\frac{K_{TB}}{J_{TS}^2} = \frac{T_{BS}}{Q_S V_{TS}^2 D_S^2} = \frac{K_{TOS}}{J^2}(J) \tag{6}$$

the value of J_{TS} and $n_S = (V_{TS}/J_{TS} \cdot D_S)$ is received.

The functions K_{TOS} and K_{QOS} are to be prepared before using the results of the *EO* – propeller test :

$$K_{TOM} = f(J) \quad \text{and} \quad K_{QOM} = f(J) \tag{7}$$

and using the standard ITTC-78 method of transforming both coefficients K_T and K_Q from model to ship conditions :

$$K_{TOS} = K_{TOM}(J) - \Delta K_T \tag{8}$$

$$K_{QOS} = K_{QOM}(J) - \Delta K_Q \tag{9}$$

The last wanted parameter, Q_{BS}, is calculated from the relation :

$K_{QOS} = f(J)$, if $J = J_{TS}$ is given, i.e. $K_{QOS} = f(J_{TS})$.

The rotative efficiency from model tests :

$$\eta_{RM} = \frac{K_{QOM}(J_{TM})}{K_{QBM}} \tag{10}$$

is (without any proof) assumed to be equal to the rotative efficiency in ship scale :

$$\eta_{RS} = \frac{K_{QOS}(J_{TS})}{K_{QBS}} = \eta_{RM} \tag{11}$$

Thus the wanted torque coefficient Q_{BS} can be calculated from the relation :

$$K_{QBS} = \frac{K_{QOS}(J_{TS})}{\eta_{RM}} \tag{12}$$

and then :

$$Q_{BS} = K_{QBS} \cdot \rho_S \cdot n_S^2 \cdot D_S^5 \tag{13}$$

THE POSSIBLITY TO REALISE THE GENERAL DEFINITION OF THE EQUIVALENT OPEN PROPELLER

The general definition of the equivalent open propeller was given before. In H.Jarzyna's papers [1÷5] this idea was deeply analyzed. The theorem was proved that there is always possible to select one and only one screw propeller $SO(A_{lim})$ from the one parameter screw family $SO(A_j)$ so that the equation set :

$$K_{TB} = K_{TOj}(J, A_j) \tag{14}$$

$$K_{QB} = K_{QOj}(J, A_j) \tag{15}$$

is to be satisfied by the values $J = J_{TQ}$, $A_j = A_{lim}$.

With the help of the parameter A_{lim} the screw $SO(A_{lim})$ is selected from the screw family. The advance coefficient $J = J_{TQ}$ introduced to the functions $K_{TO}(J, A_{lim})$ and $K_{QO}(J, A_{lim})$ assures that the following values are equal :

$$K_{TB} = K_{TO}(J_{TQ}, A_{lim}) \tag{16}$$

$$K_{QB} = K_{QO}(J_{TQ}, A_{lim}) \tag{17}$$

In solving the equation set of (14) and (15) the step-by-step calculation method is to be used. In the *j*-step, for given parameter A_j, the equations (14) and (15) are solved individually giving J_{Tj} from (14) and J_{Qj} from (15). The parameter A_{j+1} in the $(j+1)$-step is to be selected in such a way that the following inequality is satisfied :

$$\left|J_T - J_Q\right|_{j+1} < \left|J_T - J_Q\right|_j \tag{18}$$

The sequences J_{Tj} and J_{Qj} tend to the common limit value $\lim J_{Tj} = \lim J_{Qj} = J_{TQ}$

The sequence A_j tends to the limit value $\lim A_j = A_{lim}$. For the selected screw $SO(A_{lim})$ from the screw family $SO(A_j)$ one can form its global characteristics such as :

$$\frac{K_{TO}}{J^2}(J, A_{lim}) \qquad \frac{K_{QO}}{J^2}(J, A_{lim}) \qquad \eta_O(J, A_{lim})$$

as well as three further equations :

$$\frac{K_{TB}}{J_{TQ}^2} = \frac{K_{TO}}{J^2}(J, A_{lim}) \tag{19}$$

$$\frac{K_{QB}}{J_{TQ}^2} = \frac{K_{QO}}{J^2}(J, A_{lim}) \tag{20}$$

$$\eta_B^A = \eta_O(J, A_{lim}) \tag{21}$$

and compare these forms of the $SO(A_{lim})$ screw with those of the behind screw *SB*.

The equations (19) and (20) can be brought to another form when it is known that :

$$\frac{K_{TB}}{J_{TQ}^2} = \frac{T_B}{\rho V_{TQ}^2 D^2} \tag{22}$$

$$\frac{K_{QB}}{J_{TQ}^2} = \frac{Q_B}{\rho V_{TQ}^2 D^3} \tag{23}$$

In such case from the following equations :

$$\frac{T_B}{\rho V_{TQ}^2 D^2} = \frac{K_{TO}}{J^2}(J, A_{lim}) \tag{24}$$

$$\frac{Q_B}{\rho V_{TQ}^2 D^3} = \frac{K_{QO}}{J^2}(J, A_{lim}) \tag{25}$$

one can receive V_{TQ} and $n = V_{TQ}/J_{TW} D$ from (24), and Q_B from (25), taking $J = J_{TQ}$.

So it is now possible to determine five needed parameters (J_{TQ}, A_{lim}, Q_B, V_{TQ}, n) by solving the equations (14), (15), (19), (20), and using the additional one :

$$V_{TQ} = J_{TQ} \cdot n \cdot D$$

A NEW METHOD OF DETERMINATION OF SHIP PROPULSIVE CHARACTERISTICS

On the basis of the new idea of the equivalent open propeller, new methods for determination of ship propulsive characteristics can be developed. As an example, the *Q-JII* method is presented below.

The Q_{BS} -*JII* – procedures of the new method can be divided into two parts.

The first part includes the equation (14) and (15) formulated for the model conditions :

$$K_{TBM} = K_{TOMj}\,(J,A_j) \qquad (26)$$

$$K_{QBM} = K_{QOMj}\,(J,A_j) \qquad (27)$$

where K_{TBM} and K_{QBM} are taken from self-propulsion tests, and K_{TOMj} (J,A_j) and K_{QOMj} (J,A_j) are obtained from the characteristics calculated for the one -parameter screw family.

Solving this equation set by the iteration method one receives J_{TQM} and A_M, the effective mean velocity $V_{TQM} = J_{TQM} \cdot \eta_M \cdot D_M$ and the screw $SO_M(A_M)$ selected from the screw family $SO(A)$. The characteristics of this screw propeller :

$$K_{TOM} = f(J,A_M) \qquad (28)$$

$$K_{QOM} = f(J,A_M) \qquad (29)$$

can be now determined. The values V_{TQM} and $K_{TOM} = f(J)$, $K_{QOM} = f(J)$ are then transformed from model to ship scale by using the well known ITTC-78 transformation principles.

One receives $(V_{TQM})_S$, the value of effective mean velocity in full scale and the thrust and torque coefficients of the open screw propeller :

$$K_{TOS} = K_{TOM} - \Delta K_T = f(J) \qquad (30)$$

$$K_{QOS} = K_{QOM} - \Delta K_Q = f(J) \qquad (31)$$

Thereafter the thrust and torque loading coefficients can be formed :

$$\frac{K_{TOS}}{J^2}(J) \qquad (32)$$

and

$$\frac{K_{QOS}}{J^2}(J) \qquad (33)$$

The second part of the Q_{BS} -*JII* – procedures deals with the equations (14), (15), (19) and (20) formed for the ship conditions :

$$K_{TBS} = K_{TOS}(J,A_j) \qquad (34)$$

$$K_{QBS} = K_{QOS}(J,A_j) \qquad (35)$$

$$B_{TS} = \frac{K_{TOS}}{J^2}(J) \qquad (36)$$

$$B_{QS} = \frac{K_{QOS}}{J^2}(J) \qquad (37)$$

First of all the equations (36) and (37) based on the functions (32) and (33) from part one of the procedure are used where the value B_{TS} is defined and calculated as :

$$B_{TS} = \frac{T_{BS}}{\rho_S (V_{TQM})_S^2 D_S^2} \qquad (38)$$

From (36) one can receive the value $J = J_{TQSO}$ satisfying the equality of thrust loading coefficient of the behind and open screw propeller. Then from the relation :

$$(V_{TQM})_S = J_{TQSO} \cdot n_{SO} \cdot D_S \qquad (39)$$

the number of revolutions n_{SO} of the propeller can be calculated.

Using the equation (37) to determine the B_{QSO} value when the advance coefficient J is equal to J_{TQSO} from the equation (36) :

$$B_{QSO} = \frac{K_{QOS}}{J^2}(J_{TQSO}) \qquad (40)$$

one can calculate the propeller torque Q_{BSO} from the relation :

$$Q_{BSO} = B_{QSO} \cdot \rho_S \cdot (V_{TQM})_S^2 \cdot D_S^3 \qquad (41)$$

Thereafter the thrust and torque coefficients K_{TBS} and K_{QBS} of the behind propeller can be determined :

$$K_{TBS} = \frac{T_{BS}}{\rho_S n_{SO}^2 D_S^4} \qquad (42)$$

$$K_{QBS} = \frac{Q_{BS}}{\rho_S n_{SO}^2 D_S^5} \qquad (43)$$

The set of equations (34) and (35) can be solved now giving the advance coefficient J_{TQS}, the screw family parameter $A = A_S$ and the open screw propeller $SO_S(A_S)$ with its hydrodynamic characteristics as follows :

$$K_{TOS} = f_T(J,A_S) \qquad (44)$$

$$K_{QOS} = f_Q(J,A_S) \qquad (45)$$

and

$$\frac{K_{TOS}}{J^2} = f_T(J) \qquad (46)$$

$$\frac{K_{QOS}}{J^2} = f_Q(J) \qquad (47)$$

The thrust and torque loading coefficients from (46) and (47) are equalized according to (36) and (37) to the adequate values of the behind propeller, B_{TS} and B_{QS}, received when the advance coefficient J taken from the equation set (34) and (35), is equal to J_{TQS}. From (48) B_{TS} value is obtained :

$$B_{TS} = \frac{K_{TOS}}{J^2}(J_{TQS}) \qquad (48)$$

and from (49) and (50) V_{TQS}^2 and n_S are calculated :

$$V_{TQS}^2 = \frac{T_{BS}}{\rho_S D_S^2 B_{TS}} \qquad (49)$$

$$n_S = \frac{V_{TQS}}{J_{TQS} D_S} \qquad (50)$$

On the other hand from (51) B_{QS} can be calculated :

$$B_{QS} = \frac{K_{QOS}}{J^2}(J_{TQS}) \qquad (51)$$

and thereafter the propeller torque Q_{BS} can be determined :

$$Q_{BS} = B_{QS} \cdot \rho_S \cdot V_{TQS}^2 \cdot D_S^3 \qquad (52)$$

The R_{TS} - and the T_{BS} – procedures are presented in Fig.1 and 2. The Q_{BS} – procedures according to the ITTC-78 principles is presented in Fig.3.

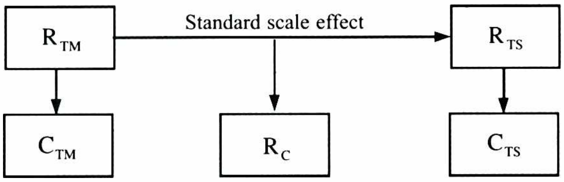

Fig.1. Block diagram of the R_{TS} – procedures

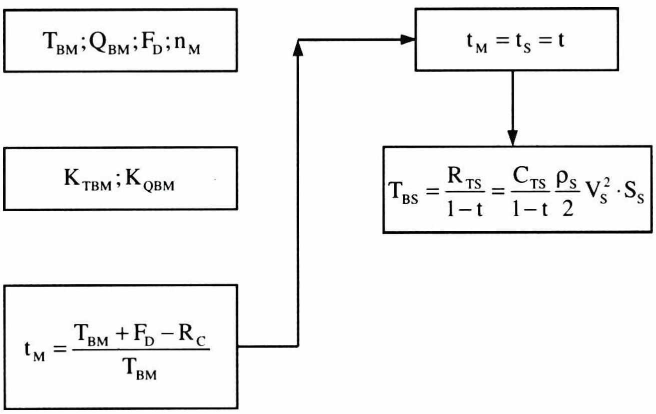

Fig.2. Block diagram of the T_{BS} – procedures

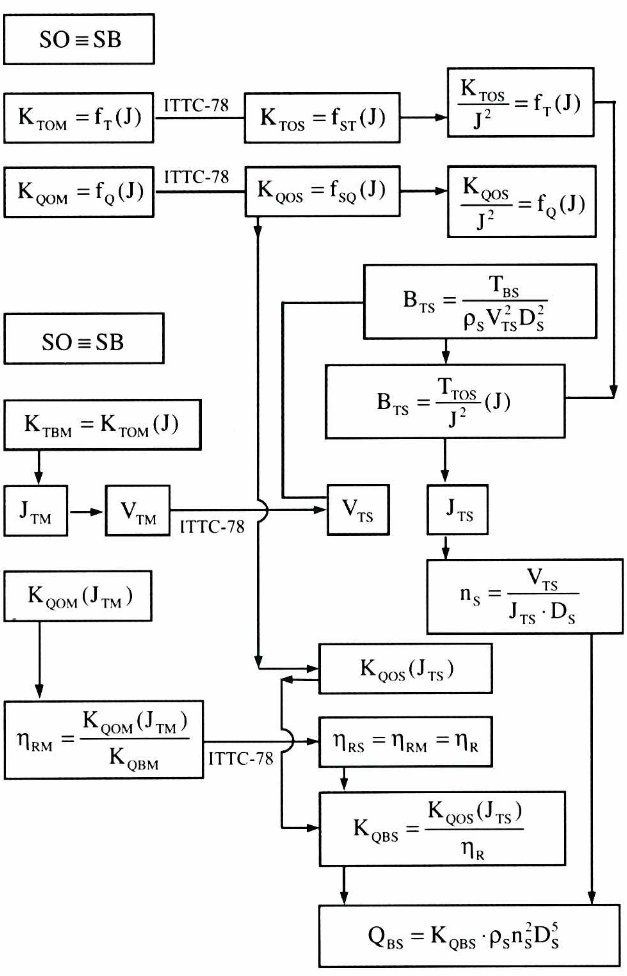

Fig.3. Block diagram of the ITTC -78 Q_{BS} – procedures

The original Q_{BS} - *JH* – procedures based on the new idea of the equivalent open propeller, presented in this paper, are shown in Fig.4.

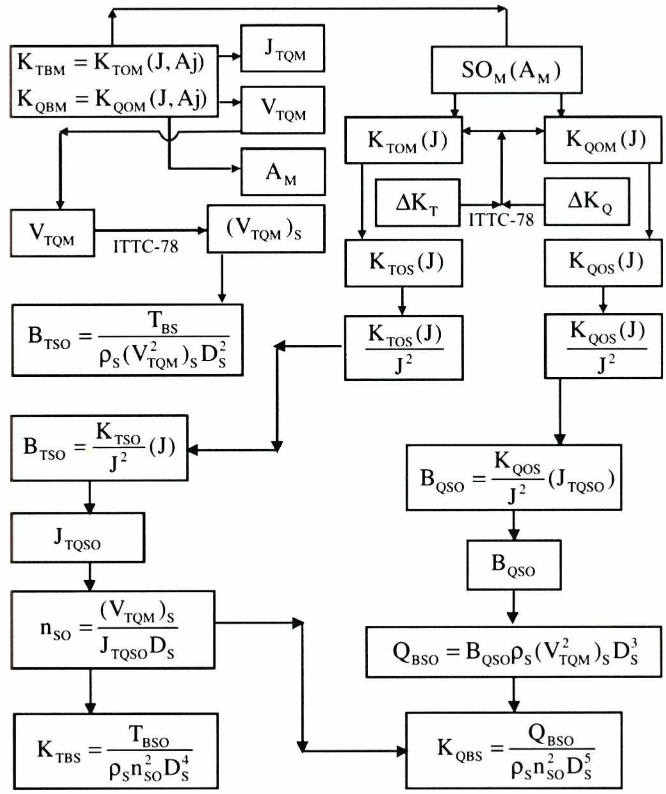

Fig.4a. Block diagram of the Q_{BS} - JH – procedures, (Part 1)

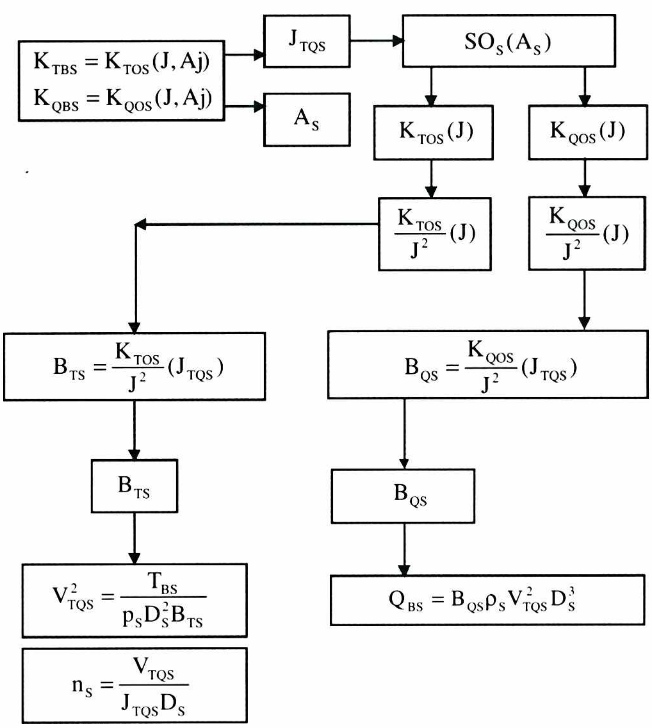

Fig.4b. Block diagram of the Q_{BS} - JH – procedures, (Part 2)

Results of comparative calculations based both on the ITTC-78 method and the above presented new method will be published in a short time.

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

NOMENCLATURE

A - screw family parameter
B - loading coefficient
C_T - resistance coefficient
D - screw propeller diameter
F_D - skin friction correction
ITTC - International Towing Tank Conference
J - advance coefficient
K_T - thrust coefficient
Q - torque
R_T - total resistance of ship hull
SB - behind - the hull screw propeller
SO - open propeller
T - propeller thrust
ΔK_T - thrust coefficient scale-effect correction
ΔK_Q - torque coefficient scale- effect correction
η - propeller efficiency
η^A - propeller efficiency related to V_A
η_R - relative rotative „efficiency"
K_Q - torque coefficient
n - screw propeller revolutions
R_C - ship resistance with ruder
S - wet surface of the ship
t - thrust deduction factor
V - velocity
ρ - water density

Indices

A - everage mean velocity (in general)
B - behind-the hull conditions
j - step number in j-iteration process
lim - limit
M - model ship
O - open - water conditions
S - full-scale ship
T - related to thrust
Q - reletad to torque

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Conference

FEM SOFTWARE IN COMPUTER AIDED ANALYSIS, DESIGN AND MANUFACTURING

From 6 to 9 December 2000 in Warszawa/Rynia - under this heading – 5th Scientific Technical Conference was held which comprised 8 topical sessions and 2 MSC SOFTWARE workshops. Representatives of 14 universities and scientific research centres prepared 32 papers dealing with different fields of engineering. Three following papers were presented by authors of shipbuilding circles :

- *FEM structural analysis of Ro-Lo ships* – by A. Szarnik, Gdynia Shipyard
- *Vibration calculations of a chemical tanker and their measurement verification* – by T. Dmitruk, M. Rozbicki, J. Szymczak, Ship Design and Research Centre, Gdańsk
- *Comparison of structural response of a tanker to sloshing loads, determined experimentally and by means of MSC/ DYTRAN software* – by L. Konieczny and H. Michniewicz of Ship Design and Research Centre Gdańsk, and P.Krzemień-Ojak of Mc Neal-Schwendler – Poland

Conference

WTM

MARINE TECHNOLOGY ODRA'01

Since 1995 the international scientific technical conference Marine Technology ODRA devoted to a broad range of shipbuliding problems has been held every second year in Szczecin. It is jointly organized by the Faculty of Maritime Technology, Technical University of Szczecin and Wessex Institute of Technology, Great Britain. The last, 4th Conference ODRA'01 in which 80 representatives of Polish and foreign scientific and production centres took part, was held from 23 to 25 May this year.

During 11 topical sessions 43 papers were presented dealing with interesting contemporary problems of shipbuilding and ship operation, namely :

- Ship design and construction
- Shipbuilding materials and engineering processes
- Ship propulsion, equipment and automation
- Ship navigation and operation
- Management of manufacturing processes
- Specific features of deep-water objects and systems.

450-page proceedings of the Conference contain papers of 88 authors, inclusive of 26 from Poland, and 62 from Australia, Canada, China, Croatia, Denmark, Finland, France, Germany, Great Britain, Holland, Iran, Italy, Japan, Spain, Turkey and USA.

Important accompanying events were a visit to GRYFIA Ship Repair Yard of Szczecin where vistors were acquainted with its technical facilities and ship repairing processes, and also that to Szczecin Maritime University which is equipped with modern didactic instruments and universal ship operation simulators.

A diversion in the Conference were direct social contacts between participants during performance of artistic entertainments and the banquet at the historical halls of the Pomeranian Princes' Castle, sponsored by the Szczecin Shipyard, Porta Holding Co.

As in the previous years the Conference has played an important role for meeting and exchanging experience between scientists and representatives of worlwide leading scientific and production centres. It also has become a forum for preliminary coordination of projects to be undertaken within the frame of EU scientific research programs.

The success of the last four Conferences of the kind has authorized their organizers to start preparing the next, 5th International Conference „Marine Technology ODRA'03" to be held in May 2003.

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